Economic Impacts of Carbon Taxes: Overview

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REPORT SUMMARY

Due to the possibility that rising concentrations of atmospheric greenhouse gases might cause undesirable climate change, policies to restrict emissions of carbon dioxide, a greenhouse gas, have been proposed. Such proposals frequently take the form of carbon taxes. This report presents an overview of the results of a detailed examination of the economic costs of carbon taxes, including where and how the U.S. economy would be impacted.

Background

The stabilization of emissions at 1990 levels has been a widely discussed proposal. Previous studies suggest that sizable taxes would be required to obtain stabilization. In the past, such studies have focused mainly on aggregate economic impacts. The present study examines this issue in more detail and looks at the impact of a carbon tax at the regional and sectoral levels. The complete and detailed results of this project are presented in a companion report, *Economic Impacts of Carbon Taxes: Detailed Results* (TR 104430-V2). This report presents an overview of the research as well as analytical insights developed from these results.

Objectives

This study examines the economic consequences of carbon taxes at the regional and sectoral levels; assesses the resulting impacts on investment and economic growth; and, traces the implications on trade and U.S. competitiveness.

Approach

The analysis is built around the impact of three alternative carbon tax scenarios on a baseline projection for the U.S. economy and its energy markets. These scenarios make it possible to analyze tax effects on energy markets. They also provide a basis for the detailed analysis of the impact of the carbon tax on consumption, investment, trade, industry, and regional economic activity.

Results

The alternative scenarios phase in carbon taxes to a level of $50, $100, and $200 per metric ton (tonne) of carbon by 2010. According to the analysis, taxes between $100 and $200 per tonne of carbon would be required to hold emissions to 1990 levels through 2010. Real GDP would fall 2.3 percent below baseline levels by 2010 with a $100 per tonne tax. Output would drop 1.2 percent and 4.2 percent for the $50 per tonne and $200 per tonne tax cases, respectively. Reduced consumption accounts for about half the loss in GDP, and reduced business investment accounts for about one third. The dramatic fall in capital spending by utilities is responsible for the largest single share of total investment decline.

EPRI Perspective

The stakes in the climate change debate are potentially large. On the one hand, stabilizing greenhouse gas emissions could lead to costs on the order of several percent of gross domestic product. On the other hand, undesirable impacts to human and natural systems could occur if climate changes significantly.

Sensible decision making should ultimately involve a careful balancing of the costs of climate change management proposals with what such proposals will buy in terms of environmental benefits. Other EPRI research is aimed at addressing crucial concerns about the impacts of climate change as well as integrated assessments of all important aspects of the climate issue. This report is aimed at a better understanding of the economic costs of climate policy. The goal of this research is to provide policy makers with methods and information that will allow better informed decisions about climate policies.

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Interest Categories

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management and assessment

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ABSTRACT

This report presents an overview of the results produced by detailed examination of the economic costs of carbon taxes, including where and how the US economy would be impacted. The analysis is built around a base line projection for energy markets and the US economy and three alternative carbon tax scenarios. The scenarios were selected to bracket the range of estimates for carbon taxes required to stabilize emissions at present levels. The alternative scenarios phase in carbon taxes to a level of $50, $100, and $200 per metric ton (tonne) of carbon, respectively, by 2010. These scenarios make it possible to analyze the effects of a range of taxes on energy markets. They also provide a basis for the detailed analysis of consumption, investment, trade, industry, and regional impacts on which much of the study focuses.

Major findings include the result that holding emissions at 1990 levels through 2010 would require carbon taxes higher than $100 per tonne. At the $100 level, GDP would decline by 2.3 percent below base line levels by 2010. Reduced consumption accounts for about half of the loss in GDP, and reduced business investment accounts for about one third. The costs of reducing emissions through 2010 are high because there are limited possibilities for fuel switching in existing equipment, vehicles, and buildings. Turnover in capital stock can take several decades. In the interim, price induced conservation, which reduces total energy demand, provides the bulk of emissions reductions.

ACKNOWLEDGMENTS

This study was a collaborative effort between Charles River Associates and DRI/McGraw-Hill. The work effort resulted in two reports, *Economic Impacts of Carbon Taxes: Overview* and the more detailed *Economic Impacts of Carbon Taxes: Detailed Results* (TR-104430, v2). David Montgomery was the designer of the overall study and principal investigator throughout. For *Economic Impacts of Carbon Taxes: Detailed Results,* Joyce Yanchar led the analysis at DRI/McGraw-Hill, and William Hughes led the analysis at Charles River Associates. David Montgomery was responsible for the literature review; Joyce Yanchar for the macroeconomic analysis and the detailed consumer, investment, and trade analyses; Mary Novak for the energy market analysis; Larry Horwitz for the inter industry analysis; William Hughes for the case studies; and Sara Johnson for the regional analysis. Major contributions also came from David Cole, who assisted in all aspects of the DRI analyses; Michael Montgomery, who assisted in the investment analysis; and Craig Romaine, Charles Trozzo, and Angela VanDerwerken, who assisted in the literature review and case studies. David Montgomery authored this report, *Economic Impacts of Carbon Taxes,* based on the work of the individuals mentioned above.

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EXECUTIVE SUMMARY

Introduction

Policies to restrict carbon dioxide emissions are under serious consideration in the United States and other countries. A number of studies have examined the possible effects of such policies on the US and world economy, but economic impacts have been depicted in a very aggregate fashion. The purpose of this study, sponsored by the Electric Power Research Institute, is to look more deeply into how and where policies to reduce carbon emissions would affect the US economy.

The analysis begins with the impacts of carbon restrictions on energy markets, and on the level and composition of consumption, investment, and international trade. Different industries would be affected differently by the changes in costs, consumer purchases, investment spending and patterns of trade that carbon policies would cause. Input output techniques are used to analyze impacts by industry, identifying which industries are likely to be hardest hit. Three of the most heavily affected industries are selected for closer study, to examine how responses within industries, or competition from other industries and countries, affect the magnitude of impacts.

Changes in energy costs and industry output will have different effects on different parts of the country. The examination of where and how carbon taxes will affect the economy concludes with an analysis of regional impacts.

Reductions in emissions are assumed to be brought about by means of a carbon tax, designed to provide an incentive to move away from fossil fuels with high carbon content. A carbon tax would be levied on oil, natural gas, and coal, based on the carbon dioxide emissions from each fuel. Three taxes of $50, $100 and $200 per metric ton of carbon are studied. These taxes would bring about different reductions in emissions, with the highest holding emissions below 1990 levels beyond the year 2010. Revenues from the taxes are assumed to be recycled into the economy through reductions in other taxes. Thus the net economic impacts of the taxes come from the ways in which they change resource allocation in the economy; they are also representative of impacts that would come from other policy instruments that have similar effects on emissions.

In summary, the study finds that policies to reduce carbon dioxide will have pervasive impacts on the economy of the United States, because for the next decade or two emissions can be held at or below current levels only by eliminating most of the growth in energy use that would otherwise occur. These impacts will be felt by households and businesses, and will reduce both personal consumption and investment. A small number of industries will bear most of the losses in output caused by limits on carbon dioxide emissions, and regions in which those industries are concentrated will therefore be differentially impacted.

Energy Results

Carbon taxes of $100 per metric ton (tonne) would reduce carbon emissions by about 7 percent from levels projected for 2000 under base-line conditions. With base-line emissions projected to rise 11 percent above 1990 levels by 2000, these reductions are insufficient to hold emissions to 1990 levels. Taxes between $100 and $200 per tonne of carbon would be required to hold emissions to 1990 levels through 2010.

- Costs of reducing emissions through 2010 are high because there are limited possibilities for fuel switching in existing equipment, vehicles, and buildings. Turnover of the capital stock can take several decades. In the interim, price-induced conservation, which reduces total energy demand, provides the bulk of emissions reductions.
- Electric utilities can switch fuels by changing the order in which existing powerplants are dispatched, and by changing the fuels for which new powerplants are designed. But the opportunities are limited over the next two decades. Even with a $200 carbon tax, fuel switching is only responsible for about 20 percent of the emission reductions achieved.
- Carbon taxes cause disproportionately large reductions in natural gas consumption through 2000. Reductions in electricity demand induced by the carbon tax lead to cancellations of capacity additions, and through 2000 most capacity additions in the base line are natural gas fired. By 2010, coal—the fuel with the highest carbon emissions—suffers the largest reduction in consumption.

Macroeconomic Effects

Real GDP would fall 2.3 percent below base-line levels by 2010 with the $100 per tonne tax. The economic impacts in the $50 and $200 per tonne cases are nearly proportionate, with output dropping 1.2 percent and 4.2 percent, respectively.

- Assuming neutral Federal Reserve policy, interest rates rise with the higher inflation. A rise in real US interest rates relative to foreign rates pushes up the real exchange rate and makes US goods less competitive, on average, in world markets.
- Higher interest rates and lower output levels depress investment, leading to a smaller productive capital stock. The decline in the capital stock accounts for two-thirds of the 1.9 percent decline in potential supply with the $100 per tonne carbon tax in 2010; lower energy usage accounts for 28 percent of the decline in potential supply; a lower technology level accounts for the remaining 8 percent.

- The growth of potential supply is the fundamental constraint on the long-term growth of demand. Thus, the decline in potential output keeps real GDP significantly below base-line levels in the long term.
- The cyclical unemployment caused by the price shock of a carbon tax is not the most important factor in causing GDP loss. Even when monetary policy is adjusted to hold unemployment at base-line levels, the $100 carbon tax reduces GDP in 2010 by 1.6 percent. The reasons for the loss in GDP are reductions in energy use and reduced capital investment.

Consumption and Investment

Reduced consumption accounts for about half the loss in GDP, and reduced business investment accounts for about one-third. The net trade balance actually improves slightly, due largely to greater domestic saving and reduced investment. The government deficit is held at base-line levels by recycling a portion of the carbon tax revenues, so that there is no net change in government's share of GDP.

- Higher energy costs lead to several adjustments on the part of consumers. They lead to reductions in expenditures on energy itself— gasoline for transportation, electricity for heating, air conditioning, lighting and appliances, and natural gas and oil for heating.
- Carbon taxes increase the cost of all forms of transportation. Higher gasoline prices depress auto sales because they make driving more expensive. Consumer spending on other transportation services, such as air travel, declines more strongly because fuel is an important component of the cost of such travel and the demand elasticity is high.
- Another important effect on consumption comes directly from the loss in real income caused by carbon taxes. There are large income-related drops in spending on consumer durables–major appliances, furniture, and new autos–and on luxury items like jewelry.
- Spending on food and housing falls, but less than in proportion to the drop in income. Some kinds of consumption, whose cost is not increased by higher energy prices and that are relatively insensitive to income, could actually increase. Recreational services are one example.

Two-thirds of the estimated decline in capital investment is attributable to the decline in output, and one-third is attributed to the rise in the real cost of capital services (real user cost). Furthermore, half of the rise in the real cost of capital services is attributed to higher real asset purchase prices and half to higher interest rates.

- Capital goods industries are more energy-intensive than average for non-energy industries. As a result, higher energy costs will raise the cost of investing in much the same way that higher interest rates do, and thus will reduce investment and economic growth.

- Carbon taxes, and reductions in energy consumption, reduce investment most in the industries that produce oil, natural gas, coal, and electricity. But these industries together account for less than 10 percent of GDP. The bulk of the decline in total investment comes in non-energy industries.
- The total reduction in electricity-related investment, including public utilities and electrical equipment, accounts for about 20 percent of the total decline in investment. The dramatic fall in capital spending by utilities and the importance of utility investment combine to make the loss in electricity-related investment equal to the largest single share of the total investment decline.
- Reduction in investment spending for computers and related equipment is responsible for the single largest share of the total reduction in investment, 20 percent. The percentage loss in sales of computers is not far off the average for investment goods, but computers are such a large share of total investment spending that they bulk large in the total impact on investment.
- Transportation-related investment falls because of the reduction in demand for automobiles and air travel caused by higher energy costs and costs of travel. Railroad investment takes a large decline because rail investment is so long lived. Thus it takes a long time for the capital stock in the rail industry to adjust to a lower level of demand for transportation services, and investment is shut off until that adjustment takes place.
- Other equipment investments, spread across the economy, account for 39 percent of the loss in total investment, with no one type of equipment standing out like
- computers. The loss in investment for mining and oil field equipment is just 1 percent of the total loss in investment

Effects Across Industries

Different industries will face different cost increases, depending on the amount and type of energy they use directly and the amount and type of energy embodied in the semi-finished goods and raw material they utilize. These cost increases find their way into the products. As a result of these price increases, and the lower incomes consumers enjoy because of the overall drag on the economy from carbon taxes, final demand patterns change. A few industries are the largest losers in the resulting shift in the structure of the economy.

- Industries that produce energy–oil, natural gas, coal, and electricity–have the largest cost increases. Carbon taxes are paid by electric utilities in the price of energy they purchase, and then passed on fully in the prices charged for electricity.
- The average cost of coal rises by 174 percent, that the average cost of natural gas sold by gas utilities rises 36 percent, and the average cost of electricity rises by 30 percent. Refined petroleum products have the smallest cost increase, 29 percent, because of large non-energy costs of refining and distribution.

- Non-energy industries whose costs are most affected by the carbon tax are typically the basic industries involved in the mining of materials and the early stages of processing.
- Cement stands out with cost increases like those of energy industries, followed by primary metals industries–aluminum, ferrous metals, and iron ore mining–with cost increases of 8 to 12 percent. The effect of carbon taxes on other industries tails off rapidly. Paper and paperboard industries have cost increases in excess of 5 percent. Plastics, certain chemicals, and metal and paper container manufacturing have cost increases in excess of 4 percent.
- Impacts of carbon taxes on industry output are highly skewed. A small number of industries, including energy industries, stand out from the rest with losses in output of 16 percent (and more for coal, the largest percentage loser). Most industries face losses in output that are within plus or minus 2 percentage points of the average output loss of 2.8 percent for the $100 tax. Very few industries have output losses of less than 1 percent, and only one is likely to gain from the shifts in demand induced by a carbon tax.
- On average, carbon taxes produce a slight gain in net trade because of the improved current account position. This result emphasizes the importance of macroeconomic conditions, and in particular the balance between domestic savings and investment, in determining trade patterns. The dollar adjusts, in response to the carbon tax, so as to restore the average competitiveness of US industry. Some industries, with above average cost increases, lose to foreign competition, but an offsetting number of industries gain.

Effects on the Aluminum Industry

A $100 per ton carbon tax, whether worldwide or on OECD countries only, would have a very great impact on the aluminum industry throughout the world. There would be a radical reduction of primary aluminum capacity and production in high-cost smelters using fossil fuels, primarily in the United States and Europe. Capacity would increase substantially at existing sites in Latin America, Canada, and Asia, where hydroelectric power is available.

- The tax would immediately increase the incremental cost of industry primary production by 40 percent. Smelters dependent on fossil fuels, most of which have been barely covering their pretax cost of sustained operation, would have increases in the unit cost of sustained operation of over 40 percent. Smelters using hydroelectric power would have increases in sustaining unit cost of 14 to 16 percent.
- The price of aluminum would increase during the first 10 to 15 years after the tax was imposed, but by much less than the amount of the tax. However, after 10 to 15 years, when greenfield capacity would have to be added to supply growth in demand, the price would increase radically. In the base case, this price increase would occur 4 to 8 years later, because more old smelters would still be in operation if there were no tax.

- Consumption of primary aluminum would decrease materially. During the first 10 years after the tax, total consumption would decrease by about 4 to 8 percent below the base-case forecast in the event of a world tax. If the tax were on OECD only, the effect would be only slightly less.. After a few years, growth in demand would resume, but demand would remain below the base-case level because of aluminum prices higher than those of the base case.
- Primary production and capacity would decline radically in the United States and Europe if a carbon tax were adopted by all OED countries. Many high-cost smelters using electricity generated from fossil fuels would become uneconomic. Nearly half of the existing capacity in the United States and Western Europe would be retired within 10 to 15 years after the tax went into effect. Other high-cost smelters would operate at substantially reduced utilization.
- Capacity at existing sites where hydro is available would increase rapidly over the first 10 to 15 years of the tax. Pretax production and capacity growth has been predominant in countries where smelters have access to low-cost power. The industry in Latin America, Canada, and parts of Asia is based on hydro power, and would experience rapid growth wherever there is expansion potential at existing sites. After 10 to 15 years, when this potential would have been largely realized, greenfield expansion would occur mainly in these countries and in other areas, such as Africa, that have potential hydro development.
- Low-cost producers using fossil fuels in countries that adopt carbon taxes will not expand until after 2000. Australia is one of the lowest-cost producing countries pretax. Aluminum production and capacity have grown very rapidly and that growth is planned to continue through the 1990s. A carbon tax adopted throughout the OECD would make Australia a medium-cost producer. Australian smelters would continue to produce after the tax, though at a lower profit, but planned expansion would be canceled. Once expansion at existing hydro-based smelters approaches saturation, expansion at existing Australian smelters would be economic, but it is unlikely that greenfield smelters would be built in Australia for many years.
- Imports by the United States and Western Europe would increase radically. The United States would import half or more of its aluminum, and the share of imports would grow over time. European imports would also increase. The dollar would decline slightly in price relative to most currencies, but competition among aluminum-exporting countries would not be significantly affected by changes in exchange rates.

The Effects of the Tax on the Steel Market

Over the first few years after the imposition of a carbon tax the steel industry would adapt to a new equilibrium involving increased steel prices, a reduced demand for domestic steel, increased electric arc furnace production (EAF), diminished basic oxygen furnace (BOF) production, increased use of scrap and direct reduced iron, and potentially a change in scrap exports.

- *Increase in Domestic EAF Production.* Carbon emissions associated with the EAF process are much smaller than emissions associated with the BOF process. EAF incremental production costs would therefore increase post-tax by much less than BOF incremental costs, giving producers an incentive to increase their output from electric furnaces. However, the tax would create excess capacity, particularly in BOFs, that could take several years to work off. New electric furnace capacity would first take the form of existing plant expansion and conversion. The excess capacity created by the tax could last for a while, putting competitive pressure on steel prices and making it difficult for a producer to recoup the costs of a new facility.
- *Decrease in Domestic BOF Production.* Because of its higher post-tax incremental costs, BOF production would decline. The amount of the decline would potentially be large, because the decline in the BOF production would have to equal the increase in EAF production plus the decrease in domestic consumption plus any increase in imports. The study team estimates the decrease in BOF production within 10 years after the tax is imposed to be about 15 to 20 percent. Plant shutdowns could occur, especially since the pretax market position of some BOF mills is already weak. Shutdowns would help tighten the capacity/demand balance of the industry and would encourage addition of new electric furnaces.
- *Scrap Price and Supply Increase. The* cost of scrap would rise steeply if demand increased by no more than 10 percent of the pretax use level. The efficiency of scrap use in electric furnaces and BOFs would increase as a result. An increase of 5 to 12 percent of overall electric furnace production would be sustainable, but the price of scrap would rise to where the use of direct reduced iron and cold pig iron in EAFs would be much more attractive.
- *Equilibrium Scrap Price and Steel Costs. The* post-tax prices of scrap and direct reduced iron would be bid up to a level effecting rough parity of BOF and EAF incremental costs, but at this equilibrium level, electric furnaces would have a significantly larger share of total production than before the tax was imposed.
- *Electric Power Consumption of the Steel Industry. The* effect of the carbon tax on most electricity-intensive industries would likely be to reduce electric energy consumption substantially. Steel may be an important exception, because of the increase in electric arc furnace production. Electric energy consumption by BOF mills would decline because production of these facilities would decrease substantially. However, electric energy consumed in preparing scrap (shredding, crushing, handling) as well as direct-reduced iron and electric energy consumed in

electric arc furnaces would increase substantially. On net balance, total electric consumption by the industry might not be much affected.

- *Regional Electricity Consumption Changes.* There would likely be major regional changes. Utilities serving the weaker mills away from the Great Lakes production would experience major losses of load and potential loss of customers that shut down their BOF facilities. Utilities with electric furnace loads would experience increased electricity sales at a time when most electricity-intensive loads would be reduced.
- *Steel Price Increase. The* post-tax price increase (over first 10 years) will be less than the increased cost the tax would cause for BOF production, because the industry would adjust to the tax so that its incremental production cost would increase by less than the cost increase imposed by the tax.
- *Decrease in Domestic Consumption.* Domestic consumption would decline largely because the decrease in Gross Domestic Product caused by the tax would reduce the demand for construction, automobiles, appliances, and other goods with income-responsive demand. There would also be a small decrease in consumption because steel prices would likely increase by more than the prices of aluminum, glass, mixed concrete, and plastics, which compete with steel.
- *Slight Increase in Imports. In* addition, increased imports of steel products, semi-finished, and fabricated steel could also reduce domestic demand for steel. In the event of a widespread tax combined with trade restrictions to keep out untaxed steel, this effect would not be large. However, protection against tax-free steel fabricated products would be difficult to enforce. Overall some increase in imports appears most likely.
- *Decrease in Demand, for Domestic Steel Products.* Overall, a decrease in demand for domestic steel products of about 4 to 8 percent appears likely, assuming that measures are used to prevent growth in untaxed imports. When superimposed on the slow growth and slack capacity/demand balance of the industry, this is a substantial decrease.

Impacts on the Chlorine Industry

The chlorine industry could suffer, as a result of a carbon tax, a decline in output very much on the same relative order of magnitude as that experienced by the steel industry.

- A $100 per tonne carbon tax would be likely to cause a fairly substantial increase in the price of chlorine. The added cost would not appear to jeopardize the use of chlorine in most applications, but the propylene oxide application has a reservation price that would be exceeded by the post-tax chlorine price. This application alone accounts for about 8 percent of total chlorine consumption. Some specific "marginal" uses in other applications might also discontinue their consumption as the price of chlorine increases by increments less than their application's average reservation price.

- The carbon tax could increase chlorine prices substantially and thereby cause a significant decrease in the amount of chlorine consumed. The industry already is confronted by a possible longer-run non-price induced loss of production stemming
- from environmental concerns. The carbon tax would, therefore, compound the serious longer-run circumstances of the industry.

Regional Economic Impact

Carbon taxes will not affect all regions of the country in the same way. The regions in which energy-related employment is concentrated will be harder hit than other regions, because energy industries have by far the largest output declines. Other manufacturing industries whose costs are increased, especially those located in regions in which electricity is generated from coal, will also lose employment.

- Higher electricity prices in regions with coal-fired electricity will also reduce the competitiveness of businesses in those regions, leading to some shifts in manufacturing employment beyond those expected from declines in output of whole industries. Changes in the competitiveness of different regions cause wage changes and ultimately migration that restore balance among regions.
- Energy-producing regions are hardest hit by a tax on the carbon content of primary fuels. The West South Central states, with their heavy concentration in the oil and gas industries, experience a 1.1 percent job loss relative to base-line levels in 2010. Total employment in the East South Central and South Atlantic coal mining regions is 0.5 to 0.6 percent below the base line.
- Regions that depend heavily on coal to generate electricity see a rise in relative costs, weakening their competitive position. As a result, manufacturing employment in the two North Central and South Atlantic regions declines 0.5 percent by 2010.
- Although the carbon tax is recycled through federal personal income taxes, indirect inflationary effects of the carbon tax erode real personal income in all regions.
- Losses in the mining and manufacturing employment base prompt slight out-migration from the Central and South Atlantic regions. Population shifts to the New England, Middle Atlantic, and Pacific regions.

Taxes versus Regulatory Approaches

Estimates of economic costs of carbon taxes also provide a basis for estimating the cost of achieving similar reductions in emissions through regulatory programs. Regulatory programs would have costs at least as high as carbon taxes, once the cyclical impacts of carbon taxes have been removed, because no regulatory program can hope to identify and change all the decisions that are reached by carbon taxes. Any regulatory program that attempts to achieve the same emissions reductions by concentrating on a narrower set of technological options, as it typically done, will incur higher costs for the same result.

- Command-and-control regulations provide perverse incentives for replacement of old equipment, or encourage greater utilization of equipment that has been made more efficient, and thereby defeat some of their own purpose. The result is a further increase in the cost per ton of emissions reduced. The only exception is a form of regulation that also uses economic incentives rather than specific technology and process standards, such as the use of tradable permits.
- Full analysis of any proposed regulations requires considerably more detail than can be included in any overall model of the economy, and is most profitably based on the kinds of detailed industry study presented for aluminum, steel, and chlorine.

Costs of regulatory programs estimated through standard deadweight loss measures based on direct impacts on energy consumption are likely to seriously underestimate overall economic impacts. Since the impacts of carbon taxes due to factors outside energy markets are about three times as large as impacts due to lower energy use, a first approximation would multiply the direct costs of regulatory programs by a factor of four as an estimate of their overall economic impacts.

CONTENTS

1

INTRODUCTION

Climate Policy Issues

This study deals with the impacts of policies to control carbon dioxide emissions on the economy. Carbon dioxide is released when fossil fuels–oil, natural gas, and coal–are burned. It is one of several greenhouse gases whose concentrations in the atmosphere are likely to increase because of human activities. Greenhouse gases serve to trap some of the sun's heat near the earth's surface. They are necessary to support life on the planet, but increasing concentrations are likely to lead to increases in average temperature and other changes in the earth's climate. Concern about the consequences of climate change has led to consideration of policies to control greenhouse gas emissions. Since carbon dioxide is responsible for a large share of predicted warming, it is central to almost all proposals.

Policy History

The signing of the Rio Treaty in 1992 was an important event in the development of policies toward climate change. The treaty was the product of years of negotiations that included the United States, other industrial countries, and developing countries. During that process numerous studies–by independent analysts, governments, scientific organizations, and international bodies–examined how greenhouse gases could affect the earth's climate and what policies to control emissions might cost. The negotiations were particularly important because climate change is a truly global problem. No industrial country, including the United States, will contribute more than a small share of greenhouse gas emissions over the next 100 years. Because of their fast growth and increasing energy use, developing countries will actually be responsible for the largest share of greenhouse gases in the atmosphere by the end of the next century. To have any noticeable effect, policies must include all countries.

The Rio Treaty enunciated a goal of returning greenhouse gas emissions from industrial countries to their 1990 levels by the year 2000, and required all countries to develop national action plans describing their efforts in support of the goal. Even before the signing of the treaty, a number of countries had announced individual goals of reducing emissions to 1990 levels or less. But according to reviews done by the International Energy Agency, none had put policies in place that would achieve the goals. As of the middle of 1994, only the United States and Great Britain had submitted national action plans. Policies under discussion in different countries include voluntary measures, taxes to discourage the use of fossil fuels that produce carbon dioxide emissions, and regulatory measures directed at improving energy efficiency and limiting energy use.

The action plan developed by the United States is based on voluntary measures. During 1993 President Clinton proposed an energy tax similar to a carbon tax, which was withdrawn after widespread opposition developed. The European Community (EC) has also considered a tax on energy, based in part on carbon emissions, but has deferred a decision. The EC has also considered a set of regulatory programs and subsidies to accompany its energy tax as part of a program to reduce carbon dioxide emissions, as have a number of European countries.

The effect of greenhouse gases on climate depends on their concentration in the atmosphere. Carbon dioxide can remain in the atmosphere for many decades, and many of the effects on climate that are of concern will not develop until late in the next century. Therefore policy issues have a very long time scale, and involve dates well beyond the year 2000. What to do beyond the year 2000 is one of the issues being taken up in the ongoing international negotiations taking place in late 1994 and early 1995.

Costs and Benefits

Climate policy can be analyzed in an economic framework. Climate change may impose costs that could be avoided, in some degree, by slowing the pace of temperature increase. Policies to reduce carbon dioxide emissions, and therefore slow temperature increase, will also impose costs. To improve economic welfare policies must do enough but not too much. That is, policies must balance the costs of reducing emissions against the costs avoided by slowing climate change.

Figure 1-1 illustrates the issues involved in that balancing. The horizontal scale measures temperature, and the vertical scale measures cost per degree of temperature change. The left hand end of the scale represents zero temperature increase, and the right hand end represents the temperature increase that might occur under business as usual conditions. The lines that rise from left to right represent the damages that could be averted through policies to reduce emissions and thereby prevent some temperature increases. As emissions rise and temperature increases become larger, damages that could be averted by reducing emissions also become larger. The area between the lines represents uncertainty about what those damages are. If emissions were reduced to the point where no temperature increase would occur, there would be no damage. This is the point at the left hand side of the graph where damages to be avoided by reducing emissions are zero.

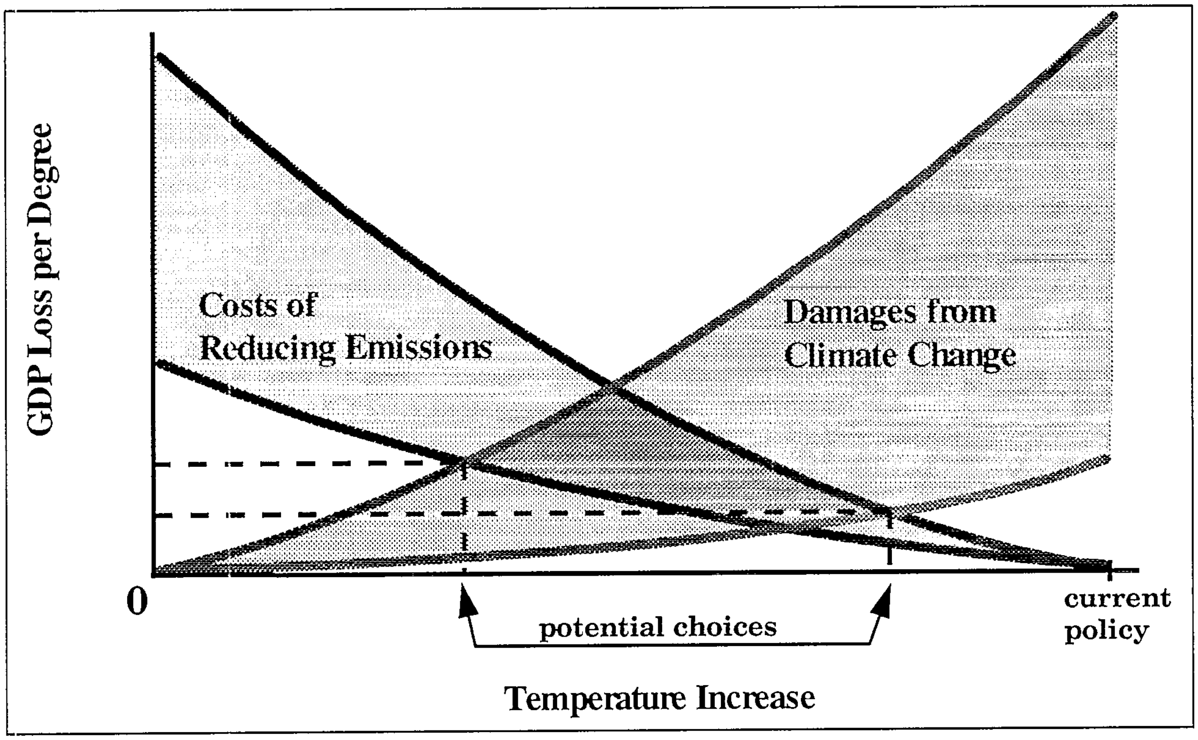

Figure 1-1
Balancing Costs and Benefits[1]

The lines that fall from left to right represent costs of reducing emissions. If emissions were reduced sufficiently to allow no temperature increase, costs of preventing the last degree of increase would be very high, as represented by the range at the left-hand side of the graph. At higher levels of emissions, costs of reducing emissions are not so large. At the right-hand side of the graph, costs of taking a very small action to reduce emissions would be close to zero.

In the middle of the chart, the cost and benefit lines intersect. These lines represent the cost of preventing some additional temperature increase and the benefit of doing so. The point at which these incremental costs and benefits are equal is the point at which economic welfare is largest—emissions are reduced up to the point that any further reduction would cost more than the avoided damage is worth. If costs of achieving additional reductions in emissions are high and avoided damages are small, then this point will be close to no action. If costs are low and damages are high, this point will be closer to no temperature increase.

This simple analysis reveals that information about the costs of controlling emissions, and the nature of damages from climate change, is valuable. The optimal decision is

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[1] . Unless otherwise noted, sources for figures are CRA and DRI.

different if costs of controlling emissions are high than it is if costs are low. This study does not deal with the damages from climate change, but only with the costs of reducing emissions. It is thus intended to contribute one part of the information needed to make a balanced decision about climate policy.

Why Study Carbon Taxes

This study is designed around three scenarios for carbon taxes, each of which is compared to a base line in which current policies continue. The carbon taxes are of $50, $100, and $200 per tonne of carbon emissions. They would be collected on sales of fossil fuels, based on the average carbon content of oil, natural gas, and coal. The taxes are assumed to be phased in evenly between 1995 and 2000.

Carbon taxes are one of several types of policies under consideration for reduction of greenhouse gas emissions. Carbon taxes provide an economic incentive for reduction of emissions. They can be set either in response to estimates of the damages that would be avoided through emissions reduction, or to reduce emissions to meet some pre-defined goal. Carbon taxes have been seriously considered, though not adopted, as a basis for climate policy in the United States and the European Community. Although carbon taxes have been adopted only in a few of the Scandinavian countries, they are likely to be considered seriously on a wider scale if decisions are made to move ahead with policies to reduce emissions beyond the year 2000.

Analysis of carbon taxes can also shed light on the costs of other policies, in particular regulatory policies. Moreover, there is a good practical reason for beginning with analysis of carbon taxes when embarking on a study of impacts of regulation. Command-and-control regulations are by their nature specific and detailed. The voluntary Global Climate Action Plan announced by the US government in 1994 claimed to contain 147 separate measures. Regulatory programs to achieve goals of holding emissions to 1990 levels further out in the future could contain an even larger number of specific measures. It is impossible to analyze the costs, economic impacts, and effects of such programs on emissions unless the precise proposed policies are defined. Many different regulatory programs might be defined to achieve similar goals. Since carbon taxes are capable of achieving emissions goals at lower cost than command and control regulations, estimates of the cost of carbon taxes provide a lower bound on the cost of other, less efficient policies directed at achieving the same emissions reductions. Thus it is possible to use estimates of the economic impact of carbon taxes as estimates of the minimum cost of regulatory programs without having to specify the regulatory programs in detail.

Plan of the Study

There have been a number of studies of the aggregate economic impacts and costs of carbon taxes. The primary purpose of this study is not to contribute still another aggregate estimate to that impressive collection, but rather to look more deeply at how and where the costs of carbon taxes would appear in the economy. The impacts of carbon taxes start with their impacts on the amount and type of energy used in the economy. Higher energy costs brought about by carbon taxes cause consumers and businesses to rearrange their spending, leading to shifts in final demand and in the structure of the economy. The first parts of this study discuss changes in energy markets, and how they affect the kinds of goods that consumers buy, the level of investment, and the trade balance. This includes a detailed look at changes in the composition of consumption and investment spending. Carbon taxes can also cause a price shock leading to greater unemployment and inflation. The nature and importance of these cyclical losses is also examined.

Then the analysis moves a level deeper into examination of how different industries are affected by the changes that propagate through the economy because of carbon taxes. A few industries are affected disproportionately by the changes in consumer investment spending and patterns of trade that a carbon tax would cause. The industries likely to contract significantly are identified first, by working back from changes in consumption, investment, and trade to determine which industries are most strongly affected.

Changes within industries may also be triggered by carbon taxes, and the terms on which various industries compete will also change. Three of the most heavily affected industries are selected for closer study, to examine how changes that might occur within industries, or competition from other industries and countries, can alter the impacts of carbon taxes.

All these effects on prices and industry output will have different effects on different parts of the country. The examination of where and how carbon taxes will affect the economy concludes with an analysis of the regional impacts of carbon taxes.

The study ends by relating the conclusions reached through detailed examination of the economic effects of carbon taxes to summary measures of the costs of controlling carbon emissions. This discussion includes an assessment of how large overall economic impacts are likely to be, and of how large the costs of command-and-control regulations would be in comparison to the costs of carbon taxes.

2

POLICIES FOR REDUCING CARBON EMISSIONS

Policies that have been considered for reducing carbon emissions include voluntary measures, economic incentives, and programs of regulations and standards. There are similarities as well as differences in the impacts of these programs. Reductions in carbon dioxide emissions can be achieved only through reductions in the use of fossil energy.[2] Reductions in use of fossil fuels—oil, gas, and coal—will have impacts on consumption patterns and on the energy industries however they are achieved. Some impacts are unique to particular policy instruments, for example the revenues that are collected with carbon taxes. The overall magnitude of economic impacts depends on how efficiently different policy instruments achieve emissions goals.

What Impacts of Reducing Energy Use Can be Expected No Matter What Policy is Adopted?

Some impacts are caused directly by the reduction of fossil energy use, no matter how those reductions are achieved. Voluntary programs will only bring about reductions of energy use through measures that pay for themselves. Whether such opportunities exist, and how much energy could be saved through their adoption, are matters of considerable controversy. The perspective taken in this study is that voluntary measures are part of the base line. Forecasts of energy use and carbon emissions under current policy are based on the assumption that consumers and businesses will make the choices about energy use that are in their own economic interest.

If there are ways of reducing fossil energy use that can pay for themselves, those measures would have merit even if there were no issue of climate change. But they are

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[2] . This is not to say that there are not other ways of reducing greenhouse gas concentrations in the atmosphere. There are other greenhouse gases, such as methane, whose reduction is also part of most climate change policies. Reforestation programs aimed at removing carbon dioxide from the atmosphere are also under serious consideration. Addressing other greenhouse gases and ways of removing carbon from the atmosphere may substitute for some reductions in carbon dioxide emission. But because carbon dioxide is such a large percentage of total emissions, reductions, in carbon dioxide emissions will remain part of any future policy. The reason that only reductions in fossil energy use are feasible to reduce those emission is that technologies for removing carbon dioxide after fuels are burned are prohibitively expensive, and the problem of how to sequester the carbon dioxide that is removed has not been solved.

not likely to be sufficient to achieve substantial reductions in concentrations of greenhouse gases over the time scales that matter for climate change. Designing policies to respond to the possibility of climate change requires going further, examining policies that can achieve greater emissions reductions, but only at some net economic cost. How to minimize the cost of achieving any particular goal, and whether the costs of achieving the goal are warranted in light of the benefits, are the fundamental questions. Thus the focus of this study is not on voluntary measures, but on carbon taxes and regulatory programs that go beyond what voluntary measures can achieve.

Energy Costs and Costs of Using Energy are Increased

Taxes and regulatory programs designed to reduce fossil energy use have the common feature that both increase the cost of energy and the cost of using energy. With taxes, this effect is apparent. A carbon tax of $100 per tonne of carbon in fossil fuels would increase the prices of oil, natural gas, and coal as depicted in Table 2-1.

Table 2-1
$100 per Tonne Carbon Tax Rates[3]

	Carbon Content * (Tonnes/mmBtu)	Tax Rate (1992 $/mmBtu)	Tax Rate (1992 $)	Price (1992 $)
Natural Gas	0.0153	$1.61	$1.66 per mcf	$1.75 per mcf
Crude Oil	0.0211	$2.11	$11.42 per barrel	$18.20 per barrel
Coal	0.0260	$2.71	$56.50 per short ton	$29.36 per short ton

*Carbon contents are based on the net heating values, which account for the latent heat of water vapor.

If carbon taxes are recycled fully, so that other taxes are reduced in exactly the same amount as receipts from carbon taxes, the collection of carbon taxes per se does not impose any net economic cost. Costs arise because of the actions that are triggered by carbon taxes. Two actions are particularly important:

- Switching away from fuels whose prices rise most because of carbon taxes; and
- Investment in energy-conservation measures that were not cost effective before the tax was imposed.

Switching fuels imposes net costs because the substitute fuels would already have been in use before the tax if it had been economic to use them. The tax would induce fuel users to make choices that have a higher total cost of use, including costs of capital,

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[3] . Unless otherwise noted, sources for tables are CRA and DRI.

fuel, and labor. More of the resources of the economy must therefore be used to produce the same amount of energy, and less are available for other purposes. The same is true when additional energy conservation measures are adopted. More resources are used in achieving the greater levels of energy efficiency than are freed up through the production of lesser amounts of energy, so that on balance there are fewer resources available for producing other goods and services.

Finally, consumers may simply decide to do with less of the services that energy provides, by lowering thermostat settings in winter or taking fewer trips in automobiles and airplanes, and using that money to buy other goods and services. Consumers reveal, through their purchase of heat and travel, that the value they place on those services is greater than the value they place on other goods and services they could purchase for the same amount of money. Thus the substitution induced by the carbon tax makes consumers less well off, even though they have the same amount of money to spend after the tax is returned through reductions in other taxes.

Regulatory programs and efficiency standards impose exactly the same kinds of cost directly by requiring the fuel switching and changes in energy efficiency that are induced by carbon taxes. For example, fuel economy standards that increase the cost of new vehicles by a larger amount than the present value of savings in gasoline consumption leave motorists with less money for purchasing goods and services other than transportation. Requirements that utilities substitute gas or solar power in situations where coal is the least-costly source raise the price of electricity and leave less resources available for producing goods and services other than electricity.

Direct Consumer Impacts of More Costly Energy, Energy Use Impacts on Industry, and Indirect Impacts on Consumers

Higher energy costs affect consumers directly and indirectly. As Table 2-2 shows, about $537 billion was spent in 1990 on energy. This chart includes oil, gas, coal, and electricity consumed by households and businesses, but excludes fuels used for electricity generation. Of this total, about $223 billion was spent directly by households for residential heating oil, for gas and electricity service, and for fuels for personal transportation. The remainder was purchased by businesses for fuels used in production of goods and services, and ultimately paid by households in the prices of goods and services they consumed. Thus, as a first approximation we might expect over 40 percent of any energy cost increase to be experienced directly by households as increases in the cost of heating, cooling, lighting, running appliances, and driving motor vehicles. The remainder would affect industries first, and then be passed on to households in the form of higher prices for goods and services.

Table 2-2
Energy Consumption and Expenditure Shares, 1990

Sector	Quads	$/mmBtu	Billion $
Residential	10.22	11.94	122
Household Transportation	10.86	9.34	101
Residential Subtotal	21.10		223
Commercial	6.68	12.23	82
Industrial	25.25	5.41	137
Transportation	11.21	8.47	95
Total	64.22		537
GDP			5,500
Energy Expenditures in GDP			10%
Household Share of Total End-Use Energy Expenditures			42%

Households. Opportunities to reduce energy use can in turn reduce the economic impacts of higher energy costs on households. Large reductions in energy use would likely require increased expenditures in other categories such as purchase of more efficient appliances and HVAC systems, or may entail sacrifices of comfort such as choice of different thermostat settings.

Industries. When industries pass on cost increases, demand for their products changes. This is obviously the case for energy industries, whose output declines as energy use is reduced. Shifts from high- to low- or zero-carbon fuels will cause some energy sectors, notably coal, to decline and others, possibly including natural gas or renewables, to grow. Suppliers of the materials and equipment used in energy industries, like manufacturers of oil field and electricity generating equipment, will also be affected. In addition, industries that use energy in production, or purchase components and materials whose production requires energy, will also face cost increases. Some of these industries will face declining sales as a result, and others, whose costs increase less than average, may find sales increasing. Sales declines may be due to reductions in domestic demand or to losing out to goods produced overseas in import and export markets. One way of reducing the cost impact is to substitute other inputs for energy or energy intensive materials. These decisions will cause additional ripple effects as purchases from supplying industries change. These changes are often referred to as shifts in the structure of the economy.

How Does the Choice of Policy Instruments Matter?

There are three major areas of difference between carbon taxes and regulatory policies that need to be recognized in comparing their economic impacts. They have to do with the uses of revenues, the avoidability of losses, and the efficiency with which emissions are reduced.

Price vs. Cost Increases

The largest difference between regulatory policies and taxes is that the direct outlays brought about by taxes contain two components: one is the additional payment for energy actually consumed and the other is the net cost of whatever measures are undertaken to switch fuels or use less energy. If revenues are fully recycled, the additional payment for energy consumed is returned to the economy, but not necessarily to the same individuals and businesses who pay the carbon tax. These "income transfers" make the distribution of the burden of regulatory programs different from the distribution of the burden of carbon taxes, even if the same changes in energy use and carbon emissions are achieved by the two different policies.

Avoidable and Unavoidable Losses

Carbon taxes directly increase the price of fossil energy and of goods and services which energy is used to produce. Regulatory programs indirectly increase prices by raising the costs of producing goods and services in industries affected by the programs. Efficiency standards applied to consumer products, such as automobiles and air conditioning systems, also raise the prices of goods that consumers purchase. Thus both tax and regulatory programs can have inflationary impacts. To the extent that regulatory programs cause losses in consumer welfare by constraining consumer choices, rather than by raising prices, their apparent inflationary consequences will be less, even if losses in economic welfare are the same or greater than those caused by taxes.

Higher price levels in turn cause a shock to the economy that can slow growth and increase unemployment. There are ways in which this shock can be reduced, if monetary and fiscal policy are adjusted appropriately. To the extent that regulatory programs also increase price levels, they will have effects similar to carbon taxes. The ways in which revenues from carbon taxes are recycled can also affect overall economic performance. The details of the management of the price shock and revenues from carbon taxes may therefore introduce some differences in economic impact between tax and regulatory policies, but the differences are not clear cut.

Command and Control vs. Incentives

The most important difference between tax and regulatory programs is that regulatory programs based on the command-and-control approach cost more to achieve the same reductions in emissions than do carbon taxes. Carbon taxes provide a uniform and comprehensive incentive to all energy users to reduce emissions up to the point that the cost of reducing emissions by an additional ton equals the tax. In contrast, command-and-control measures apply to only a limited set of options, usually technologies or fuels that are mandated for use in particular applications. Other nonregulated activities that affect emissions are left with no incentive to reduce emissions at all.

For example, automobile fuel economy standards require that the new fleet vehicles produced by each manufacturer must meet a minimum fleet average standard. No incentives are provided for changes in driving behavior. The effect of the standard is to raise the price of new vehicles, leading to lower sales and slower replacement of old vehicles by newer, more efficient vehicles. At the same higher fuel economy means lower cost of driving, so that more miles are driven in the new vehicles. This leads to estimates that the same reductions in carbon dioxide emissions that come from fuel economy standards could be achieved at less than one-tenth the cost through a carbon tax that affected all energy choices.[4]

The same is true in the case of appliance efficiency standards. For example, the efficiency ratings of new heat pumps and air conditioners are the subject of an upcoming rulemaking. Raising the efficiency standards for those pieces of new equipment could be a more expensive way to reduce carbon dioxide emissions than improvements in building shells or changes in behavior. Yet those areas are neglected because they are more difficult to control through uniform command-and-control regulations. The result is a more costly approach to reducing residential energy use. The same emissions reductions could be achieved by shifting some resources from high-cost approaches like very stringent efficiency standards to lower-cost approaches in areas where there is no incentive beyond market prices to reduce energy use. This is precisely the effect that carbon taxes have–providing a uniform incentive over and above market prices for all actions that could reduce carbon emissions.

An alternative that shares the efficiency of carbon taxes but avoids some of the issues of collection and use of revenues is a system of marketable permits issued through a revenue neutral auction or allocation. The prototype for this approach is the sulfur emissions credit trading program set up under the Clean Air Act Amendments of 1990 for electric utilities required to reduce sulfur oxide emissions.

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[4] Charles River Associates, *policy Alternatives for Reducing Oil Use and Greenhouse Gas Emissions,* Washington, DC, 1992.

What Does It Take to Reduce Fossil Energy Use Through 2010?

Carbon taxes can be related to specific levels of emissions reduction, though with a considerable degree of uncertainty. A recent study done by the Energy Modeling Forum (EMF) at Stanford University brought a number of economic modelers together to analyze carbon taxes. They differed by a factor of 5 in their conclusions about how large a tax would be required to achieve specific emissions goals.

Our study is based on an independent estimate of the impacts of various carbon taxes on energy use, carbon emissions, and the economy. Figure 2-1 shows the carbon emissions associated with the carbon taxes examined. A tax of $100 per tonne is not quite sufficient to bring emissions back to 1990 levels by 2000 and leaves emissions considerably above 1990 levels by 2010. A tax of $200 per tonne would be more than enough to eliminate growth in emissions. Based on these scenarios, a tax rising to between $100 and $200 per tonne would be required to achieve the frequently discussed goal of keeping carbon dioxide emissions at 1990 levels from 2000 to 2010.

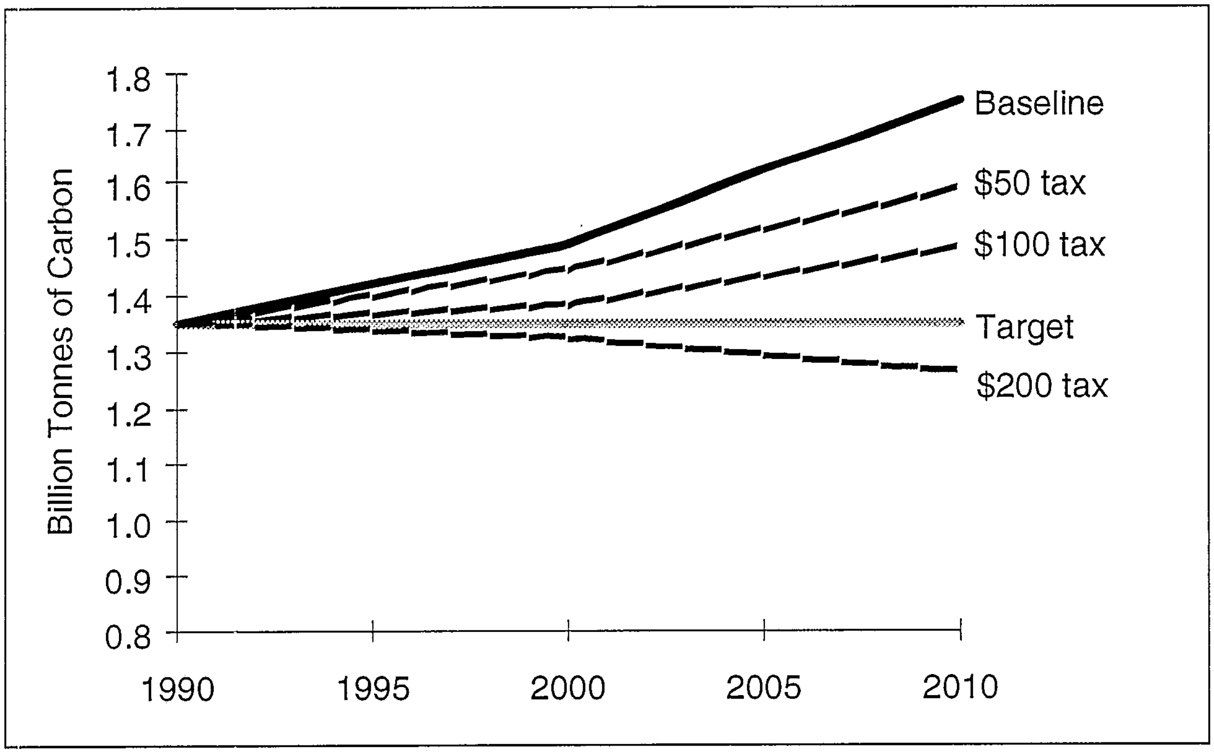

Figure 2-1
Carbon Taxes and Emissions Scenarios

A carbon tax achieves these reduction in emissions by reducing overall energy consumption and inducing a shift away from fuels with high carbon dioxide emissions and toward fuels with low carbon dioxide emissions. As indicated in Table 2-1, coal is the fuel with the most carbon per unit of energy. Natural gas has about 60 percent of the carbon emissions of coal, and oil about 80 percent. Figure 2-2 indicates how much of the reduction in emissions from different carbon taxes comes from reductions in total energy use, and how much from switching between fuels.

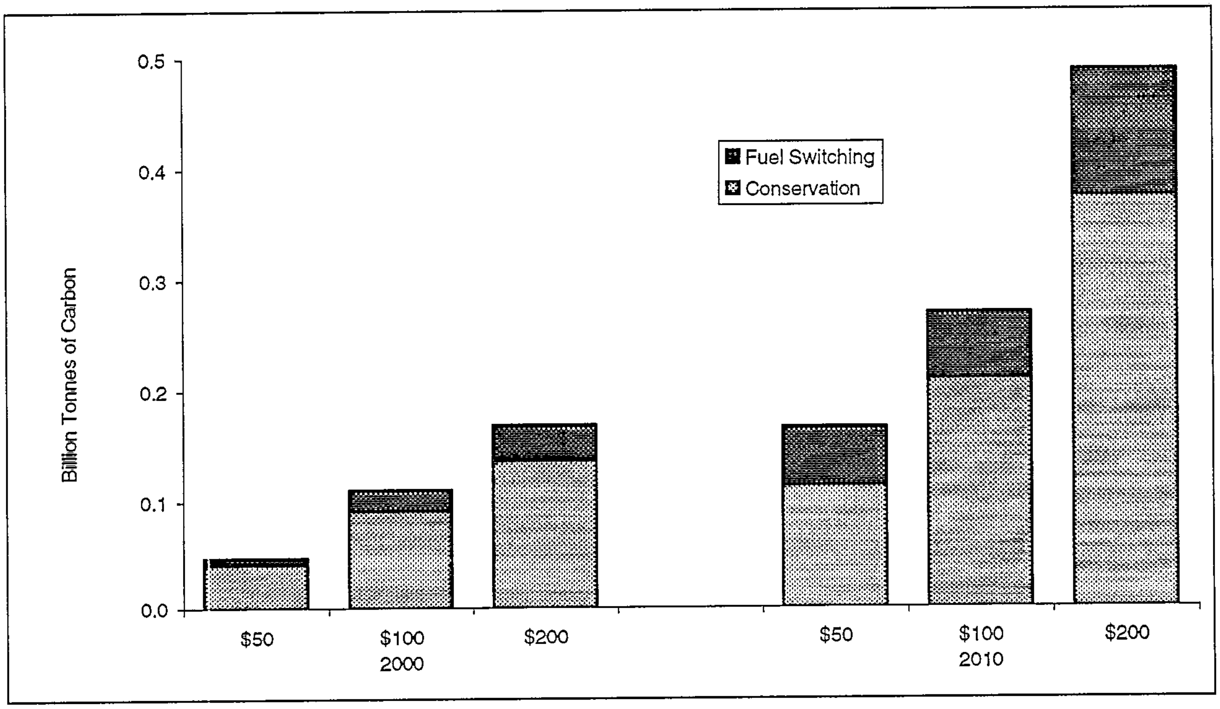

Figure 2-2
Fuel Substitution and Conservation

What Determines The Cost Of Reducing Fossil Energy Use Over This Time Frame?

Fuel Switching

Between now and 2010 opportunities for fuel switching are relatively few. There are limited possibilities for switching fuels in existing fuel-burning equipment. In the transportation sector, fuel switching to reduce carbon emissions is very expensive until existing vehicles are replaced. In residential, commercial, and industrial sectors, surveys of fuel-switching indicate that the capabilities of existing equipment are limited. Where switching in existing equipment is possible, natural gas, the fuel with least carbon emissions, is generally in use already. Thus fuel switching that would reduce carbon emissions from end-use sectors occurs mostly when existing capital equipment reaches the end of its useful life and is replaced. For fleet vehicles, this may be a period of five years. For heating and cooling systems, it may be 10 years or much longer. For large boilers, turnover can take several decades.

Utilities have some dual-fired oil and gas units, but those already burn natural gas whenever they can. Utilities can also dispatch their power plants differently to use natural-gas-fired generators more of the time and coal-fired less. But the capacity of existing natural gas generators that can run continuously is limited, and the emissions reductions achievable are limited. Even with $200 carbon taxes, it is too costly to retire an existing coal-fired power plant prematurely and replace it with a natural gas unit. Thus the pace of fuel switching is determined by the pace of utility capacity additions, and of retirement of existing oil- and coal-fired units at the end of their normal lives.

Table 2-3 portrays some of the possibilities for switching fuels in existing equipment, and for substitution away from high-carbon fuels as new equipment is purchased. The limited possibilities from changing the fuels used in existing equipment imply that emissions reductions on a time scale shorter than the turnover of the capital stock must come from reductions in energy use. This price-induced energy conservation becomes increasingly expensive as larger emissions reductions from the base line are desired.

Table 2-3
Fuel Switching Possibilities and Time Scales

End Use	Fuel Switching In Existing Equipment	Fuel Substitution In New Equipment	Time For Stock Turnover
Transportation	Negligible; retrofits not economic for older vehicles	Small emissions reductions from CNG and electric vehicles	Up to 10 years
Space Heating	None	Conversion from oil to gas may become economic trader carbon taxes	10+ years
Boilers	Some oil and gas switching now mostly on gas	Oil, gas, and coal compete	20+ years
Power Generation	Gas units can be dispatched ahead of coal, up to their excess capacity	Gas and coal compete now; nuclear and carbon-free fuels in future	30+ years

Price Elasticities

The limited opportunities for reducing carbon dioxide emissions through fuel switching imply that reductions can only come through reductions in total energy use. This can come about through reductions in end-use consumption of oil, natural gas, coal, or electricity. Figure 2-3 shows the reductions in total energy consumption for each of the carbon taxes studied.

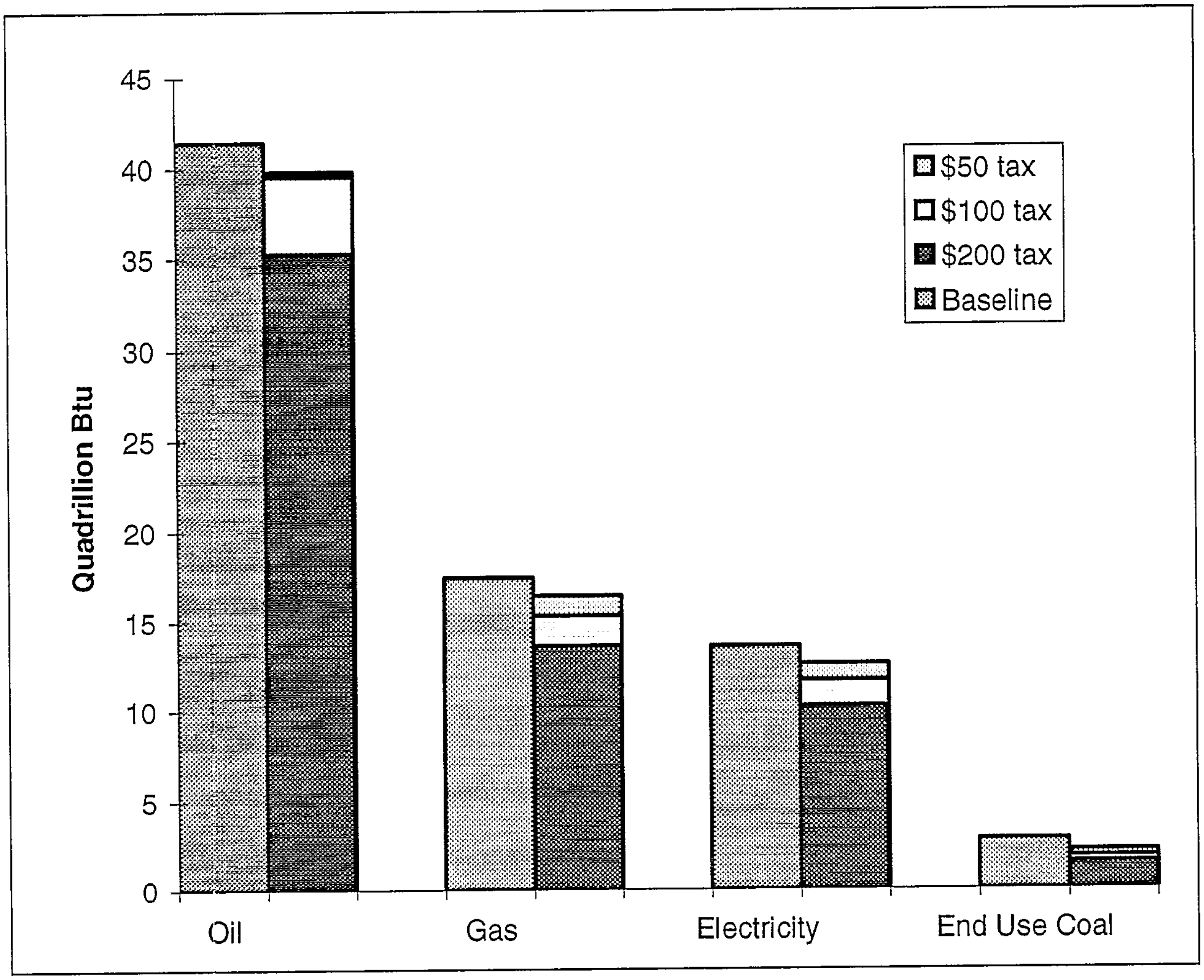

Figure 2-3
Total End-Use Energy Consumption in 2010
for $50, $100, and $200 Carbon Taxes

How easy or difficult it is to reduce consumption of a particular fuel is measured by the *price elasticity of demand. The* price elasticity measures the percentage change in consumption, of total energy or a particular fuel, that is caused by a one percent increase in the price of that fuel. An elasticity of one means that the demand for energy declines in strict proportion to the increase in price, and an elasticity less than one means that demand declines less than proportionately to the price increase.

Price elasticities used in this study are all significantly less than one over the entire time period studied. It is easier to reduce energy consumption in the long run than in the short run, because again turnover of the capital stock makes opportunities available that are excessively costly if equipment must be replaced prematurely. Automotive fuel economy can be improved through manufacture of more efficient vehicles, but since new car sales are typically about 10 percent of the total fleet of vehicles on the road, moving the entire fleet to a higher fuel economy takes over a decade.

Improvements in building energy efficiency that are most economically incorporated in new buildings may take many decades to penetrate to even half of the stock of buildings.

Over a shorter time period, either more expensive measures involving premature retirement or retrofit must be adopted or changes in behavior having to do with fewer energy services are required. With rising carbon emissions between 1990 and 2010, as depicted in Figure 2-1, more and more has to be done each year to prevent growth in emissions. The costs of carbon taxes are based on the costs of bringing about lower use of energy during a time period when technological options are limited because of the slow turnover of the capital stock and the limited role for fuel switching.

3

ENERGY MARKET IMPACTS

Carbon taxes will raise the prices of all forms of energy that contain carbon. By raising those prices, carbon taxes provide the incentive for reductions in total energy use and switching toward lower carbon fuels. These reductions in energy demand are the only currently feasible way to reduce carbon dioxide emissions. They take place through changes in energy consumption at the end use level, and by changes in how electricity is generated. Reductions in energy use also produce a contraction of the energy industries, which is the starting point for exploring how carbon taxes affect the overall structure of the economy.

Energy Price Effects

Figure 3-1 shows how prices of four forms of energy are increased by a carbon tax. Prices before the tax are measured as average prices at the end-use level for sales of oil, natural gas, and electricity. The base-line price of coal is the average price paid by electric utilities. The price of coal rises most in percentage terms. This is partly because coal is the fuel with the highest carbon content, and partly because coal is by far the least-expensive fuel per unit of energy or carbon emissions. Thus increases in the price of coal are large in both absolute and percentage terms.

Electricity experiences the next largest percentage increase in price because so much electricity is generated by burning coal. Natural gas experiences the next largest percentage increase in price, even though natural gas is the fossil fuel with the smallest carbon emissions. The reason is that natural gas costs less at the end-use level than refined oil products, so that the carbon tax is a larger percentage of the end-use price. Oil products see the smallest price increase because of the large refining and distribution costs and the taxes included in the retail price, especially for gasoline.

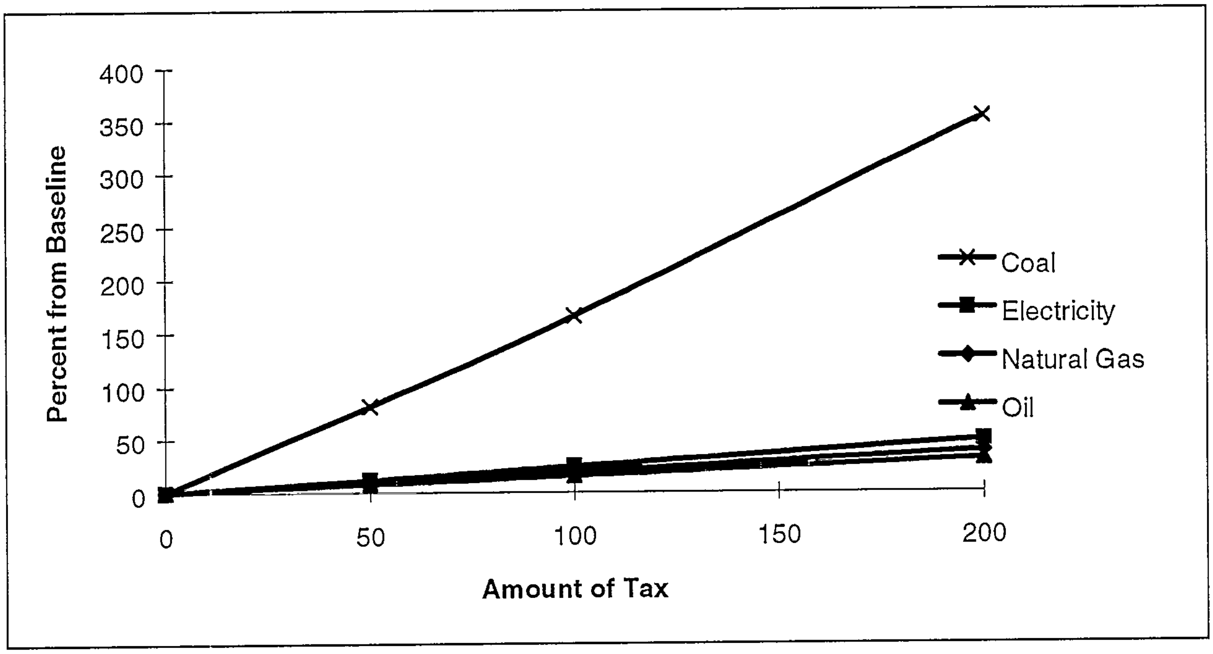

Figure 3-1
Change in Energy Prices Due to Carbon Taxes

Consumption Impacts

Figure 3-2 shows the reductions in total consumption and in end-use consumption of oil, natural gas, and electricity due to the carbon taxes. A $100 per tonne carbon tax, the middle case examined, reduces total energy consumption by 6 percent in 2000 and 12 percent in 2010. In 2000, demand for each of the fuels falls from 5 to 7 percent, with coal seeing the largest decline.

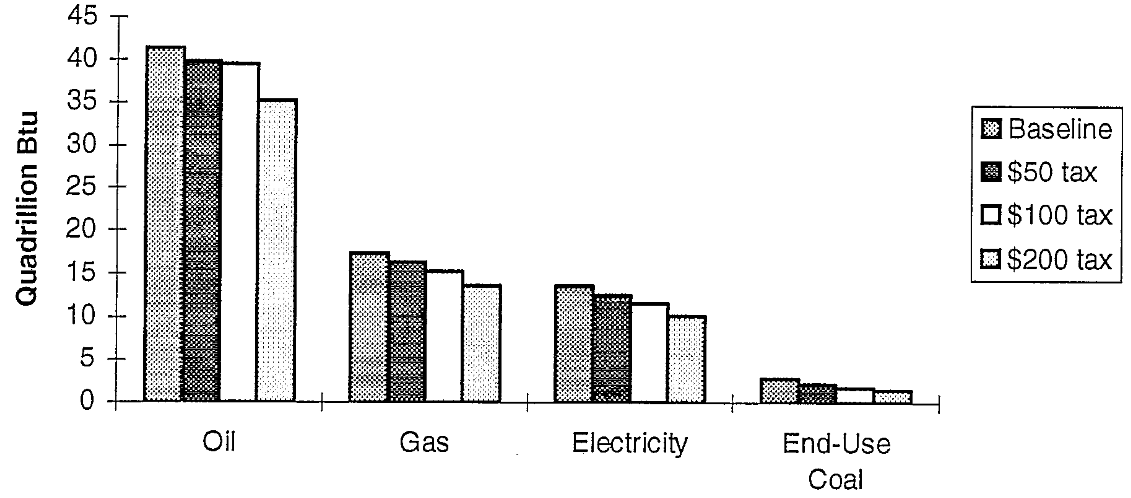

Figure 3-2
Change in Energy Consumption Due to Carbon Taxes in 2010

In 2010 electricity demand drops by over 14 percent, with smaller reductions in natural gas and oil. The same patterns are seen with the other taxes. End use of coal is small in these comparisons because most coal is burned for electric power generation.

Electric Utility Impacts

Reduction in Electricity Demand

Figure 3-3 takes another look at growth in electricity demand for three carbon taxes. A $100 carbon tax cuts growth by more than 50 percent, and a $200 carbon tax practically halts growth in demand through 2010. Taxes between $100 and $200 per tonne would be required to hold carbon emissions at 1990 levels. As the figure indicates, this goal implies something between substantial reduction and virtual elimination of growth in electricity generation nationwide for the next 15 years.

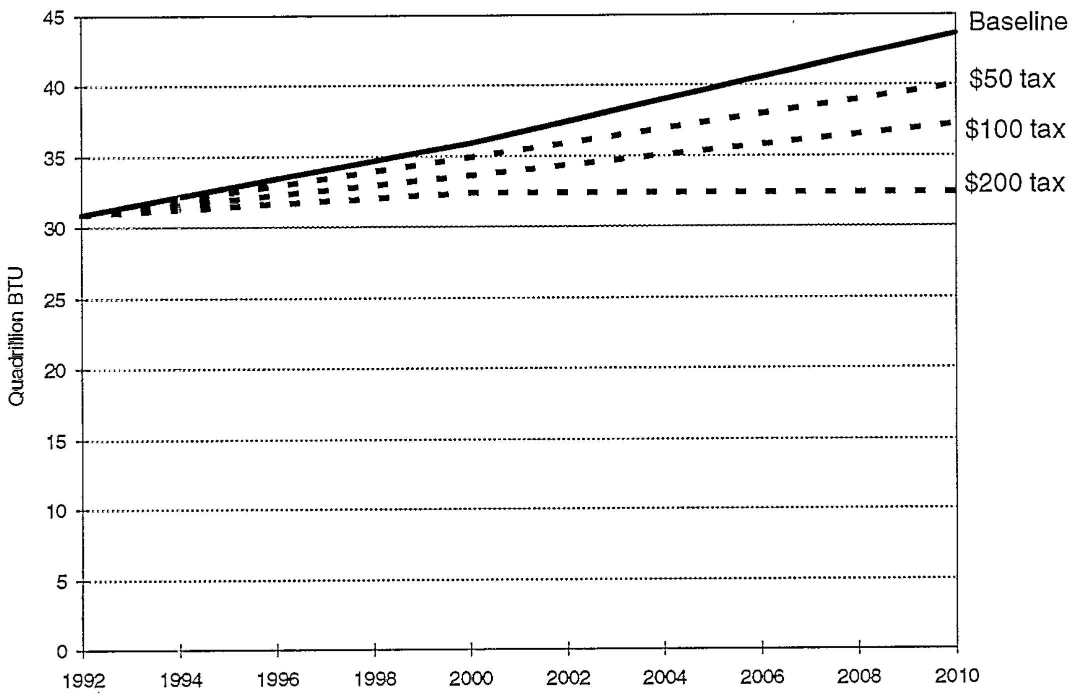

Figure 3-3
Demand for Electricity

The reduction in electricity demand causes changes in utility fuel use and reduces the need for construction of new generating capacity. Figure 3-4 shows the reduction in capacity requirements associated with the slower growth in electricity demand. With the $100 tax, capacity additions would be cut in hall and with the $200 tax, net additions would total only about 30 gigawatts.

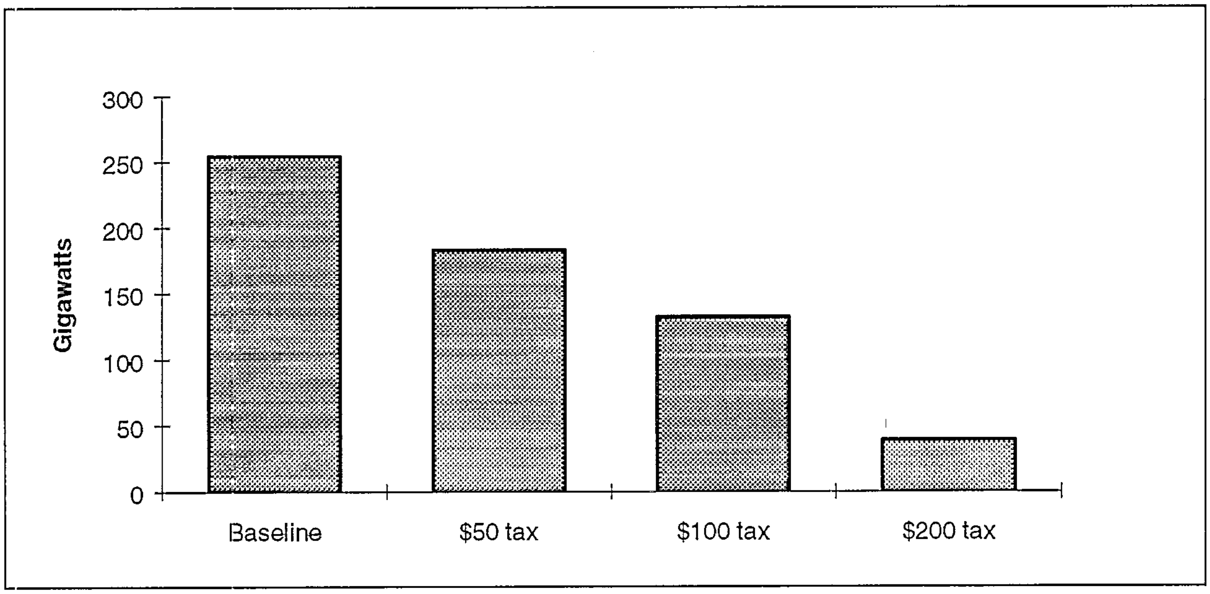

Figure 3-4
Cumulative Net Capacity Additions by 2010

In response utilities cut back capacity additions. Even so, capacity margins grow through 2010 because cancellation of new capacity additions is not sufficient to reduce capacity in line with reductions in demand.

Gas vs. Coal Prices

Changes in the relative prices of natural gas and coal due to the carbon tax give utilities an incentive to dispatch existing generating capacity differently, and to choose different fuels for new power plants. When natural gas prices exceed coal prices by less than some critical value, the lower capital cost of a natural gas generator makes natural gas the preferred fuel. Figure 3-5 depicts the spread between natural gas and coal prices, for the baseline. Currently natural gas appears to be the preferred fuel for new capacity. However, natural gas prices are forecasted to rise much more rapidly than coal prices. At some point between 1995 and 2000, the spread without carbon taxes is sufficiently narrow that choosing between natural gas and coal in new capacity is a very close call. After 2000 the spread increases in the base line, and utilities choose coal over natural gas for new base-load power plants in some regions.

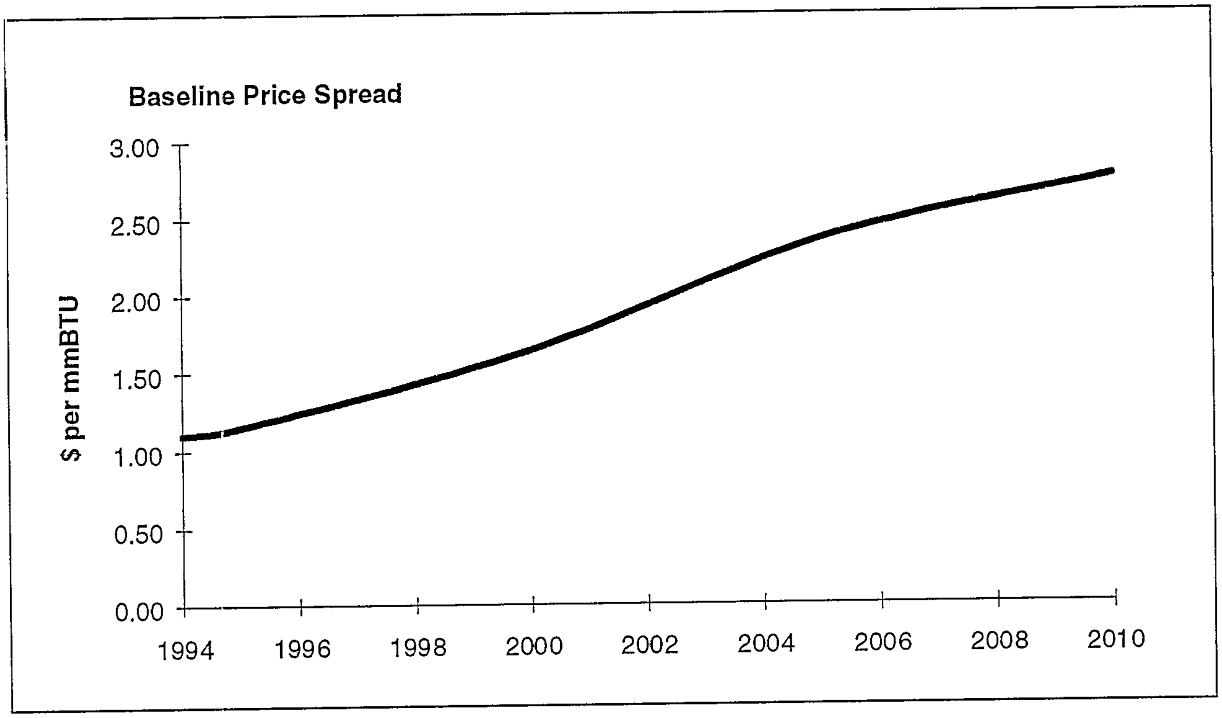

Figure 3-5
Coal and Natural Gas Price Spread

Changes in Capacity Additions at Different Taxes

Utilities face important decisions about what fuel to use in the new generating capacity they do build, and about whether to extend the lives of existing coal plants or to replace (or repower) them with natural gas. The next two charts (Figures 3-6 and 3-7) illustrate the cost comparisons involved in this decision for two regions: the Middle Atlantic Area Council (MAAC) and the Mid-America Power Pool (MAPP). They show the levelized cost of generating electricity in two regions, in different power plants, for the base line and three carbon taxes. The comparisons must be done at this level because the relative economics of coal and natural gas vary significantly across regions.

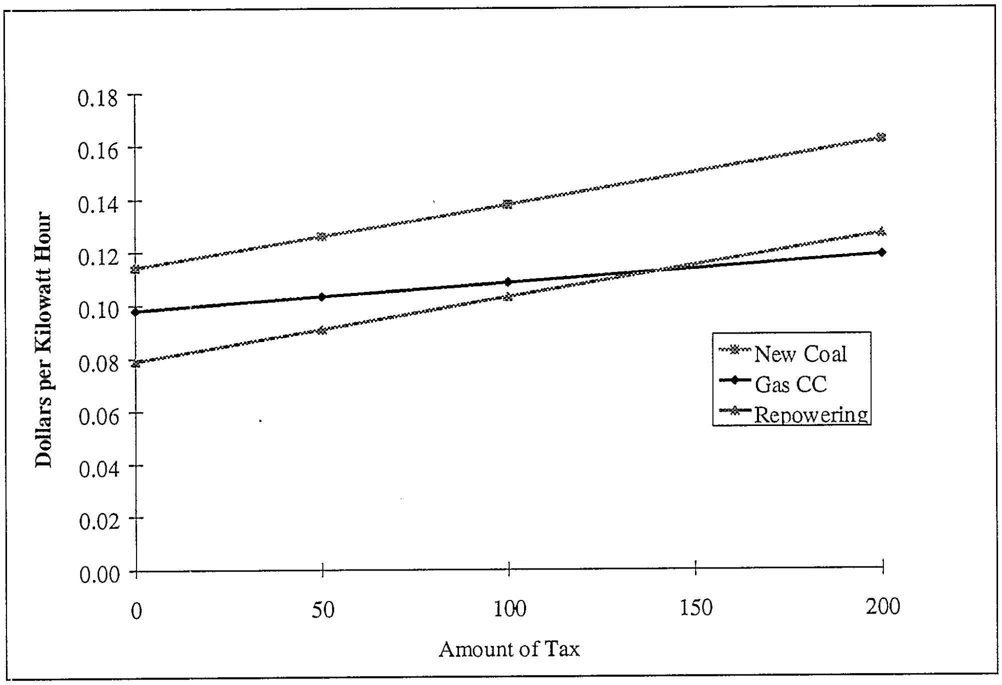

Figure 3-6
MAAC Base-load Costs of Generation

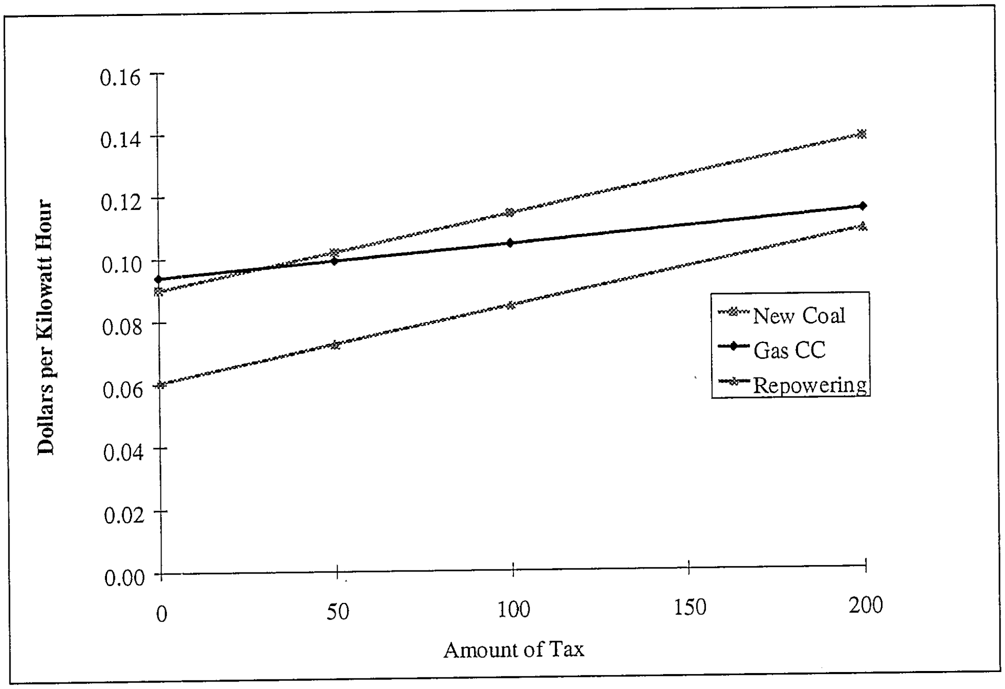

Figure 3-7
MAPP Base-load Costs of Generation

In MAAC, new gas combined-cycle is less costly than new coal in the base line, and under all the carbon taxes. However, for carbon taxes of $100 or less, repowering an existing coal plant with coal at the end of its nominal life is less costly than building a new combined-cycle gas unit. When carbon taxes reach $200, this is no longer true, and economics favor retiring a coal plant at the end of its nominal life and replacing it with a new gas combined-cycle unit.

In MAPP, economics in the base line favor new coal units over gas combined-cycle with no carbon tax. When the carbon tax reaches just $50, gas combined-cycle becomes less costly than new coal. However, even with a $200 carbon tax gas combined-cycle stays less economic than repowering coal in this region in 2010.

Gross Additions/Retirements from Utility Generating Capacity

The economics of choices among new and repowered coal and natural gas determine the impacts of different carbon taxes on electric generating capacity. Figure 3-8 depicts capacity additions and retirements under different carbon taxes. In the baseline, generating capacity is projected to expand by 85 gigawatts between 1992 and 2000. Most of the increase in generating capacity is natural-gas-fired (32 gigawatts of utility-owned, 18 gigawatts of non-utility generators), reflecting the need for capacity to meet intermediate and peaking requirements.[5] Most of the projected natural gas capacity additions are currently under construction. Coal plays a smaller role in meeting new capacity requirements, with utilities adding only 13 gigawatts (net) during this period and non-utility generators adding only 6 gigawatts. Of these coal additions, 63 percent are forecast to come from repowering aging coal capacity. The construction of all of the new coal capacity this decade is currently at least 50 percent completed. Seven gigawatts of nuclear capacity are also added during the period, and this capacity is also nearly completed. During 2001-2010, total electric generating capacity is projected to increase 87 gigawatts, with coal capturing a greater share of the addition.

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[5] This includes some oil-fired capacity, but only in the form of combustion turbines in locations where it is costly or impossible to provide natural gas service. The amount of fuel burned and electricity generated in there units is not a significant part of the story of fuel choice or switching.

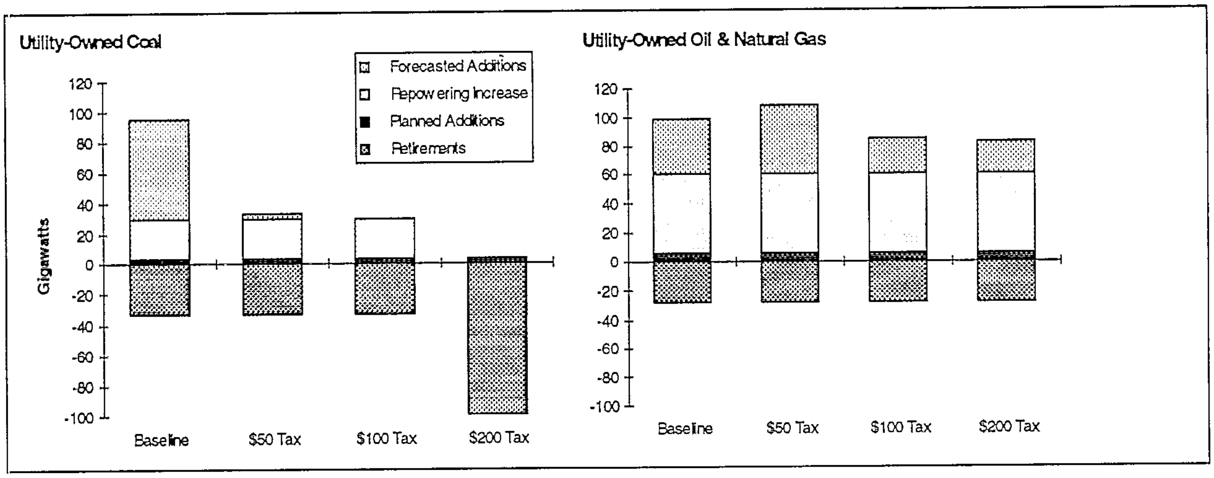

Figure 3-8
Electric Utility Net Generating Capacity Changes

The reduction in electricity sales induced by the carbon tax translates into a reduction in generating capacity requirements. Proposed capacity additions are canceled or delayed, depending on each plant's status in the planning and construction schedule. Retirement of coal-fired capacity in favor of new natural gas (or other) capacity is not economic until carbon taxes get to $200 per tonne. Consequently, changes in carbon emissions due to changes in the generating mix are limited to what can be accomplished by fuel share changes in new capacity, and dispatching changes in existing capacity. Lower electricity demand growth further limits utilities' ability to shift the fuel mix by reducing new capacity additions.

Coal-fired units are targeted first for cancellation, because new gas-fired traits are less costly than new coal-fired ones with a carbon tax of $50 or more. What happens to natural-gas-fired units depends on whether there is still need for additional capacity after all new coal-fired units are canceled.

There are strikingly different changes in utility capacity decisions with different carbon taxes. The $50 tax is sufficient to cause utilities to cancel most of the forecasted additions of coal-fired capacity in the 2001-2010 time period. Furthermore, electricity demand growth is still high enough for utilities to increase their construction of natural-gas-fired capacity to substitute for some of the canceled coal units.

Coal is at more of a disadvantage to natural gas in the $100 tax case, but there are no remaining new coal units to cancel. The reduced need for capacity, therefore, must come out of natural gas. A significant proportion of planned natural gas combined-cycle units must also be canceled or delayed. The utilization of natural gas units is increased as much as possible, however, providing a small, offsetting increase in natural gas demand.

After 2000, considerably more coal units are planned in the base line than in the earlier period. Consequently, most of the cancellations during this period are coal plants. Some new generating capacity is still required to meet increases in electric sales and to replace retiring coal capacity in the $100 tax case. Due to their cost advantage, natural gas combined-cycle units play the dominant role in meeting this need.

Non-utility generators bear a large share of the reduction in electricity sales because of their substantial expected expansion in the base line. Non-utility generating capacity falls from 165 gigawatts in 2010 in the base line to 123 gigawatts with the carbon tax, with 28 gigawatts of the reduction in coal-fired units and 14 gigawatts in gas-fired units.

With a $200 tax, another break point is passed. It now becomes cheaper to build a new, natural-gas-fired power plant than to repower a coal plant at the end of its normal life. Thus the coal units are retired, and new natural gas units are built in their place.

Fuel Switching at Different Taxes

The changes in the relative prices of coal and natural gas combine with cancellations of new capacity to change the fuel mix at electric utilities. Figure 3-9 depicts utility fuel use under different carbon taxes. Delaying new natural gas combined-cycle generating units in the late 1990s significantly reduces utility natural gas demand relative to baseline levels, despite the fact that relative price shifts provide the variable cost incentive to dispatch natural gas ahead of coal in some instances. With the $100 carbon tax in 2000, utility coal demand is about 5 percent below base-line levels, while natural gas use and petroleum use is about 25 percent lower. This impact is largely reversed by 2010 as the new capacity is projected to be principally fueled by natural gas. In 2010, utility natural gas use is down only 6.5 percent from base-line levels and petroleum use returns to base-line levels, while coal use declines 18 percent.

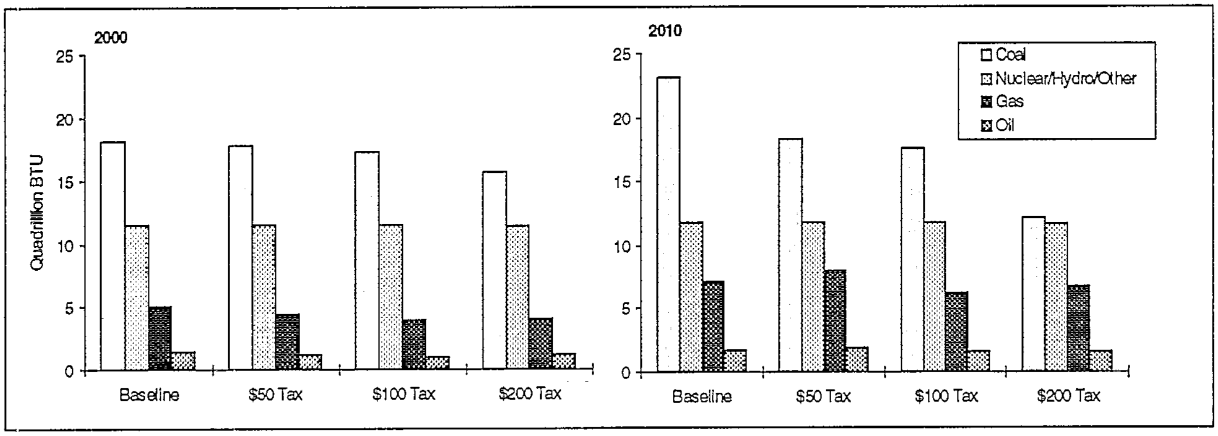

Figure 3-9
Electric Utility Fuel Consumption in 2000 and 2010

In 2000 all carbon taxes reduce the consumption of natural gas, despite the advantage that natural gas is given over coal, because a large share of the new generating units now planned for 2000 are gas-fired. The reduction in electricity demand thus leads to a disproportionately large drop in natural gas capacity. The $100 tax does drive the variable cost of generation from natural gas combined-cycle traits below that of coal in some regions through 2000, so that in some cases natural gas is dispatched ahead of coal. With minimal excess natural-gas-fired combined-cycle capacity, however, this dispatching is limited to just 100 trillion cubic feet (tcf).

In 2010 coal consumption does fall, especially at the higher taxes. After 2000, considerably more coal units are planned in the base line than in the earlier period. Consequently, most of the cancellations during this period are coal plants. Some new generating capacity is required by 2010 to meet increases in electric sales. With a $50 carbon tax, there is enough growth that switching new construction from coal to natural gas increases natural gas consumption. In the $100 case new construction is cut so far that even switching new capacity to gas leaves natural gas consumption below baseline levels. In the $200 case it is worthwhile to replace retiring coal units with natural gas rather than repowering them. Due to their cost advantage, natural gas combined-cycle units play the dominant role in meeting this need. Cancellation of forecasted new coal plants works together with the incentive to dispatch natural gas ahead of coal in this time period, so that natural gas consumption is higher with a $200 carbon tax than with a $100 tax. The import is that it takes either modest or very ambitious goals for emissions reduction to bring about any increases in natural gas use. Goals of holding emissions to 1990 levels through 2010 appear to be in the range where natural gas use would decline–planned capacity would be deferred but replacing rather than repowering coal units would not be necessary.

Primary Energy Supply Impacts

Changes in fossil energy use in the end-use sectors and at electric utilities in 2010 are summarized as total primary energy impacts in Figure 3-10. Primary energy supply is different from total end-use consumption described in Figure 3-2. Primary energy supply includes oil, gas and coal used for generating electricity, as well as the amount consumed directly in the end use sectors. Thus impacts on primary coal supply are much larger than impacts on end use coal consumption, because most of the reduction in coal use comes at electric utilities. Impacts on primary natural gas supply are less, at least for the $50 tax, than are impacts on end use natural gas consumption, because natural gas use at electric utilities increases while end-use consumption of natural gas falls.

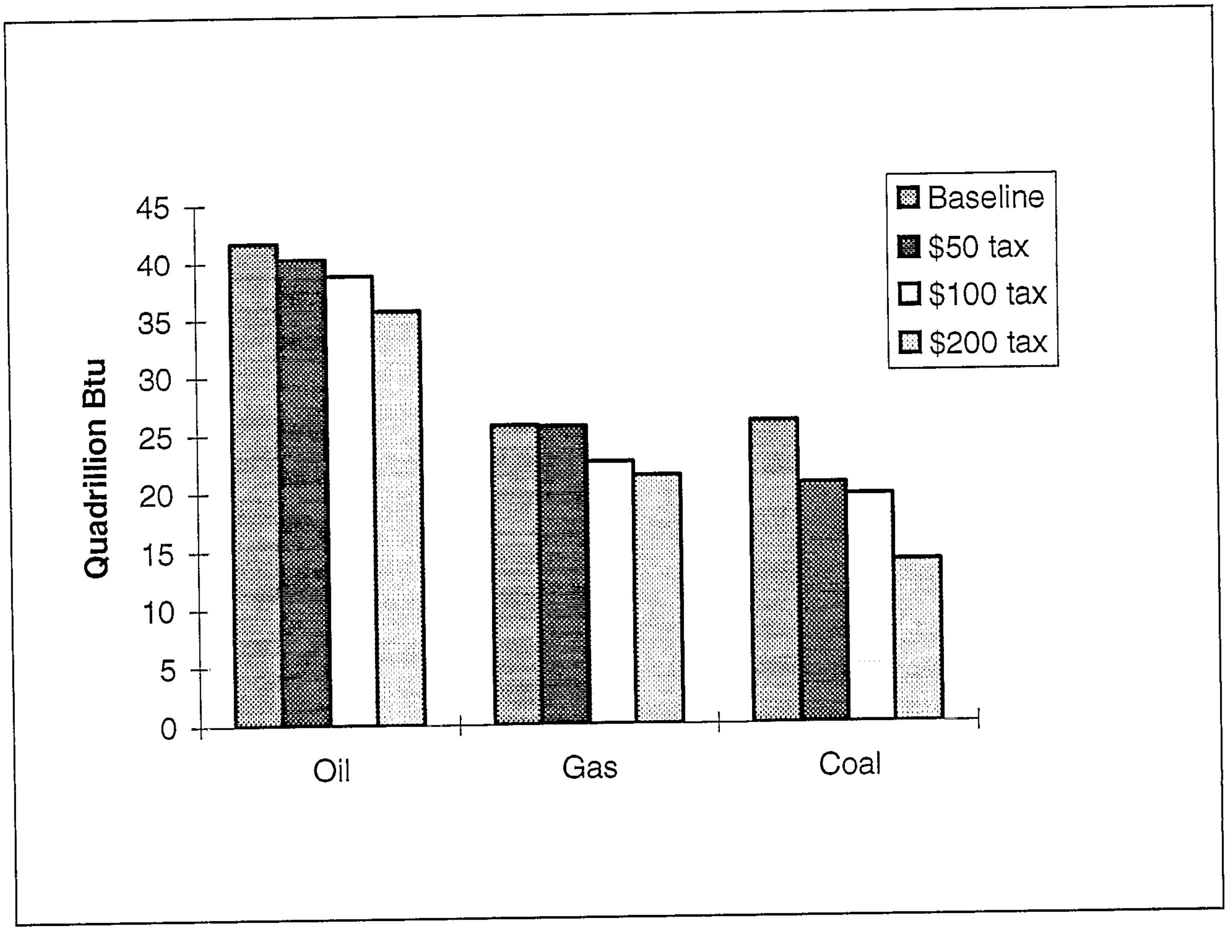

Figure 3-10
Primary Energy Impacts in 2010

A $50 carbon tax has no effect on natural gas consumption, as reductions in end-use consumption of natural gas are offset by utility fuel switching into natural gas and off coal. The 9.5 percent reduction in carbon emissions from base-line levels in 2010 attributable to the $50 tax comes almost entirely from reductions in coal use in electric utilities.

The $100 carbon tax reduces emissions in 2010 by 15.4 percent from base-line levels. The limited opportunities for substituting natural gas for coal are largely taken up with the $50 tax, so that the reductions in total energy demand from the $100 tax are spread more evenly across all fuels. Coal consumption is not very different between the $50 and $100 taxes, but natural gas use is significantly reduced. Oil shows the smallest decline compared to the other fuels because of a lack of fuel-switching possibilities and the lower percentage price increase attributable to the carbon tax.

The $200 tax reduces emissions in 2010 by 27.9 percent from base line. The reduction comes from lower consumption of both coal and oil, with small additional reductions in natural gas. At that level of tax, the price advantage of natural gas is sufficient to produce a significant change in utility capacity expansion plans away from coal repowering and toward natural gas. This swing offsets most of the reduction in end-use natural gas demand due to the higher tax on gas.

4

WHAT ACCOUNTS FOR THE IMPACTS OF THE HIGHER ENERGY COSSTS ON THE OUTPUT OF THE ECONOMY

Overview of Impacts

Carbon taxes affect the overall performance of the economy in two important ways. The most immediate effect of carbon taxes appears in the form of a *price shock.* Higher energy prices contribute to inflation and depress consumer spending. The Federal Reserve Board has in the past been unwilling to accommodate such price shocks fully, and has pursued a neutral monetary policy that leads to higher interest rates, which retard investment and further slow the economy. This action offsets some of the inflationary pressure of energy price increases, but also leads to at least a temporary period of depressed economic activity and higher unemployment. The resulting losses in GDP are referred to as the cyclical impacts of a carbon tax.

Carbon taxes also have a longer lasting effect on the productive potential of the economy. The higher costs of energy brought on by carbon taxes mean that more resources must be used to produce energy services and less resources are available for producing other goods and services that consumers enjoy. These economic impacts of energy taxes can be measured as *reductions in potential GDP,* which is defined as the value of goods and services that could be produced when using all available resources fully.

The impacts of carbon taxes on real GDP are composed of both cyclical effects and losses in potential GDP. Figure 4-1 summarizes the overall losses in real GDP from the three carbon taxes studied. The $100 carbon tax results in the loss of 2.3 percent of GDP by 2010. Losses rise with higher carbon tax rates, and doubling the tax rate approximately doubles the loss in GDP.

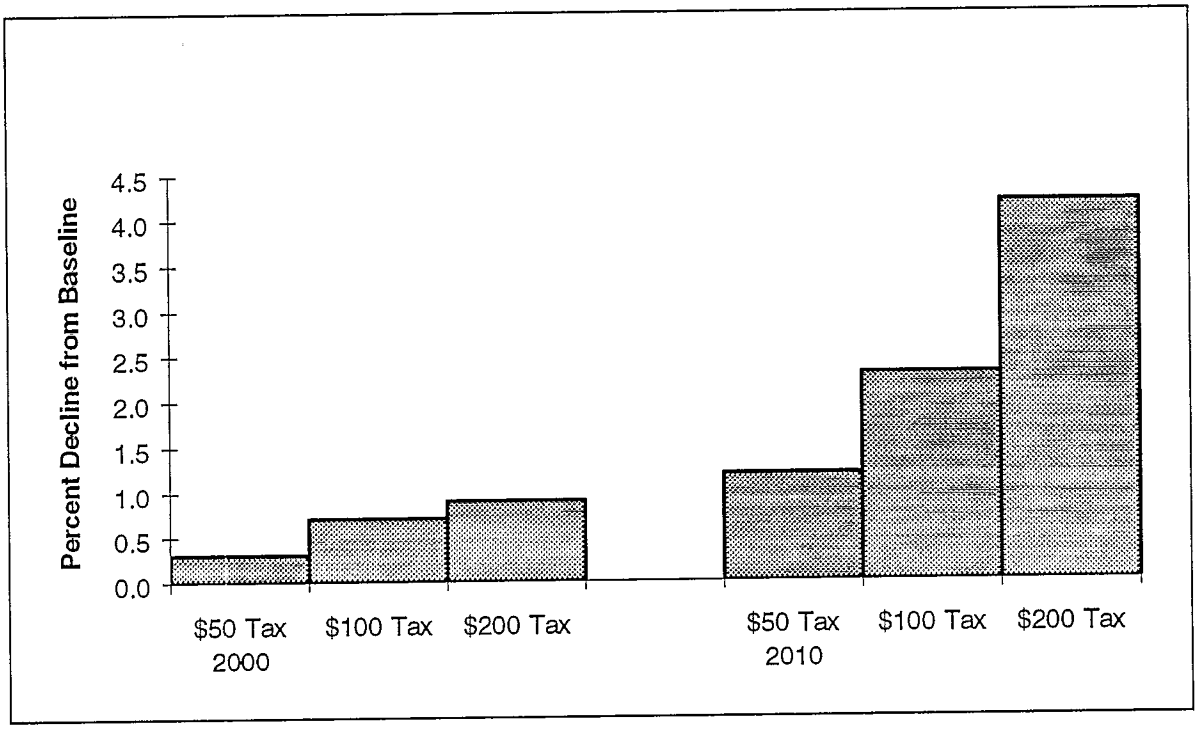

Figure 4-1
Real GDP Losses from Carbon Taxes

Table 4-1 provides more detail on the aggregate economic impacts of carbon taxes, which include cyclical effects and reductions in potential GDP. Some highlights of the impacts for a $100 carbon tax are described below.

Carbon Tax Receipts

Annual carbon tax receipts climb to $186 billion by 2000 and $277 billion by 2010, and total $2.9 trillion over the 1995-2010 period. In 1987 dollars, receipts equal $122 billion in 2000, $128 billion in 2010, and total $1.6 trillion between 1995-2010.[6] Nominal receipts represent 2.1 percent of base-line GDP in 2000 and 1.8 percent in 2010.

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[6] Real dollar statistics are specified in 1987 dollars for consistency with the real dollar GDP statistics projected in this report. In 1992 dollars, carbon tax receipts equal $147 billion in 2000, $155 billion in 2010, and total $1.9 trillion between 1995-2010. Statistics are converted from 1987 dollars by multiplying 1.209.

Carbon Tax Recycling

Carbon tax revenues are recycled through lump-sum reductions in personal income taxes. That is, average personal income tax rates are reduced from base-line levels, white marginal tax rates are maintained at base-line levels. The amount of carbon tax revenues actually recycled through personal income tax reductions is constrained by the need to keep the *ex post* federal deficit at base-line levels.

Table 4-1
Macroeconomic Impacts of Alternative Carbon Taxes

		2000			**2010**	
Difference from Base Line	**50**	**100**	**200**	**50**	**100**	**200**
Carbon Tax Receipts (Billion $)	97	192	363	148	277	500
Percent of Base Line GDP	1.1	2.1	4.0	1.0	1.8	3.2
Prices (%)						
GDP Price Deflator	1.1	2.3	3.9	2.0	3.9	7.2
Interest Rates (Basis Points)						
Real 10-Year Bond Rate	5	14	31	27	51	85
Exchange Rates (%)						
Nominal	-0.8	-1.8	-2.6	-1.1	-2.2	-4.3
Real GDP (%)	-0.3	-0.7	-0.9	-1.2	-2.3	-4.2
Consumption	0.0	-0.3	-0.1	-1.0	-1.9	-3.7
Business Fixed Investment	-1.2	-2.5	-4.0	-2.4	-4.6	-8.5
Residential Investment	-1.0	-2.3	-3.8	-1.5	-3.2	-6.2
Exports	-0.2	-0.4	-0.7	-0.9	-1.9	-3.2
Imports	-0.5	-1.2	-1.5	-1.5	-2.9	-5.9
Employment (Thousands)	-100	-300	-400	-300	-500	-1100
Net Effective Capital Stock (%)	-0.4	-I.1	-1.5	-2.2	-4.3	-7.7
Potential GDP (%)	-0.2	-0.5	-0.6	-1.0	-1.9	-3.4
Unemployment Rate	0.04	0.11	0.14	0.09	0.18	0.39

With the $100 carbon tax, only 47 percent of its revenues are used to reduce personal income taxes over the 1995-2010 period. The remainder of the receipts must be used to cover increases in federal expenditures or retained to offset reductions in other tax receipts induced by the carbon tax. Another 17 percent is recycled to consumers through higher transfer payments (due to the higher unemployment rate); 20 percent flows to both consumers and businesses to cover increased federal interest payments (due to the higher interest rates); and 4 percent goes to businesses to cover the higher prices associated with constant real-dollar federal purchases. The government retains 8 percent to offset reductions in corporate income taxes and 1 percent to offset reductions in other federal tax receipts.

Inflation

Assuming the tax is fully passed on to consumers in the form of higher prices and that wage rates, productivity, exchange rates, and energy usage rates are not affected by the tax, the magnitude of the tax relative to GDP suggests roughly a 2 percent rise in the GDP price level in the 2000-2010 period. However, nominal wage and compensation rates are pushed 0.4 to 0.5 percent above base-line levels in response to the tax. Furthermore, the tax reduces energy usage and the productive capital stock, leading to a 0.7 to 2.4 percent reduction in productivity. Consequently, unit labor costs (compensation rates divided by productivity) are 1 to 2.8 percent above base-line levels in the 2000-2010 period. This raises US production costs significantly above that suggested by the initial energy price increases. In addition, the nominal exchange rate falls 2 to 3 percent in response to higher US prices, and this leads to a rise in the costs of imported goods. The effects of slightly higher wage rates, and significantly lower productivity and nominal exchange rates are only slightly offset by increased energy efficiency.

The carbon tax ultimately pushes the GDP price deflator 2.3 percent above base-line levels in 2000, and 3.9 percent above in 2010. Inflation rates average 0.2 to 0.3 percentage point higher between 2001 and 2004, and 0.1 percentage point higher between 2005 and 2010.

Interest Rates

This analysis assumes a neutral Federal Reserve policy. That is, no increase in bank reserves relative to the base line is assumed to accommodate the carbon tax, nor is a decrease assumed to offset its inflationary impact. This neutral monetary policy stance was taken in order to study just the effects of the tax, without confusing such fiscal policy effects with accompanying monetary effects. It should be noted, however, that monetary accommodation would reduce the negative real GDP impact but raise the inflation burden, while monetary restraint would increase the negative GDP impact but reduce the inflation burden.

With neutral monetary policy, the real federal funds rate rises 53 basis points above base-line levels in 2000 and 118 basis points above in 2010. Real long-term rates climb less than short-term rates (only 14 basis points above the base line by 2000, and 51 basis points above the base line by 2010) as inflation expectations improve, the economy remains weak, and foreign interest rate movements trail the US moves.

Exchange Rates

With a carbon tax, changes in the dollar's trade-weighted exchange rate (measured in foreign currency units per dollar) are primarily induced by changes in US prices relative to foreign price levels and changes in real long-term interest rate differentials.

US prices rise approximately 4 percent by 2010 in response to the unilaterally imposed carbon tax, compared with only a 0.3 percent rise in foreign prices; real US bond yields rise over 50 basis points by 2010, compared with only a 25 basis point rise in foreign yields.

The small rise in foreign prices is attributed to the higher prices the foreign economies must pay for imports from the United States. The 50 percent movement in real foreign rates relative to US rates is based on ongoing analysis of international interest rates by DRI. DRI's analysis concludes that foreign rates respond to changes in US rates. However, the magnitude of the foreign rate response depends on why the US rates move. US rate moves caused by world oil price shocks or world recessions are likely to be matched one-for-one in foreign bond markets; US rate moves caused by US fiscal policy changes, however, are matched half-way on average.

The increase in relative US prices, taken by itself, lowers the nominal exchange rate relative to base-line levels by an equal amount (or equivalently, maintains the real exchange rate). Such an exchange rate move would maintain purchasing power parity and the same level of US competitiveness, on average, in world markets. (Of course, goods with below-average energy content would experience a relative price fall and goods with above-average energy content would experience a relative price rise.)

The dollar is not able to fully reflect relative price changes, however, since relative increases in real US interest rates push the real exchange rate higher. The nominal exchange rate falls only 1.8 percent in 2000 and 2.2 percent in 2010 (as opposed to just under 4 percent), as the real exchange rate is pushed up 0.4 percent in 2000 and 1.8 percent in 2010. The rise in the real exchange rate makes US goods less competitive, on average, in world markets.

Real Disposable Income

Recycling carbon tax revenues through reductions in personal income taxes only maintains consumers' real disposable income through 2000. In the post-2000 period, once the tax is fully phased in and its full impact on the economy is felt, proportionately more of the tax revenues must be retained to hold the deficit to baseline levels. In addition, the real wage component of disposable income posts stronger declines as unemployment drives down both man-hours and the real wage rate. Consequently, recycled tax revenues are not large enough to compensate for these wage losses and offset the higher prices consumers must pay for goods and services.

Where Do the Economic Losses from Carbon Taxes Show Up?

GDP measures the total output of goods and services in the economy. When this total falls, there are different changes in each of its components. Each component contributes in its own way to economic well-being, and looking deeper into how carbon taxes affect the economy begins with a look at how the components of GDP are changed. In order to look in greater detail at economic impacts, we focus on the $100 carbon tax case.

Reduced consumption accounts for about half the loss in GDP, and reduced business investment accounts for about one-third. The net trade balance actually improves slightly, due largely to greater domestic saving and reduced investment. The government deficit is held at base-line levels by recycling a portion of the carbon tax revenues, so that there is no net change in government's share of GDP.

Higher inflation and interest rates lead to a 0.7 percent ($43 billion in 1987 dollars) reduction in real GDP from base-line levels in 2000 and a 2.3 percent ($168 billion) reduction in 2010. Investment suffers most from a carbon tax with lump-sum recycling in percentage terms. Consumption is supported by the recycling in the near-term, but weakens significantly in the post-2000 period. While not hit as hard as investment in percentage terms, as the largest component of GDP it posts the largest dollar decline. Net trade provides an offsetting boost to GDP (see Figure 4-2).

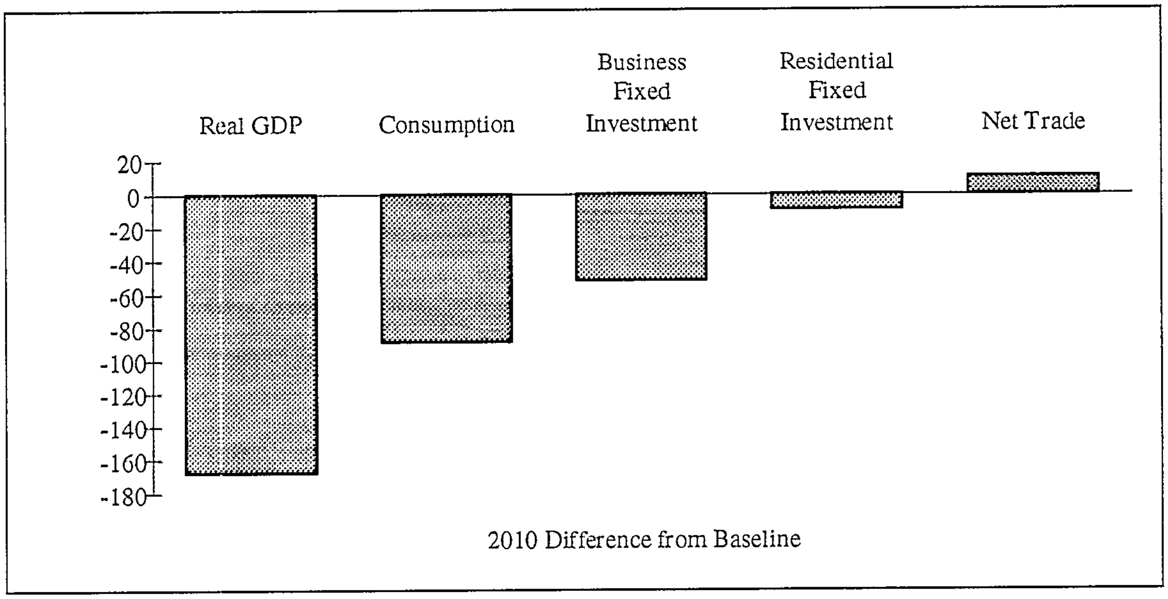


Figure 4-2
Changes in the Components of Real GDP (Billions of 1987 Dollars, 2010)

With lump-sum recycling, real consumption declines proportionately less than aggregate GDP, but more than real disposable income. Real consumption declines 0.3 percent below base-line levels in 2000, and 1.9 percent in 2010, leading to a 0.7 percentage point rise in the saving rate by 2010. The rise in the saving rate is attributed to higher interest rates and unemployment, and lower consumer confidence.

Exports suffer from a slight decline in foreign GDP and a rise in the real exchange rate (induced by the rise in real interest rates). Foreign GDP slips 0.3 percent below baseline levels by 2010 due to reduced US demand for foreign exports. The rise in the real exchange rate leaves average US export prices nearly I percent above competitive foreign prices in 2000, and 2 percent above in 2010. This drives real exports down 0.4 percent ($3 billion) below base-line levels in 2000, and 1.9 percent ($29 billion) in 2010.

While imports have a competitive price advantage over domestically produced goods as a result of the carbon tax, lower domestic demand more than offsets the price effect on import demand. Real imports fall 1.2 percent ($11 billion) below base-line levels in 2000, and 2.9 percent ($39 billion) below in 2010. Net trade thus improves by $8 billion in 2000, and $10 billion in 2010.

What Will Consumers Have Less Of?

Higher energy costs lead to several adjustments on the part of consumers, including reductions in expenditures on energy itself–gasoline for transportation, electricity for heating and air conditioning, lighting and appliances, natural gas and oil for heating. These show up as the largest percentage reductions in categories of consumer spending in Figure 4-3.

Demand for some consumer durables and services is also directly affected by energy prices. Higher energy costs drive up fuel prices, and therefore increase the cost of all forms of transportation. Higher gasoline prices have a slight depressing effect on auto sales because they make driving more expensive, and may also lead consumers to purchase smaller, more fuel-efficient vehicles that cost less. These price effects lead to only a small decrease in spending on new automobiles because gasoline is not a dominant component of the cost of automobile travel and older vehicles must be replaced eventually. Moreover, some improvements in fuel economy make automobiles more costly. Consumer spending on other transportation services, such as air travel, is influenced more strongly because fuel is an important component of the cost of such travel and the demand elasticity for air travel is relatively high.

Both these declines in consumption result from price effects–energy and transportation become more expensive than other goods not so strongly affected by energy price increases. Higher energy prices lead consumers to make do with less energy and transportation services in order to keep some income available for spending on other goods and services that now appear relatively less costly and more worthwhile.

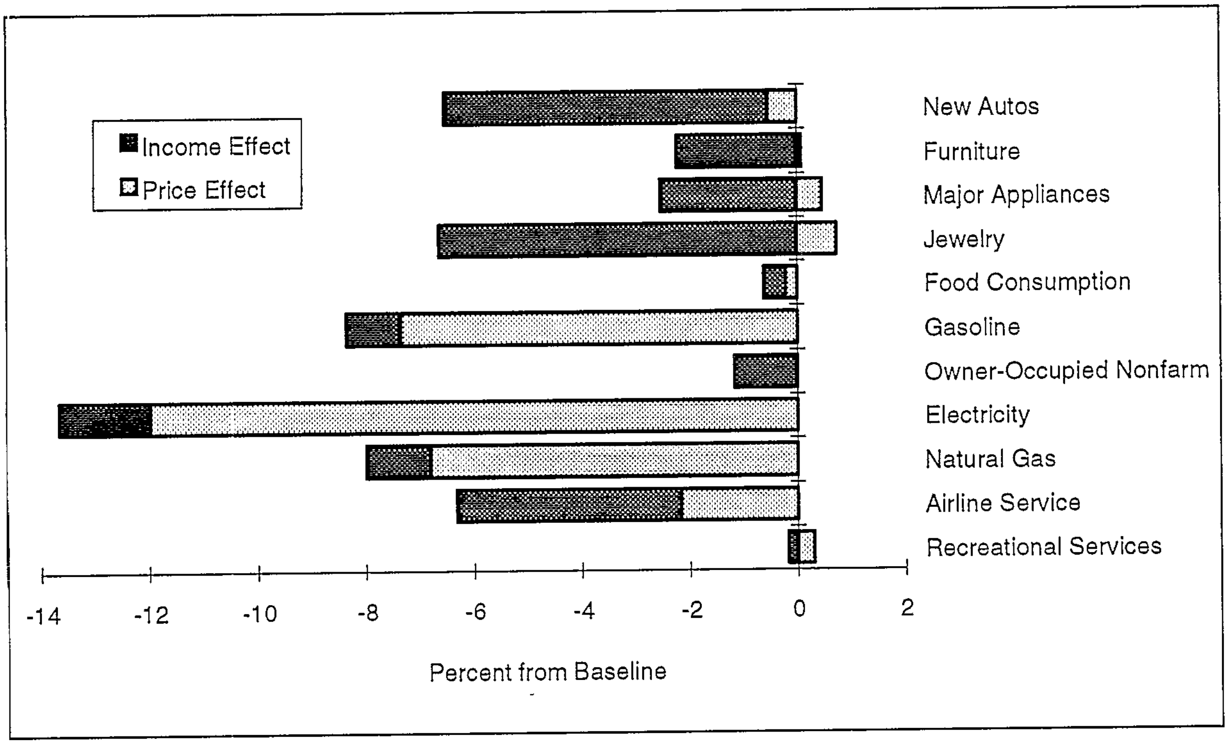


Figure 4-3
Effects on Consumption by 2010

Another important effect on consumption comes directly from the loss in real income caused by carbon taxes. Spending on some categories of consumption is particularly sensitive to income, and spending on other categories is quite insensitive. Figure 4-3 shows that there are large income related drops in spending on consumer durables–major appliances, furniture, and new autos–and on luxury items like jewelry. Spending on these items drops more than proportionately to the drop in real disposable income due to the carbon tax. In the case of major appliances, furniture, and jewelry, the rise in the price of energy actually leads to diversion of some spending toward these items, but the price effect is overwhelmed by the effect of reduced income. There is some income-related decrease in spending on food and housing, but less than in proportion to the drop in income. Some kinds of consumption, whose cost is not increased by higher energy prices and that are relatively insensitive to income, have roughly offsetting price and income effects. Recreational services are one example.

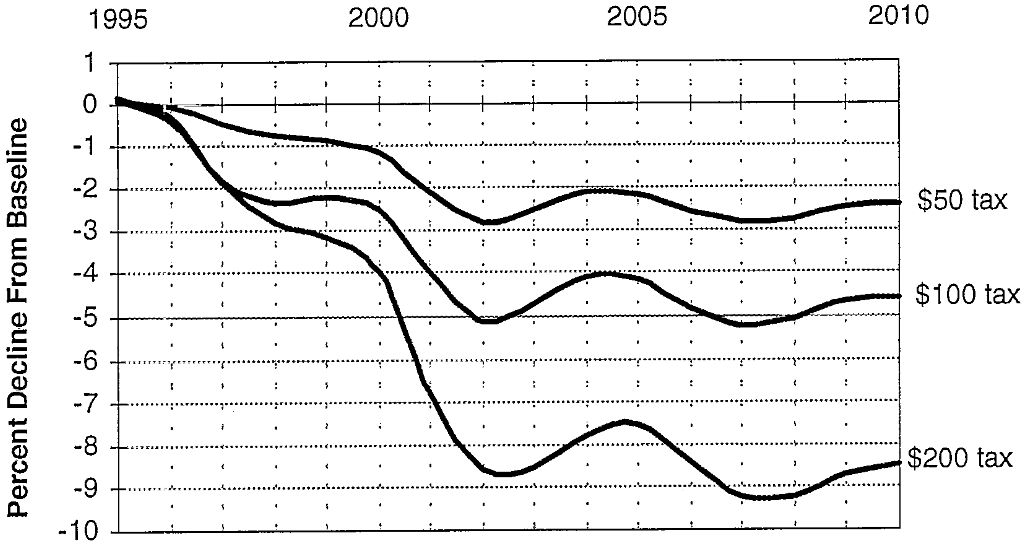
Investment and Economic Growth

Business fixed investment is pushed down proportionately more than aggregate GDP (2.5 percent in 2000 and 4.6 percent in 2010) in response to higher real asset purchase prices, higher interest rates, and lower domestic demand. Equipment and structures used by energy producers and suppliers are hardest hit.

Investment in residential structures drops 2.2 percent below base-line levels in 2000, and 3.1 percent by 2010 as the cost of owning and operating housing units rises 5 percent more than disposable income by 2010. Costs are driven up primarily by higher mortgage rates and utility bills.

Figure 4-4 shows how investment declines over time due to carbon taxes, and resulting changes in the aggregate capital stock. Investment drops rapidly to about 2003, and then cycles up and down. As a result of this lower annual rate of investment, there are smaller additions to the capital stock and the capital stock falls progressively further below its base-line levels.

Real Business Fixed Investment



Net Effective Capital Stock

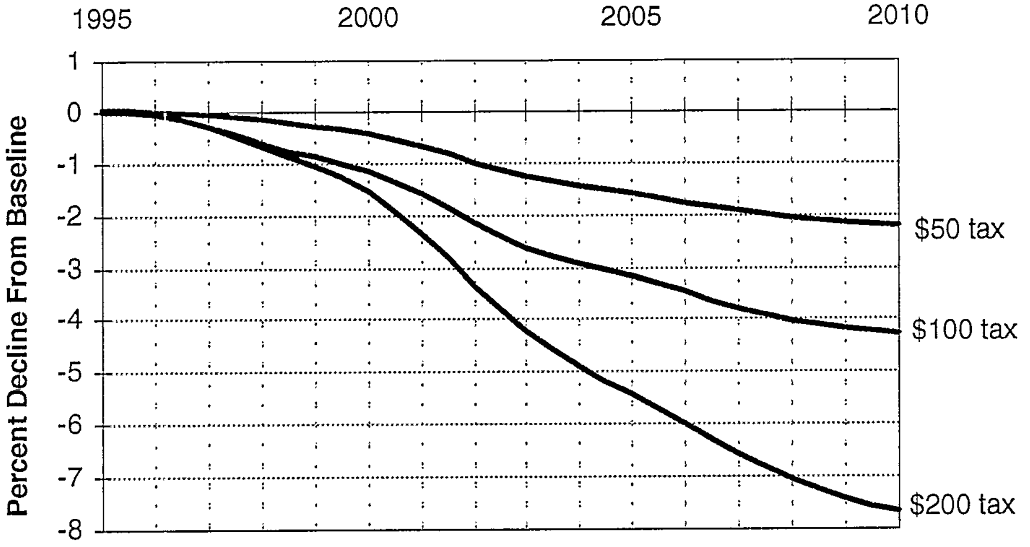


Figure 4-4
Impacts of Carbon Taxes on Investment

The decline in the capital stock is considerably greater than the drop in output, and is induced by an increase in the real cost of capital services. The real cost of capital services rises throughout the analysis period, leading to 2 percent decline in the capital-to-output ratio in 2010. The capital-to-output ratio rises relative to base-line levels in the initial years of the carbon tax, however, as the decline in output idles exiting capital (Figure 4-5).

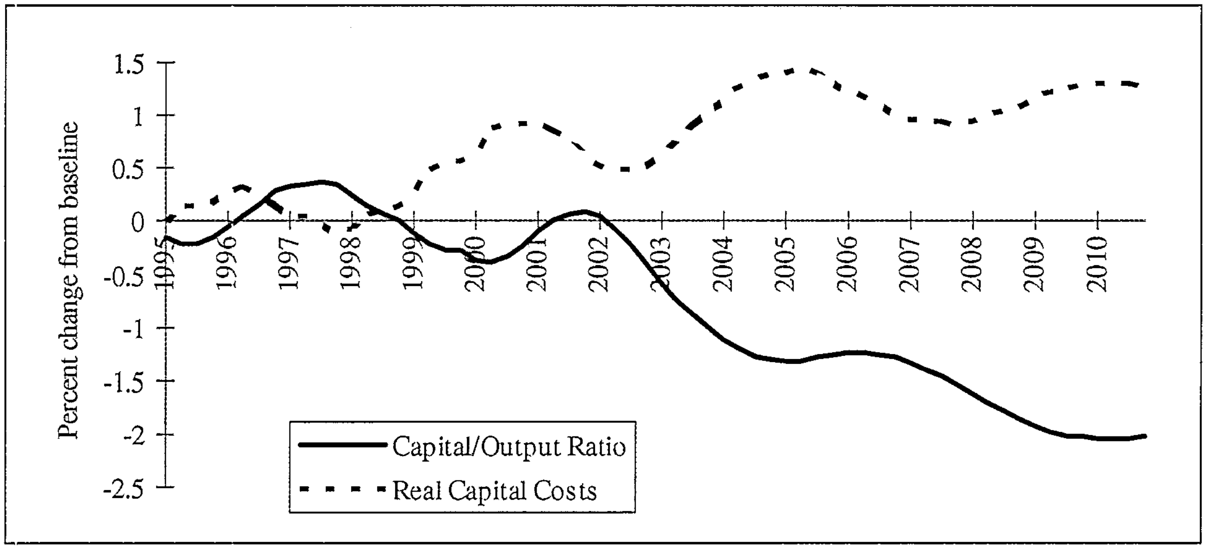


Figure 4-5
The Capital-to-Output Ratio Fails as Capital Costs Rise

To the extent that carbon taxes reduce the rate of investment, they imply lower future stocks of capital than would otherwise be the case. With lower capital stocks, the economy's productive capacity is lowered, implying lower levels of future output than would be achieved if there were no carbon tax.[7] While a carbon tax can be expected to permanently lower the path of GDP, a constant carbon tax is not likely to have a permanent effect on the rate of growth of GDP. According to conventional neoclassical growth analyses, the long-run rate of growth of the economy is determined by the rate of labor force and labor productivity growth. Such analyses predict that there is no long-run effect of a carbon tax on the rate of investment as a share of GDP, and that the rate of capital formation will ultimately conform to the rate of labor force and productivity growth. Thus, traditional analyses predict that, although a carbon tax may reduce the size of the capital stock and of GDP in any given year (relative to their size under a business-as-usual scenario), the long-run rate of growth of the capital stock and the economy as a whole will be unaffected by this tax.

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[7] With a lower capital stock, aggregate output must be lower unless the carbon tax has an offsetting positive impact on the productivity of variable inputs such as labor, energy, and materials. There is little reason to expect that an offsetting impact of this kind would occur.

During the adaptation to an energy cost increase, however, the rate of growth will be less if productive investment is retarded. How long this transitional period will be, and how great the loss in growth, are questions that matter both for economic performance in the near term and for the ultimate long-term reduction in the level of GDP.

Investment enhances productivity by building a larger stock of capital equipment–machinery, buildings, equipment. These additions to the capital stock are the basis for economic growth, making it possible to produce more goods and services with the same effort from the labor force. Lower levels of investment and capital translate, for a period of several decades, into lower rates of economic growth. At some point, the smaller additions to the capital stock and the size of the stock itself come into balance, and investment represents the same percentage increase in capital that it represented before the carbon tax was imposed. At this point the economy returns to its long-term rate of economic growth, but at a permanently lower level of output because of the lower capital stock.

This steady state is just reached by 2010. In that year the percent reduction in investment, roughly 4 percent for the $100 tax and 8 percent for the $200 tax, is matched by the reduction in the capital stock. From 2010 onwards investment is sufficient, in relation to the size of the capital stock, to maintain growth of the capital stock at the same rate as in the base line.

In terms of impacts on growth rates, the economy returns to its long-term growth rate of 2.23 percent by 2010. During the 1995-2010 period the annual rate of growth is reduced from 2.23 percent to 2.11 percent, a drop of 0.12 percent.

Why is Investment Reduced?

Economic analysis and experience have shown that there is not a fixed relationship between economic growth and growth in energy use. This decoupling of energy and economic growth rates means that even goals for zero growth in emissions do not require zero economic growth. However, there are connections between energy prices and investment that do suggest that higher energy costs will affect economic growth. These connections have to do with the effects of energy prices (and taxes) on the *output, on the cost* of capital goods, and on *interest rates.*

As Figure 4-6 indicates, two-thirds of the estimated decline in capital investment is attributable to the decline in output, and one-third is attributed to the rise in the real cost of capital services (real user cost). Furthermore, half of the rise in the real cost of capital services is attributed to higher real asset purchase prices and half to higher interest rates.

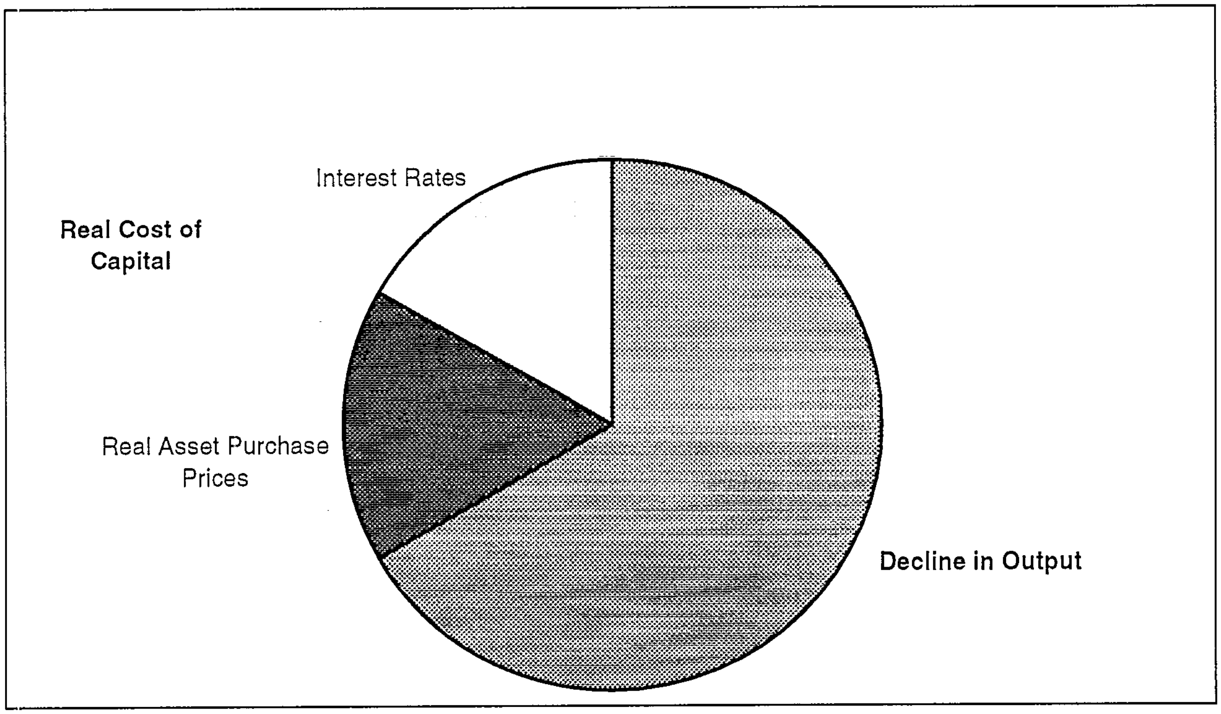

Figure 4-6
Decline in Capital Investment Components

Cost of Capital Goods. Capital goods industries are more energy-intensive than average for non-energy industries. As a result, higher energy costs will raise the cost of investing in much the same way that higher interest rates do, and thus will reduce investment and economic growth. Nominal asset prices rise somewhat less than the aggregate price level, suggesting *a fall in the* real cost of capital goods. However, the carbon tax drives a wedge between the prices consumers pay for goods and services and the prices producers receive. Deflating nominal asset prices by producers' after-tax product prices, rather than the aggregate price level, implies a *rise* in all real asset prices. Table 4-2 lists the average changes in real asset prices from the carbon tax for 30 investment categories for the 2001-2010 period. (Changes in real asset prices for the "other" public utility structures and "other" buildings are not reported since these categories are defined as residuals.) On average, real asset prices rise 1.3 percent above base-line levels over the 2001-2010 period. Increases in real asset prices range from 0.1 to 3.6 percent. Real asset price increases associated with 90 percent of investment fall in the slightly narrower range of 0.7 to 3.0 percent.

Table 4-2
Impact of the Carbon Tax on Investment Determinants
(Percentage Change from Base Line, 2001-2010)

	Share of Total Investment (%)	Real Asset Price	Real User Cost	Output
Equipment	77.00			
Autos	5.71	0.70	1.50	-2.14
Computers	26.49	1.23	2.09	-2.14
Other	44.80	1.38	2.71	-2.81
Structures	23.00			
Public Utility	3.96	1.67	4.00	-10.89
Buildings and Other Structures	17.15	1.21	3.27	-1.89

Interest Rates. Changes in real user costs result from changes in real asset purchase prices and changes in the cost of funds (i.e., a weighted average of debt and equity costs). After-tax interest rates are driven up an average 30 to 44 basis points above baseline levels, while equity costs rise 4.4 percent in response to the carbon tax. On average, increases in real asset prices account for 51 percent of the rise in user costs relative to base-line levels over the 2001-2010 period, and increases in the cost of funds account for 49 percent.

The increases in real user cost may be more important in evaluating the deadweight loss from a carbon tax than its small absolute magnitude suggests. Evidence from many economic studies on the deadweight losses from taxation of capital suggests that there is already a large tax distortion discouraging investment. One estimate is that an additional $1 of revenue from the corporate income tax causes a deadweight loss of $0.47. (Jorgenson and Yun 1990). A simple rule-of-thumb for estimating deadweight losses from taxation is that deadweight loss increases in proportion to the square of the tax, so that with high tax rates the marginal loss from an additional dollar of tax revenue is far higher than the marginal loss from the first dollar. Higher capital good prices due to the carbon tax have the same effect on investment as an increase in the corporate income tax (Bovenberg and Goulder 1993). Therefore the deadweight loss from the portion of a carbon tax passed on to capital goods prices is the same as the deadweight loss from increasing the corporate income tax. Even a small carbon tax would cause a deadweight loss of $0.47 for every dollar of revenue attributable to energy use in capital goods industries.

Output Effects. All output drivers decline relative to base-line levels in response to the carbon tax (Table 4-2). While the average decline in output over the 2001-2010 time frame is 2.7 percent, declines in output drivers by investment type vary from as little as

1.4 percent for agricultural machinery to as much as 10.9 percent for public utility investment. These losses in output show up in reductions in investment in Figure 4-7. The types of investment most heavily affected by reduction in output are public utility structures and mining and exploration. These types of investment are highly sensitive to activity levels in coal mining, natural gas production, electric generation, petroleum refining, and chemical production. Reduction in the consumption of oil, gas, and coal, and deferral of most electric utility construction plans, causes investment spending in those industries to dry up.

Which Industries Have the Largest Percentage Reductions in Investment?

The bulk of the investment decline (two-thirds) is attributed to the decline in economic activity in the markets serviced by the investment goods. Investment declines in the 2001-2010 period range from 1 to 2 percent for "other" equipment and "other" buildings to 26 percent for electric and gas utility structures (see Figure 4-7). The average output effect over the 2001-2010 time frame is -3.2 percent. The largest output effects are associated with energy-related equipment such as public utility structures, mining and exploration equipment, mining and oil field machinery, engines and turbines, aircraft, fabricated metals, and railroads (Figure 4-8). Output effects associated with 90 percent of investment lie within the much narrower range of -1 to -4.3 percent.

Investment for Conservation and Investment for Growth

Some studies have sought to identify the additional investments that a substantial carbon tax would induce (US Office of Technological Assessment 1991). These investments to reduce energy use, or substitute away from fossil fuels, affect the economy in much the same way as mandated pollution-control investments. They raise the amount of capital required per unit of output of goods and services. The difference between energy-efficiency and pollution-control expenditures is that pollution control expenditures reduce the environmental damage from facilities where they are installed, but provide no economic benefit to plant owners. Energy-efficiency expenditures do provide such a benefit by reducing energy costs. But if the costs of energy-efficiency investments are not repaid through energy expenditure reductions sufficient to cover the levelized cost, they will crowd out more profitable, productive investments. The energy-efficiency investments compete with other investment opportunities for available savings. For this reason, GDP would have to be lower than it would be without such investments.

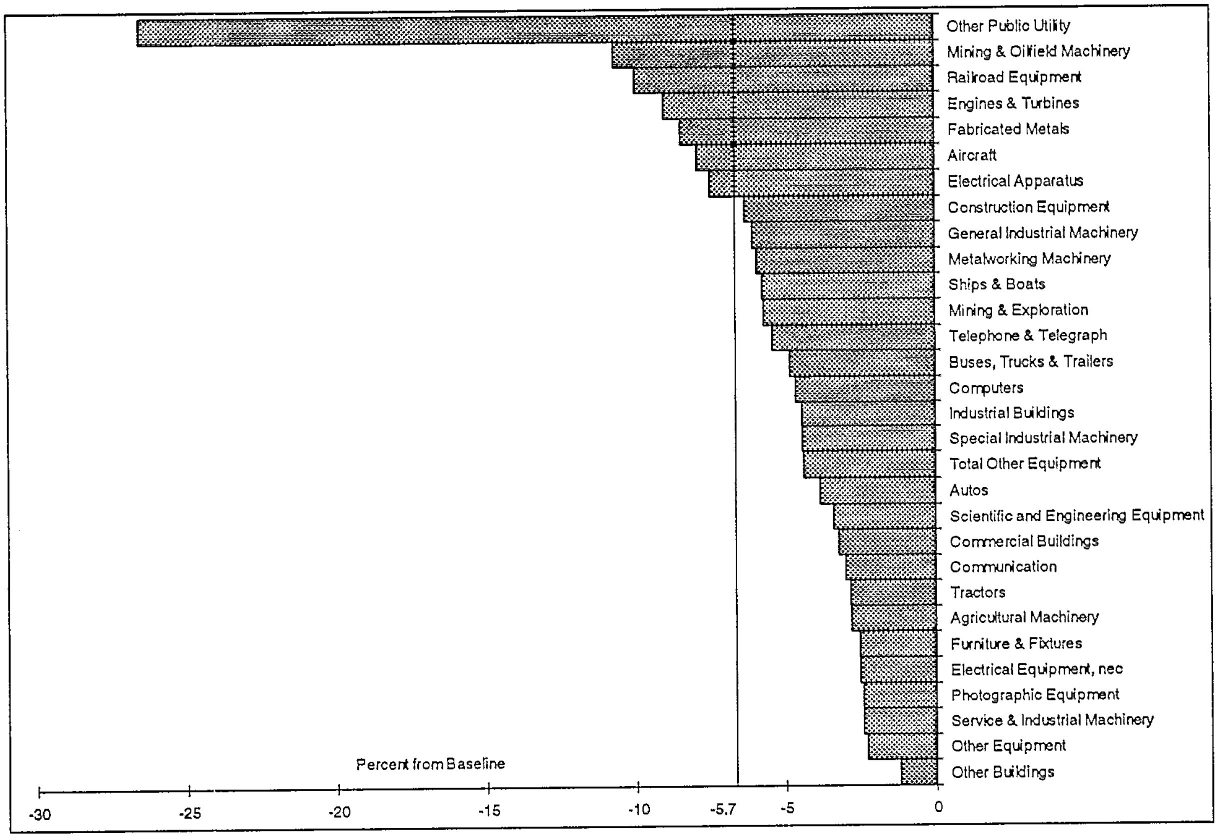

Figure 4-7
Impacts on Investment by 2010

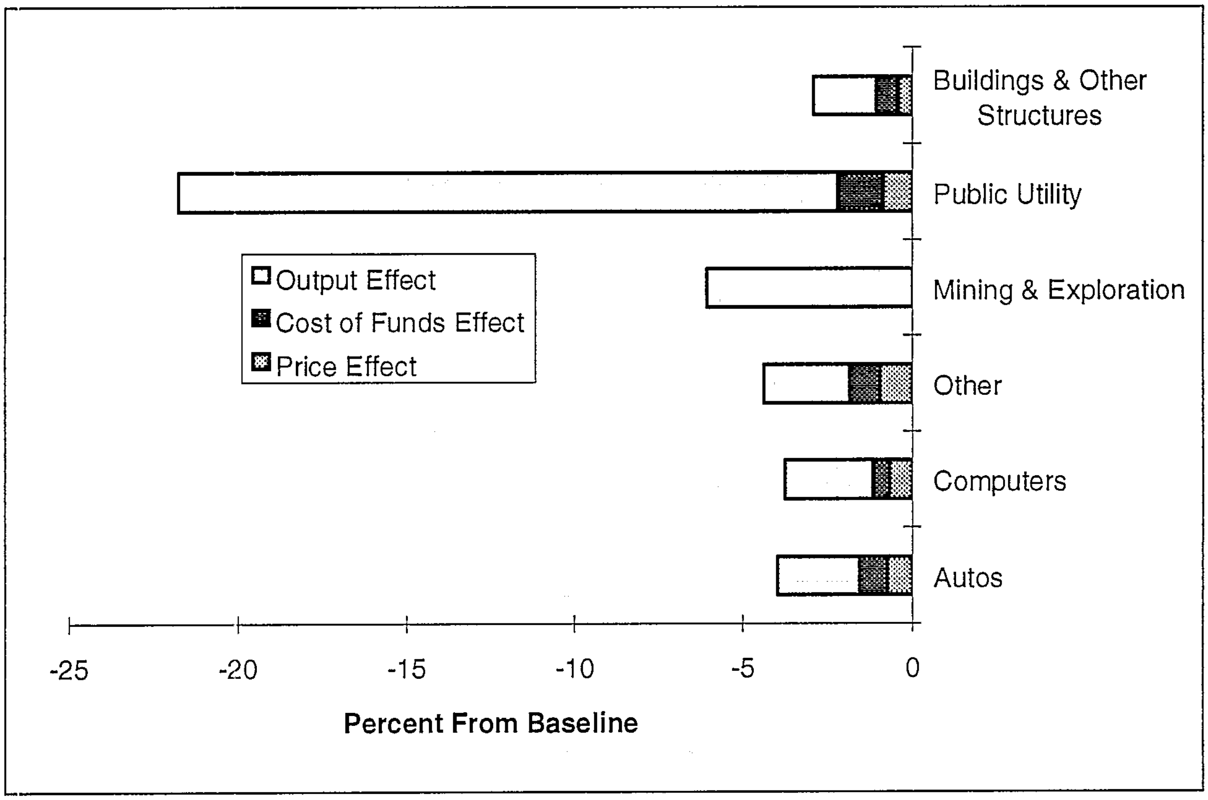

Figure 4-8
Investment Impacts by Effect

Some analysts have cited benefits of carbon taxes in terms of the investment that improvements in energy efficiency would stimulate, while others have expressed concern that higher energy prices would make much of the existing capital stock economically obsolescent, reduce its utilization rates, and reduce investment[8] Yet both responses involve taking away resources that would otherwise provide consumer goods and services. One case involves a diversion of the capital stock to reducing energy use at a cost greater than the value of energy savings on a pretax basis. In the other case, capital simply does not accumulate. In either case there is less capital available to produce goods and services for consumers.

Which Industries are Responsible for the Aggregate Decline in Investment?

Carbon taxes, and reductions in energy consumption, naturally reduce investment most in the industries that produce oil, natural gas, coal, and electricity. But these industries together account for less than 10 percent of GDP. The bulk of the decline in total investment comes in non-energy industries that experience increases in the real user

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[8] See Hulten Robertson, and Wykoff (1989) for an interesting discussion of the obsolescence issue.

cost of capital even though their losses in output do not compare to those in the energy sector (Figure 4-9).

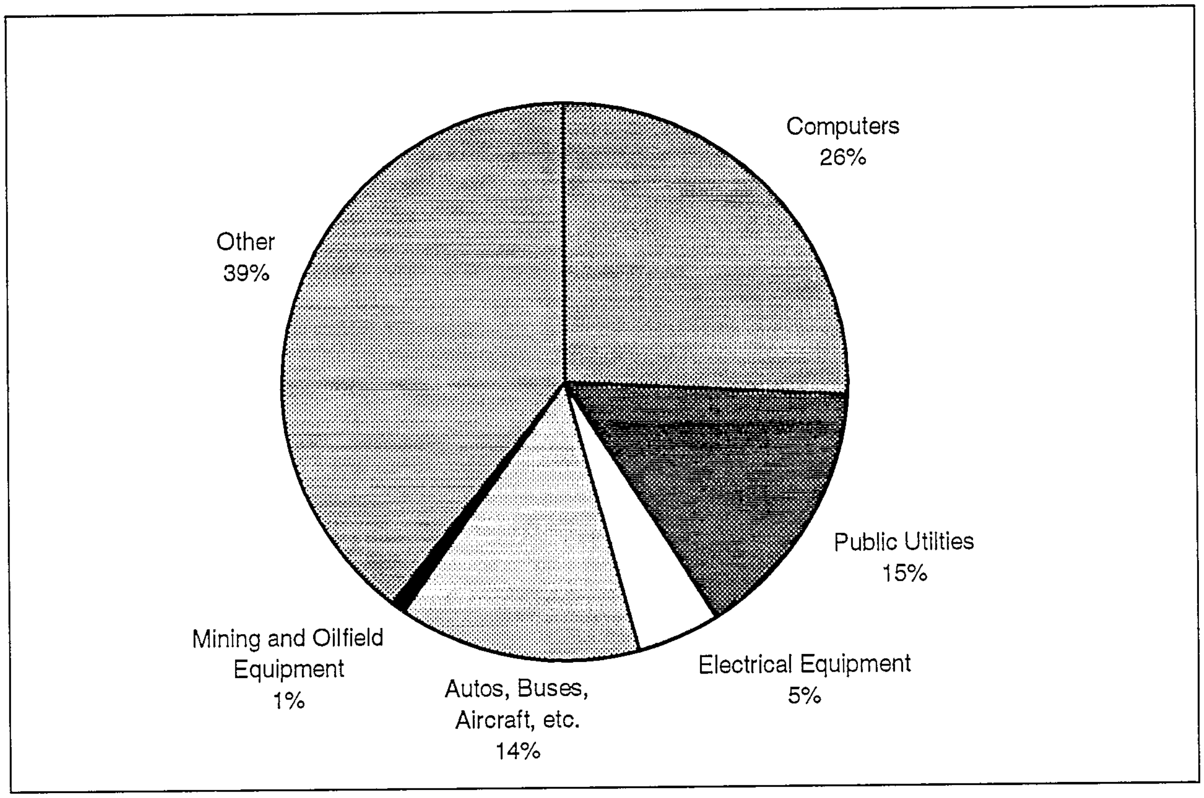

Figure 4-9
Shares Total Investment

Reduction in investment spending for computers and related equipment is responsible for the single largest share of the total reduction in investment, 26 percent. The percentage loss in sales of computers is not far off the average for investment goods, but computers are such a large share of total investment spending that they bulk large in the total impact on investment.

The total reduction in electricity-related investment, including public utilities and electrical equipment, also accounts for about 20 percent of the total decline in investment. The dramatic fall in capital spending by utilities and the importance of utility investment combine to make the loss in electricity-related investment equal to the largest single share of the total investment decline.

Transportation-related investment falls because of the reduction in demand for automobiles and air travel caused by higher energy costs and costs of travel. Railroad investment takes a large decline because rail investment is so long lived. Thus it takes a long time for the capital stock in the rail industry to adjust to a lower level of demand for transportation services, and investment is shut off until that adjustment takes place. This is the third largest category.

Other equipment investments, spread across the economy, account for 39 percent of the loss in total investment, with no one type of equipment standing out like computers. The loss in investment for mining and oil field equipment is just 1 percent of the total loss in investment. Despite the large fall in output for coal and other energy production, the total amount of spending for this purpose is such that the impacts of its loss on total investment are negligible.

Trade Balance and Competitiveness

Macroeconomic Determinants of Trade Balances

The current account deficit totaled $66 billion in 1992. Surpluses in the services ($56 billion) and investment ($6 billion) accounts were more than offset by $33 billion in net transfers to foreigners and a $96 billion deficit in the merchandise account. In the baseline forecast, the merchandise deficit is projected to reach $252 billion in 2010. A substantial surplus in the services account, however, will net an $80 billion surplus in the current account. Since net transfers to foreigners are exogenous inputs to the model and the investment account is relatively small, the impact of the carbon tax that matters is the one on merchandise and service exports and imports.

The current account deficit is determined by the levels of saving and investment in the US relative to those in other countries. The current account is purchases and sales of goods and services and transfers to and from other countries, while the capital account is purchases and sales of assets. Thus, the balance-of-payments deficit equals the current account deficit plus the capital account surplus. Balance-of-payments equilibrium requires that the current account deficit equal the capital account surplus. This fundamental principle can also be derived directly from the national income identity

$$S - I - (G + TR - TA) \equiv NX$$

where S is saving, I is investment, $(G + TR - TA)$ is government purchases plus transfers minus taxes, and NX is net exports. According to this identity, the excess of saving over investment plus the government deficit equals net exports. If, as has been the case for some years, investment plus the government deficit exceed savings, net exports must be negative. In this case the nation borrows from overseas to cover the net savings deficit, and imports the goods that are purchased in excess of what is produced domestically.

The standard IS-LM framework shows that, with flexible exchange rates and freely mobile capital, measures like carbon taxes cannot affect net exports. The reason is that under these assumed conditions, there can be no permanent difference in interest rates between the United States and other countries. Any decrease in exports leads to an interest rate differential, a balance of payments deficit, and currency depreciation, all of which increase demand for exports and reduce demand for imports. The result is that higher costs that appear to harm net exports only change the value of the dollar, not output (Dornbusch and Fischer 1990, 208).

Only if these macroeconomic aggregates change–for example, because of interest rate movements–will the overall level of the trade deficit change. The procedure in this study follows this route, by first determining the level of saving and investment and then splitting the resulting trade deficit up among industries. Since the DRI model is based on empirical studies that show that a policy change like a carbon tax results in a combination of increasing interest rate differentials and dollar depreciation, there is an impact on the overall trade deficit. The dollar falls enough to offset some, but not all, of the cost impacts of carbon taxes. The trade deficit improves due to higher domestic interest rates that increase domestic saving and decrease total investment. The improvement in trade is then balanced between services and manufacturing (because of differences in import and export demand). The net change in trade then sets an average around which some industries gain and some lose.

Exchange Rates And Conditions in Other Countries

The $100 carbon tax lowers the nominal exchange 2.2 percent below base-line levels by 2010, but raises the real exchange rate 1.8 percent. US prices rise an average 4.3 to 4.4 percent above base-line levels by 2010 in response to the unilaterally imposed carbon tax, compared with only a 0.3 percent rise in foreign prices. (The small rise in foreign prices is attributed to the higher prices the foreign economies must pay for imports from the United States.) The increase in relative US prices, taken by itself, lowers the nominal exchange rate relative to base-line levels by an equal amount (or equivalently, maintains the real exchange rate). The dollar is not able to fully reflect relative price changes, however, since relative increases in real US interest rates push the real exchange rate higher. The 2.2 percent fall in the nominal exchange rate pushes dollar-denominated foreign prices up only 2.5 percent, leaving US goods less competitive, on average, in world markets.

Exports suffer from the rise in the real exchange rate (the loss of competitiveness) and a slight decline in foreign GDP. (Foreign GDP slips 0.3 percent below base-line levels by 2010 due to reduced US demand for foreign exports.) This drives real exports down 1.9 percent ($29 billion) in 2010 (see Table 4-3).

While imports have a competitive price advantage over domestically produced goods as a result of the carbon tax, lower domestic demand more than offsets the price effect on import demand. Real imports fall 2.9 percent ($39 billion) below base-line levels in 2010. Net trade thus improves by $10 billion in 2010.

Table 4-3
Impact of a Carbon Tax on Real Trade Volumes, 2010

	Percent From Base Line			Difference from Base Line (billion 1987$)
	Relative Price Effect	Output Effect	Total Effect	Total Effect
Exports	-1.5	-0.4	-1.9	-28.7
Merchandise Exports	-1.8	-0.2	-2.0	-23.2
Services	-0.5	-1.1	-1.6	-5.5
Non-oil Imports	1.2	-3.8	-2.6	-32.1
Merchandise Imports	1.4	-3.8	-2.5	-27.0
Services	0.1	-3.2	-3.1	-4.8
Oil Imports	–	-8.2	-8.2	-6.9

Overall Current Account Balance Improves Because of Increased Net Saving

While real merchandise and service exports are reduced 1.9 percent ($28.7 billion) below base-line levels in 2010 as a result of the $100 carbon tax, export prices rise an average 4.4 percent. Consequently, nominal exports rise 2.5 percent ($59.0 billion). At the same time, a 2.4 percent average rise in import prices relative to base-line levels, coupled with a 2.9 percent ($31.8 billion) decline in real merchandise and service imports, cuts the decline in nominal imports to 0.6 percent (-$13.9 billion). Net trade in merchandise and service thus improves $72.9 billion. Surpluses in the US merchandise and service accounts lead to improvements in the US net international investment position (increases in US assets abroad and reductions in foreign assets in the United States). Income from US assets abroad expands $86.9 billion with both higher asset levels and foreign interest rates. While income paid on foreign assets in the United States is also boosted by higher US interest rates, the decline in foreign asset stocks relative to base-line levels holds the increase to just $58.4 billion. The investment income balance thus improves by $28.5 billion. In total, the carbon tax raises the current account $101.3 billion above base-line levels by 2010 (see Table 4-4).

These changes in net exports reflect changes in basic macroeconomic aggregates. As discussed above, foreign investment equals the negative of the current account. Exchange rate and interest rate changes lead to greater domestic saving, and lower total investment. This means less foreign investment, which is equal (with constant budget deficits) to the difference between domestic saving and total investment. As a result of the decrease in foreign investment, the trade deficit (current account) improves. If there were less movement of US interest rates relative to foreign interest rates, the exchange rate would increase more and there would be less change in the current account.

Specifically, with the $100 carbon tax, total savings are up $88 billion in 2010, largely because of greater household saving due to higher interest rates and lower consumption. Total investment falls $13 billion, so that foreign investment is down $101 billion, and net exports rise by a like amount.

Table 4-4
Current Account Balance

	Real		**Nominal**		
	Exports	**Imports**	**Exports**	**Imports**	**Net Trade**
Percent From Base Line, 2010	**(Billion 1987 Dollars)**		**(Billion Dollars)**		
Current Account Balance					101.3
Merchandise	-23.2	-27.0	41.1	-14.9	56.0
Services	-5.5	-4.8	17.9	1.0	16.9
Investment Income			86.9	58.4	28.5
Transfers	0.0	0.0	0.0	0.0	0.0

Long Run and Transitory Effects

What effect does reduced investment have on growth? It is important to distinguish the long-run effects of a carbon tax due to changes in resource allocation stemming from higher energy costs, and effects coming from the shock of higher prices that may be transitory. One reason this distinction is important is in applying the results of studies of carbon taxes to estimate the impacts of regulatory programs. If regulatory programs and taxes have similar effects on the costs of using energy, their long-run impacts on potential GDP will be the same. On the other hand, some of the costs of regulatory programs, such as losses in consumer welfare due to restricted choices, may not show up in measures of inflation. In this case, there could be less of a price shock from regulatory programs. Thus it is appropriate to use the loss in potential GDP from a carbon tax as an estimate of the minimum cost of a regulatory program achieving the same goal.

Long-Run Effects of Carbon Taxes

The economic impacts of carbon taxes are not confined to energy markets. The impacts of carbon taxes on investment are even more important than direct impacts on energy markets in reducing the overall productive potential of the economy. Aggregate supply, or the economy's potential real GDP, is defined by a production function that combines factor input growth and total factor productivity. The rise in energy prices reduces the supply of the energy factor input directly. It also reduces the supply of the capital factor input and total factor productivity indirectly through its impact on investment. Lower factor inputs and factor productivity define a lower level of aggregate supply.

Labor productivity is defined by a trend and cyclical component. The trend or "full-employment" component of labor productivity is determined by potential output relative to full-employment man-hours. Labor productivity thus declines as aggregate supply declines. Lower labor productivity levels raise unit labor costs and trigger additional inflation. The inflation generated by the decline in aggregate supply dampens aggregate demand and helps to bring it in line with aggregate supply. Hence, the growth in aggregate supply becomes the fundamental constraint on the long-term growth of aggregate demand.

In the DRI model, aggregate supply (or potential GDP) is estimated by a Cobb-Douglas production function that combines factor input growth and improvements in total factor productivity. Factor input equals a weighted average of labor, business fixed capital, and energy. Based on each factor's historical share of total input costs, the elasticity of potential GDP with respect to labor is 0.62 (i.e., a 1 percent increase in the labor supply increases potential GDP 0.62 percent); the capital elasticity is 0.33; and the energy elasticity is 0.05. Factor supplies are defined by estimates of the full-employment labor force, the full-employment capital stock net of pollution abatement equipment, and the energy demand that would prevail at full employment. Total factor productivity depends on the stock of research and development capital and trends in technological change.

Potential supply falls 0.5 percent below base-line levels in 2000, and 1.9 percent in 2010. As seen in Figure 4-10, the majority (64 percent) of the decline in 2010 is attributed to lower capital inputs as a result of lower investment levels throughout the 1995-2010 period; lower energy usage accounts for 28 percent of the decline in potential; a lower technology level, resulting from lower investment in research and development capital, accounts for 8 percent of the decline.

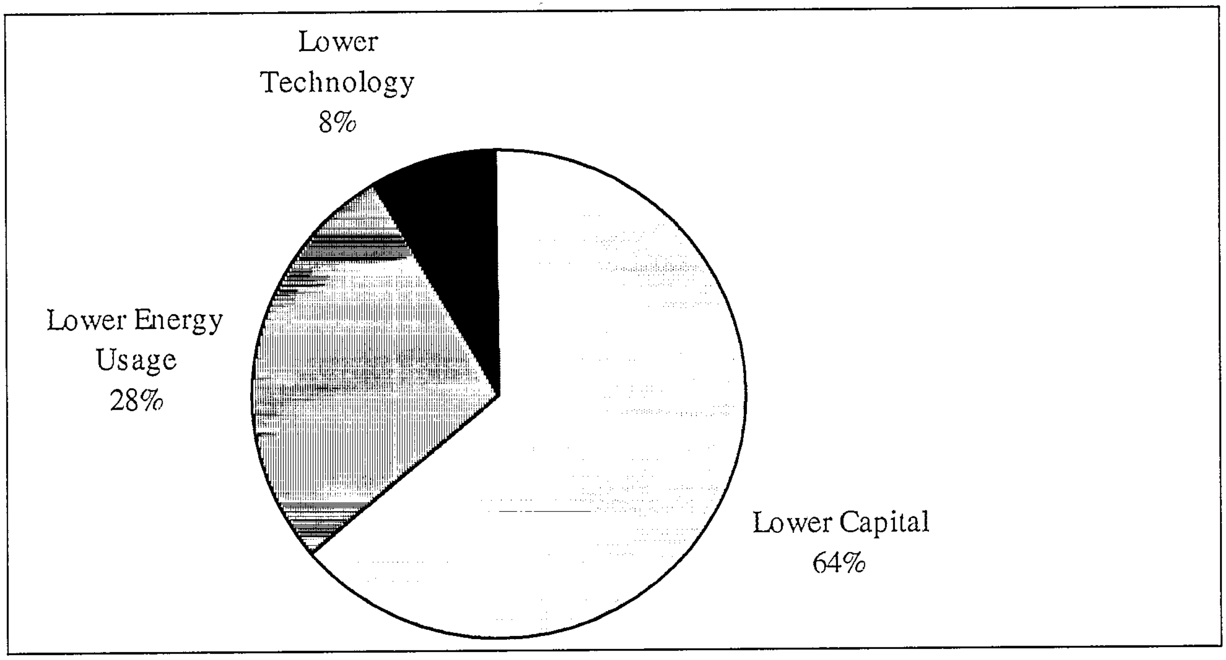

Figure 4-10
Factors Contributing to the Decline in Potential GDP (Percent of total decline, 2010)

Short-Run Problems: Price Stability versus Employment

***Cyclical Impacts**. The* carbon tax, like any other excise tax, is inflationary. It directly raises the cost of energy, a key production factor. In this analysis, the carbon tax is recycled through lump-sum reductions in personal income taxes. This recycling option was chosen over alternative options since it does not directly alter the costs of the other factors of production, i.e., labor and capital. Recycling carbon tax revenues through employer-paid payroll tax reductions, for example, would directly reduce the price of labor; recycling through investment tax credits or corporate income tax cuts would reduce the price of capital. Any of these alternative recycling options would directly offset the inflationary effects of the carbon tax and thus would conceal the impact of the carbon tax. Lump-sum reductions in personal income taxes, on the other hand, do not.

The carbon tax raises energy prices, leading to higher producer and consumer prices. Assuming neutral Federal Reserve policy (unchanged nominal credit), the real credit supply falls in response to the tax and real interest rates rise. Higher prices would also reduce real disposable income and wealth, but the recycling of revenues through personal income tax reductions partially offsets the initial income loss. Higher interest rates and lower income and wealth reduce most components of aggregate demand (particularly the durable consumption, investment, and export components of real GDP). Lower demand levels translate into lower employment and income levels, which further reduce all consumer, investment, and import demands.

Unemployment is determined in the DRI model by the gap between aggregate demand and potential supply. The unemployment rate includes a structural or full-employment component and a cyclical component. The cyclical component of the rate is determined by an inverted Okun's Law: the difference between actual unemployment and the full-employment rate is related to the gap between gross domestic product and potential gross domestic product. If actual output is 1 percent below potential, for example, the cyclical unemployment rate rises by 0.5 percentage point.

With the carbon tax, aggregate demand is pushed down faster and deeper than aggregate supply, thus generating unemployment. The gap between aggregate supply and demand reaches a maximum 1 percent in 2002, causing the unemployment rate to rise 0.5 percentage point above base-line levels. This unemployment generates offsetting downward pressures on credit costs and wage rates that narrow the gap between aggregate demand and supply to just 0.4 percent and moderate the unemployment rate effect to just 0.2 percentage point above the base line by 2010 (Figure 4-11).

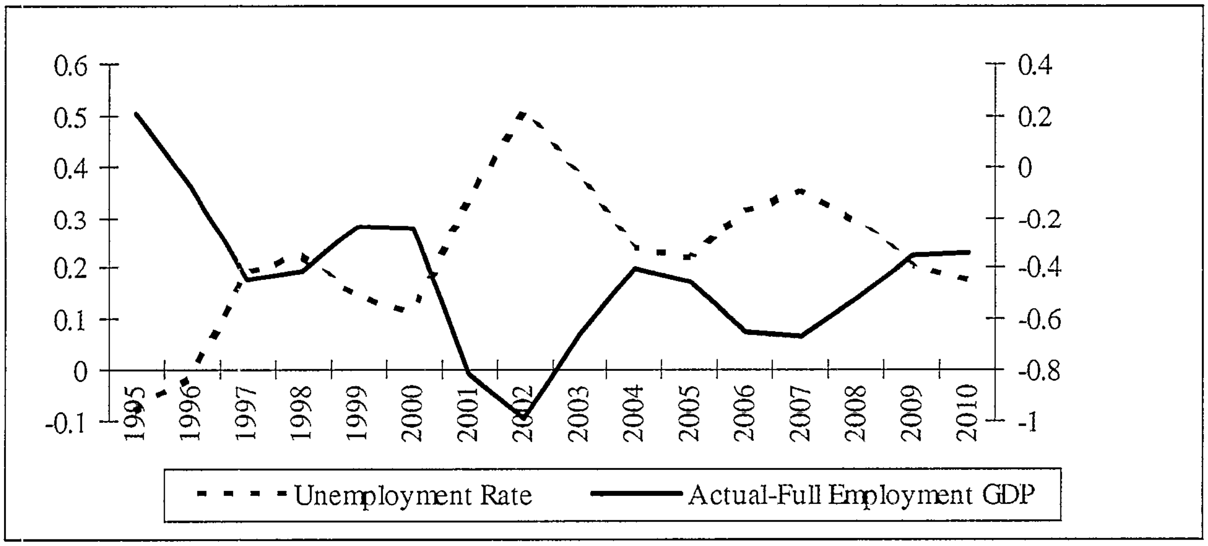

Figure 4-11
The GDP Gap and the Unemployment Rate

Policies to Offset Impacts. Cyclical unemployment contributes to the negative effect of the carbon tax on potential supply. During discussions of the energy tax proposed early in the Clinton Administration there was considerable controversy over whether the adverse economic impacts of the tax could be avoided with a sufficiently accommodating policy from the Federal Reserve Board. There is a real problem in speculating about such discretionary policy moves. At any point the Board could ease the money supply, lower interest rates, and stimulate the economy. It would at the same time increase the rate of inflation. That the Board does not do so indicates its preferences between inflation and unemployment. Assuming that the Board accommodates a carbon tax and eliminate its impacts on GDP implicitly assumes that the Board has changed its preferences over inflation and unemployment. Such an assumption credits the carbon tax for an improvement in the unemployment rate that could have been achieved at any time the Board desired, with or without the carbon tax. It is especially unlikely that the Board would change its preferences with a revenue neutral carbon tax, since in the past the Board has been inclined to ratify inflationary impacts of tax increases only as part of a deficit reduction strategy.

It remains, however, necessary to decide on a reasonable assumption about the Board's preferences. The scenarios described thus far have assumed a neutral monetary policy, of keeping non-borrowed reserves constant, since this assumption mirrors past Board policy. An alternative assumption, more generous to carbon taxes, is that the Board could decide to target an unemployment rate, and tolerate enough additional inflation to prevent any increases in unemployment. This policy gives a "best-case" assessment of the unemployment impacts and cyclical losses to be expected from a carbon tax.

The analysis of long-term losses in GDP indicates that the decline in the capital stock is the biggest contributor to the decline in potential supply. Part of the decline in the capital stock is also attributable to the cyclical unemployment induced by the tax.

In order to quantify the importance of this cyclical effect, monetary policy was used in an alternative simulation of the DRI Macro Model to keep aggregate demand in line with aggregate supply. That is, non-borrowed reserves were expanded so as to hold the unemployment rate near base-line levels through 1995-2010.

Countering the unemployment induced by the carbon tax with offsetting monetary stimulus would hold the decline in aggregate demand and supply to just 0.7 percent in 2002 (the year in which unemployment peaked in our neutral monetary policy scenario) and 1.6 percent in 2010 (Table 4-5). Potential supply would thus be 0.3 percent higher than in our analysis in 2010, due to a 0.8 percent higher capital stock and a 0.33 capital elasticity. It should be noted, however, that this monetary policy requires a 3.2 percent increase in reserves relative to base-line levels by 2010, which results in significantly higher inflation. The monetary stimulus raises prices 7.2 percent above base-line levels by 2010, compared with 3.9 percent with neutral monetary policy.

Table 4-5
A Comparison of Potential Supply Impacts
With and Without Cyclical Unemployment

	2002		2010	
Percent From Base Line	**With Unemployment**	**Without Unemployment**	**With Unemployment**	**Without Unemployment**
Actual GDP (%)	-1.8	-0.7	-2.3	-1.6
Potential GDP (%)	-0.8	-0.7	-1.9	-1.6
Capital Stock (%)	-2.2	-1.5	-4.3	-3.5
Employment (%)	-0.7	0.0	-0.3	0.0
Unemployment Rate (%)	0.5	0.0	0.2	0.0
Non-borrowed Reserves (%)	0.0	1.8	0.0	3.2
GDP Price Level (%)	2.8	3.4	3.9	7.2

Unavoidable Losses

There has been considerable debate about whether the economic impacts of energy taxes can be offset through changes in monetary and fiscal policy. GDP losses with constant unemployment are a lower bound on the unavoidable losses from a carbon tax.

Figure 4-12 compares the two measures of GDP loss from carbon taxes in 2010. Total GDP loss includes all the effects of a carbon tax, including cyclical and potential GDP effects. Loss in potential GDP includes only the unavoidable losses from higher energy costs, estimated by adjusting monetary policy so that unemployment does not change after the imposition of the tax.

It is quite significant that the three-quarters of the loss in investment due to a carbon tax still appears when all of the cyclical impacts of the carbon tax are eliminated. This indicates that a large part of the investment impact is associated with the basic changes in energy costs, and reductions in output of energy and transportation-related industries directly attributable to those higher costs. These are impacts that are also likely to be seen if regulatory programs are adopted rather than carbon taxes.

GDP losses, even with no increase in unemployment and none of the cyclical impacts that could be expected from a carbon tax, are still 1.6 percent in 2010. This is the result of a carbon tax that is not quite sufficient to hold emissions to 1990 levels through that period. Almost twice the inflation, measured as the cumulative increase in the price level, would have to be tolerated to hold GDP losses down even that far.

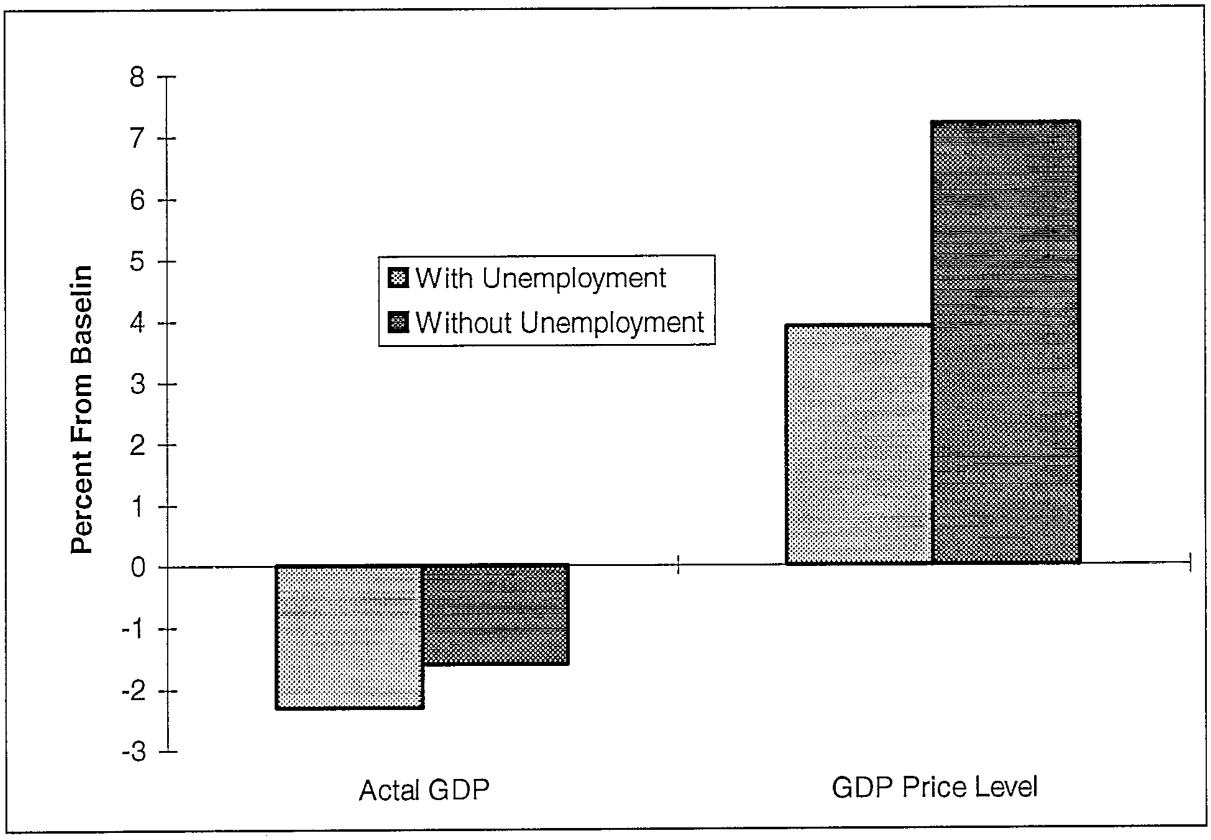

Figure 4-12
Avoidable and Unavoidable Losses

References

Bovenberg, A. L., and L. H. Goulder. 1993. *Integrating Environmental and Distortionary Taxes: General Equilibrium Analysis.* Conference on Market Approaches to Environmental Protection at Stanford University.

Dornbusch, Rudiger, and Stanley Fischer. 1990. *Macroeconomics* (Fifth Edition). New York: McGraw-Hill.

Hulten, C. R., J. W. Robertson, and F. C. Wykoff. 1989. "Energy, Obsolescence, and the Productivity Slowdown." In D. W. Jorgenson and R. Landau, eds., *Technology and Capital Formation.* Cambridge: MIT Press.

Jorgenson, D. W., and K.-Y. Yun. 1990. "Tax Reform and Economic Growth." *Journal of Political Economy* 98, pp. 5151-93.

US Congress Office of Technological Assessment. 1991. *Changing by Degrees.* Washington, DC.

5

GOING DEEPER—IMPACTS ACROSS INDUSTRIES

Cost Impacts by Industry

Higher energy costs serve to increase costs of doing business, and costs of goods and services delivered to final demand, in two ways. A *direct price effect* comes from the purchase of energy at higher prices, and an *indirect price effect* comes from purchasing goods and services whose prices are driven up by higher costs of energy used in their manufacture. As described earlier, over 40 percent of any energy cost increase will be experienced directly by households, as increases in the cost of heating, cooling, lighting, running appliances, and driving motor vehicles. The remainder would affect industries first, and then be passed on to households in the form of higher prices for goods and services. These are the indirect impacts of carbon taxes.

Businesses themselves experience higher energy costs both directly and indirectly. Common measures of energy intensity, such as those derived from the EIA Manufacturing Energy Consumption Survey, deal only with energy purchased directly by an industry. But a substantial part of the costs of many businesses is in the commodities they buy from other industries–in the form of raw materials, components, semi-finished goods, capital equipment, etc.–and these commodities experience cost increases because of carbon taxes. Accounting for the full impact of carbon taxes on any industry requires estimation of both direct and indirect costs.

Different industries will face different cost increases, depending on the amount and type of energy they use directly and the amount and type of energy embodied in the semi-finished goods and raw material they utilize. These cost increases find their way into the products that consumers buy, as described in the previous chapter. As a result of these price increases, and the lower incomes consumers enjoy because of the overall drag on the economy from carbon taxes, final demand patterns change.

There are four categories of final demand that matter: consumption, investment, exports, and government purchases. The previous chapter described the changes in each of these categories that come about because of carbon taxes. It is now time to work back from these changes to identify the industries that face losses in output because of reactions to carbon taxes.

For this cross-cutting analysis of all industries, we assume that no industry changes the amount of energy used per unit of output, or its purchases from other industries per unit of output. In the next chapter, which deals with case studies of industries facing potentially large impacts, the implications of such changes are examined.

Price and Cost Impacts on Energy Industries, Including Utilities

Industries that produce energy–oil, natural gas, coal, and electricity–naturally have the largest cost increases because carbon taxes are assumed to be collected on energy at the point where it is produced or imported. Carbon taxes are assumed to be paid by electric utilities in the price of energy they purchase, and then passed on fully in the prices charged for electricity.

Table 5-1 shows that the average cost of coal rises by 174 percent, that the average cost of natural gas sold by gas utilities rises 36 percent, and the average cost of electricity rises by 30 percent. The large share of coal in electric power generation produces that large a cost increase despite the large share of capital charges in electricity rates. Refined petroleum products have the smallest cost increase, 29 percent, because of large non-energy costs of refining and distribution.

Table 5-1
Total Price Effects of the $100 Carbon Tax on Energy Industries
(Percentage Change from Base Line, 2000)

Rank		Sector	Total
1	7	Coal Mining	173.716
2	84	Gas Utilities	36.008
3	83	Electric Utilities	29.629
4	37	Petroleum Refining	28.629

These cost increases make energy industries the top four industries in percentage cost increases, standing out from almost all non-energy industries.

Skewed Distribution of Direct and Indirect Cost Impacts on Non-Energy Industries

Figure 5-1 shows all the non-energy industries that experience a total, direct and indirect, cost increase greater than the national average of 3.3 percent. Cement stands out with cost increases like those of energy industries, followed by primary metals industries–aluminum, ferrous metals, and iron ore mining–with cost increases of 8 to 12 percent. The effect of carbon taxes on other industries tails off rapidly.[9] Paper and paperboard industries have cost increases in excess of 5 percent. Plastics, certain chemicals, and container manufacturing both metal and paper–have price increases in excess of 4 percent.

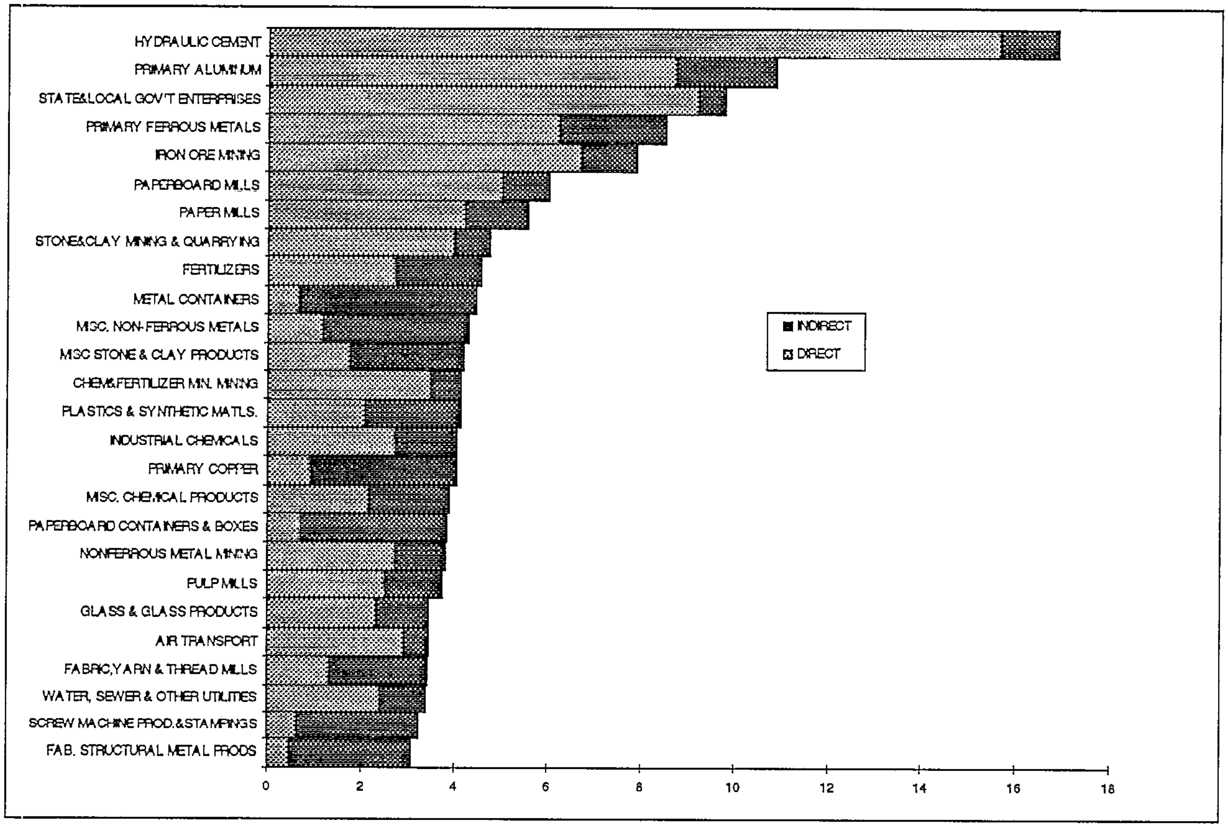

Figure 5-1 Total Price Effect of the $100 Carbon Tax on Top 25 Non-Energy Industries (Percentage Change from Base Line, 2000)

Non-energy industries whose costs are most affected by the carbon tax are typically the basic industries involved in the mining of materials and the early stages of processing. They include hydraulic cement; primary metals (and mining of ore); paper and paperboard; fertilizers and chemicals; stone, clay, and glass (including mining); plastics; and metal containers. Only six of the industries are not considered to be basic

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[9] In the next section, the aluminum and steel industries are examined in more detail. That analysis estimates price increases larger than the cited average cost increases of 8 to 12 percent. There are two reasons for these differences. Prices are based on marginal costs, and costs in some aluminum smelters–those using electricity from coal-fired power plants–will rise much more than the average. Moreover, the analysis in the next section examines only aluminum smelters, and the activities in the industry designated "primary aluminum" contain some downstream activities taking place at integrated facilities.

industries (air transportation, metal and paper containers, and some fabricated glass and metal products).

Most industries ranked at the top of the list are also the most intensive direct consumers of energy. Several industries, however, are very intensive in their use of materials that themselves embody lots of energy. Metal containers, for instance, exhibit a 4.5 percent price increase, of which 3.8 percent comes indirectly from the use of such inputs as aluminum and steel. The total price impact for metal containers is thus 6.9 times the direct effect.

Nine of the heavily affected non-energy industries have indirect price impacts that are significantly more important than their direct price impacts; however, none of the nine rank in the top one-third of the group. The nine industries are metal containers; miscellaneous nonferrous metals; fabricated structural metal products; miscellaneous nonferrous metals products; primary copper; miscellaneous stone and clay products; paperboard containers; fabric, yarn, and thread mill products; and screw machine products. Thus, the impact of the carbon tax on intermediate goods cannot be ignored for such industries.

Nature of Responses to Higher Prices

The skewed distribution of higher energy costs suggests that there will be very different, and concentrated, impacts of carbon taxes on specific sectors of the economy. These changes will occur as consumers and businesses act to avoid some of the costs of carbon taxes by shifting their purchases away from goods and services whose prices have increased most.

Changes in Final Demand. Changes in consumption patterns, induced by either increases in the price of consumption goods, or by reductions in income, play a large role in changing the structure of industry. These shifts in consumption work their way back from the industries that supply consumer goods to their suppliers. Likewise reductions in investment reduce purchases from industries that supply capital goods.

Substitution Away from Carbon-Intensive Intermediate Goods. Businesses also have some choices about what type of intermediate goods and materials to use in producing their products. Manufacturers may reduce purchases from industries that have larger than average cost increases because of the energy content of their products and substitute other inputs. These reductions in demand in turn ripple back through the system. This set of changes is addressed in the case studies of affected industries in the next chapter.

Substitution to Switch and Conserve Energy Inputs. Both businesses and consumers facing higher energy prices can find ways to conserve energy, to switch to lower carbon fuels, and to purchase more expensive equipment and structures to improve energy efficiency. These changes in energy use will reduce the output of the coal industry, as electric utilities shift from coal to natural gas, and of energy industries in general as both consumers and businesses reduce energy use. Industries that are largely dependent on the energy industries as customers will also suffer.

Cost Reduction, Contraction of Output, and Regional Shifts. *The* pattern that emerges is of changes in purchasing patterns to reduce cost by shifting away from goods that have high-cost increases due to carbon taxes. Paying for more costly energy also makes less income available for purchasing other goods and services, whose consumption then falls. These shifts in purchasing patterns in turn lead to a contraction of output in certain industries. Industries are not distributed uniformly around the United States. Thus the pattern of changes in the structure of the economy also creates a pattern of different regional impacts.

Output Impacts Across Industries

As Figure 5-2 shows, impacts of carbon taxes on industry output are highly skewed. A small number of industries, including energy industries, stand out from the rest with losses in output of 16 percent (and more for coal, the largest percentage loser). Most industries face losses in output that are within plus or minus 2 percentage points of the average output loss of 2.8 percent for the $100 tax. Very few industries have output losses of less than 1 percent, and only one is likely to gain from the shifts in demand induced by a carbon tax.

No Winners Due to GDP Loss. It might be expected that changes in energy prices would benefit some industries while harming others. In relative terms, some industries raise prices relative to the average and some lower prices. However, the loss in GDP from the carbon tax, which reaches 2.3 percent for a $100 carbon tax in 2010, is sufficiently large that only one industry fares enough better than average to actually increase output. The other reason for the uniformly negative impacts of carbon taxes on industry output is that there are a few industries with an energy content in the cost of their products that is very much greater than the average. These include the energy and many primary metal and extraction industries. There is no industry that has an impact from carbon taxes very much less than the average, because on average a $100 per tonne tax increases cost by 3.3 percent. Having an impact less than average means having cost increases between 3.3 and zero percent. Having cost increases that are higher than average can mean the increases are greater than 100 percent of the value of output.

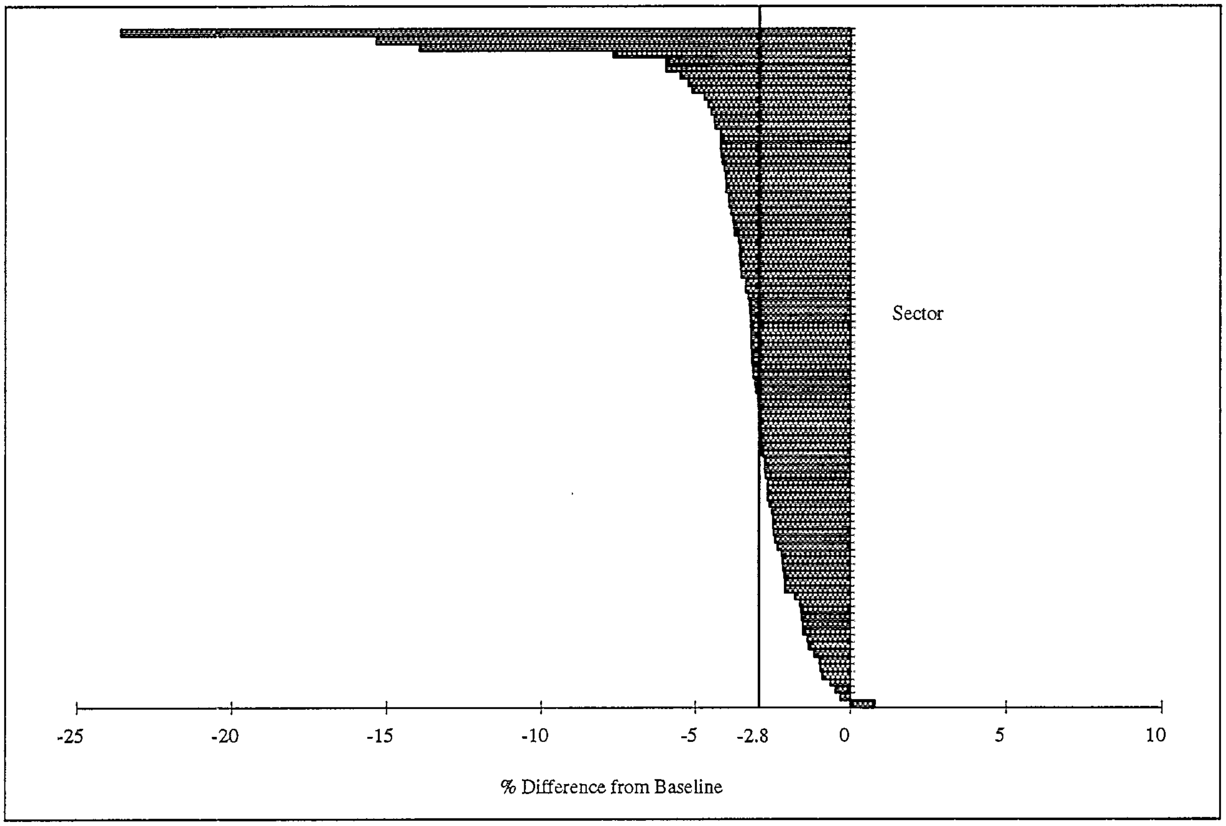

Figure 5-2
Distribution Of Output Reduction By Industry

Reasons for Impacts on Industry Output. There are three causes of reductions in output for an industry. These are:

- Own-price effects: increases in the price of goods sold by the industry;
- Complementary price effects: increases in the prices of goods that are used together with the goods sold by the industry; and
- Income effects: reductions in demand attributable to reduction in income.

Figure 5-3 breaks down the reasons for output losses for the industries that suffer an output loss of 4 percent or more. The important groups of industries are energy industries, autos and other transportation-related industries, mining and extractive industries, and electricity generation and electricity-related industries. The energy industries top the list of negatively affected industries. The four non-energy industries with the largest output losses have relatively small price increases due to carbon taxes. Their losses in output are due to factors beyond own-price effects. There are several reasons why many industries have below-average price effects, but larger-than-average output losses. As discussed, some of the strongest impacts on final demand come from income effects, and from reductions in demand for energy-using and energy-related equipment. Some industries also face particularly severe import competition. Most of the other industries with higher than average output losses are in basic industries that faced large own-price effects.

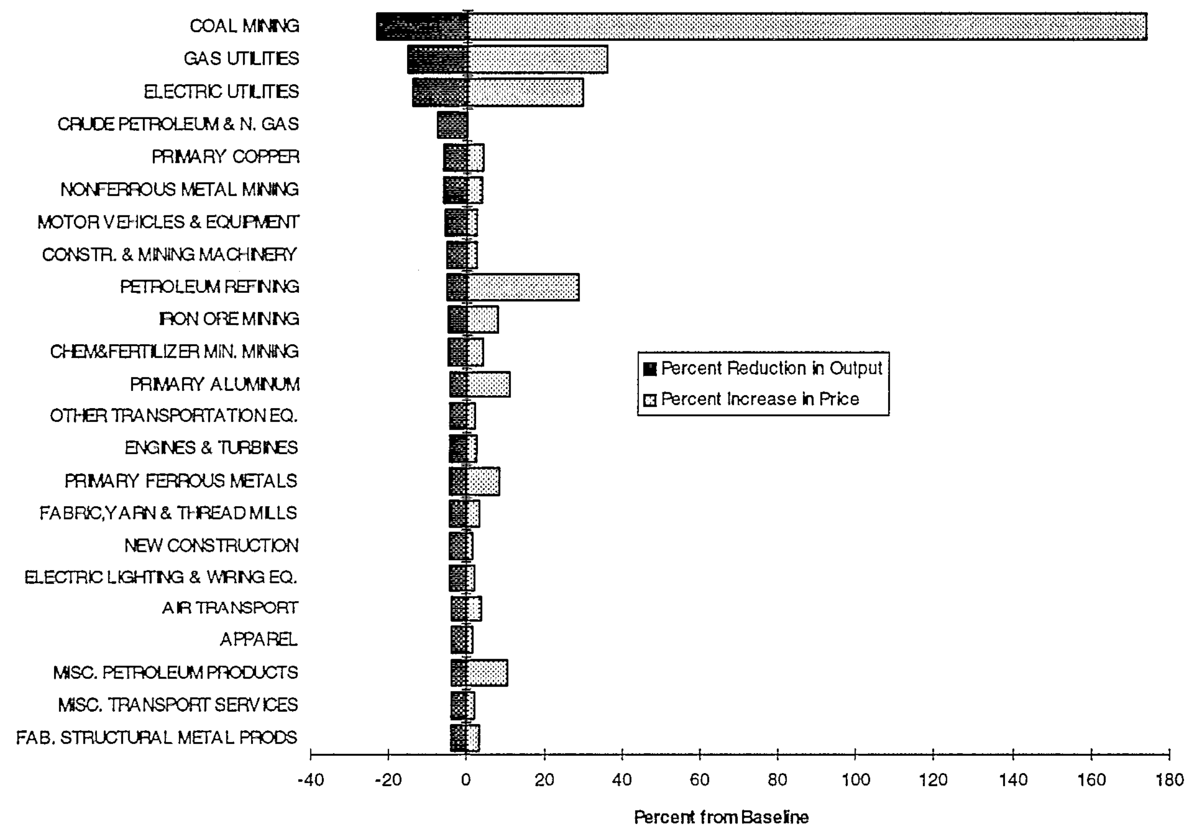

Figure 5-3
Ranked Industry Output and Price Effects

Average to below-average declines in industry output are largely attributed to the general decline in overall economic activity. However, several of the heavily affected industries with above-average price effects turn out to have below-average output effects, because demand for their products is particularly insensitive to price or because they have little competition from substitutes. The particular factors that go into the output losses for each of the industries in Figure 5-3 are discussed in turn.

The industries with highest percentage cost increases, and therefore most at risk, were primary aluminum, primary ferrous metals, iron ore mining, paper mills, chemical and fertilizer mineral mining, industrial chemicals, nonferrous metal mining, and pulp mills. All of these except paper mills, pulp mills, and industrial chemicals are among the top ten non-energy industries in terms of output loss.

Coal Mining. Coal mining decreases with the reduction in coal demand. Since coal is the fuel with the greatest carbon content and the largest percentage increase in price, it has the largest output loss.

Gas Utilities. The reduction in natural gas demand is also reflected in reduced sales from gas utilities.

Electric Utilities. Demand for electricity declines when the higher costs of fuels used to generate electricity are passed through into the price of electricity

Crude Petroleum and Natural Gas. Crude oil and natural gas decline because of the reduction in natural gas demand, which reduces domestic natural gas production. Since the reduction in oil demand comes out of imports, there is little reduction in domestic oil production in the combined loss in crude oil and natural gas.

Primary Copper. Primary copper suffers losses in output greater than would be expected based on price increases alone. The industry is first among energy industries in output loss but 21st in price impact. Copper output is affected by lower electricity demand and capacity, and also by the drop in output of autos and new construction. All of these reductions in demand for goods and services whose production requires copper are caused by increases in energy prices that affect the cost of those goods and services directly, rather than through the cost of copper.

Nonferrous Metal Mining. Output losses for nonferrous metal mining are also greater than would be expected on the basis of its price increases: the industry is second among energy industries in output loss but 24th in price impact. It is subject to intense import competition, and thus faces a much more elastic demand than accounted for in the inter-industry analysis.

Motor Vehicles and Equipment. The demand for motor vehicles and equipment is affected not just by the price of vehicles, but also by the cost of driving. Demand for automobiles drops because of the increase in the price of gasoline, which increases the cost of driving and reduces new car sales, and the overall reduction in income. The total reduction in new car sales due to gasoline price increases and income loss is so strong that autos are near the top of the list of heavily affected industries.

Construction and Mining Machinery. Construction and mining machinery is off because of lower investment levels in the overall economic outlook, and because of the drop in output in coal and natural gas production as well as other mining industries.

Petroleum Refining. Output of petroleum refining falls because of the drop in demand for refined petroleum products, but the drop is moderated because some of the reduced demand is likely to be reflected in reduced imports of refined products.

Iron Ore Mining. This industry is among those with the highest percentage cost increases and is vulnerable to import competition.

Chemical and Fertilizer Mineral Mining. Chemicals and chemical fertilizers are among the industries with highest percentage cost increases, and for this reason exports are significantly reduced by a carbon tax. Chemical and fertilizer mineral mining falls because of the loss in output in the chemical and fertilizer industries.

Primary Aluminum. Primary aluminum has relatively large output losses because of its high rank in direct and indirect price impacts of a carbon tax, its vulnerability to import competition, and the lack of substitution possibilities for reducing direct and indirect energy use per unit of output.

Other Transportation Equipment. Output of other transportation equipment falls because of the drop in demand for other transportation services, attributable to the drop in disposable income and higher fuel costs that reduce demand for travel.

Engines and Turbines. Output of engines and turbines falls because of lower investment overall, and specifically because of reductions in electricity demand and generation capacity.

Primary Ferrous Metals. The primary metals industries are among those with the highest price increases, because of their large energy use, and have commensurate output losses.

Fabric, Yarn, and Thread Mills. Fabric, yarn, and thread mills have relatively high indirect price impacts from carbon taxes, though few other sources of competition. Their reduction in output is tied to the fall in output of the domestic apparel industry, which is largely made from domestically produced fabric.

New Construction. New construction is strongly affected by cyclical downturns in economic activity and reductions in investment, explaining a much higher rank in terms of output loss than in terms of own-price impacts.

Electric Lighting and Wiring Equipment. Output of and electric lighting and wiring also falls because of lower investment overall, and specifically because of reductions in electricity demand and generation capacity.

Air Transport. Output of air transport falls because of the overall drop in disposable income, which reduces demand for travel, and also because of higher fuel costs, which significantly increase the price of air travel.

Apparel. Apparel industries have below-average price effects but are subject to very strong import competition

Miscellaneous Petroleum Products. Output of miscellaneous petroleum products declines along with other types of oil consumption because of the large own-price effects of carbon taxes on oil.

Miscellaneous Transport Services. Output of other transportation services also falls because of the drop in disposable income and higher fuel costs that reduce demand for travel.

Fabricated Structural Metal Products. Fabricated structural metal products have relatively high indirect price impacts from carbon taxes. As components of structures and heavy equipment, they are also sensitive to the drop in investment and construction activity brought about by the carbon tax.

Relatively Unaffected Industries. Table 5-2 lists the industries that seem impervious to the effects of carbon taxes in that their losses in output are significantly less than would be expected based on their price increases. The relatively small loss in output for the hydraulic cement industry is difficult to explain. Hydraulic cement is the industry that faces the greatest price increases of any non-energy industry, yet its output loss puts it back in the pack of average impacts. The inter-industry analysis shows that cement is used widely in the economy, and is a small component of cost in any particular product. The fact that highway construction is held constant by virtue of the assumption of constant real government purchases means that there is no reduction in demand for an important use of cement. Since the only demand effects analyzed in the inter-industry analysis are effects of higher direct and indirect energy costs on final demand, and since higher cement prices do not cause a significant increase in the relative price of any good delivered to final demand, there is no substitution away from products produced using cement. As a result, there is a relatively small decrease in cement output. The cement industry also appears to benefit in terms of net exports, as discussed below.

Table 5-2 Industries with Less than Expected Impact

Output Rank	Price Rank	Sector	Total Price Effect	Output Effect
35	5	Hydraulic cement	16.890	-3.53
76	23	Paperboard containers & boxes	3.846	-2.17
84	15	Metal containers	4.464	-1.53
86	69	Electronic components & accessories	1.66	-1.40
87	80	Ordnance & accessories	1.32	-1.35
88	54	Other agricultural products	1.94	-1.18
89	59	Livestock & products	1.87	-1.02
90	53	Food & kindred products	1.97	-0.97
91	86	Misc. services	1.07	-0.91
92	76	Personal services except auto	1.55	-0.64
93	85	Amusements	1.13	-0.49
94	91	Radio & TV broadcasting	0.73	-0.32
95	88	Office, computing, & accounting machines	1.05	0.78

Paperboard and metal containers are likewise used widely in the economy, but are not a significant share of the cost of any particular product. Their prices are driven up by higher costs of metals and of paper, but they show relatively small losses in output. The reasons are much the same as those for hydraulic cement. Higher container costs do not make any particular commodity more expensive than another, and income reductions do not affect products in containers more than products without containers. As a result there is no substitution at any level away from products incorporating the output of the container industries.

Food and livestock are industries that have much smaller losses in output than would be predicted given their price increases. The reason is largely that the elasticity of demand for food is relatively low, so that price increases showing up in consumption goods do not produce much change in final demand.

The remaining industries in the table rank near the bottom in terms of price impacts, and near the bottom in output impacts. Many are service industries, using little or no energy, whose costs barely increase under a carbon tax. Because of the skewed distribution of price and output impacts, there are a number of industries at or just below the average impact price impacts, and almost no output loss .

One industry shows an increase in output. This is the "office computing machines" industry. The carbon tax produces an increase of about 1 percent in the price of office computers, while the overall fall of 1.8 percent in the real exchange rate means that the price of computers exported from the US actually falls in real terms. Thus there is a significant change in computer net exports, more than enough to offset a decline in domestic sales.

Industries Affected by Trade. International competition is a frequently cited concern in discussions of energy taxes. Competition from foreign producers, assumed not to be subject to a carbon tax, is included in the estimates of industry output effects. In only one or two cases is import or export competition an important positive or negative factor in the overall impact of carbon taxes on a particular industry. Only a few industries face trade losses of even 1 to 2 percent, as seen in Figure 5-3. These include tobacco, pulp mills, fertilizers, coal, military equipment, some mining industries, household appliances, and plastics. In general, industrial supplies and materials are the largest losers.

Figures 5-4 and 5-5 reveal that trade impacts are also highly skewed, but in a different way from output impacts. There are a number of industries with losses of 1 to 2 percent of their trade position, and a few industries with gains of 3 to 15 percent. There are also substantial increases in exports or reductions in imports for some industries. The biggest trade gain comes from reductions of over 14 percent in oil imports. Oil imports are reduced because the carbon tax is assumed to be applied to imported fuels, but not to other imported goods. Thus foreign producers of energy-intensive manufactured goods or raw materials gain an advantage over US producers that is not accorded to oil imports. Thus the entire reduction in domestic petroleum demand shows up in reduced crude and product imports. Other significant gains appear in services and capital goods, including autos and computers.

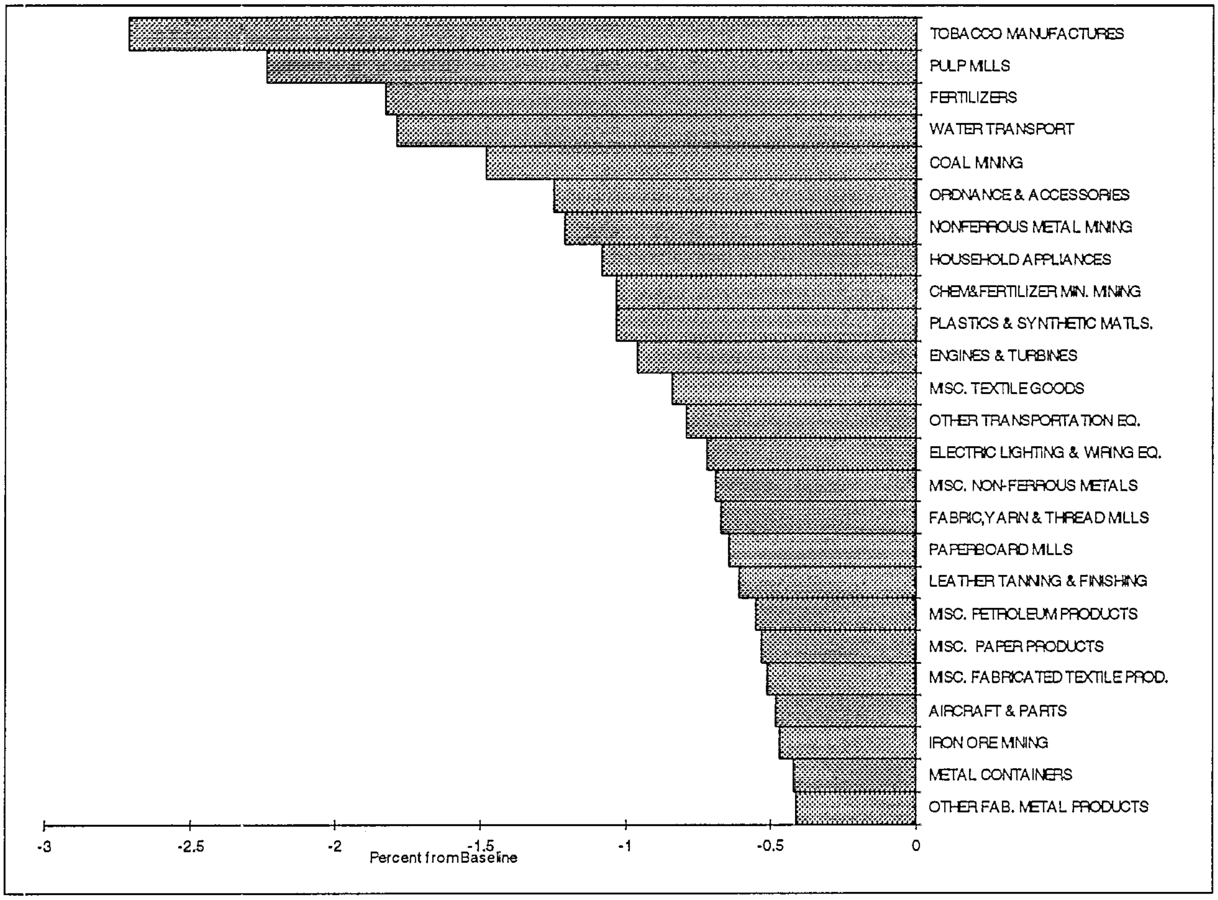

Figure 5-4
Distribution of Impacts on Net Trade, 2010, Top 25 Sectors

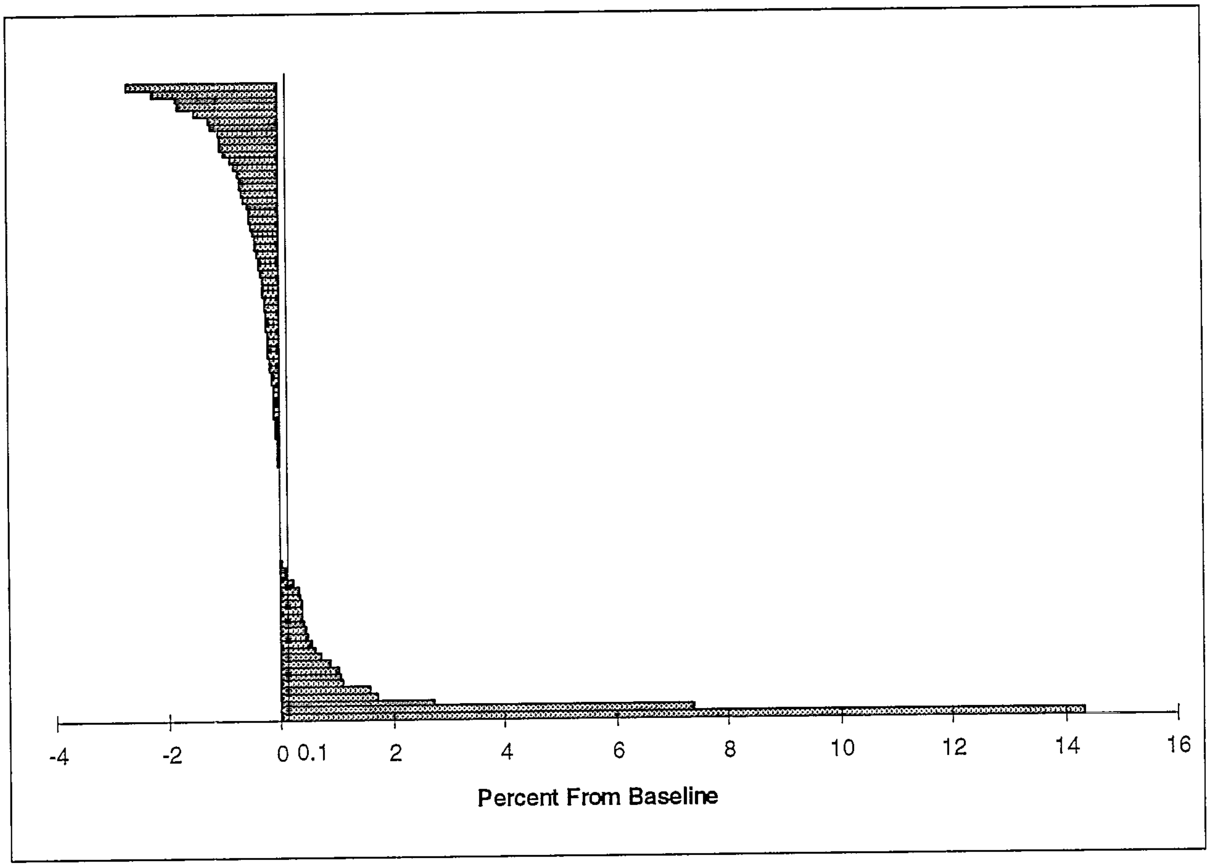

Figure 5-5
Distribution of Impacts on Net Trade, 2010, All Sectors

On average, carbon taxes produce a slight gain in net trade because of the improved current account position. This result emphasizes the importance of macroeconomic conditions, and in particular the balance between domestic savings and investment, in determining trade patterns. The dollar adjusts, in response to the carbon tax, so as to restore the average competitiveness of US industry. Some industries, with above average cost increases, lose to foreign competition, but an offsetting number of industries gain. In rough terms, those industries with cost increases less than the decline of 1.8 percent in the value of the dollar gain, and those with cost increases greater than 1.8 percent lose.

Price Effects. US export prices and the prices of domestic goods competing with imports rise an average 4 to 4.4 percent above base-line levels in 2010 as a result of a carbon tax. Industrial supplies and materials, and food, feeds, and beverages post above-price increases (6 to 6.8 percent) because their production processes are more energy-intensive than average. Energy-intensive industries supplying goods in these categories include agriculture, aluminum, steel, and chemicals. Prices associated with consumer export goods post average increases, while automobile, computer, and services prices rise less than average.

With dollar-denominated foreign prices rising only 2.5 percent above the base line in 2010, US goods lose competitiveness. On average, US exports prices rise 1.9 percent relative to comparable foreign prices (see Table 5-3). Industrial supplies and materials exports are placed at the greatest disadvantage, rising 4.2 percent relative to competing foreign prices, followed by foods, feeds, and beverages with relative prices up

3.4 percent. Similarly, import prices fall 1.4 percent relative to domestic prices, with industrial supplies and materials imports gaining a 4.2 percent price advantage, and imports of foods, feeds, and beverages gaining a 3 percent advantage.

Table 5-3
Factors Affecting Real Trade Volumes

Percent Difference from Base Line, 2010	US Price	Foreign Price	Relative Price
Exports	4.4	2.5	1.9
Non-oil Imports	4.0	2.4	-1.4

On average, relative price changes induce a 1.5 percent decline in real export demand relative to base-line levels, and a 1.2 percent increase in real import demand. The relative price effect is largest in consumer goods exports (-4.6 percent), followed by industrial supplies and materials exports and imports (-3.1 percent for exports and +2.9 percent for imports). Consumer goods exports post an above-average decline, in spite of their average increase in relative prices, due to the high elasticity of consumer export demand with respect to relative price changes. The decline (rise) in industrial supplies and materials exports (imports) is attributed to their large relative price increase, coupled with an average price elasticity of demand. Exports and imports of foods, feeds, and beverages exports and imports are relatively price-inelastic. Consequently, exports decline only 0.7 percent relative to base-line levels and imports rise only 1.7 percent in response to the relatively large US price disadvantage.

Output Effects. The output effect of the carbon tax is defined as the percentage change in real export and import demand attributed only to changes in foreign GDP and domestic spending. As with the price effect, the output effect on each trade category depends on both the category's output change and its output elasticity.

Exports are affected little by output effects, but imports decline strongly because of the reduction in US GDP. Capital goods imports face the largest declines in domestic demand, with domestic automotive demand down 5.5 percent, computer demand down 3 percent, and other capital goods spending down 4 percent.

Total Effect. The total effect of the carbon tax is the sum of the relative price effect and the output effect. Export demands are negatively affected by both factors. On average, relative price changes are responsible for 79 percent of the total reduction in US export demand and output changes are responsible for the remaining 21 percent. In contrast, relative price effects stimulate import demand, while output effects depress import demand. The output effect is three times larger than the relative price effect, leading to a percentage decline in import demand that exceeds the percentage decline in export demand.

Consumer goods, industrial supplies and materials exports, and computer and "other" capital goods imports are hardest hit by the carbon tax in percentage terms. In billions of 1987 dollars, however, reductions in exports of industrial supplies and materials and capital goods excluding autos and computers are most significant, accounting for 48 percent of the decline in real exports; reductions in imports of capital goods excluding autos account for 64 percent of the decline in real' non-oil imports and 52 percent of the decline in total imports.

Impacts on Labor Markets and Transition Costs

One of the effects of declines in industry output is displacement of workers. This displacement, or movement of a worker from a job that he or she now occupies to a job in a different industry because of layoffs due to carbon taxes, entails costs not measured in static equilibrium analyses. Although we do not have a methodology for measuring the magnitude of such costs, which include retraining, physical relocation, lower productivity, and psychological costs, we can indicate how many jobs would be affected, in absolute terms and in comparison to total employment.

These job losses are also unlikely to be remediable through monetary policy measures, such as those used in this study to hold unemployment constant after a carbon tax. As Robert Solow (1994) pointed out in a recent *Electricity Journal,* changes in the composition of industry mean that there will be displaced workers shifted from industries that lose output to industries that gain. Until markets again settle down in equilibrium, there will be unavoidable transition costs and job losses. These are also job losses that are just as likely to occur if higher energy costs and reduction in energy consumption are brought about through regulatory programs as they are if carbon taxes are implemented.

These transition costs are also important because they can be masked in aggregate analysis. If total industrial output remained constant, aggregate analysis would be unable to identify costs. But if beneath the constant total output, there were some industries that gained significantly and others that lost significantly, there could be substantial transition costs.

The key question in gauging transition costs is whether existing workers will lose their jobs. It is much less of a problem if projected job growth does not materialize. Thus, employment with the carbon tax in each of the years 2000, 2005, and 2010 needs to be compared to actual 1995 employment to identify the industries in which current workers would lose jobs if all turnover occurred within the industry and no workers left the industry to find jobs elsewhere.[10] The results of this analysis are presented in Figure 5-6.

With the carbon tax of $100, only four industries would have employment in 2000 or later years less than employment in 1995, and six industries would have lower employment with the $200 carbon tax. All other industries that would suffer job losses compared to base-line employment have enough growth built into the base line that they still end up with greater employment in 2000 and later years than in 1995, even after imposition of a carbon tax.

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[10] Normal turnover of workers leaving one industry and gaining employment in another should in principle be subtracted from 1995 employment to estimate truly displaced workers. However, turnover rates between industries can be computed only through a very laborious process. Turnover rates for workers leaving an individual business, and presumably finding another job in the same industry, are so high that they imply virtually no problem of displacement. The average turnover ratio for US manufacturing (the percentage of workers leaving their jobs in a given year) is 10.3 percent. This means that after n years only $(1-.103)^n$ of the workers employed in the initial year will still be working in the industry. In the most heavily affected industry, coal, output and employment are down by 10 percent from base line by 2000, and 24 percent by 2010. Using the above formula, 42 percent of the workers employed in 1995 would have departed through normal attrition by 2000, and 80 percent by 2010 if the same turnover rate true of overall manufacturing were to apply in the coal industry. Thus, for even the most heavily affected industry normal attrition far exceeds job loss due to the $100 carbon tax. With a $200 carbon tax, job losses would be about twice as large (because the impact of carbon taxes on output is approximately linear)—20 percent in 2000 and 48 percent in 2010. If turnover in coal were half the national average, 5 percent per year, normal attrition would remove 13 percent of the original workers by 2000 and 54 percent by 2010. Thus in 2000, the higher carbon tax might produce job losses in excess of normal attrition. Turnover between industries is likely to be much smaller than turnover between firms in a given industry, and should be used in any effort to incorporate turnover.

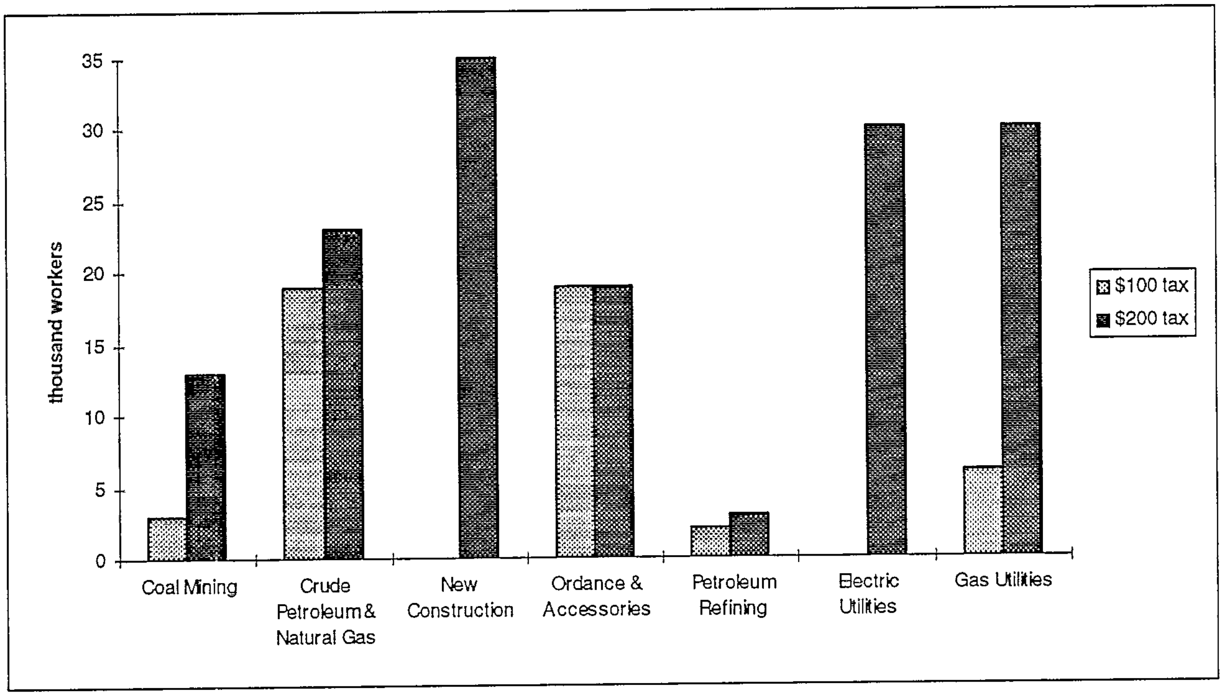

Figure 5-6
Workers Displaced Due to the Carbon Tax, $200 tax

The most heavily affected industry is crude petroleum and natural gas, losing 19,000 to 34,000 jobs existing in 1995. Ordnance and accessories also faces an absolute job loss of 19,000 workers in 2000 because of a carbon tax, but that is because defense spending cuts make ordnance a declining industry in the base line, so that there is no normal growth to offset the impact of carbon taxes. Petroleum refining also suffers. Coal, the industry heaviest hit in terms of loss in output compared to base-line levels, is projected to grow so strongly in the base line that employment is only 1,000 jobs below current levels by 2010.

With the $200 carbon tax, three more industries have employment reduced below 1990 levels— electric and gas utilities and new construction. The hardest hit industries fall below 1995 employment by 30,000 to 35,000 jobs in 2000 and 43,000 to 44,000 jobs in 2010. In 2000 the hardest hit are existing workers in new construction and gas and electric utilities. In 2010 the hardest hit existing workers are in gas utilities and crude petroleum and natural gas production.

The $200 tax scenario returns emissions to about 1995 levels by 2000, so that displacements of existing workers in the $200 case are approximately what would be expected of any policy designed to hold emissions to current levels.

In percentage terms, displaced workers amount to less than one-tenth of one percent of the total labor force in the $100 tax case and about one-tenth of one percent in the $200 tax case. These aggregate numbers by industry may also mask specific pockets of unemployment if there are shifts within industries not accounted for in the industry analysis, such as disproportionate reductions in demand for higher-cost coal produced in specific mines or regions.

Reference

Solow, Robert M. 1994 "DSM: Not for Jobs, but on its Merits." *The Electricity Journal 7,* No. 4 (May): 80-81.

6

IMPACTS WITHIN INDUSTRIES

The primary impacts of a carbon tax bear unevenly on the industries in the economy. A carbon tax of $100 per tonne would reduce the output of most industries by less than 3 percent, and effects of the tax on price would also be small for most industries. Impacts are concentrated in just a few industries that have price and output effects of more than 5 percent. These include the fuels industries, electric power, motor vehicles, and a few energy-intensive manufacturing industries, including some metals and chemicals.

The concentration of major carbon tax impacts on a limited number of key industries suggests a need. to know more about how these industries would be affected by carbon taxes. In order to examine patterns of impacts across industries it is necessary to ignore some of the changes that might occur within industries due to carbon taxes, and to concentrate on average conditions in the industry. Analysis of key industries supplements the inter-industry and macroeconomic analyses by examining each key industry in greater depth than the macroeconomic and inter-industry analyses can afford. In particular, it makes it possible to identify the marginal plants and processes in an industry, to examine ways in which the industry could adapt to carbon taxes and reduce their cost impacts, and to determine how much competition the industry faces from foreign suppliers or substitutes for its output.

This chapter reports the results of case studies of three energy-intensive industries: aluminum, steel, and chlorine. Each of the industries would be heavily affected by the tax, but the nature and magnitude of the effect is very different in each case.

Aluminum

Summary

Primary aluminum is identified in the inter-industry analysis as facing large cost increases due to carbon taxes and as being vulnerable to competition from imports.

The most striking effect of the tax on the aluminum industry would be to cause the retirement of many smelters in the United States and Western Europe and the expansion of capacity in countries such as Venezuela, Canada, Indonesia, and Brazil that are rich in hydroelectric resources and where there are many existing sites at which expansion can occur. Price increases of over 40 percent would occur initially, but the price would fall as new capacity displaced old smelters dependent on fossil fuels. Eventually, the tax would lead to price increases greater than the amount of the tax, because the early retirement of smelters using electricity from fossil fuels would make it necessary to add high-cost greenfield smelters earlier than otherwise necessary.

The carbon tax would also reduce the demand for aluminum. Reduced national income and price increases would both contribute to this effect. Prices of aluminum ingot received by domestic producers would increase by 35 to 45 percent of base-line prices during the first 20 years after the tax was imposed. Production and consumption of primary aluminum would decrease by 4 to 8 percent. The price impacts are much larger than those calculated from the macroeconomic and inter-industry analysis, and the output impacts are also larger.

The Aluminum Industry

Aluminum is an electricity-intensive industry subject to international competition among smelters that use electric energy generated from fossil fuels and smelters using hydroelectric energy. The cost of smelting with electricity from fossil fuels would increase substantially as a result of the carbon tax. A tax of $100 per tonne of carbon would increase the unit cost of primary aluminum produced from electricity burning fossil fuels by more than 40 percent, whereas the unit cost of aluminum in hydro-based smelters would go up by about 15 to 18 percent. The difference in the impact of the tax on the costs of the fossil fuel and hydro-based smelters would cause a major change in the industry throughout the world. In the Unites States, hydro-based smelters are located in the Pacific Northwest and New York state; the remainder, shown in Figure 6-1 use electricity generated largely from coal.

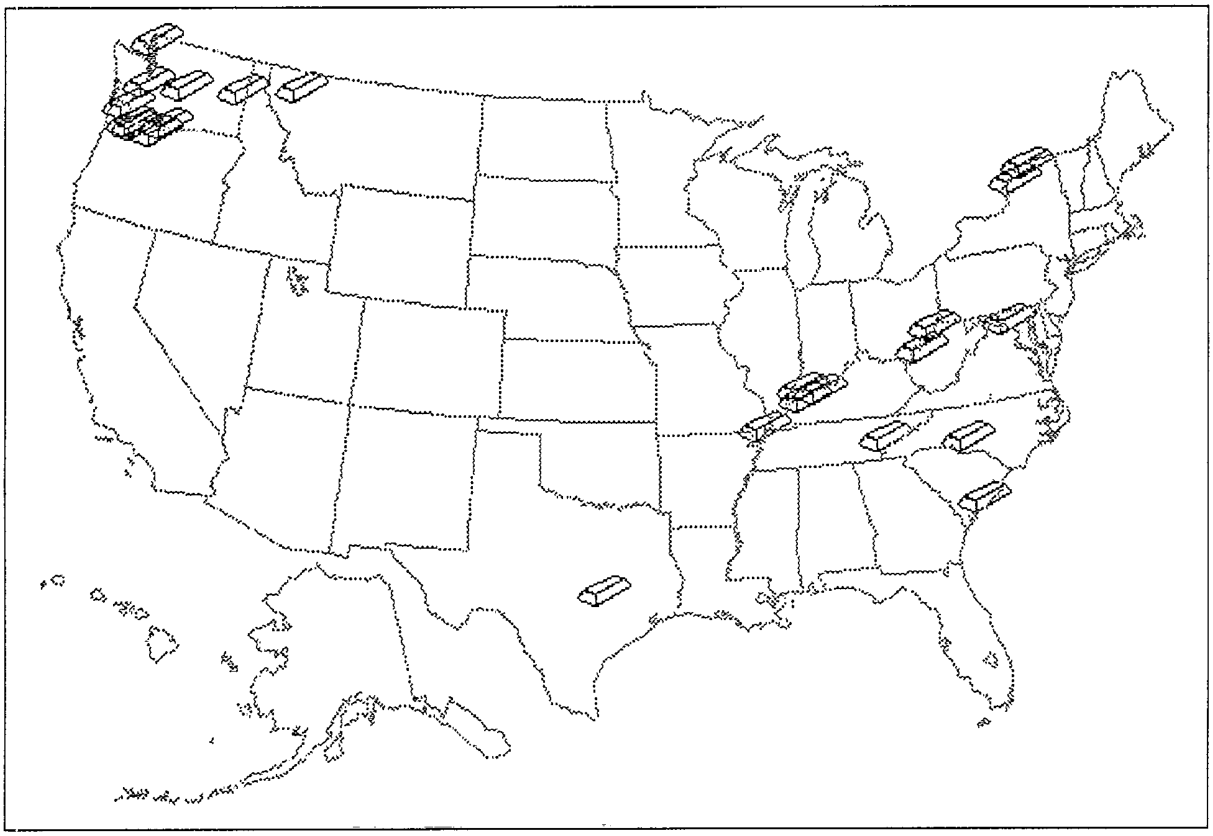

Figure 6-1
US Aluminum Smelters, 1992

World Markets for Aluminum. World consumption of aluminum has grown on average at about 2.3 percent per year since 1977 and is expected to continue growing at a similar pace. Asia, Latin America, Oceania, and Canada have experienced rapid growth, while Eastern Europe and the USSR have had very slow growth. Consumption in the United States, Japan, and Western Europe has grown at intermediate rates. The United States and Western Europe account for over half of world consumption but that share has been declining steadily.

The distribution of the growth in primary production is very uneven. Table 6-1 shows that in the United States and Western Europe, where costs of expanding production are relatively high, there has been virtually no growth in primary production over the last 15 years. Output expansion has occurred in Latin America, Canada, Oceania, Asia (outside of Japan), and Eastern Europe.

Table 6-1
World Primary Production by Region (Thousand Tonnes)

	1977	1982	1987	1992
United States	4,118	3,274	3,343	4,042
Eastern Europe	2,129	2,317	2,920	3,466
Western Europe	3,462	3,521	3,816	3,448
Asia excluding Japan	780	1,066	1,536	2,446
Latin America	361	795	1,486	1,983
Canada	973	1,065	1,540	1,972
Oceania	393	544	1,256	1,479
Japan	1,188	351	41	19
Total	13,779	13,433	16,514	19,467

(SOURCE: Metallgesellschaft *Metal Statistics)*

Secondary recovery has increased at about 4 percent per year over the last 15 years because aluminum is an extremely durable material and most of it is recovered and recycled. It currently accounts for about 40 percent of the total aluminum supply in the United States. It is also growing in other countries, accounting for 24 percent of total worldwide supply. As cumulative production, past and present, grows, potential secondary production also grows. Secondary production is substantially less carbon-intensive than primary production.

Since 1982, European primary capacity has remained flat, while US capacity has declined by nearly 20 percent. In Australia (Oceania), there has been rapid growth in smelters using very low cost (8 mills per kWh operating cost) coal-fired electric generation. In Venezuela, Canada, Brazil, and other countries, rapid expansion of hydroelectric capacity has occurred. Table 6-2 shows that the contraction of US capacity has taken place primarily through plant closures.

Table 6-2
US Smelter Capacities, 1977-1992

Company	Location	Capacity (Thousand Tonnes) 1977	1982	1987	1992
Alcan	Seebree, KY	109	163	163	163
Alcoa	Alcoa, TN	195	200	160	200
Alcoa	Badin, NC	114	115	115	115
Alcoa	Warrick, IN	263	270	270	270
Alcoa	Massena, NY	195	205	127	127
Alcoa	Palestine, TX	14	15	r	r
Alcoa	Point Comfort	168	r	r	r
Alcoa	Rockdale, TX	282	310	205	310
Vanalco	Vancouver, WA	104	110	110	110
Alcoa	Wenatchee, WA	186	205	205	205
Intalco-Alumax	Ferndale, WA	236	254	254	266
Eastalco-Alumax	Frederick, MD	160	160	160	160
Alumax	Mt. Holly, SC	0	179	181	181
Columbia Falls	Columbia Falls. MT	163	163	163	163
Columbia	Goldendale, WA	109	168	168	168
Consolidated	Lake Charles, LA	33	r	r	r
Consolidated	New Johnsonville,TN	131	131	r	r
Kaiser	Chalmette	236	236	r	r
Kaiser	Mead, WA	200	200	200	200
Ravenswood	Ravenswood, WV	148	148	110	166
Kaiser	Tacoma. WA	73	73	73	73
NSA	Hawesville, KY	163	163	172	172
Noranda	New Madrid, MO	127	204	204	204
Northwest	The Dalles, OR	82	82	82	82
Ormet	Hannibal, OH	236	245	245	245
Revere Copper&Brass	Scottsboro, AL	102	105	105	r
Reynolds Metals	Arkadelphia	62	62	r	r
Reynolds Metals	Jones Mills, AK	113	113	r	r
Reynolds Metals	Listerhill, AL	183	183	r	r
Reynolds Metals	Longview, WA	191	191	191	204
Reynolds Metals	Massena, NY	114	114	114	123
Reynolds Metals	Corpus Christi, TX	103	103	r	r
Reynolds Metals	Troutdale, OR	118	118	118	121
Total		**4,713**	**4.988**	**3.895**	**4,028**

r = retired

Structure of the Aluminum Industry. The production of aluminum involves some seven processing stages starting with the mining of bauxite and concluding with the manufacture of hundreds of fabricated products containing aluminum. Each stage contributes to the total carbon use associated with production of aluminum and fabricated products, but the critical stage for analysis of the carbon tax is the production of primary aluminum. This is the stage at which the industry’s energy consumption and carbon use are concentrated. One of the main effects of the carbon tax would occur via the international competition that would take place between smelters using electricity generated from fossil fuels and smelters using hydroelectric power.

The output of the primary aluminum industry is aluminum ingot. Most aluminum ingot is not sold in the open market, because the major aluminum companies are vertically integrated into the production of rolled, extruded, forged, and cast products. The aluminum is typically transferred from the producer's smelter directly into its own facilities for producing these products.

There are hundreds of plants that fabricate aluminum mill products to make numerous semi-fabricated goods and final products using processes of varying energy intensity. The products made from aluminum include, for example, soft drink containers, conductors for electric transmission, automobile engine blocks, siding, storm windows, and aircraft bodies. More than 175 of the 500 sectors defined in the 1987 input-output tables used aluminum products directly.

The demand for aluminum ingot ultimately derives from the demand for these numerous manufactured products. Consequently, the effect of the carbon tax on the *demand* for aluminum depends on demand for these manufactured products, as well as on the competition between aluminum and other materials in producing these products.

The effect of a carbon tax on competition between low-carbon and high-carbon producers of aluminum occurs at the fabricated products level as well as at the aluminum ingot level. There is competition among producers of ingot sold in the open market, among aluminum and substitute materials for parts of a given final product, and competition between final products (e.g., siding) containing aluminum and competing products containing substitute materials (e.g., wood or vinyl).

For analytical purposes it is appropriate to treat the aluminum market as a worldwide, competitive market. This market includes both primary and secondary aluminum, reflecting close substitution between the two. It is also a worldwide market because the aluminum companies compete on an international basis. It is also a competitive market. Six companies produce 33 percent of world primary aluminum. Secondary aluminum is produced by a partially different set of companies and is less concentrated than primary production. In combination, there are enough companies for the market to perform competitively, and the actual behavior of aluminum prices is indicative of market competition.[11]

Economics of Primary Aluminum Production. Primary aluminum is produced in an electrolytic process that reduces alumina (a concentrated raw material made from the bauxite ore) in a molten bath of cryolite. The process is carried out in carbon-lined reduction cells or "pots" assembled in series called potlines. This is the most electricity-intensive part of the overall process flow sheet of aluminum production. Of critical importance for present purposes are the sources of the electricity used in this stage of the production process.

A smelter using electricity generated from the burning of fossil fuels uses about 2.5 times as much carbon as a plant that obtains its electricity from a hydropower generator. A tax of $100 per tonne of carbon would increase the unit cost of primary aluminum from a typical smelter using electricity from fossil fuels by more than 40 percent, whereas the unit cost of primary aluminum produced in hydro-based smelters would increase by only about 15 percent.

The United States is currently the largest single producer of primary aluminum in the world, but that position would probably not be maintained in the event of a carbon tax. Nine of the 23 smelters in the United States, with about half of the capacity, are served by predominantly fossil fuel systems. One is served by a mixed nuclear and coal-fired utility, and one is supplied with electricity generated from 60 percent hydro and 40 percent fossil fuel. Coal is the dominant fuel in smelters using electric energy generated from fossil fuels. Bonneville Power Authority, a predominantly hydro system that also includes large nuclear costs in its cost of service, serves ten smelters at relatively high rates, and the New York Power Authority, a largely hydro system, serves two smelters.

Expansion of the US industry would likely be with electricity from natural gas or coal, because major expansion of hydroelectric capacity is not economically and environmentally feasible. The same is true of Western Europe. In Latin America, Canada, and Africa, hydroelectricity is the predominant power source for expansion. Australian smelters are supplied by very-low-cost power generated from coal. In a few countries in the Middle East, natural gas is a waste product that would normally be flared. In those countries, gas at very low prices would be used for generating power for a new aluminum smelter.

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[11] In response to expanded exports by producers in the former Soviet Union, some of the leading aluminum producers have been meeting recently to establish an agreement to restrain outputs and limit price competition. Such efforts are not unusual in the international metals markets and could succeed temporarily. However, such efforts have rarely had much effect, and none have succeeded for more than a few years in industries with market concentration as low as that of the aluminum industry.

Effects of a Carbon Tax on Aluminum Production Costs

Marginal Cost Curve. In order to determine how carbon taxes will affect competition among existing and new aluminum smelters, two concepts of cost are needed. One is the cost of sustained operation in existing plants, and the other is the cost of creating new capacity. The cost of sustained operation is the minimum cost that must be covered to make continued operation economically justified. An existing plant will be operated even if price does not cover depreciation or a return on invested capital, because those are sunk costs. There are, however, some investments that must be made to keep a plant in operating condition, and these investments as well as variable costs are included in the sustaining costs. A new facility, or expansion at an existing site, must be able to cover the full costs of investment, including a return on capital, as well as sustaining costs if it is to be profitable.

The tax would immediately increase the incremental cost of industry primary production by 40 percent. Smelters dependent on fossil fuels, most of which have been barely covering of their cost of sustained operation pretax, would have increases in the unit cost of sustained operation of over 40 percent. Smelters using hydroelectric power would have increases in sustaining unit cost of 14 to 16 percent.

Figure 6-2 compares base-period sustaining unit costs of representative smelters in the United States, Germany, Australia, Canada, and Venezuela to total costs when the carbon tax is included. The smelter in the United States using coal-fired electricity would have a 28 cents per pound unit increase in cost, whereas the hydro-based smelters would have an 8 cent cost increase. The coal-dependent Australian smelter, which has low-unit costs pretax, would experience a large cost increase as a result of the carbon tax.

The tax would increase the sustaining cost of smelters burning fossil fuels so that it would cost less to add new capacity at existing sites rather than to invest in sustaining the life of old smelters dependent on fossil fuels.

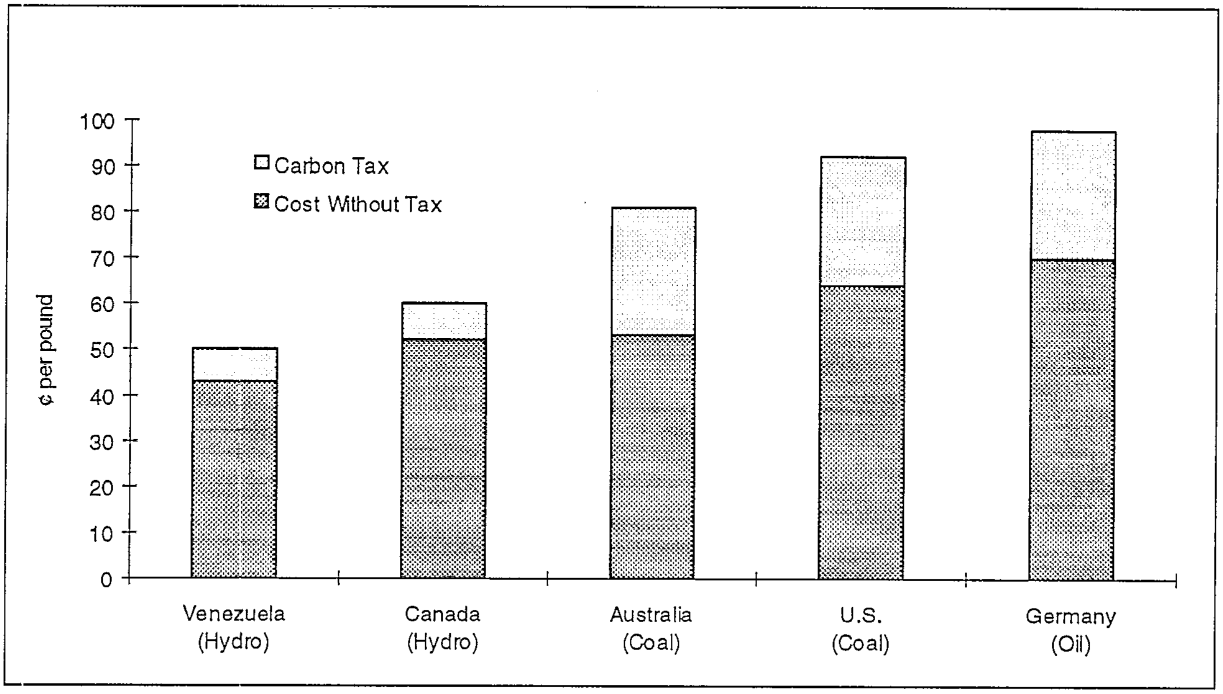

Figure 6-2
Unit Sustaining Cost of Representative Smelters with a $100 per Tonne Carbon Tax

Figure 6-3 compares the cost of expansion at existing sites for smelters of the types previously shown in Figure 6-2. When compared with Figure 6-2, Figure 6-3 demonstrates that the unit lifetime cost of expansion at existing low-cost sites is lower than-the cost of operating existing smelters in the United States and Europe that depend on fossil fuels. For example, the sustaining cost of the US smelter using coal-fired electric power would increase to 92 cents per pound, whereas the lifetime cost of new capacity in Venezuela and Canada would be 78 and 87 cents per pound, respectively.

Before the tax was imposed, expansion at greenfield sites already cost substantially more than expansion at existing sites. Because expansion at a new site would involve some carbon-using investments in infrastructure that would not be necessary when capacity was added to an existing site, the tax would widen the gap between the costs of greenfield expansion and incremental expansion at existing sites.

The lifetime unit cost of greenfield expansion would remain substantially higher than the cost of expansion at existing hydroelectric sites. Consequently, as long as existing hydroelectric sites had the potential for expansion, the tax would not provide an incentive for greenfield expansion. However, eventually the potential for expansion at existing sites would be realized, perhaps after 15 to 20 years, at which point greenfield expansion would probably become economic.

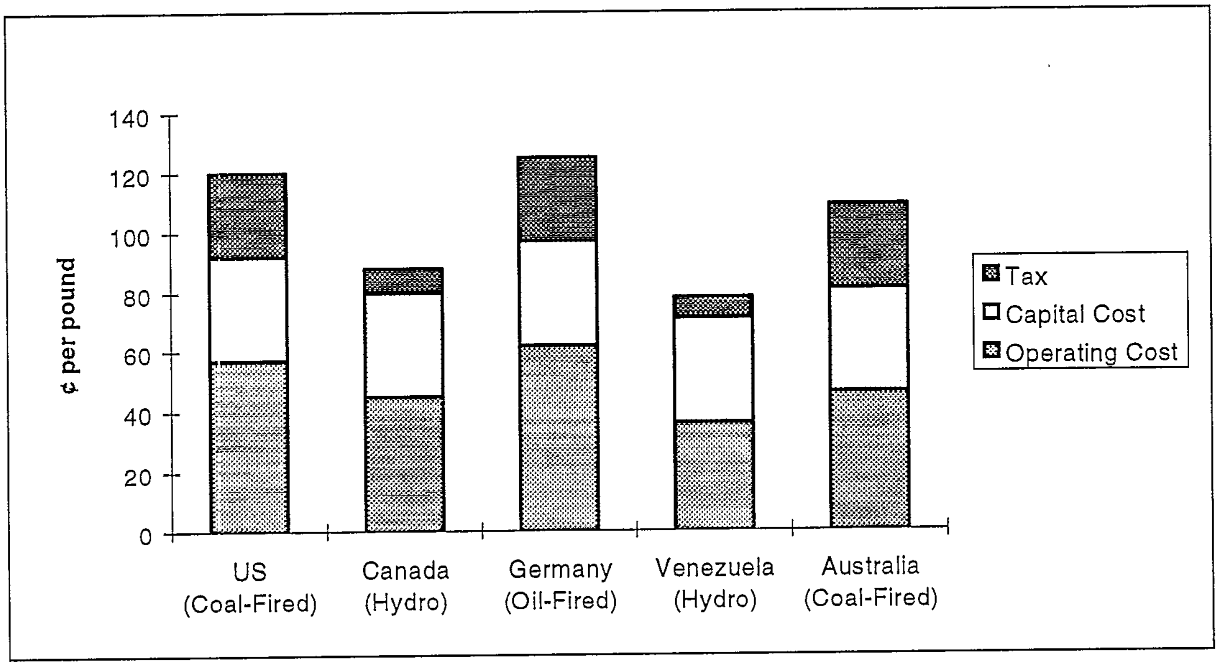

Figure 6-3
Unit Costs of Producing Aluminum in Expanded Capacity at Existing Facilities

By changing these cost relationships, carbon taxes would make many existing US facilities unable to compete with expanded capacity in countries with available hydroelectric power resources. Primary production and capacity would decline radically in the United States and Europe. Many high-cost smelters using electricity generated from fossil fuels would become uneconomic. Nearly half of the existing capacity in the United States and Western Europe would be retired within 10 to 15 years after the tax went into effect. Other high-cost smelters would operate at substantially reduced utilization.

Capacity at existing sites where hydro is available would increase rapidly over the first 10 to 15 years of the tax. Production and capacity growth pretax is already predominant in countries where smelters have access to low-cost power. The industry in Latin America, Canada, and parts of Asia would experience rapid growth wherever there is expansion potential at existing sites. After 10 to 15 years, when this potential would have been largely realized, greenfield expansion would occur mainly in these countries and in other areas, such as Africa, that have potential hydro development.

Low-cost producers using fossil fuels will not expand until after 2000. Australia is one of the lowest-cost producing countries pretax. Aluminum production and capacity have grown very rapidly and that growth is planned to continue through the 1990s. The tax would make Australia a medium-cost producer. Australian smelters would continue to produce after the tax, though at a lower profit, but planned expansion would be canceled. Once expansion at existing hydro-based smelters approaches saturation, expansion at existing Australian smelters would be economic, but it is unlikely that greenfield smelters would be built in Australia for many years.

Economics of Aluminum Demand

Nature of Substitution Responses. The demand for aluminum is derived from the demand for its various end uses. A carbon tax could affect this demand through the income effect of reduced national income on demand for end-use products containing aluminum, through price-induced substitution between aluminum and other materials that can be used to produce the end-products, and by substitution between end-products made from aluminum and competing products. Price potentially affects aluminum demand through several kinds of substitution.

The effects of price on demand are of three types. First, the effect of the carbon tax on the aluminum price and the prices other inputs to end-use products could affect the prices for those products and, in turn, the demand for those products. Second, the carbon tax would also affect the prices of aluminum and substitute materials used in producing end-use products, potentially causing substitution between aluminum and competing materials. Finally, the carbon tax would create an incentive for economizing on the total amount of material used in the end-use product. By redesigning the end product using existing technology and, potentially using technological improvements developed in response to the carbon tax, producers of end-use products could reduce the amount of aluminum embodied in those products.

<u>Price-Induced Substitution at End Users Level</u>. The cost of aluminum contained in most end products is a very small share of the price of the total product. Beverage containers are the major end use with an aluminum cost share of more than a few percent; the aluminum in a soft drink accounts for 8 to 9 percent of the producer's cost of the canned beverage. In the case of automobiles, houses, and planes, the aluminum is a negligible share of the total cost. Even large changes in the price of aluminum would have only a very small effect on the cost of producing the total end-use product.

The tax would affect production costs of all inputs to the aluminum end product, and to the cost of competing products. Because the prices of all end-use products would increase, the effect on end-product demand of increases in aluminum prices caused by the tax will be very small. For instance, the tax would increase the cost of both steel and aluminum cans.

<u>Substitution Between Aluminum and Other Materials</u>. The carbon tax may induce substitution between aluminum and other materials in response to changing market prices caused by the tax. Market competition among materials usually involves technological change to reduce Costs or improve performance. Aluminum competes with, for example, vinyl and wood for siding, wood for storm windows, steel for motor vehicle engine parts, copper for some electrical conductor applications. The range of

substitution possibilities for aluminum is large, but most of the substitution potential is with steel, wood, plastics, glass, and copper.

The tax would not cause much price-induced reduction in aluminum demand because of substitution among materials. Most of the materials with which aluminum competes are also produced in energy-intensive processes. In some cases, such as the use of steel and aluminum in automobiles, the weight-based energy-saving advantage of aluminum may even lead to increased use of aluminum at the expense of steel.

Effect of Tax on Product Design. Economizing on aluminum can be accomplished through changes in design of the product that reduce total material use without directly substituting materials. For example, consumer demand for automobiles may shift to a mix containing smaller vehicles in order to conserve on fuel and limit auto price increases by economizing on the total cost of materials–steel, aluminum, and plastic–that would increase in price as a result of the tax.

Income Effects on Demand. The demand for aluminum will also be affected by the "income" effect of the tax on the demand for end products using aluminum, induced not by the aluminum price but by the economy-wide pattern of changes in demand that affects all aluminum-using industry. The net impact of these income effects is likely to be to decrease aluminum demand. A very large share of aluminum output goes into the production of motor vehicles, aircraft, and wiring and other components associated with electric power. These are all industries that suffer significant output declines because of the carbon tax, and their decline reduces demand for aluminum.

The electric power industry, a large user of aluminum conductors for transmission and distribution lines, is one of the most carbon-intensive industries in the economy. The value of electric power output would decline by about 14 percent due to a $100 carbon tax.

Motor vehicle production, particularly passenger automobiles, would be reduced significantly by the tax, because purchase of vehicles is income-elastic. Motor vehicle production is expected to decline by 5.5 percent because of the effect of the tax on national income and on the cost of driving. In addition, smaller vehicles, using less aluminum, would be purchased, in response to both reduced income and the increased cost of motor fuel and materials, so the overall effect could exceed 5.5 percent.

Output and Price Over Time

Consumption of primary aluminum would decrease materially due to a carbon tax. During the first ten years after introduction of a $100 carbon tax, total consumption would decrease by about 4 to 8 percent below the base-case forecast in the event of a world tax. If the tax were on OECD only, the effect would be only slightly less. The decrease in primary consumption might be slightly different because of increased secondary production. After a few years, growth in demand would resume, but demand would remain below the base-case level because of higher aluminum prices.

Market demand for aluminum would decrease after the tax. The decrease in demand induced by the aluminum price alone would be small. The cost of aluminum is a small share of the prices of the end use products, and the effect of the tax on materials substitution would also be small, because the main materials that compete with aluminum are energy intensive. Though the cost of aluminum would likely increase more than the costs of some competing materials, such as wood, the prices of others, such as steel and concrete, may increase substantially. In any event, the *relative* price changes would be much smaller than the absolute changes.

In addition to the effects of the aluminum price on the demand for aluminum, there would likely be a significant decrease in demand for aluminum as a result of the reduced demand for materials in end use markets, particularly in motor vehicles and electric power transmission and distribution. The decrease would reflect two factors: the effect of decreased national income on demand for final end use products such as motor vehicles and the effect of increased prices of all materials combined. The study team estimates that the total reduction in demand for primary and secondary aluminum (relative to the base case) would be 4 to 8 percent within ten years after the tax went into effect. The first year's reduction might be only 1 or 2 percent, but most of the effect would be apparent by the mid–1990s.

Figure 6-4 illustrates the equilibrium paths of consumption over time for the base and carbon tax cases. The carbon tax causes a widening gap over time, though both would grow at a similar compound rate after the first five years or so.

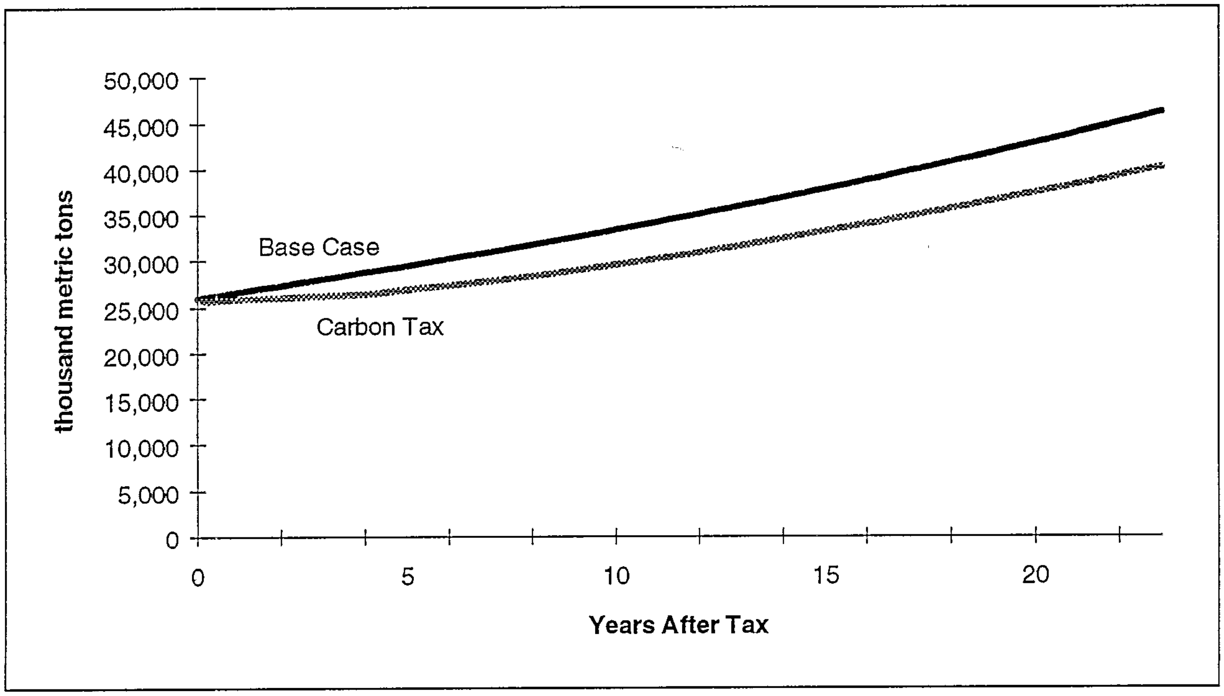

Figure 6-4
Illustrative Equilibrium Paths of Consumption and Production of Primary Aluminum

The price of aluminum would increase, but by much less than the amount of the tax. During the first 10 to 15 years after the tax was imposed, the price of aluminum would exceed that of the base case by only about 70 to 75 percent of the amount of the tax per pound of aluminum. However, after 10 to 15 years, when greenfield capacity would have to be added to supply growth in demand, the price would increase radically. In the base case, this price increase would occur 4 to 8 years later because more old smelters would still be in operation if there were no tax.

Figure 6-5 illustrates the price impact over time. The chart abstracts from the normal volatility due to fluctuations in demand and production. The base-case price rises gradually over time and, in equilibrium, would be governed by the cost of expanding capacity at existing smelters for the first 10 to 15 years after the tax. Retirement of old capacity would occur, but only gradually, so that the industry would be able to supply growing demand for at least ten years before new greenfield capacity would become economic. In contrast to the base case, if a carbon tax were imposed all at once, the price would rise sharply immediately after the tax was imposed, initially exceeding the base price by approximately the per ton cost of the tax. Figure 6-5 also shows the subsequent decline of the price as decreased demand and increased secondary production create excess capacity. During the next five years or so, after tax prices would be governed by the cost of expansion at low cost sites. If the tax were phased in, the price spike would be avoided, and prices would rise gradually to the level based on the cost of expansion at low cost sites plus the tax. In the base case, less capacity would be retired and less new capacity would be needed.

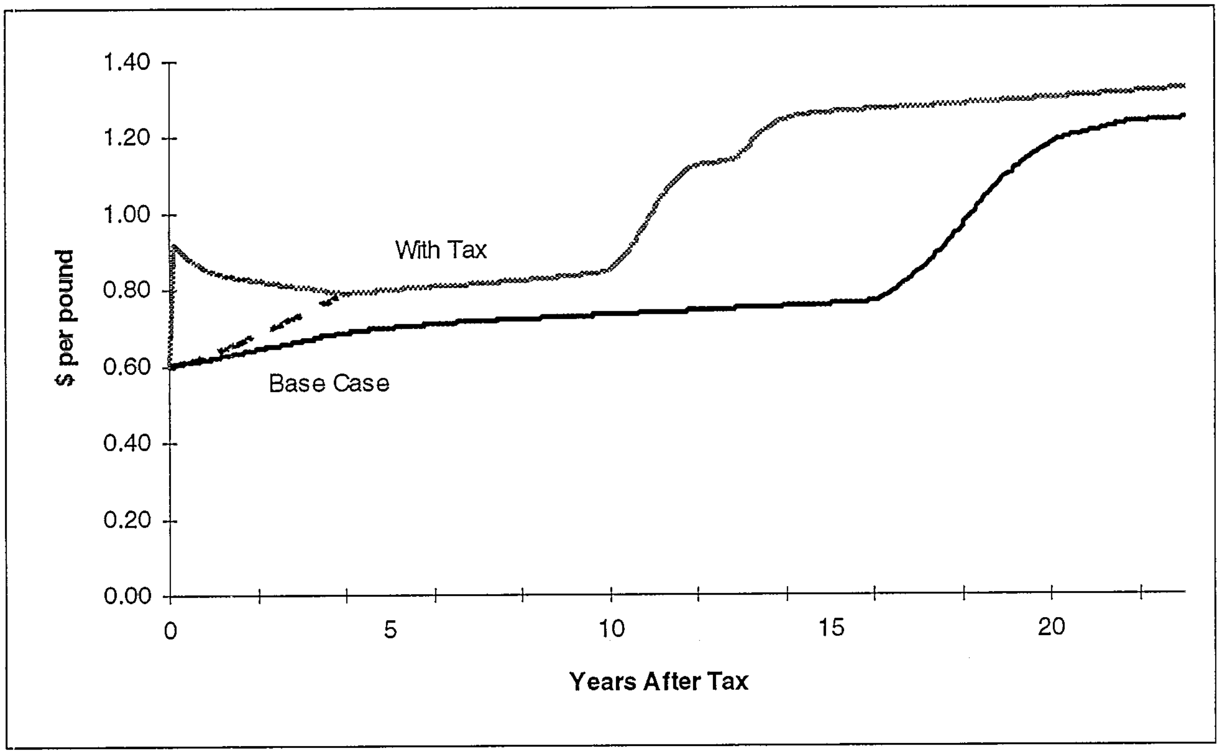

Figure 6-5
Illustrative Price Path: Base Case and World Tax Scenario

In the base-case scenario, many years of expansion could occur from existing sites, because of the slow rate of retirement of existing smelters. In contrast, the carbon tax would induce retirements of most high cost smelters, and addition of much more new capacity from 1995 through 2000. In the tax case, the price would remain governed by the cost of expansion at existing sites for a much shorter period than in the base case, because replacement of the capacity retired due to the tax would use up at least half of the available expansion sites.

As the expansion of capacity approached saturation of existing sites with expansion potential and available hydro power, some high cost fossil fueled capacity would return to active status. In addition, some Australian capacity would become economic at prices in the $1.05 to $1.15 range. At some point after 2000, probably after 2005, the price would ramp up rapidly to a new path governed by the lifetime cost of new greenfield capacity, which would range from $1.25 to $1.50. That path would have a rising trend as expansion progressed from the best sites to sites with higher costs.

As a result of the shutdowns projected to occur in the 1990s, unused smelter capacity would overhang from about 1996 to 2003; the ability of unused capacity to produce at high prices would limit increases in aluminum prices during periods of high demand. After 2000, when prices rise above $.90 per pound, shutdown capacity would be reactivated.

There would likely be a role for a few existing smelters in the United States and Europe that rely on electricity from fossil fuels, because they are quite likely to be the most efficient source of capacity for meeting cyclical peaks and providing standby capacity.

Trade and Regional Impacts

Effects of the Tax on International Competition. A $100 per tonne carbon tax, whether worldwide or on OECD countries only, would have a very great impact on the aluminum industry throughout the world. There would be a radical reduction of primary aluminum capacity and production in high cost smelters using fossil fuels, primarily in the United States and Europe. Capacity would increase substantially at existing sites in Latin America, Canada, and Asia, where hydroelectric power is available.

The United States, which already experienced a decline of 20 percent in primary aluminum capacity from 1982 to 1992, would experience a much greater decline during the first 10 to 15 years after the tax was imposed. Most of the smelters using coal fired electric energy would likely be retired or relegated to standby and peaking use. The generally high cost smelters served by the Bonneville Power Administration would probably be helped by the tax, as long as their rates were based on embedded hydro and nuclear costs that would not be increased much by the tax.

Venezuela, Brazil, Canada, and other low cost, hydro-based producing countries that would gain as a result of the tax already have a high rate of capacity, which would accelerate substantially.

The tax would stop or substantially reduce planned growth in Australian capacity. In the base case, Australia would continue to be one of the low cost producing countries of the world, with unit costs comparable to those of Canadian smelters. After imposition of the carbon tax, existing Australian smelters would still be able to operate profitably, but adding new capacity would be deferred for at least ten years.

Eastern European capacity, which has not grown much over the past 20 years, would lose competitive position. In recent years, Russia and other former Soviet Union countries have had excess capacity and have been exporting to the world market. If the exporters had to pay the carbon tax, or if the importing countries imposed tariffs or quotas to achieve the same result, Eastern Europe would cease to be a significant exporting region.

Imports by the United States and Western Europe would increase radically. The United States would import half or more of its aluminum, and the share of imports would grow over time. European imports would also increase. The dollar would decline slightly in price relative to most currencies, but competition among aluminum exporting countries would not be significantly affected by changes in exchange rates.

The aluminum companies would probably continue their fabricating and manufacturing operations in the United States and Europe, just as Japan did not cut back significantly its fabrication in the 1980s, when it virtually exited from primary aluminum production. Energy cost is not a primary factor in plant location in most aluminum fabricating operations. Proximity to the market and availability of a skilled work force are more important. Access to imported or domestic aluminum at the world price would put fabricators in the developed countries in a good competitive position, because the tax would have only a minor effect on the cost of fabrication of most aluminum products.

Bauxite and alumina production would be affected by the tax, but only to a much lesser extent than primary aluminum. The location of bauxite deposits will continue to determine the location of new mines, and there would be no need for new mining capacity for more than ten years after the tax is imposed, at least partly because consumption would take some time to grow back to the 1992 level. Alumina capacity would also not increase for a similar period. When capacity growth resumed, the location of new capacity would be similar to the base case.

Regional Effects in the United States. The Pacific Northwest (ten hydro-nuclear smelters) and New York (two hydro-based smelters) would likely be winners as a result of the tax. Nearly all smelters in other regions would be at substantial risk of shutdown. The one exception is a smelter in North Carolina that is supplied by a system that is more than 50 percent nuclear. The remaining ten smelters, using electricity generated mainly from coal, are dispersed in eight different states, as indicated in Table 6-2. Fabricating industries are even more dispersed.

A 100,000 ton smelter would have a payroll of about $3.4 million per year. A shutdown would be important locally, but it would not in itself be a major event in the overall economy or region.

Small producers with only fossil fuel driven capacity would experience substantial losses. Hydro-based producers and large multinational firms with a good hydro base could even profit from the tax. Nevertheless, the market would remain competitive. Market concentration would probably increase as a result of the shakeout of high cost producer and the concentrated ownership of sites with hydro available. However, the overhang of unused smelter capacity and the large number of surviving competitors would prevent substantial and sustained departures from market prices based on competition.

Iron and Steel

Summary

The carbon tax would also have substantial effects on the steel industry. The case study reported here focused on one major effect: the differential impact of the carbon tax on electric arc furnaces and basic oxygen furnaces (BOF). The effect of the tax would be to increase the costs of an existing BOF in the Chicago area by about $120 per tonne, whereas an electric arc furnace in the same area would experience a cost increase of only about $70 to $80. Allowing for increased steel imports and decreased consumption of steel, it is still quite possible that electric power consumption by the steel industry in the United States would not decrease, because a larger share of steel production would be in electric arc furnaces. However, the economics of expanding electric furnace production depend on the supply and price of steel scrap. Today nearly all of the scrap that is relatively easy to recover is being recovered and used as an input in steel production. Higher scrap prices following a carbon tax of $100 per tonne would induce added scrap recovery, but the increase in scrap supply would likely be moderate in the range of 5 to 10 percent above the base line level. At scrap supply levels in that range, we would expect scrap prices to be bid up to the point where the competitive advantage to electric furnaces caused by the tax would be neutralized.

The Steel Industry

Competition and Substitution Between Types of Processes. There are two important competing processes for production of steel: electric arc furnaces (EAF) and basic oxygen furnaces (BOF). These two steelmaking processes use very different amounts of carbon per ton of steel, partly because they use different raw materials: the BOF uses mainly iron ore or pellets made from ore, and the EAF uses primarily steel scrap. The geographic locations of the two processed are depicted in Figures 6-6 and 6-7.

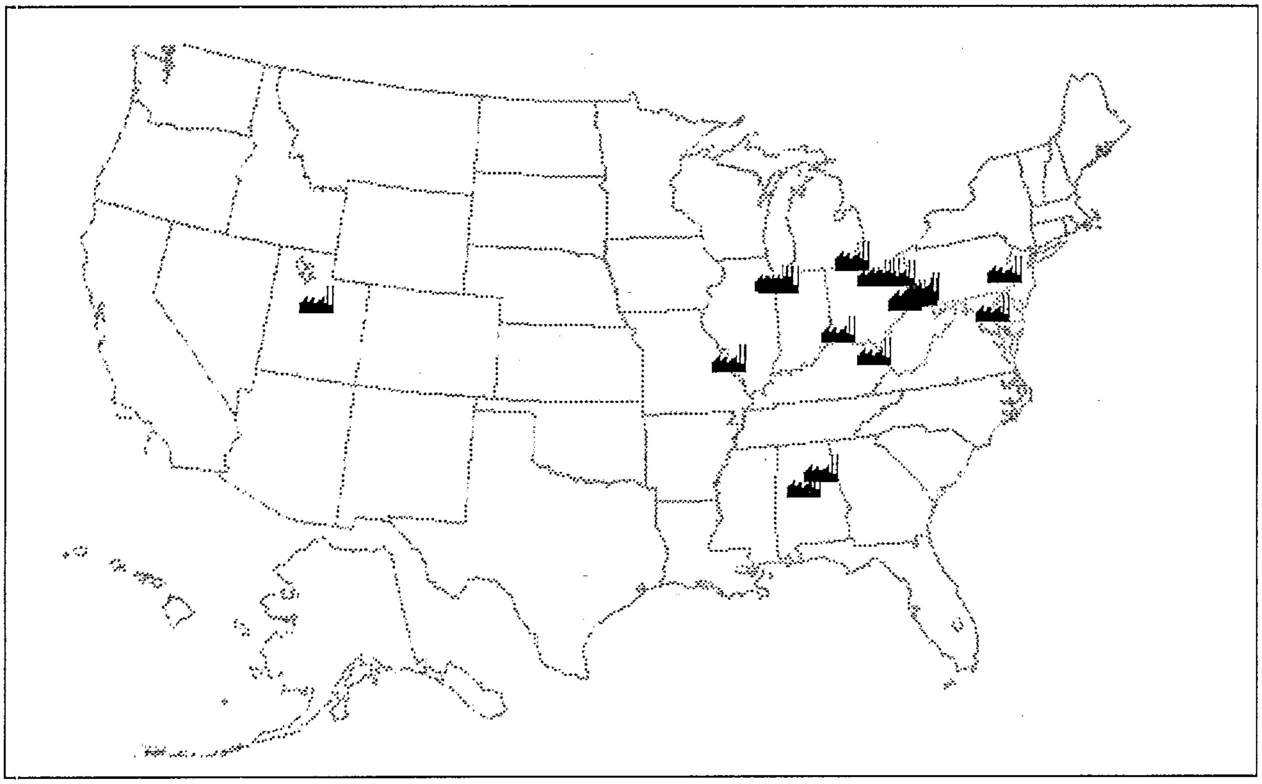

Figure 6-6
Location of Basic Oxygen Steel Plants in the United States, 1992

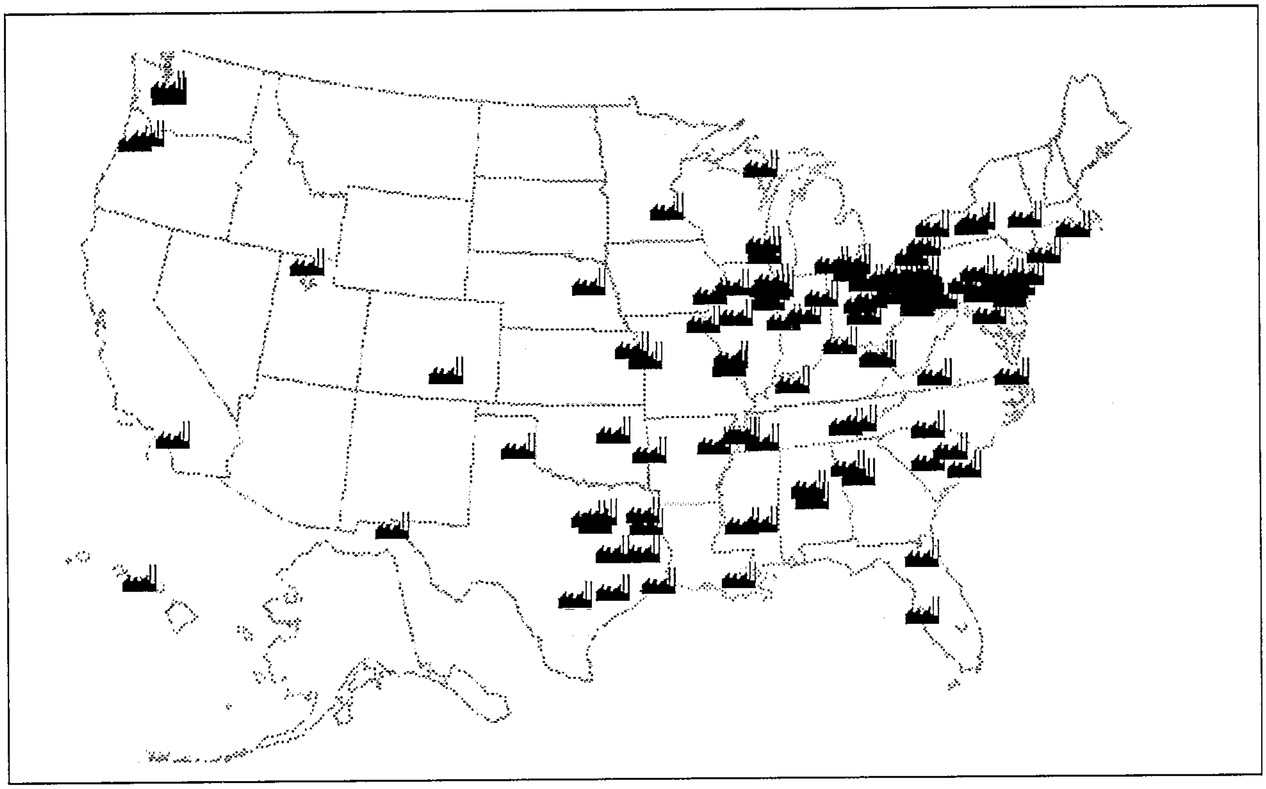

Figure 6-7
Location of Electric Arc Furnace Steel Plants in the United States, 1992

Current basic oxygen furnace mills are mainly on the Great Lakes and the Mississippi River system. This is, at least partly, due to the accessibility of raw materials at those locations. As recently as 1980 there also were mills at Fontana, California (East of Los Angeles), Pueblo, Colorado (which has been converted to electric arc) and Lackawanna, New York (near Buffalo). There has also been a substantial number of closing/dismantlings around other parts of the Great Lakes and Pittsburgh areas. The plant Utah was converted from open hearths to BOFs in the late 1980s.

Figure 6-7 shows the very wide dispersion of electric arc furnace mills. Using primarily steel scrap, this technology can be advantageously located dose to ultimate product markets that produce adequate quantities of country scrap and/or steel-using establishments that generate a sufficient quantity of prompt scrap. The geographic dispersion of steel mills may well be affected by the imposition of a carbon tax, depending on the relative effects such a tax may have on the different technologies and the geographic dependence of the technologies.

The dualism in raw steel production technology illustrates an important type of effect of a carbon tax, because steel is one of a number of industries in which substitute processes are differently affected by the tax. A little more than 60 percent of US raw steel is produced in the integrated blast furnace/basic oxygen furnace process, while a little less than 40 percent is produced in electric arc furnaces. The two processes use substantially different mixes of raw materials which, in part, are the basis for the processes' very different patterns of energy and carbon use. However, a recent technological development, direct reduced iron, could decrease the differences between the raw material mixes, as well as the processes' energy requirements.

Steelmaking Processes. There are very significant differences across the various processes used to make steel and these differences have substantial consequences for the industry's use of energy and carbon. Currently, two processes are predominant: 1) the integrated process that combines blast furnaces and basic oxygen furnaces, and 2) the non-integrated process which uses almost exclusively electric arc furnaces. Until recently, another integrated process, combining blast furnaces and open hearth furnaces, was in use in the United States. However, outside of Eastern Europe such facilities have been largely phased out and are not relevant to the study.

Integrated Blast Furnace/Basic Oxygen Furnace Process. The integrated process for making steel begins with the extraction of natural raw materials, iron ore, coking coal, and limestone. These raw materials are themselves cleaned, concentrated, and sized at their mine sites to make them more suitable for the subsequent production steps. At the steel mill, the coking coal is first fed into coke ovens where it is "baked" for several hours. This drives off the volatile gases in the coal leaving the blocky cellular mass called coke.

Iron ore pellets, limestone, and coke are charged continuously into the top of the blast furnace, where they are transformed into molten pig iron by a series of thermal and chemical reactions. In these reactions, impurities and extraneous matter in the raw materials separate into a "slag" that can be removed periodically without contaminating the iron. The molten iron is "charged" into the basic oxygen furnace along with recycled steel scrap. A very high velocity stream of extremely pure oxygen is directed into this metallic charge, setting off the chemical and thermal reactions that refine the metal to "carbon steel" qualities and raise its temperature to maintain it in molten form. Lime and other fluxes are added to the furnace at different points during the process to form a slag containing the various impurities removed from the metal during the refining.

Non-Integrated Electric Arc Furnace Process. The charge of metallics into the electric arc furnace is *mainly* steel scrap, that is, recycled steel, but more recently increased amounts of cold pig iron[12] and direct reduced iron are also being used.

After the materials are charged into the furnace, carbon electrodes are lowered into their midst. High voltage electrical power is turned on, creating an arc across the electrodes with the scrap and other materials, thereby generating very high temperatures and intense heat. This melts the materials and sets off the refining

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[12] Cold pig iron is molten pig iron that has been poured into molds and allowed to cool and solidify.

reactions that remove impurities from the steel being made. Lime and other fluxes are added to combine with the impurities and form a slag. High-purity oxygen is frequently injected to accelerate the reactions.

Direct Reduced Iron. Partly in response to the very high capital costs of blast furnaces and the need for iron bearing materials that can be used in electric furnaces where scrap is in short supply, another series of technologies has been developed. These are the Reduced Iron Feeds (RIF), most commonly referred to as Direct Reduced Iron or DRI. There are several currently in operation or development. All basically use iron ore (concentrates or pellets) extracted from natural deposits and a fuel, such as natural gas, to produce a solid iron product that is at least as pure as pig iron. This product can be used directly in art electric furnace as a substitute for scrap[13] Currently, it is also being used as an "enriched" blast furnace charge material (very much like scrap is used to increase blast furnace productivity) and in basic oxygen furnaces.

Prominent among the DRI processes is the Midrex method. It uses natural gas to produce a briquetted high grade metallized iron product, for use as a charge material in electric furnaces. However, it is relatively expensive except where flare gas can be used. Because DRI uses gas rather than coke, its carbon consumption is less than that of making an equivalent amount of pig iron in a blast furnace.

Processing Subsequent to Raw Steel Form. Subsequent processing of the raw steel consists first of pouring the molten metal into its first *solid* form. This may be done by one of two methods. One involves pouring the molten metal into ingots which are subsequently rolled into slabs (rectangular cross section) in a slabbing mill, blooms (square cross section) in a blooming mill, or billets (smatter square cross section) in a combined blooming and billet mill.

The second and .newer process is the continuous casting strand. In it the molten steel is poured down through a chamber of rolls, in which the steel is shaped into slabs, blooms, or billets as it exits from the strand. This process avoids several of the energy using steps in the ingot alternative, as well as the substantial yield losses involved when ingots are rolled into slabs or blooms. Continuous casting is the preferred process; it has been displacing the ingot method dramatically and shortly will become the only method of interest.

Shaping and treating processes subsequent to the first solid form are, for the most part, specific to the particular steel mill product being made, not related to the processes used to make raw steel or the first solid form, and similar across plant locations (except

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[13] It can also be used in some proportion along with scrap to help dilute any trouble–causing alloys that might be present and unknown in the scrap.

for vintage). In light of these considerations, the remainder of the study treats all the processes subsequent to the making of raw steel as a single production step.

Differences in Direct Energy Use. Table 6-3 highlights some of the relevant differences among these processes in terms of their direct use of energy. Note that these data are in terms of the specific energy form consumed in each of the processes listed at the head of the columns. However, these differences are only the tip of the iceberg. The analysis below builds on them and the relationships that exist among the stages of the processes to develop more complete measures of the differences in total carbon consumed by the processes.

Table 6-3
Direct Energy Use by Steelmaking Processes Per Net Ton of Product.

Product	Coke (NT)	Natural Gas (000 Cubic Feet)	Petroleum Products (Gallons)	Electricity (kWh)
Basic Oxygen Steel	0.000	0.200	0.0	30
Pig Iron	0.487	1.487	4.0	25
Iron Ore Pellets	0.000	0.275	2.2	164
Limestone	0.000	0.005	0.2	2.6
Shredded Scrap	0.000	0.000	0.0	243
Electric Steel	0.000	0.100	0.0	500
DRI	0.000	10.000	0.0	100

The domestic steel industry has contracted since the early 1970s. Current raw steel production capacity is down about 30 percent since then. Production has been fairly stagnant, fluctuating between 85 and nearly 100 million tons per year. This record is not atypical. Production in the European Union and Japan has also been stagnating. Eastern European (including the Commonwealth of Independent States countries) production has declined dramatically. Only in Mainland China, South Korea, and some Latin American countries has steel production grown.

In the face of this stagnation, in total steel capacity, domestic electric arc furnace process capacity has grown and its production has taken over an increasingly larger share of total steel output. Also, the continuous casting process, which displaces the ingot/blooming mill sequence as the first step subsequent to making raw steel, has grown rapidly in the US during the 1980s and early 1990s.

Employment in the domestic steel industry has declined at a rate faster than the decrease in production, reflecting the increased productivity that has occurred. According to Bureau of Labor Statistics data, steel industry employment exceeded 500,000 in 1980 but had declined to about 250,000 by 1992, a 50 percent decline while production fell 17 percent.

In the face of capacity and production declines, steel mills have become more geographically dispersed. While integrated mills have become more concentrated, reflecting the sources of their raw materials, the dispersion is due to the growth of the number of electric furnace plants located with respect to their scrap sources and the markets they serve.

Cost Effects of a Carbon Tax

Investigating the effects of a carbon tax on steel production and how those effects cascade through the industry's markets begins with estimating the impacts of the carbon tax on production costs in the industry. Figure 6-8 and Figure 6-9 represent, in simplified terms, the conceptual framework of this analysis. Figure 6-8 depicts hypothetical supply (cost) functions for the two steelmaking processes, as well as the resulting total supply function without a carbon tax. Given a particular total output (95 million tonnes) and the cost at which it is produced, ($300 per tonne), it is possible to trace back the shares of the two processes (50 million tonnes BOF, 45 million tonnes EAF).

Figure 6-9 shows the shift that would take place in these supply functions if there were a new, constant unit cost increase such as a carbon tax that was different for each process, say $50 per tonne on BOFs and about $10 per tonne on EAFs. At the originally given unit cost level, (shown in Figure 6-8 as $300 per tonne), this cost increase would not only lead to a lower total level of output (65 million tonnes), but it would also affect the shares of the two steelmaking processes in that new lower level of output (25 million tonnes BOF, 40 million tonnes EAF). As shown in Figure 6-9, even if the original output level (95 million tonnes)were maintained at the higher cost, the relative amounts produced in each steelmaking processes shift in favor of the process with the lesser cost increase, in this case 42 million tonnes BOF and 53 million tonnes EAF.

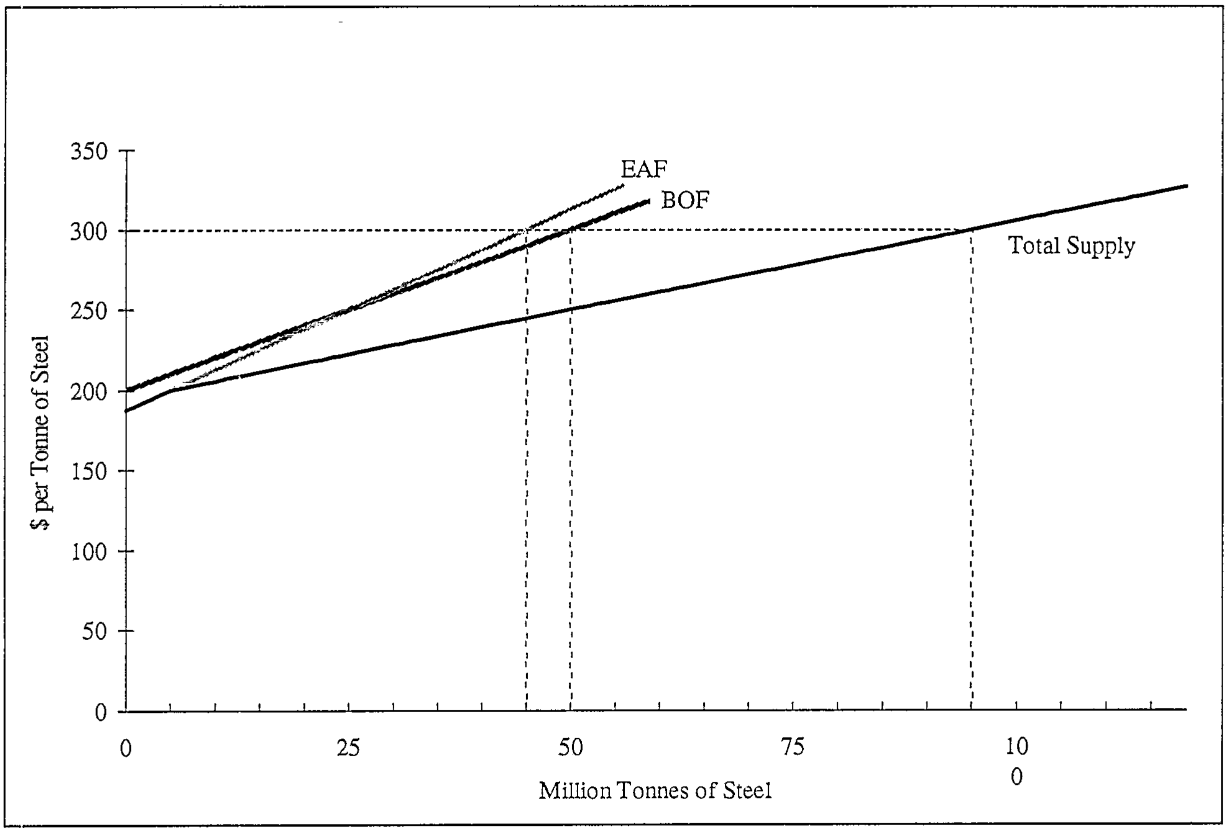

Figure 6-8
Simplified Model of US Steel Supply Without a Carbon Tax.

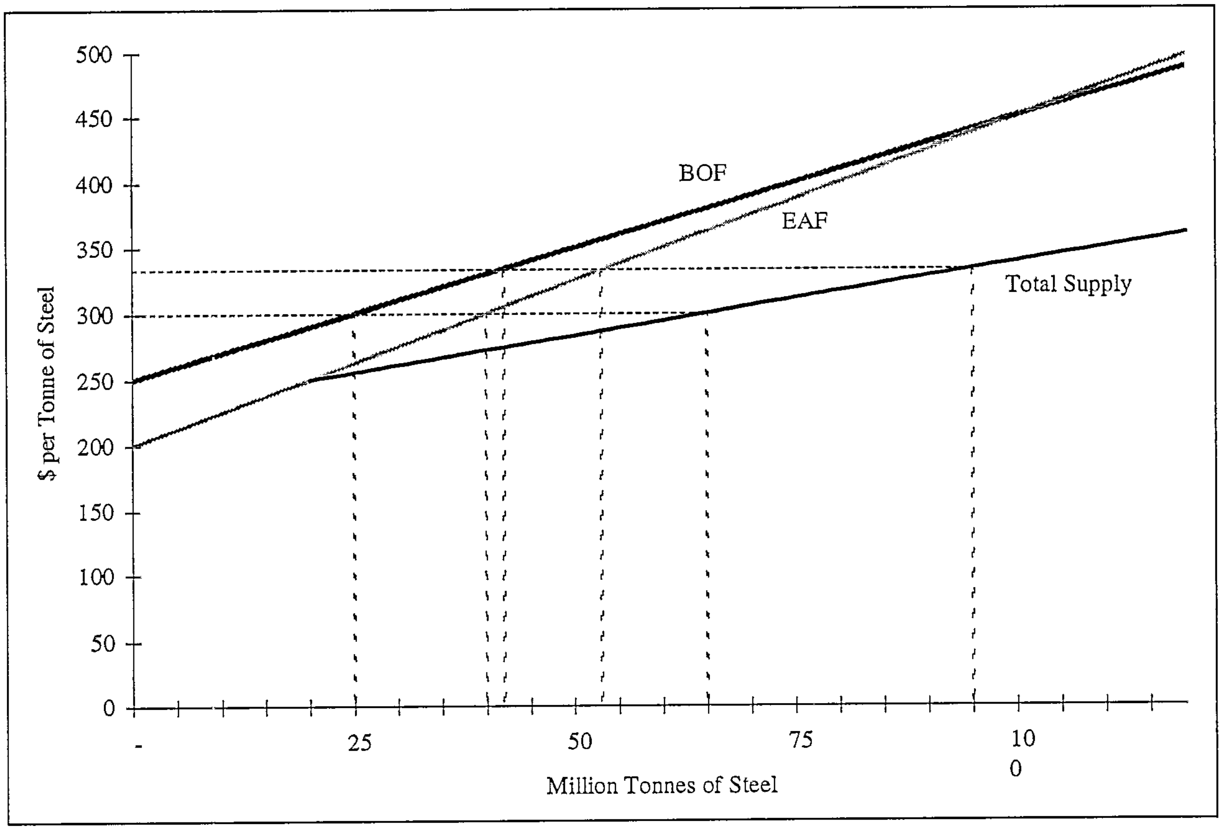

Figure 6-9
Simplified Model of US Steel Supply With a Carbon Tax.

Two Types of Mills. Table 6-4 lists for an "average mill" in the Chicago area the net tons of carbon consumed in the steelmaking processes computed by the methods described above. Cumulative carbon consumption is shown for the processes through both the raw steel and the final steel mill product stages.

The single set of numbers for the basic oxygen process reflects the assumption that an average mix of inputs would be used in that steelmaking method. In contrast, for the electric arc furnace process, there are three different estimates of carbon consumption. These result from three alternative material input mixes for making steel by that process. The first of these is based on a "metallics" mix of steel scrap alone. The second includes 1 percent cold pig iron with the steel scrap; the third uses 20 percent direct reduced iron in combination with steel scrap. These alternatives are important to understanding the effects of carbon tax on this process as evidenced by their differences in carbon consumption.

As indicated in Table 6-4, the electric furnace process uses less carbon per ton of raw steel and final mill product than does the basic oxygen furnace. But the amount less depends on the raw material mix used in the electric furnace. The cumulative carbon consumed in producing final mill products takes into account: 1) a yield of .9 tons of mill product per ton of raw steel, and 2) the energy used in the rolling processes that make mill products from raw steel.

Table 6-4
Total Carbon Use by Steelmaking Processes.

		Tons of Carbon per Ton Output	
		Raw Steel	**Mill Product**
Basic Oxygen Process		0.76	1.14
Electric Furnace Process	100% Scrap	0.29	0.62
	1% Pig Iron, 99% Scrap	0.30	0.63
	20% DRI, 80% Scrap	0.37	0.70

The net tons of carbon consumed can be converted directly to the cost impact of the carbon tax by applying the magnitude of the tax to the amount of carbon consumed. For example, a $100 per tonne carbon tax implies that the cost of raw steel made by the basic oxygen furnace process would increase by $75.80 per ton. The cost of an average mill product made with BOF raw steel would increase by almost $114 per ton.

The implications of these cost differences come about because producers, consumers, and markets dealing in steel will attempt to minimize or offset these cost effects. The first effect of the changes in process costs resulting from a carbon tax would be a shift in the shares of the two processes in total raw steel output. It is dear that producers and consumers should take steps to increase the electric furnace share of total steel output. As long as other costs remain the same, the substitution of a ton of mill products made by the electric furnace process for one made by the basic oxygen furnace process will avoid as much as $50 in carbon tax charges. Figures 6-7 and 6-8 illustrate conceptually how this would work. Figure 6-8 shows that if, after the tax, one were to try to maintain the original shares of the quantity set under the pretax conditions of Figure 6-7, some buyers taking BOF steel would have to pay more than necessary for their steel. Such buyers could save by shifting their purchases to electric furnace producers.

Role of Scrap Markets. For electric furnace steel production based solely on scrap to increase substantially in response to the carbon tax, the supply of steel scrap must increase substantially[14] ." A moderate increase in scrap supply could occur and be sustained at a higher scrap price, but it is unlikely that an increase of more than 5 to 10 percent would occur, because the sustainable increase is limited by the cost of recovering country scrap and by the amount of country scrap that is readily recoverable. To increase the supply of scrap by more than a few percent, the industry would have to recover types of scrap that are substantially more costly to recover and process. These sources are more dispersed, present greater difficulties in separating the steel from other materials, and are not typically within easy reach of regular collection channels. To expand scrap production materially, much higher scrap prices would be necessary and scrap buyers would need time to extend their gathering systems.

As the price of scrap increases, however, both cold pig iron and direct reduced iron become attractive substitutes for scrap in the electric furnace. Both pig iron and direct reduced iron contain known impurities in lesser amounts than scrap. Therefore, they not only can be refined more easily in the electric furnace, they can also be used to produce higher quality steel mill products based on electric furnace raw steel. As a consequence, they become *effective substitutes* for scrap at scrap prices somewhat less than their costs of production.[15] The cost of production of direct reduced iron is thus the "backstop" or ceiling price for scrap, since the cost of producing DRI is probably lower than that of pig iron.[16]

Net Impacts of Carbon Taxes on Steelmaking Processes, Prices, and Output. A carbon tax of $100 per tonne would add more than $110 per ton to the cost of steel mill products made in the integrated process but less than $70 per ton for those made in the electric arc furnace. These cost increases compare to a price of about $450 per ton for cold-rolled sheets, a benchmark mill product, at the end of 1992.

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[14] . In table 6-4 BOF is shown to use less than .3 tons of scrap per ton of raw steel output, whereas the electric furnace uses 1.111 tons of scrap per ton of output. Consequently, if electric furnaces, using a 100 percent scrap charge, produced 42 percent of total steel output, instead of 38 percent at the base level total output of 93,000,000 the demand for scrap would increase by nearly 3 million tons. This would all have to come from the country scrap stock, increasing the annual flow from it by more than 10 percent

[15] Because producers can also mix direct reduced iron with lower quality scrap to dilute the troublemaking alloys in the latter, it is also a complement to scrap as well. To maintain output quality, as production levels are increased , an increased amount of DRI would be used with an increased amount of scrap.

[16] This ceiling price is not a constant because DRI is derived from natural ore deposits and uses different quality fuels from different locations. Consequently, there are, undoubtedly, low- and high-cost

Competition among suppliers with these cost increases can be expected to lead to an expansion of electric furnace production relative to integrated plant output. Ironically, while such a shift would lead to the use of less carbon overall, it would also result in the steel industry's using more electricity per unit of output.

This shift to electric furnace production would increase the demand for steel scrap and thereby bid up its price. This price increase would be limited by the prices of cold pig iron or direct reduced iron, which could be substituted for scrap when their prices are competitive.

The Demand for Steel Mill Products

Users of steel mill products would respond to a carbon tax in at least two ways. The first of these is the same response users would make to any attempt by steel producers to increase prices of mill products—they consume less and pass on any remaining cost increase. The second response is to change the prices of their own products in reaction to a combination of: 1) the increase in the costs of their other material inputs resulting from carbon tax charges on their direct and indirect suppliers, and 2) the carbon tax these users may be required to pay directly as a result of their own specific consumption of carbon-containing materials or energy. Any attempt on the part of these steel users to pass along to their customers the increases in their costs should induce their customers to react similarly.

The earlier analysis examined the decreases in demand that would take place within the final demand sectors on the basis of a full passthrough of the carbon tax. Inasmuch as only a minuscule amount of steel products flow directly to final demand sectors, the effects of attempts to increase the price of steel are taken into account to the extent that they are reflected in final goods such as automobiles, appliances, or building rents. The approach taken in the inter-industry analysis resembles the second response of steel mill product users to a carbon tax. This section investigates more closely the makeup and reactions within the markets for steel mill products themselves.

Users of Steel Mill Products. The inter-industry flows of steel mill products in the 1987 500—sector inter-industry transactions tables reveal several interesting features about the makeup of steel demand.[17] First, less than half of the 500 sectors in the input-output

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producers with gradations between.

[17] The American Iron and Steel Institute publishes member shipments, by individual steel mill product, to several market classifications. These are very useful data but for present purposes do not identify the users as well as the inter-industry transactions tables do. The AISI data, for example, do not show the sectors that purchase imported steel mill products; they also do not identify the users of steel mill products that are shipped to service centers or commercial warehouses. The inter-industry transactions data do not identify the specific steel mill products and grades of steel used in the consuming sectors.

model use any steel directly. Outside of the international trade accounts, governments are the principal final demand sectors using steel mill products. However, the quantities are hardly noticeable relative either to total government expenditures or to total steel use in the economy. Personal consumption takes only a minuscule amount of products made in steel mills.

Second, steel use is distributed quite unevenly across the sectors of the economy. Of the 240 odd sectors using steel directly, 12 account for more than 50 percent of total direct use and 50 account for 85 percent.

Third, the "steel intensities," or amounts used per unit of output, of the different consuming industries vary over a very wide range. The ten most steel-intensive sectors use more than $.20 of steel products per $1 of output. Nearly forty sectors have steel intensities of .1 or higher. This is important, of course, because a sector is more likely to respond to (i.e., substitute away from) a commodity price increase if it expends a significant amount on that commodity.

More importantly, however, steel is perceived to permeate the economy both in terms of physical dependence and in terms of being a general indicator. While less than half of the sectors in the economy use steel directly, it is safe to say that all sectors depend on it with more or less immediacy. Public concern about prices and conditions in the steel industry is hardly a matter of dispute.

Consequently, steel users would be bound to respond to steel industry attempts to increase prices by the amounts the carbon tax is likely to increase steelmaking costs. In the short run, the more concrete responses will be in the forms of conserving on steel use and of searching out alternative sources of supply. But given time to adjust their production processes and product designs, steel users and other affected sectors would be able to make significant changes in their relative use of steel.

Steel User Responses to Higher Steel Prices. Inasmuch as steel users are not inclined to incur costs unnecessarily, they will attempt to substitute away from those materials whose prices are rising more substantially than others that might be used. This may be accomplished in several ways. Users of steel mill products will: 1) substitute for steel wherever it pays to do so in the immediate run, especially using housekeeping and conservation measures; 2) change the mix of inputs they use in their production processes so as to substitute for steel, given the technological flexibility to do so and the time needed to adjust their processes (including undertaking the research and development needed to increase that flexibility); and 3) redesign and re-engineer their products in such ways that use less steel and that pay to do so.

It is virtually certain that the principal users of steel mill products would take such actions. They could ill afford to ignore a price increase passing on the carbon tax. A $100 per tonne carbon tax would add to costs more than $110 per ton of mill product made by the basic oxygen process and between $60 and $70 per ton made by the electric furnace process. At the end of 1992, domestic producers were quoting cold-rolled sheets, a bellwether mill product, at $570 per ton, while imports were at about $410 per ton[18] The carbon tax would, therefore, result in cost increases of almost 25 percent.

While in principle, steel users *will* take actions to mitigate the effects of steel prices on them, the empirical evidence of such behavior is not very robust because there are so many factors influencing these actions. Sometimes factors other than the price changes are more dominant determinants of the steel users' actions. These observations do not, however, constitute a rejection of the proposition that steel users will decrease their use of steel as its price rises relative to its substitutes. There is sufficient explanation for the past changes in steel use by the automobile industry, as we discuss below.

There was a very strong nonprice-induced decrease in the use of steel during the period in question. Steel use in automobiles declined while relative steel prices were declining for the simple reason that reducing the weight of the average car was the easiest and fastest way to achieve greater fuel economy. Automobile designers and producers appropriately took a wider systems approach to the conditions existing at the time. In the wake of concerns for the effects of the cutoffs of oil imports from the Middle East, the federal government imposed fuel-efficiency standards on new automobiles. Detroit responded by reducing the size of automobiles and making them lighter. Reducing the size resulted in the use of less steel; making cars lighter involved substituting aluminum and plastics for steel wherever possible. It is rather likely, therefore, that the changing requirements for automobile performance led to a substitution against steel in an amount greater than would have occurred on the basis of steel price changes alone. Any further substitution against steel based on price might then require much greater relative steel price increases.

The Effects of the Tax on the Stool Market. The actions taken by producers and users of steel mill products, described above, make up the change that would occur in the market supply and demand for these products and can be best summarized in those terms. Over the first few years after the tax is passed the steel industry would adapt to a new equilibrium involving increased steel prices, a reduced demand for domestic steel (relative to the slow growth that would occur without the tax), increased electric arc furnace production, diminished BOF production, increased use of scrap and direct reduced iron, and potentially a change in scrap exports.

Because EAF incremental production costs would increase post-tax by much less than BOF incremental costs, producers would have an incentive to increase their output from electric furnaces. However, the tax would create excess capacity, particularly in BOFs, that could take several years to work off. New electric furnace capacity would

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[18] Metal Bulletin's *Prices and Data,* 1993. Trade press accounts indicate that domestic producers were discounting the "quoted" price by as much as $100.

first take the form of existing plant expansion and conversion. The excess capacity created by the tax could last for a while, putting competitive pressure on steel prices and making it difficult for a producer to recoup the costs of a new facility.

Because of its higher post-tax incremental costs, BOF production would decline. The amount of the decline would potentially be large, because the decline in the BOF production would have to equal the increase in EAF production plus the decrease in domestic consumption plus any increase in imports. The study team estimates the decrease in BOF production within ten years after the tax is imposed to be about 15 to 20 percent. Plant shutdowns could occur, as discussed below, especially since the pretax market position of some BOF mills is already weak. Shutdowns would help tighten the capacity-demand balance of the industry and would encourage addition of new electric furnaces.

The supply curve for scrap would rise more steeply at a supply increase of no more than 10 percent of the pretax use level. The efficiency of scrap use in electric furnaces and BOFs will increase. An increase of 5 to 12 percent of overall electric furnace production would be sustainable, but the price of scrap would rise to a point where the use of direct reduced iron and cold pig iron in EAFs would be much more attractive. The post-tax prices of scrap and DRI would be bid up to a level effecting rough parity of BOF and EAF incremental costs, but at this equilibrium level electric furnaces would have a significantly larger share of total production than before the tax was imposed.

This is summarized in a simplified and exaggerated fashion in Figure 6-10, which superimposes a hypothetical demand function for steel onto parts of the hypothetical supply functions shown in Figures 6-8 and 6-9. Figure 6-10 shows only the total supply of steel prior to the tax, but it includes the supply functions for the EAFs and BOFs as well as total supply after the tax is levied. Prior to the tax, the equilibrium is shown to be at $300 per tonne with a total output of 95 million tonnes. Recall that the division of output in Figure 6-8 was 50 million tonnes BOF and 45 million tonnes EAF. The *hypothetical* shift in the separate supply functions caused by the carbon tax in Figure 6-9 ($12.50 for EAFs and $50 for BOFs) translates into an upward shift of $33 per ton (at output levels above 20) in the total supply function. When the demand function is superimposed on these pre- and post-supply functions, the result is a $22 increase in price (to $322) and a 10 unit decrease in production from 95 to 85 million tonnes. The division of the latter would be 49 million tonnes EAF and 36 million tonnes BOF.

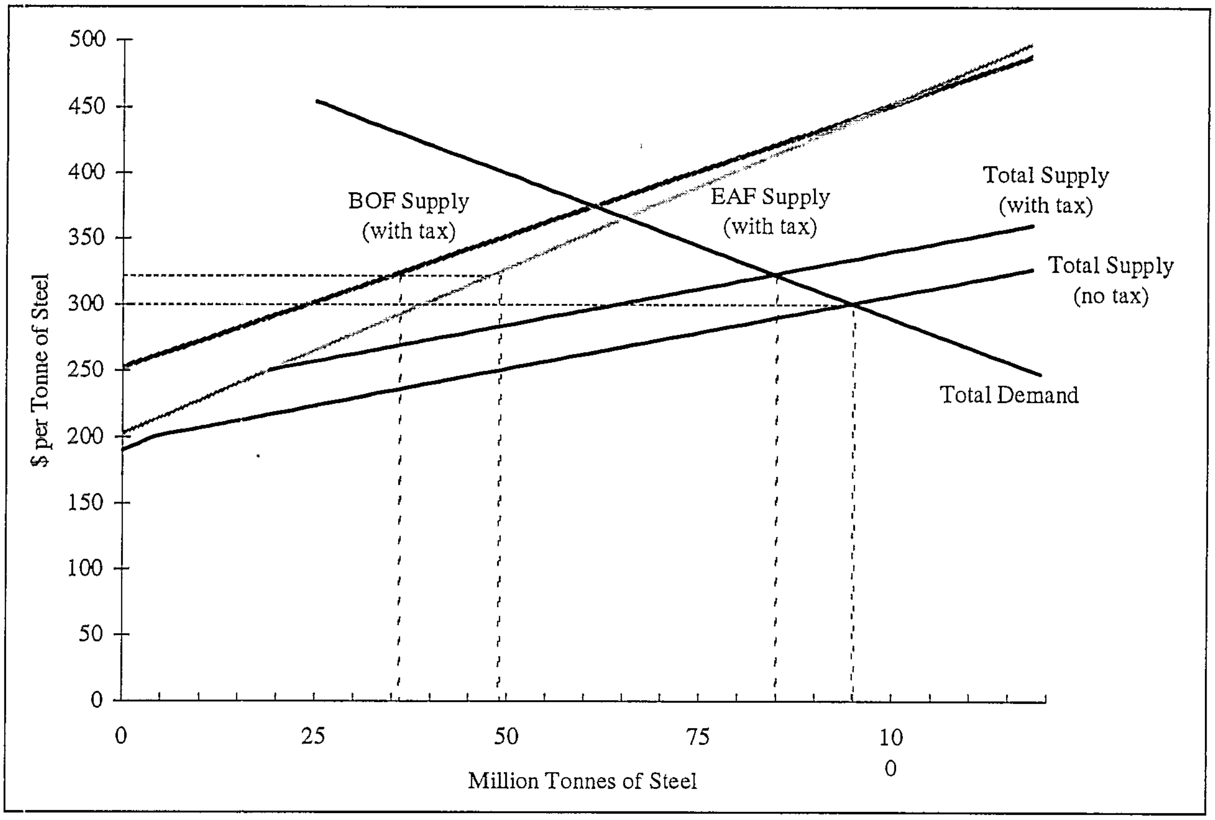

Figure 6-10
Simplified Model of Steel Carbon Tax Effects

Imports of steel mill products would add another component to the total supply function, shifting it farther to the right and toward the original total supply function. However in this case, total output demanded would be shared among the two types of domestic supply and imports.

The effects of lower income on steel demand would cause the demand function to shift to the left. Such a shift would lead to a further reduction in the level of production, and *in fact* would probably cause the larger portion of the decline in output.

If OECD and other countries impose a like carbon tax on their economies, imports of steel mill products would probably decrease absolutely in line with the overall decline in steel product consumption. In instances where producers in other countries are able to take advantage of production efficiencies that may not be possible in the United States, such as continuous casting, their exports to this country could increase. If other countries do not impose a like tax, imports would grow very substantially.

Steel is used directly in a limited number of industries in the United States. Only a few of those, such as automobiles, construction, and appliances, account for a substantial portion of total direct steel sales. Review of the experience in the automobile industry indicates that such users would significantly decrease their demand for steel in response to an increase in the price of steel mill products relative to substitutes. Most materials that substitute for steel–for example, cement plastics, aluminum, glass, and wood–are themselves energy-intensive and would experience cost increases as a result of the carbon tax. Thus, the relative prices of goods containing steel and other materials would not change much. Nevertheless, it appears that steel would have larger cost increases than most of the major substitute materials.

Although the effect of price on demand for steel would probably be small, the carbon tax would still reduce the demand for steel through its effect of reducing gross domestic product. The final outcome is that the costs and prices of domestic steel mill products would increase as the result of the carbon tax but by somewhat less than a full passthrough of the tax. *Also,* steel industry production levels would fall. As a result, employment in the steel industry would continue to decline, possibly at a faster rate, and the geographic dispersion of capacity and production would continue because of the heavier reliance on electric furnaces.

Impacts of Carbon Taxes on Electricity Consumption. The increased share of electric furnaces in total steel production would increase the use of electricity per ton of a given level of output.[19] The method used to compute carbon consumption by each steelmaking process estimates at the same time the electricity use by each process. Table 6-5 shows that electric furnace steel uses overall about one-third more electricity than the basic oxygen furnace.

Table 6-5
Total Electricity Use in Production of Steel Mill Products

		kWh per Net Ton	
		Raw Steel	**Mill Product**
Basic Oxygen Process		362	907
Electric Furnace Process	100% Scrap	671	1,251
	1% Pig Iron, 99% Scrap	673	1,253
	20% DRI, 80% Scrap	718	1,303

Figure 6-11 shows the change in electricity use that would occur under different scenarios. Each line sloping up to the right in that chart represents a different total raw steel output level, the lowest, 85 million tons, for example. Moving from left to right along a given line indicates the change in electricity use resulting from the electric arc furnace's increased share of total production. For example, the middle line indicates that, if the output level were to remain the same as in 1992, 93 million tons, electricity

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[19] While the BOF uses more carbon in total, it is less electricity-intensive. Consequently, using more electricity in a case such as this may result ultimately in less carbon being consumed.

use would increase by about 1 billion kilowatt hours if the proportion of the total steel made in electric furnaces were to increase to .42 (from the 1992 level of .38). Such a growth in the electric furnace share is quite reasonable, given its recent increase without the added impetus of the effects of a carbon tax.

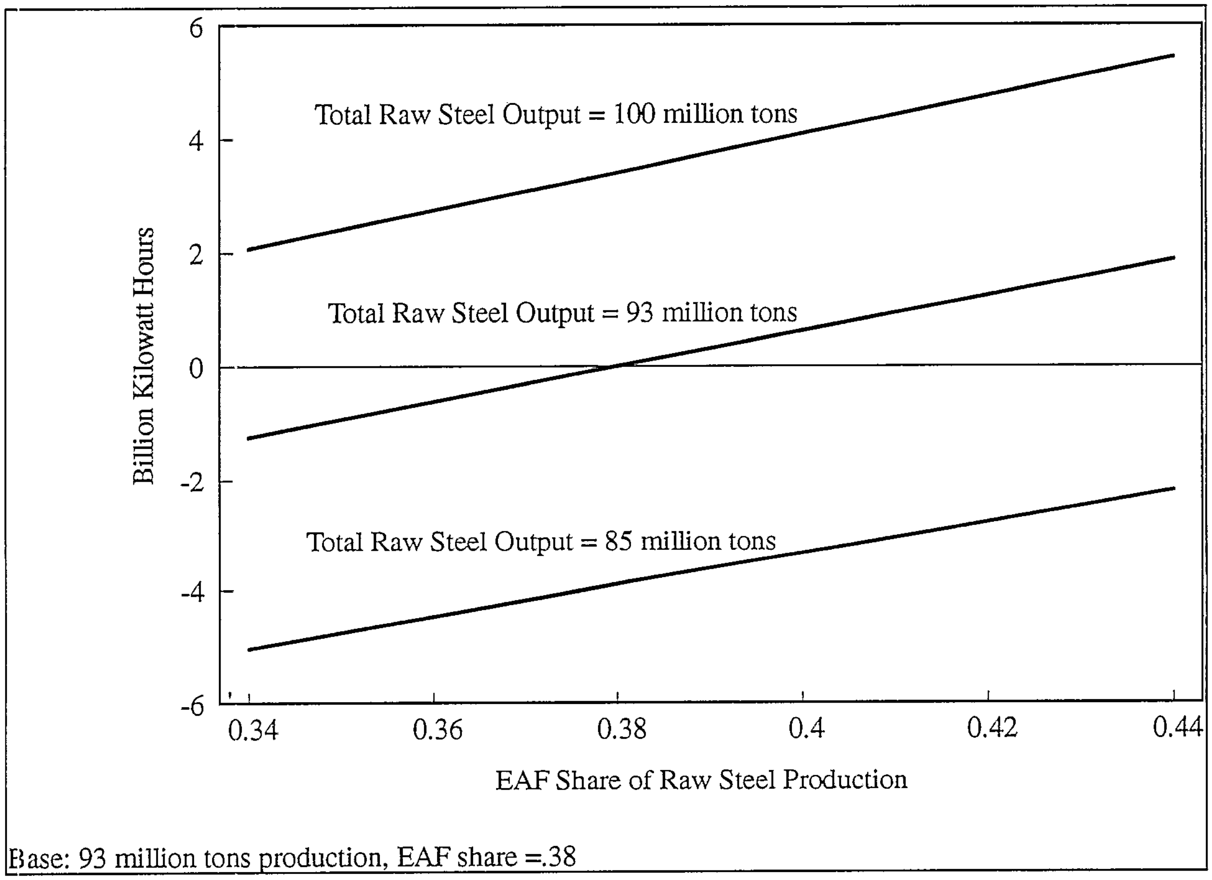

Figure 6-11
Change in Steel Industry Electricity Use With Carbon Tax

Employment in the Steel Industry. It is obvious from the above that imposition of a carbon tax will result in changes to employment. This is illustrated in Figure 6-12, which shows the increase or decrease in employment that can be expected from 1992 levels under different production conditions. For example, the middle line in the graph traces the changes in employment that would occur if the output of raw steel were to remain the same as in 1992 but the share of electric furnace output were to continue to increase. It indicates that even if production levels were to remain constant at 93 million tons, a growth in the share of electric furnace output to .40 would result in lower steel industry employment by about two million hours. A decline in total raw steel output would result in a correspondingly greater decrease in employment, as the lowest line in the chart shows.

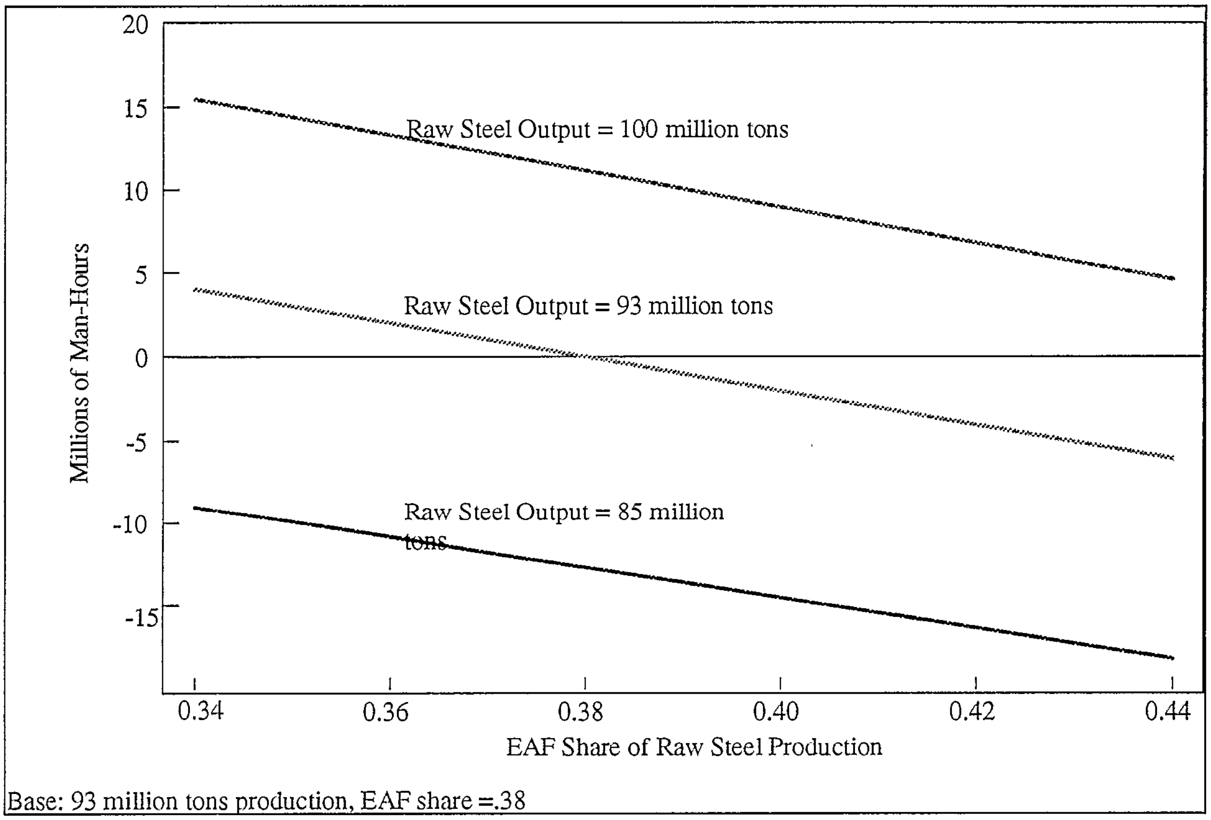

Figure 6-12
Change in Steel Industry Employment With Carbon Tax

Geographic Distribution of Domestic Steel Capacity. The results reached above will also affect the geographic distribution of domestic steel capacity. This will take place largely because of the substantial shift of production away from the basic oxygen process toward electric furnace steelmaking.

During the 1980s, several relatively new, by steel industry standards, basic oxygen furnace mills were shut down fully or largely dismantled. This continued, even accelerated shift to electric furnaces after a carbon tax could well result in more closures. These can be expected to occur among those plants located at some distance from the Great Lakes. Being dependent on molten pig iron for the main portion of their metallic charge, BOFs are best located where they can assemble blast furnace raw materials *and* supply markets most economically.[20] The Ohio River system probably no longer is a location that offers such advantages. Instead, it would appear that plants on the lower Great Lakes as far east as Cleveland "dominate" those somewhat removed from the lakes. While it is possible to locate more disadvantageously than on that river system, as the market areas that can be supplied from such sites shrink, more of the

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[20] These conditions loosely define the element of technical efficiency for the basic oxygen process.

BOFs there will become vulnerable. Consequently, a carbon tax would accelerate the concentration of BOF capacity onto the Great Lakes.

The prospects for those BOF mills located in Eastern Pennsylvania, Maryland, Alabama, and Utah will depend on the specifics of their raw materials sources and the span of the markets to which they can ship with a hauling advantage. Alabama, Eastern Pennsylvania, and Maryland mills use ores imported from South America and Eastern Canada as well as other overseas sources. Of these, the deepwater plant at Sparrows Point, Maryland, appears to be most advantageously located. The other two require transshipment and rail hauls of their ores.

The Utah plant, at which the BOFs were installed relatively recently, currently relies on the Mesabi Range in Minnesota for most of its iron ore pellets. The freight charge to move pellets from the Mesabi Range to the Utah plant is about $47 per gross ton (2,240 pounds), which alone substantially exceeds the total delivered cost of pellets to BOF mills on the Great Lakes (*Skillings' Mining Review 1993*).

Given the current distribution of electric furnace capacity, as shown in Figure 6-6, the continued and increased shift to that steelmaking process alone will involve greater dispersion of both capacity and production. This process relies primarily on steel scrap for its metallic charge. As a result of electric furnaces expanding output and gaining a larger share of total steel output, greater reliance will need to be placed on "country" scrap relative to prompt industrial scrap. As pointed out above, "country" scrap is much more widely dispersed, corresponding to the geographic patterns of where the products made of steel are used and finally discarded.

Chlorine

Summary

Chlorine is an industry that is likely to shrink as a result of government environmental protection policies that have begun to prohibit or restrict some of its end uses, such as refrigerants and bleaching of pulp and paper. The carbon tax could increase chlorine production cost in the United States by as much as 60 percent. As a result, chlorine prices would increase, adding an economic inducement to decrease demand to the environmental pressure that will exist without the tax. However, the effect of the tax on demand appears to be moderate, comparable to the effect of the tax on the demand for steel or aluminum. A detailed analysis of the cost of using the best available substitutes for each end use and the resultant value of using chlorine indicates that the post-tax price of chlorine would be materially below the average value of chlorine to most users in most major end-use categories. The carbon tax would increase prices and costs materially but would affect only relatively low-value uses within each category and would not eliminate any major end use. One of the largest chlorine products, polyvinyl chloride, is used to make plastic pipe in competition with steel and other energy-intensive materials that would also have large price increases in response to the carbon tax. Consequently the increase in price relative to substitutes would be substantially smaller than the absolute increase.

The Chlorine Industry

Production Technology. Chlorine is produced in electrolytic cells as a joint product with caustic soda. Salt brine is the basic raw material feed to these cells. This brine is broken down by electrolysis, in a single step, into chlorine and caustic soda. A general rule is that 1.75 tons of salt are needed to make one ton of chlorine and 1.1 tons of caustic soda.

The process is electricity-intensive. About 25 percent of total chlorine and caustic sales revenues were spent for electricity according to the 1987 inter-industry transactions tables published by the US Department of Commerce. Other data indicate that the process uses 2,400 kWh of electricity per ton of chlorine. That is almost double the amount used in the production of steel mill products by the electric arc furnace process. It is also only about 15 percent of the amount of electricity used in the production of a ton of primary aluminum ingots.

Much of the production of chlorine is captive. That is, it is produced at the same location or by the same company that uses it for further processing as a chemical feedstock, catalyst or facilitator, or as a bleaching agent. Probably less than two-thirds of the total production of chlorine is sold and bought in "arms length" transactions between two independent parties. Producers who make it "captively" enter the market to buy when their own production is not sufficient for their downstream needs. They are also suppliers to the market when their production is greater than those needs. At least partly as a result of this, the long-term contract price for chlorine fluctuates over a wide interval, from less than $50 to more than $175 per ton since 1991.[21]

Because chlorine is a hazardous substance, it must be transported with extreme care in highly specialized tanks and its transportation is subject to rigorous carrier regulation. As a result, there are locational "pulls" at the sources of the salt brine used as the principal raw material feed and at the places where the chlorine is used. Some of the latter, such as water treatment plants and pulp and paper bleaching operations, cannot be moved to the sources of salt. Consequently, as can be seen in Figure 6-13, the locations of chlorine-producing facilities in the United States are fairly widespread, and tend to be close to the market or the salt supply.

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[21] Very little material is sold in spot transaction, about 60 percent is sold by long-term contracts, the prices of which are re-established every three months (see Ira Breskin 1993, 1A).

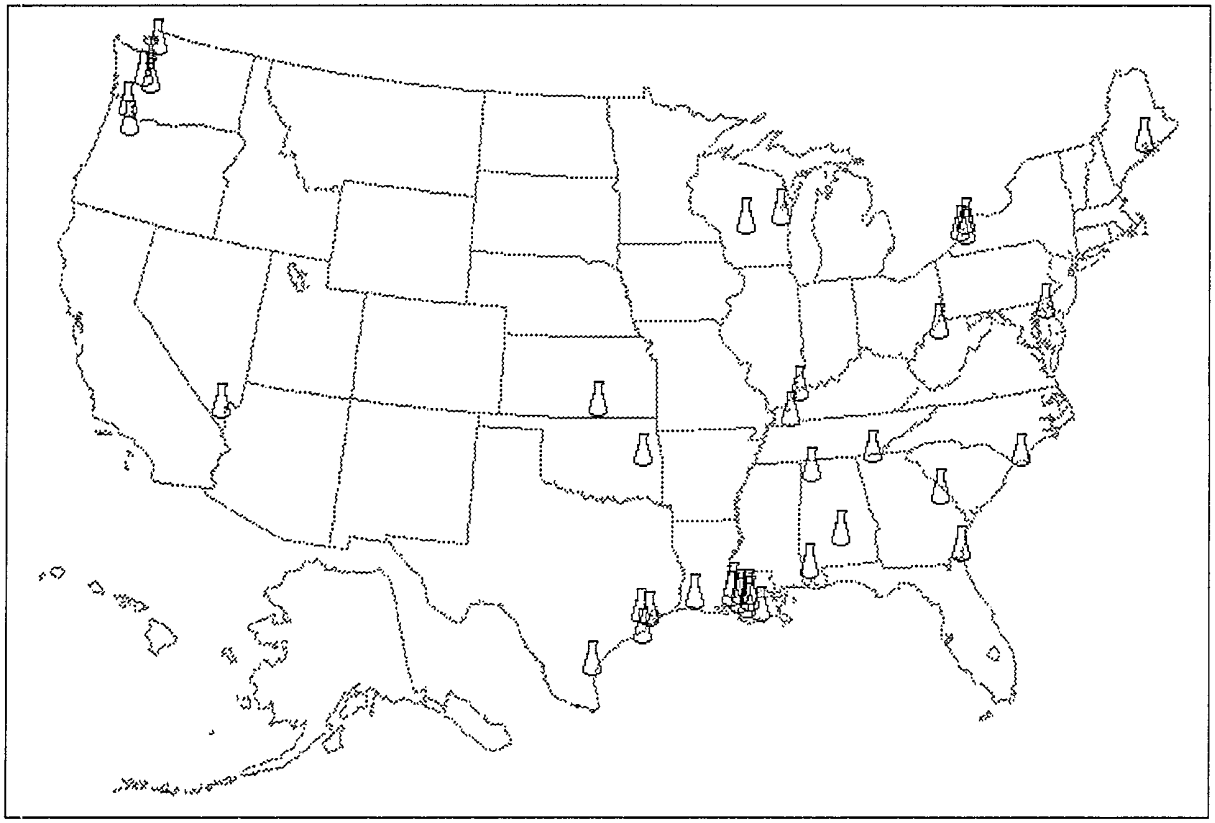

Figure 6-13
US Chlorine Production Facilities Based on Salt

Demand Curve Based on Cost of Substitutes. The uses of chlorine lend themselves to classification into three major groups. One of these groups consists of the direct applications of chlorine itself. Another includes those uses in which chlorine is a component of the product, generally as a chemical compound. Finally, chlorine or products containing chlorine are used to "facilitate" the manufacture of other products but the chlorine products do not become, themselves, components of the final product.

The consumption of chlorine includes many end users. The major categories of chlorine use are shown in Table 6-6. Five categories PVC products, pulp bleaching, chlorinated solvents, hydrogen chloride, and propylene oxide–account for 71 percent of total use.

Table 6-6
Major Consumers of Chlorine in the United States

Application	Type of Chlorine Use	Consumption of Chlorine (000 Tons per Year)	Share of Total (%)
PVC Products	C	3,530	29%
Pulp Bleaching	D	1,950	16%
Chlorinated Solvents	C	1,210	10%
Hydrogen Chloride	C	950	8%
Propylene Oxide	F	930	8%
Total		8,570	71%

D=Direct Use

C=Contains

F=Facilitates

(SOURCE: Charles River Associates, *Assessment of the Economic Benefits of chlor-Alkali Chemicals to the United States and Canadian Economies,* Boston, MA, 1993.)

The two principal direct uses of chlorine are in pulp and paper manufacture and water treatment. In the pulp and paper industry, chlorine is used as a powerful bleach in the pulping process to make quality white papers. This end use accounts for 16 percent of consumption. Virtually all municipal water systems use chlorine to disinfect potable water prior to its distribution. This end use accounts for 5 percent of consumption.

Chlorine is a component of many widely used and readily identified products. The most widely used of these, accounting for 29 percent of total consumption, are polyvinyl chloride (PVC) products. Rigid PVC products are used extensively in construction, including pipe, siding, flooring, and window frames. In flexible form PVC is used in wiring insulation, shower curtains, sheeting and lining, and architectural fabrics. Both forms are used in toys, automotive furnishings, bottles, and packaging.

Chlorine is also a component of solvents that are used to clean a variety of things from manufactured parts to clothing. It is part of hydrochloric acid used as a feedstock in other chemical processes, a chemical cleaning media for removing oxides from in-process steel products, and a material input in some food-processing technologies. It is a component of bleaches and disinfectants as well as insecticides and fungicide used in crop protection. Chlorine is also used in flame retardants that are added to textiles and plastics to reduce their flammability. Other plastics-based products that contain chlorine include weather stripping, coated fabrics, footwear, and weatherproofing sheetings, also film wrapping materials used in medical and food packaging.

Chlorine and chlorine derivatives are used to facilitate the production of a very wide range of products as a catalyst or chemical intermediate that does not go on to become a part of the final product. Among the products so facilitated are pharmaceuticals:

polyurethane resins used in polyesters, adhesives, plastics, and coatings; epoxies; titanium pigments used in household and industrial paints, paper coatings, and other whiteners; refrigerants; polycarbonate resins used for bulletproof glass and for construction and automotive applications; and fluoropolymer resins used for stick-proof cookware coatings.

The demand curve for chlorine is based on the costs that would need to be incurred to replace chlorine in its various applications. When each application is inspected individually, these costs represent the "reservation price" that the users of chlorine would pay in order to avoid having to substitute for it in that application. These data are, in effect, raw material for the demand curve for chlorine of microeconomic analysis. In other words, they measure the amounts of chlorine that the various users would buy to apply to a particular use as long as the price is less than it would cost those users to substitute for chlorine[22]

Chlorine Supply and Demand. Figure 6-14 depicts the reservation prices for each of the types of uses of chlorine, taken in order from most to least valuable. It has the appearance of a step-wise demand curve, downward sloping from left to right. It shows, reading from the far right to the left, that if the price of chlorine were increased to higher levels, an increasing number of applications would no longer use it. That is because the users could employ an alternative material, production process, or approach to satisfy the demand for their products without resorting to chlorine[23]

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[22] This claim is a bit exaggerated. The demand for chlorine is a "derived demand," that is, it depends on the demand for the product that the chlorine is used to produce, such as paper, drinking water, polyvinyl chloride pipe, etc. To the extent that the demand for the final product might decrease or completely disappear as the price of chlorine increased to the level of the cost of completely replacing it, the quantity of chlorine demanded would decrease more or less gradually along with the increase in chlorine price.

[23] As alluded to above in footnote 25, the problem with this construct is that it assumes that the prices consumers are willing to pay for the products made with chlorine can vary over *a very wide range* before consumers decrease their purchases of those products.

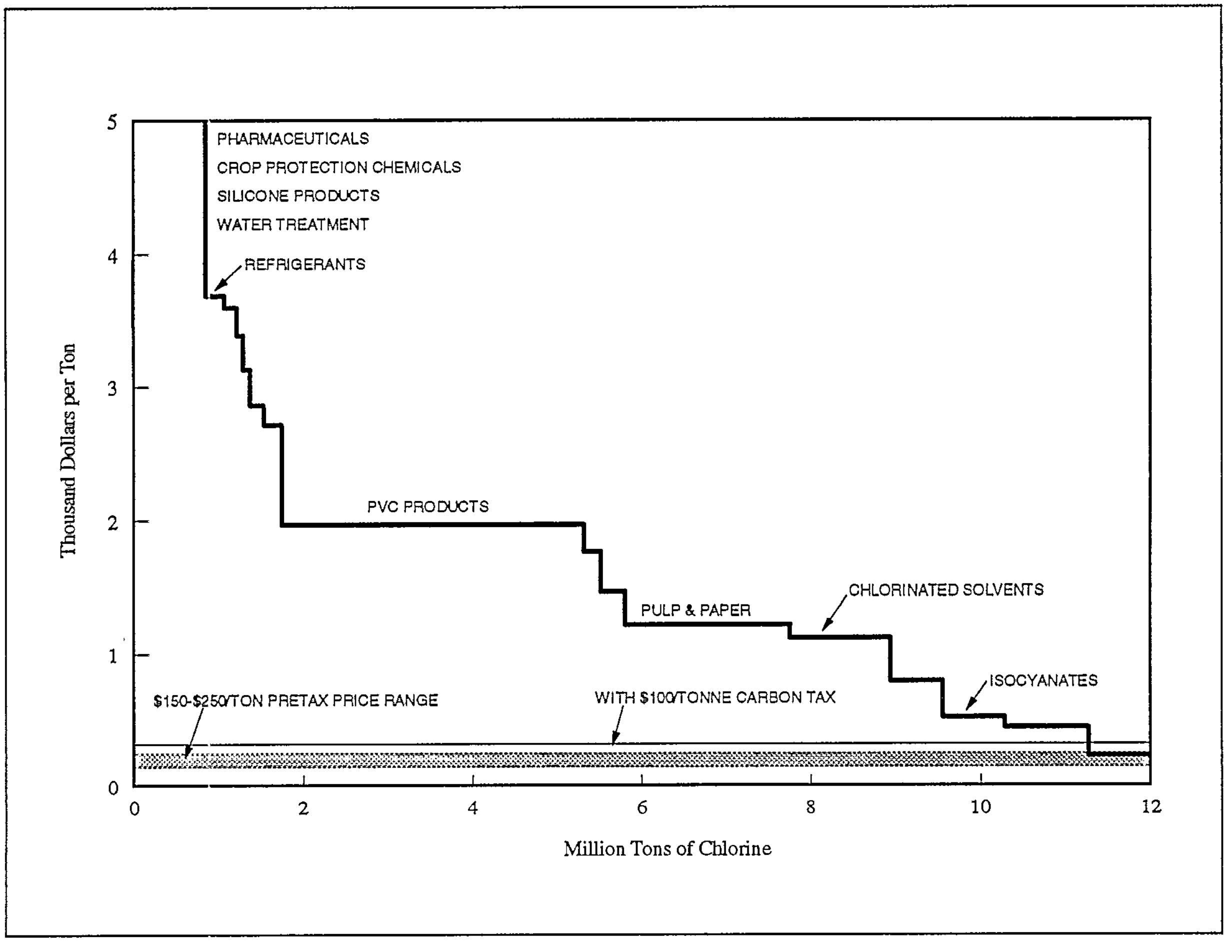

Figure 6-14
Derived Demand for Chlorine, with Pretax Price Range and Carbon Tax

It should be kept in mind, however, that these steps measure the responses of "representative" or average users of chlorine in each application. Within each application, individual users or small groups might use a substitute satisfactory for their own particular purpose at a cost somewhat less (or more) than the average substitution or displacement cost. For example, users of titanium dioxide in some paints might find that other pigments or coatings perform satisfactorily in their particular application as the cost of chlorine is increased. Therefore, instead of continuing to use chlorine to produce titanium pigment until the price of chlorine reached $1,455 per ton, these particular users would discontinue using it when long-term prospects are that the price will exceed, say, $450 per ton. An additional breakdown of the applications and their "reservation price" for chlorine, such as this, leads to much smaller steps in the "derived demand" curve[24]

Historically, chlorine has been bought and sold in independent, arms-length transactions. The prices at which those transactions have taken place provide a fairly reliable guide to the base onto which the carbon tax would need to be added.

Although in very depressed periods chlorine contract prices have fallen as low as $50 per ton, this level must be considered out of the ordinary. Recent prices are probably more characteristic of the level that chlorine producers normally expect to receive. Contract prices have risen to more than $150 per ton, while spot prices are about $250.[25]

This interval, $150 to $250 per ton, is superimposed on the derived demand function for chlorine in Figure 6-14. As should be expected, the applications actually using chlorine and for which there are data on quantities used have reservation prices above the historical range of prices. However, as pointed out above, all of the specific uses within a particular type of application might not have reservation prices as high as the "average" shown by the demand curve.

Price and Output Impacts of Carbon Tax

To investigate the effects of the carbon tax, it is necessary first to estimate the additional costs that the carbon tax would impose on the industry. A conservative approach is, then, to treat these costs as a straight add-on that chlorine producers must recover by means of a simple passthrough to chlorine buyers.[26] That is, by adding the tax cost to the interval $150 to $250 per ton, that was set out above as the base price, it should be possible to tell which applications might be at risk and the possible loss of chlorine sales.

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[24] Such a breakdown may also lead to some shifting or "curling" of the demand curve to a lower level.

[25] See Ira Breskin (1993) and *The Journal of Commerce* (1994, 6B).

[26] This is a conservative approach because it entails "allocating" the full cost of the carbon tax to That is the maximum the price of chlorine must cover because it may be possible that the price of caustic soda can also make some contribution to covering the carbon tax.

The Added Costs Resulting from the Carbon Tax. The production of chlorine and caustic soda require between 2,400 and 2,500 kilowatt hours of electric power per ton of chlorine produced, net the electricity used in salt or brine mining. This translates into the use of about .9 tons of carbon (in the coal consumed to generate that much electricity) per ton of chlorine output.[27]

Consequently, the $100 per tonne carbon tax could add as much as about $90 to the price of a ton of chlorine, on a straight passthrough. On the base price interval of $150 to $250 per ton, the amount of the carbon tax would entail between a 36 and 60 percent price increase.

Results. A $100 per tonne carbon tax would be likely to cause a fairly substantial increase in the price of chlorine. At first blush, as depicted in Figure 6-14, this added cost would not appear to jeopardize the use of chlorine in most applications.

However, the propylene oxide application has a reservation price that would be exceeded by the post-tax chlorine price. This application alone accounts for about 8 percent of total chlorine consumption. As was pointed out above, some specific "marginal" uses in other applications might also discontinue their consumption of chlorine as the price of chlorine increases by increments less than their application's average reservation price. These and the "income-effect" decreases in consumption discussed earlier add to the possible loss of chlorine use in propylene-oxide-related consumption.

As a consequence, the chlorine industry could suffer, as a result of a carbon tax, a decline in output very much on the same relative order of magnitude as that experienced by the steel industry.

In sum, the carbon tax could increase chlorine prices substantially and thereby cause a significant decrease in the amount of chlorine consumed. The industry already is confronted by a possible longer-run, nonprice-induced loss of production stemming from environmental concerns. The carbon tax would, therefore, compound the rather serious longer-run circumstances of the industry.

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[27] Coal consumption in electricity generation is about .00048897 tons per kWh. Coal contains on average about 76 percent carbon, including both the fixed-carbon and carbon-in-volatile forms.

Outlook for Chlorine Under Other Environmental Policies

Chlorine production capacity in the United States has been on the decline since the early 1980s (Figure 6-15). A number of environment-related developments have probably contributed most substantially to the industry's current condition.

Almost everyone in the United States has been affected by the efforts to substitute other refrigerants for CFCs in air conditioning units in households and automobiles. This has received dramatic attention because the ultimate release of these CFCs into the atmosphere is understood to deplete the ozone layer that envelopes the world and buffers it from the sun's radiation. Major chemical companies have announced the development of effective substitutes for CFCs in refrigeration and total displacement should take place gradually over the next few years. However, the use of chlorine in the objectionable refrigerants accounts for less than 2 percent of total annual US chlorine consumption.

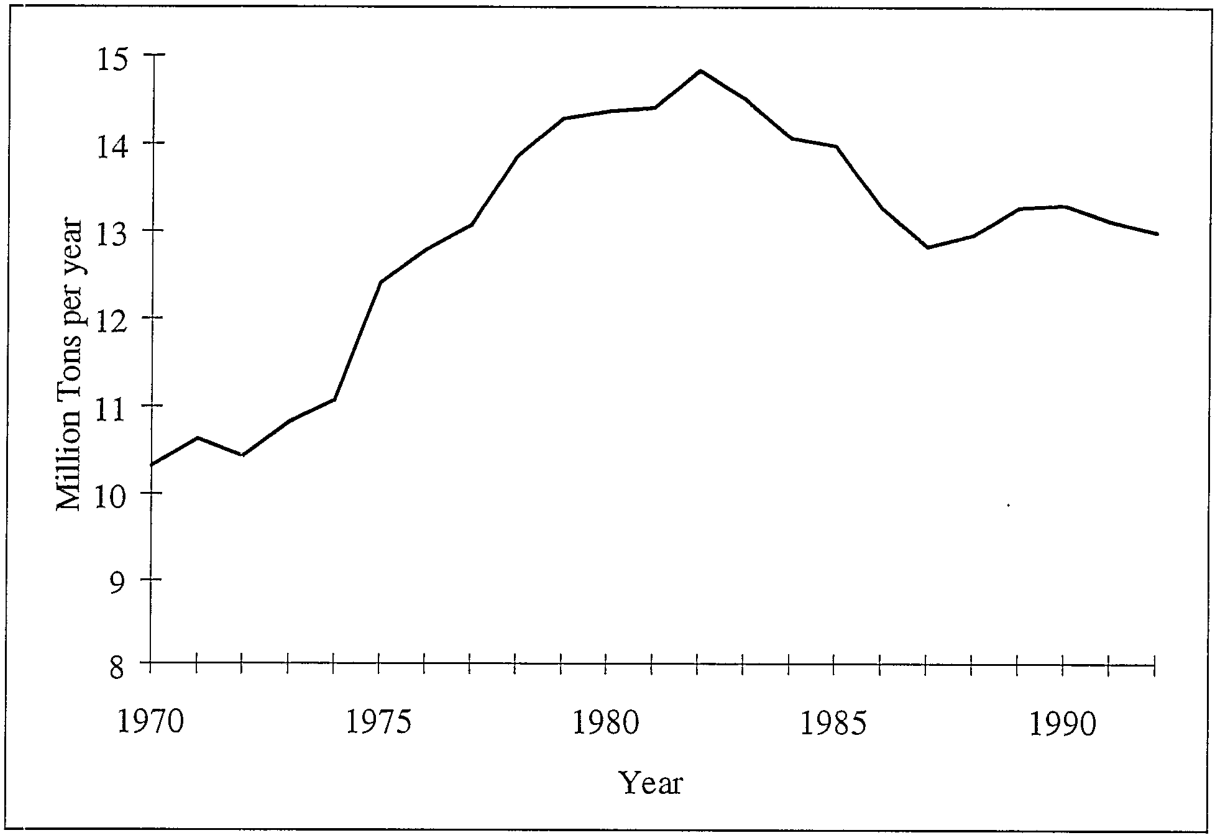

Figure 6-15
US Chlorine Production Capacity

Other efforts grounded in environmental concerns are substantially more serious in the sense that they could result in a very large, if not total, decline in chlorine production.

- The 1992 and 1994 recommendations by the independent agency, the US-Canadian International Joint Commission on Great Lakes Water Quality, set a timetable for totally phasing out the use of chlorine as an industrial feedstock.
- Reauthorization of the Clean Water Act in February 1994 calls for a study of reducing the use of chlorine in the manufacture of pulp and paper, chlorinated solvents, polyvinyl chloride, and drinking water.
- The Environmental Protection Agency has developed a set of "cluster rules" for pulp and paper mills. Under these rules, it is believed there will be much pressure to reduce or eliminate the use of chlorine in paper production. Steps have already been taken at some mills to introduce oxygenation and other processes as substitutes for the chlorine-using approaches[28] The pulp and paper application of chlorine accounts for nearly 15 percent of total annual consumption. Its loss would be a serious blow to the domestic industry.
- The Canadian and some European environmental protection agencies are setting timetables for phasing out organochlorines.

All of these actions place increasing focus on the likelihood that chlorine use and production will be reduced. A complete ban on chlorine use and production does not appear likely. However, the sheer number of government studies, recommendations, and policy initiatives and the potential gravity of the consequences being attributed to chlorine have created substantial noncost pressures to reduce chlorine production.

Carbon taxes would thus be imposed on an industry already facing loss of a large number of markets because of regulatory actions. Those regulatory actions appear more likely to restrict or ban the use of chlorine in certain applications than to raise the cost of either chlorine or processes using chlorine. Because of this, there is little interaction between carbon taxes and the other environmental regulations. Other environmental regulations could drastically reduce the demand for chlorine, but it does not appear that they would greatly increase or decrease the differential impact of a carbon tax.

The step-wise demand curve identifies the amount of chlorine that goes into the specific uses. It can be used to assess the cost and the loss of chlorine output associated with restricting each of the specific uses. This is the way that command-and-control regulations work–targeting specific technologies or uses. A carbon tax works differently, since it imposes a penalty on the use of chlorine in all applications and affects the less valuable uses of chlorine in each step on the demand curve. Thus as chlorine output is severely restricted by other environmental regulations, carbon taxes could remove a significant proportion of the remaining demand by causing chlorine to be replaced where its use has less-than-average value.

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[28] See the Associated Press release, "Use of Chlorine in Paper Tears at Maine Industry" *(The Journal*

For example, if polypropylene oxide is one of the major remaining uses of chlorine, a carbon tax could cause substitution away from chlorine in some applications for production of polypropylene oxide. This could be a larger share of remaining chlorine production if environmental regulations restrict other uses, and is difficult to predict based on average costs for chlorine substitutes.

References

Associated Press. 1993. "Use of Chlorine in Paper Tears at Maine Industry." *The Journal of Commerce* (December 28).

Breskin, Ira. 1993. "Chlorine Prices Soar on Vinyl Demand." *The Journal of Commerce* (October 26).

The Journal of Commerce (March 17, 1994).

Skillings' Mining Review 82, No. 11 (March 13, 1993).

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of Commerce 1993, 5B).

7

REGIONAL ECONOMIC IMPACTS

Introduction

Carbon taxes will not affect all regions of the country in the same way. The regions in which energy-related employment is concentrated will be harder hit than other regions, because energy industries have by far the largest output declines. Other manufacturing industries whose costs are increased, especially those located in regions in which electricity is generated from coal, will also lose employment. Higher electricity prices in regions with coal-fired electricity will also reduce the competitiveness of businesses in those regions, leading to some shifts in manufacturing employment beyond those expected from declines in output of whole industries. Changes in the competitiveness of different regions cause wage changes and ultimately migration that restore balance among regions.

The key conclusions about regional impacts are:

- A tax on the carbon content of primary fuels hits energy-producing regions the hardest. The West South Central states, with their heavy concentration in the oil and gas industries, experience a 1.1 percent job loss relative to base-line levels in 2010. Total employment in the East South Central and South Atlantic coal mining regions is 0.5 to 0.6 percent below the base line. (Figure 7-1 displays the regions referred to in these discussions.)
- Regions depending heavily on coal for electricity generation experience a rise in relative costs that weakens their competitive position. As a result, manufacturing employment in the two North Central and the South Atlantic regions drops 0.5 percent by 2010.
- Although the carbon tax is recycled through federal personal income taxes, its indirect inflationary effects erode real personal income in all regions.
- Mining and manufacturing employment base losses prompt slight out-migration from the Central and South Atlantic regions to the New England, Middle Atlantic, and Pacific regions.

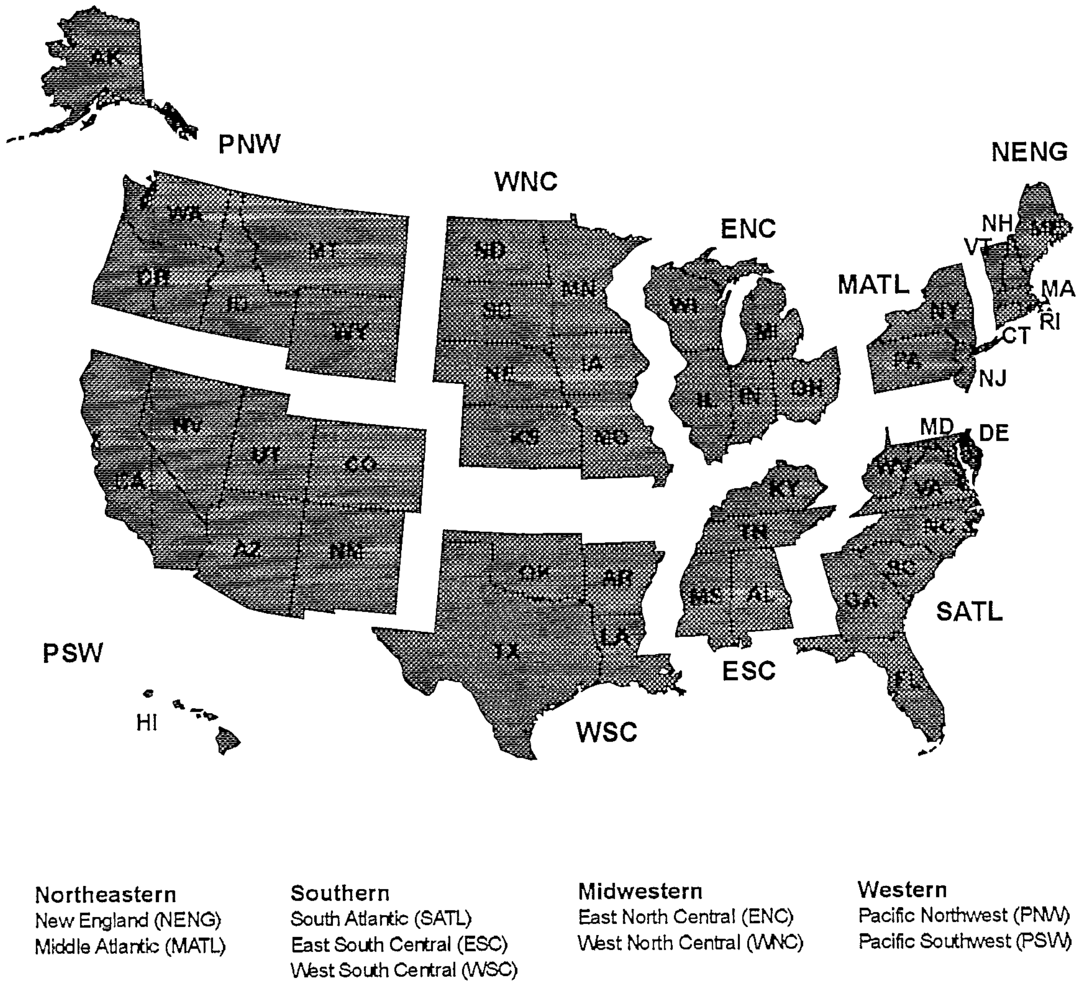

Figure 7-1
Regions in the DRI/McGraw-Hill Regional Modeling System

Methodology

In a simulation of a carbon tax's effects, electricity prices are a key factor in the shift of manufacturing activity among regions. Regions relying more heavily on coal for electric generation are put at a competitive disadvantage by a carbon tax.

Lower demand for coal reduces employment and income in the coal-producing regions. The loss of income, in turn, cuts spending on local goods and services, leading to lower levels of employment in trade, services, and finance. Meanwhile, reduced tax revenues prompt cutbacks in state and local government payrolls.

Impact of a Carbon Tax

Energy Markets

A tax on primary fuel carbon content has the most adverse effect on coal-producing and coal-consuming regions. The electric utility price of coal climbs 165.8 percent from the base line by 2010 (Table 7-1). Residual fuel and natural gas prices are rise by 37.1 percent and 34.9 percent, respectively. Coal is particularly sensitive to price changes because of the fuel-switching capabilities of electric utilities, as the table shows. Total fuel demand for coal drops 24.6 percent from the base line by 2010, petroleum demand decreases 7.3 percent, and gas 12.1 percent.

Table 7-1
National Assumptions (Percentage Difference from Base Line)

	2000	**2010**
Energy Prices		
Coal (EU)	189.9	165.8
Residual Fuel (EU)	50.4	37.1
Natural Gas (EU)	51.9	34.9
Electricity (Industrial)	37.2	34.2
Total Energy Demand		
Coal	-6.9	-24.6
Petroleum	-5.0	-7.3
Natural Gas	-10.1	-12.1
Electricity	-6.2	-14.2

Mining Employment

Coal mining accounts for 29 percent of US mining employment; oil and natural gas account for 49 percent, and construction-related and metals-mining employment account for the remainder. Mining employment varies by region. Mining in the Middle Atlantic, South Atlantic, and both East Central regions is dominated by coal. In the West South Central and Pacific Northwest, employment in oil and natural gas predominates. Those regions relying more on coal, oil, and natural gas find mining employment hit hardest by the tax. Because the carbon tax does not directly affect construction-related or metals mining, Regions with high concentrations in construction-related or metals mining are not as affected because the tax does not influence these two categories directly.

Table 7-2 presents regional distribution of coal and oil and gas mining employment in 1990. Four regions–the Middle Atlantic, South Atlantic, and the two East Central ones–account for over 80 percent of coal mining employment. Oil and gas mining employment is even more concentrated. More than 90 percent of the US total is found in the West South Central and Pacific Southwest regions.

Table 7-2
National Concentration of Mining Employment (Percentage of US Total)

	Coal Mining	Oil & Gas Mining
New England	0.0	0.1
Middle Atlantic	21.0	1.2
South Atlantic	25.1	1.3
East North Central	13.9	4.2
East South Central	21.4	1.8
West North Central	1.3	3.9
West South Central	2.3	68.7
Pacific Northwest	3.9	5.6
Pacific Southwest	6.3	13.2

The reduced coal demand most severely affects the higher-cost and relatively more labor-intensive coal producers in the Middle Atlantic, South Atlantic, and the two East Central regions (Table 7-3); these regions see mining employment fall 15 to 19 percent below base-line levels by 2010, a decrease which constitutes 41 percent of the national mining employment losses.

The West South Central region is dependent on the, oil and natural gas industries and so also suffers. The carbon tax reduces the region's mining employment 9.3 percent below base-line levels in 2010, or another 38 percent of the national mining employment losses.

Table 7-3.
Mining Employment Under a $100 Carbon Tax

	Difference from Base Line (%)			Difference from Base Line (Thousands)		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	-4.9	-9.2	-11.1	-28.4	-51.5	-58.6
New England	-1.5	-2.0	-3.3	-0.1	-0.1	-0.1
Middle Atlantic	-5.0	-10.4	-17.2	-1.2	-2.3	-3.3
South Atlantic	-4.6	-9.5	-16.6	-2.6	-5.2	-8.4
East North Central	-4.7	-9.4	-14.6	-2.0	-3.6	-4.8
East South Central	-5.2	11.1	-18.9	-2.3	-4.7	-7.6
West North Central	-3.6	-6.3	-7.3	-1.1	-1.8	-2.0
West South Central	-5.6	-10.0	-9.3	-14.0	-24.7	-22.2
Pacific Northwest	-4.2	-7.9	-9.8	-1.5	-2.8	-3.2
Pacific Southwest	-3.9	-7.0	-8.2	-3.7	-6.4	-7.0

Electricity Prices

A carbon tax on primary fuels changes the relative costs of generating electric power and thus affects a region's competitiveness. By 2010, a $100 carbon tax boosts the national average industrial price of electricity 34.2 percent above the base line. Regions depending more on coal for electricity generation experience sharper price increases than those with higher concentrations of nuclear and hydropower (Table 7-4).

Table 7-4
Regional Industrial Electricity Prices Under a $100 Carbon Tax (Percentage Difference from Base Line)

	2000	**2010**
US Total	37.2	34.2
New England	20.2	26.4
Middle Atlantic	28.4	30.3
South Atlantic	43.9	41.3
East North Central	50.3	48.5
East South Central	38.5	35.3
West North Central	56.8	54.4
West South Central	52.6	45.1
Pacific Northwest	30.1	23.4
Pacific Southwest	21.4	16.8

Table 7-5 shows that over 70 percent of electricity generation comes from in the four Central regions and the South Atlantic is coal-, oil-, or natural-gas-fired. Consequently, electricity-intensive industries in these regions find their competitive position deteriorating. The carbon tax has less of an impact in the New England, Middle Atlantic, and the two Pacific regions because nuclear and hydropower represent a greater share of electricity generation. Manufacturers in these areas gain a competitive advantage because electricity prices there rise relatively less.

Table 7-5
Regional Electricity Generation by Fuel Type (Percentage of Total Generation, 1992).

	Coal	Oil & Natural Gas	Nuclear	Hydropower	Other
New England	19.2	30.4	44.9	5.1	0.5
Middle Atlantic	41.8	14.4	34.4	9.3	0.0
South Atlantic	59.0	10.4	28.1	2.4	0.0
East North Central	73.9	1.0	24.4	0.7	0.1
East South Central	72.7	2.2	16.8	8.3	0.0
West North Central	74.4	1.4	18.6	5.4	0.2
West South Central	49.6	36.3	11.9	2.1	0.1
Pacific Northwest	37.2	2.6	5.1	52.5	2.6
Pacific Southwest	44.4	22.3	17.8	14.3	1.2

Other Employment

The two North Central regions suffer the largest losses in manufacturing employment, followed by the West South Central and South Atlantic (Table 7-6). By 2010, manufacturing employment in the East North Central region falls 0.9 percent below base-line levels. This figure denotes the region's higher relative electricity prices and higher concentrations of electricity-intensive industries.

The carbon tax engenders inter-regional shifts in manufacturing employment in industries such as metals; stone, clay, and glass; pulp and paper; rubber and plastics; and textiles. Some regions lose employment and some gain. For example, the lower rise in electricity prices in the New England, Middle Atlantic, and Pacific regions improves their relative cost competitiveness and thus attracts manufacturing jobs.

Table 7-6
Total Manufacturing Employment Under a $100 Carbon Tax

	Difference from Base Line (%)			Difference from Base Line (Thousands)		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	-0.2	-0.2	-0.1	-36.8	-27.7	-11.4
New England	0.6	1.2	1.1	6.0	12.7	10.9
Middle Atlantic	0.4	0.7	0.7	9.0	15.7	14.7
South Atlantic	-0.3	-0.3	-0.3	-8.0	-10.2	-9.1
East North Central	-0.7	-1.0	-0.9	-30.3	-40.6	-36.0
East South Central	-0.2	-0.1	0.1	-2.7	-1.9	-0.9
West North Central	-0.6	-0.9	-0.9	-8.7	-12.9	-12.6
West South Central	-0.5	-0.7	-0.6	-8.4	-11.0	-8.7
Pacific Northwest	-0.2	0.0	0.1	-1.4	-0.3	0.7
Pacific Southwest	0.3	0.9	1.3	7.6	20.7	29.5

On the other hand, the Pacific Northwest loses jobs in spite of its below-average rise in electricity prices. The region's dominant industry, aircraft, is severely hurt by the rise in fuel prices. The Pacific Northwest also has a high concentration of other transportation equipment manufacturers and metals producer industries, and all transportation equipment is depressed by higher user costs.

Table 7-7.
Employment Except Manufacturing and Mining Under a $100 Carbon Tax

	Difference from Base Line (%)			Difference from Base Line (Thousands)		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	-0.2	-0.4	-0.3	-164.3	-412.8	-371.7
New England	0.1	0.3	0.4	7.4	18.6	28.5
Middle Atlantic	0.0	-0.1	0.0	-4.0	-15.8	-1.3
South Atlantic	-0.2	-0.4	-0.5	-35.8	-95.9	-112.0
East North Central	-0.2	-0.5	-0.4	-38.6	-90.4	-85.1
East South Central	-0.3	-0.6	-0.6	-14.8	-36.5	-40.8
West North Central	-0.3	-0.6	-0.5	-21.8	-47.8	-41.8
West South Central	-0.5	-1.0	-1.0	-52.7	-124.5	-131.1
Pacific Northwest	0.0	-0.1	-0.1	-0.1	-7.4	-2.9
Pacific Southwest	0.0	-0.1	0.1	-3.8	-13.0	14.7

Total Non-farm Employment

In most regions, mining employment constitutes a small proportion of jobs. In the West South Central region, however, oil and gas employment makes up a significant percentage of total employment. Oil and gas work provided 261,000 jobs (92.6 percent of 281,900 jobs) in this region in 1990, which amounts to 2.5 percent of the region's non-farm employment. The East South Central region had the heaviest coal mining concentrations—0.7 percent of the total jobs. The South Atlantic region also showed strong mining employment (0.3 percent of total jobs). In the Pacific Northwest region, coal, oil, and gas mining combined provided 0.7 percent of employment.

The economic activity and total employment in most regions are further weakened by deterioration in mining employment. Income losses in coal mining areas are a factor in the relative poor performance of service and trade industries, as well as an out-migration of population. By 2010, total employment in the West South Central drops as much as 1.1 percent; in the two East Central and South Atlantic regions, where coal, oil, and natural gas mining employment accounts for the largest share of total employment and electricity prices increase significantly more than the national average, total employment falls 0.5 to 0.6 percent (Table 7-8). Manufacturing jobs in the Pacific Northwest are boosted by the below-average increase in electricity prices, but the rise isn't enough to counter non-manufacturing job losses. In contrast, the New England, Middle Atlantic, and Pacific Southwest regions see total employment climb above baseline levels by 2010 due to improvements in their relative competitiveness.

Table 7-8
Total Non-farm Employment Under a $100 Carbon Tax

	Difference from Base Line (%)			Difference from Base Line (Thousands)		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	-0.2	-0.4	-0.3	-229.5	-492.0	-441.6
New England	0.2	0.4	0.5	13.4	31.3	39.3
Middle Atlantic	0.0	0.0	0.1	3.8	-2.5	10.1
South Atlantic	-0.2	-0.5	-0.5	-46.5	-111.3	-129.5
East North Central	-0.3	-0.6	-0.5	-70.9	-134.7	125.9
East South Central	-0.3	-0.6	-0.6	-19.8	-43.2	-49.2
West North Central	-0.3	-1.6	-0.5	-31.6	-62.5	-56.4
West South Central	-0.6	-1.2	-1.1	-75.1	-160.2	-162.0
Pacific Northwest	-0.1	-0.2	-0.1	-3.1	-10.4	-5.3
Pacific Southwest	0.0	0.0	0.2	0.2	1.3	37.2

Personal Income

Mining employment losses and manufacturing employment shifts affect regional incomes. All regions benefit somewhat from the offsetting stimulus provided by the recycling of carbon tax revenues through a lump-sum rebate of personal income taxes. However, in spite of the fact that the carbon tax's effect on employment varies across regions, real personal income drops below base-line levels in all regions. Every region does experience a rise in nominal wages above base-line levels, but because the full passthrough of the tax burden by producers results in higher inflation, which erodes real personal incomes (Table 7-9 through 7-11). Not surprisingly, real personal income falls the least in New England and the Pacific Southwest, the two regions that experience the highest employment gains. The West Central regions are on the other end of the scale. Hardest hit in terms of employment by the tax, the West North Central and the West South Central suffer real personal incomes decreases of 2.9 and 3.2 percent, respectively.

Table 7-9
Average Annual Wages Under a $100 Carbon Tax (Percentage Difference from Base Line)

	Total			Manufacturing			Non-manufacturing		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4
New England	0.4	0.5	0.5	0.3	0.4	0.4	0.4	0.5	0.5
Middle Atlantic	0.4	0.5	0.5	0.3	0.4	0.4	0.4	0.5	0.5
South Atlantic	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3
East North Central	0.2	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3
East South Central	0.3	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4
West North Central	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
West South Central	0.2	0.1	0.1	0.3	0.2	0.2	0.2	0.1	0.1
Pacific Northwest	0.4	0.5	0.5	0.3	0.3	0.3	0.5	0.5	0.5
Pacific Southwest	0.4	0.5	0.5	0.3	0.5	0.5	0.4	0.5	0.5

Table 7-10
Wages and Salary Disbursements Under a $100 Carbon Tax (Nominal Dollars)

	Difference from Base Line (%)			Difference from Base Line (Billions)		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	0.2	0.0	0.1	7.3	2.0	6.8
New England	0.6	0.9	1.0	1.5	3.1	4.3
Middle Atlantic	0.5	0.5	0.6	3.3	4.9	6.8
South Atlantic	0.1	-0.1	-0.2	1.0	-1.1	-2.4
East North Central	-0.1	-0.3	-0.3	-0.6	-3.3	-3.5
East South Central	0.1	-0.2	-0.2	0.1	-0.5	-0.8
West North Central	0.0	-0.3	-0.2	-0.1	-1.1	-1.0
West South Central	-0.3	-1.0	-1.0	-1.5	-6.0	-7.3
Pacific Northwest	0.4	0.3	0.4	0.7	0.8	1.2
Pacific Southwest	0.4	0.5	0.7	3.0	5.2	9.3

Table 7-11
Real Personal Income Under a $100 Carbon Tax (1987 Constant Dollars)

	Difference from Base Line (%)			Difference from Base Line (Billions)		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	-1.5	-2.0	-2.3	-75.2	-110.1	-133.9
New England	-1.1	-1.2	-1.4	-3.2	-3.8	-4.7
Middle Atlantic	-1.2	-1.5	-1.8	-9.8	-13.5	-16.9
South Atlantic	-1.6	-2.2	-2.6	-13.4	-21.3	-27.5
East North Central	-1.7	-2.3	-2.6	-13.4	-20.1	-23.7
East South Central	-1.8	-2.4	-2.8	-4.4	-6.5	-8.0
West North Central	-2.2	-2.7	-2.9	-7.3	-9.8	-11.0
West South Central	-2.0	-3.0	-3.2	-9.3	-15.5	-18.5
Pacific Northwest	-1.5	-1.9	-2.0	-3.0	-4.2	-5.0
Pacific Southwest	-1.3	-1.6	-1.7	-11.4	-15.5	-18.5

Resident Population

Changing job opportunities also have an effect on population migration patterns. Mining and manufacturing job losses help push a slight out-migration from the two South Central and the East North Central regions (Table 7-12). On the other hand, the New England, Middle Atlantic, and Pacific regions see an influx of population relative to the base line because of employment gains or below-average employment losses.

Table 7-12 Resident Population Under a $100 Carbon Tax

	Difference from Base Line (%)			Difference from Base Line (Thousands)		
	2000	**2005**	**2010**	**2000**	**2005**	**2010**
US Total	0.0	0.0	0.0	0.0	0.0	0.0
New England	0.1	0.4	0.5	17.7	58.7	71.4
Middle Atlantic	0.1	0.2	0.2	32.9	79.4	91.9
South Atlantic	0.0	0.0	-0.1	2.1	-10.2	-38.4
East North Central	-0.1	-0.1	-0.1	-24.5	-55.8	-63.8
East South Central	0.0	-0.1	-0.1	-6.8	-14.4	-22.9
West North Central	-0.1	-0.2	-0.1	-12.9	-32.0	-30.7
West South Central	-0.1	-0.3	-0.4	-30.3	-109.1	-134.1
Pacific Northwest	0.0	0.1	0.1	0.2	7.1	14.4
Pacific Southwest	0.0	0.1	0.2	21.6	76.4	112.3

8

WRAP-UP

Two topics are worth a second look in light of these explorations of how and where the impacts of carbon taxes show up in the economy. One is the question of just how large the overall economic impacts of carbon taxes are, and how they relate to the direct costs that appear in energy markets alone. The second is the question of what estimates of the costs of carbon taxes have to say about the impacts of alternative command-and-control regulations.

Economic Impacts vs. Direct Costs in Energy Markets

Consumer Surplus vs. GDP Losses

Estimates of the economic costs of taxes are frequently based on measures of deadweight loss. These measures reflect the loss of economic welfare from higher costs of energy and of using energy, as discussed in the introduction to this study. They can be derived from econometrically estimated demand curves, because demand curves provide information about the amount that consumers are willing to pay for energy. The deadweight loss from a tax that reduces energy consumption is the amount that consumers would have been willing to pay for the foregone consumption, less its cost of production before taxes. The simplest deadweight loss calculations are based only on the demand for the commodity taxed, such as energy. Thus the deadweight loss from a carbon or energy tax is calculated from estimated changes in the after-tax price and demand for energy. As this study has shown, taxes on intermediate goods like energy find their way into all goods and services produced and consumed in the economy. There are likely to be additional deadweight losses in other markets, caused by carbon taxes, that are ignored in the simplest calculation of direct impacts and deadweight losses in energy markets alone.

Table 8-1 reports estimates of deadweight loss from the $100 carbon tax based on energy market impacts alone. In an economy with roughly constant employment, deadweight losses and GDP losses should be comparable to each other, as long as there is not a significant shift in the share of investment. Since the demand curves do not incorporate feedback effects from lower employment and GDP in the relation between demand and price, deadweight losses are properly compared to losses in potential GDP for the case in which unemployment is neutralized through monetary policy.

Table 8-1
Deadweight and Potential GDP Losses (Billions of 1987 Dollars in 2010)

	Carbon Tax Cases		
	50	100	200
Potential GDP Loss	89	172	311
Potential GDP Loss Due to Lower Energy Use	24	46	84
Deadweight Loss In Energy Markets	6	19	73
Per-Existing Tax Loss	10	24	46
Total Deadweight Loss	16	43	119

It was noted earlier that only about 27 percent of the deadweight loss from a carbon tax is directly attributable to reductions in energy demand. The remainder is attributable to effects in other markets: reductions in investment brought about by higher energy costs, interest rates and reduction in the optimal capital-output ratio. The GDP loss thus attributable to carbon taxes is also reported in Table 8-1, as is the GDP loss attributable to lost investment. It can be seen that the GDP loss attributable to reduced energy consumption is somewhat greater than the estimated deadweight loss in energy markets.

Pre-existing Distortions

The difference between deadweight and potential GDP losses could well be explained by the existence of other taxes that increase the deadweight loss attributable to every dollar of a carbon tax. A rigorous analysis of how pre-existing tax distortions amplify the costs of any other taxes is provided by Bovenberg and Goulder (1993). They demonstrate that the marginal deadweight loss from a very small carbon tax is not close to zero, but equal to the reduction in energy use caused by the carbon tax times the pre-existing tax distortion (expressed in terms of the price of energy).

The reason for this result can be traced back to theoretical papers by Diamond and Mirrlees (1971), and Stiglitz and Dasgupta (1971); more recent work by Bovenberg and de Mooij (1993) and Goulder (1994) reinforces this result. The theory indicates that carbon taxes, as taxes on intermediate inputs to production, are more costly than taxes on primary factors (payroll taxes and personal and corporate income taxes) or taxes on net output (value-added taxes and general sales taxes). The basic intuition is that taxes on intermediate inputs are all shifted back to factor markets and distort factor markets as much as equal-revenue factor or income taxes do. Moreover, intermediate input taxes produce distortions in markets for intermediate goods and downstream consumer goods.

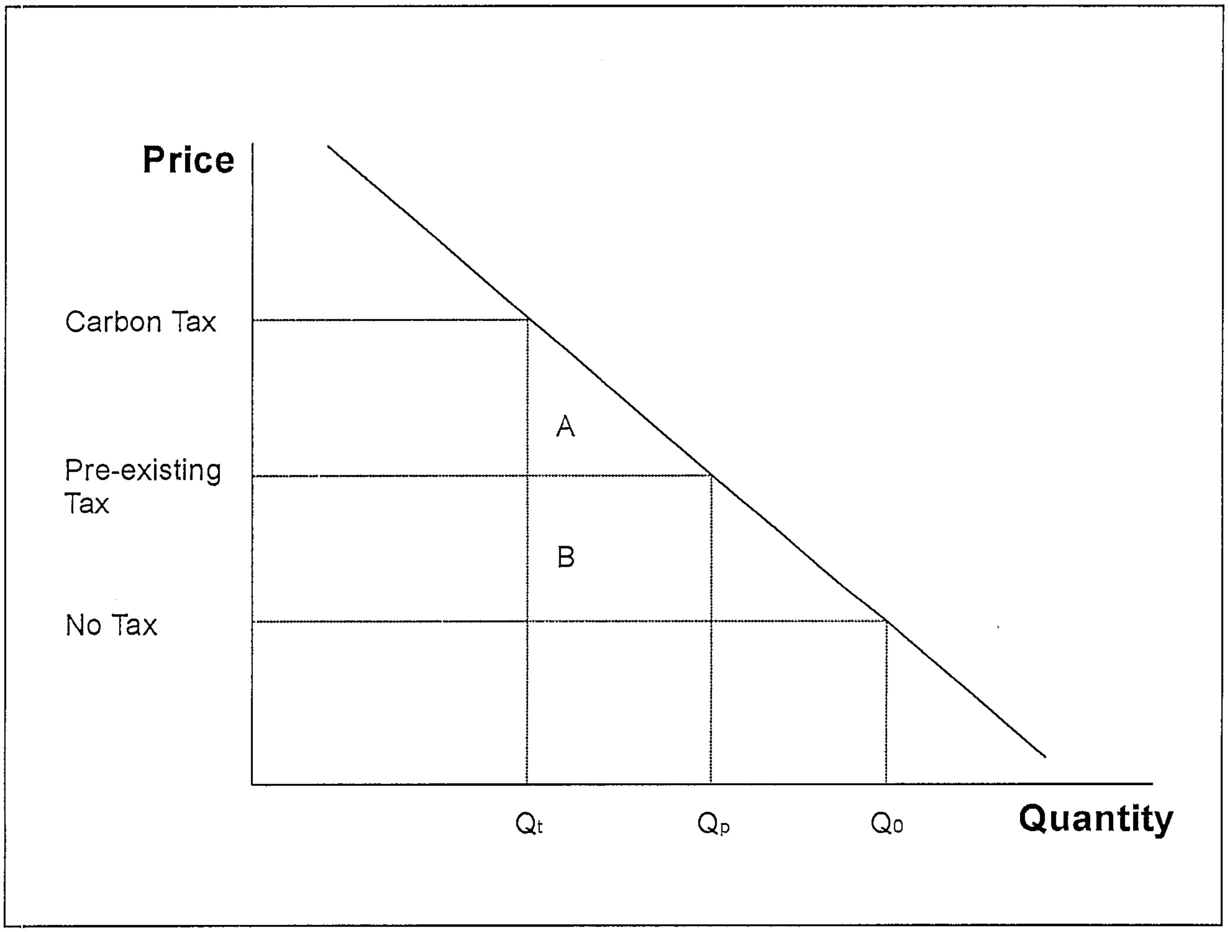

Figure 8-1
Deadweight Loss with Pre-existing Taxes

These pre-existing distortions could take the form of existing taxes on energy. This is an important source of additional deadweight loss in Europe and other regions with high gasoline and other energy taxes, but in the United States most of energy tax collections represent user fees, going for highway construction and maintenance. However, income from investment is taxed at a high rate, and therefore subject to serious distortions, as are labor inputs through social security and other payroll taxes. If taxes on intermediate goods, such as energy, are in large part shifted back to labor and capital, the original factors of production, carbon taxes are effectively levied on top of existing taxes.

For illustrative purposes, assume that the pre-existing taxes equal 20 percent of the price of energy. Estimates of a marginal tax burden of 50 percent from the provisions of the corporate income tax relating to income from investment are supportable, but at the high end of the range of published estimates (see Jorgenson and Yun 1990). Losses from exacerbating prior distortions are approximately linear in the tax rate, because they are calculated as the pre-existing tax rate times the change in energy use due to carbon taxes. As illustrated in Table 8-1, this closes the gap between GDP loss attributable to energy markets and deadweight loss measures.

Reduction in Investment and Reduction in Energy

Higher energy costs do not affect only energy markets. They also affect investment by raising the cost of investment goods and increasing the interest rate. These factors reduce the optimal amount of capital equipment per unit of output, and therefore lead to lower investment until the capital stock has declined to a level constant with the desired post-tax capital-to-output ratio. The losses in GDP due to this reduction in investment are not included in estimates of deadweight losses in energy markets, and are only recognized when a full treatment of carbon tax impacts on all markets is essayed. The difference between narrowly estimated deadweight losses has also been noted in studies of economic impacts of environmental regulation is done by Dale Jorgenson and his associates, and by Raymond Kopp and Michael Hazilla (1986). Hazilla and Kopp find that the total economic cost of environmental regulations exceeds their direct cost by a factor of four. Thus their findings are almost exactly the same as those in this study, that direct costs are only about one-quarter of total economic losses.

Taxes vs. Command-and-Control Regulations

Economic Impacts of Regulations and Taxes

Impacts appear to differ when aggregate economic impacts of carbon taxes are compared to welfare losses from regulatory programs measured only in energy markets. In particular, carbon taxes often appear more onerous to the industries to which they are applied because regulatory programs impose only their costs of compliance. A carbon tax could conceivably induce an industry to adopt the same measures that would be required by a regulatory program—for example, to replace lighting systems with more efficient ones. But then the industry pays two costs directly—the cost of installing the more efficient system, which it would also pay trader a regulatory regime, plus the tax on all its remaining energy use.

When a carbon tax is recycled, as we assumed in this study, the revenue collections are returned somewhere in the economy. Thus on balance, the costs of a carbon tax are no larger than those of a regulatory program. However, tax reductions may well be targeted toward individuals, or returned in other ways that provide no direct benefit to industries incurring the highest costs.

In a competitive market, a tax will be passed through to the prices at which the output of an industry is sold to consumers. However, there may not be a dollar-per-dollar passthrough if demand is elastic and if there are marginal producers whose costs, after tax, are higher than others in the industry. This is exactly the situation described in the analysis of the aluminum industry. The result is that prices of delivered goods rise by less than the tax, some firms in the industry shut down, and lower profits are earned in total by the industry. If firms in the industry are affected differently by the tax, as in the case of aluminum where there are hydro- and coal-based producers who face different cost increases, profits may be shifted from the high-cost surviving firms to the lower-cost surviving firms.

Very similar effects also occur under regulatory programs. Businesses will also try to pass on costs of complying with regulatory programs. Costs for some marginal producers may be pushed to a level higher than the prevailing market price, demand may fall, and some producers may exit the industry.

The market impacts of command-and-control regulations thus seem very similar to the impacts of carbon taxes. The difference that command-and-control regulations achieve reductions in emissions at a much higher direct cost than carbon taxes, and that higher direct cost propagates through the economy to create larger economic impacts for any emissions reduction goal.

There are two reasons why the direct costs of command and control must be higher. The first is that the base on which regulatory programs build is much narrower than the base of carbon taxes, and therefore costs of achieving the same result in terms of total emissions reductions are higher. Second, regulatory approaches tend to build in incentives for forms of behavior that defeat part of their purposes, so that the emissions reductions achieved are less than anticipated.

The Base for Regulatory Programs

Carbon emissions are a pervasive result of use of fossil fuels, and every decision that bears on the use of fossil fuels will affect these emissions. Regulatory programs can only be brought to bear on a finite subset of these decisions, where specification of a requirement, monitoring, and enforcement are possible. Typically, regulations set standards for the performance of new equipment or limit the types of fuels that can be used in certain applications. Examples in energy markets include corporate average fuel economy standards for automobiles (CAFE), new source performance standards for electric power plants (NSPS), and requirements for alternative fuel vehicles in the Energy Policy Act.

Adding up all the regulatory programs that could be devised will still leave out many decisions affecting energy use not anticipated by Congress or regulators. The way this omission increases cost can be seen through a simple example. Suppose that energy consumption in some industry could be reduced through one change in the design of new equipment, and emissions would be reduced by 100,000 tonnes at a cost of $10,000,000, and that a second change in design could reduce emissions by an additional 10,000 tonnes for an additional $10,000,000. Suppose in addition that there is a way of carrying out activities in the industry, unobservable by regulators, that could achieve an additional 10,000 tonne reduction in emissions at a cost of $1,000,000, in conjunction with the first design change. A carbon tax of $100 per tonne would provide an incentive to undertake both the first design change and the unobservable change in activity, at a cost of $11,000,000. A regulatory program focused more narrowly on equipment design would cost $20,000,000 to achieve the same 110,000 tonne reduction in emissions, because of the diminishing returns to tighter and tighter standards.

Regulatory programs focusing on equipment efficiency have two additional perverse effects. They raise the cost of investing in new equipment, and thus have a "new source bias" that discourages replacement of old equipment. Since, as discussed throughout this study, the turnover of the capital stock is one of the most important routes by which cost-effective fuel switching or efficiency improvements are accomplished, the new source bias raises cost. Second, regulations like CAFE that improve fuel efficiency reduce the cost of energy-consuming activities. The result is that driving increases, "taking back" some of the estimated efficiency improvements.

Economic incentives, whether provided through carbon taxes or through tradable permits that achieve the same emissions reduction, do not create a new source bias or a take-back effect. Rather, they encourage faster turnover of the capital stock, for example, the replacement of coal-fired generating capacity that could have been life-extended. In addition, they have the desired effect on behavior, rather than a perverse take-back effect. In sum, the costs of command-and-control regulations exceed those of carbon taxes for the same emissions reductions.

Scope of Impact Analysis

Tax impacts are larger when viewed in the context of the entire economy than when measured solely by welfare losses in energy markets. When regulatory programs have similar impacts on energy costs, they are likely to have similar impacts on other markets, such as investment, and have larger impacts on the whole system than measured in energy markets alone. The part of the increase in the "real user cost of capital" attributable to higher energy costs is created by regulatory programs that raise costs as well as by carbon taxes. Increases in real interest rates may or may not be caused by regulatory programs, depending on their impact on price levels.

Analyzing either regulatory programs or tax programs in terms of their impacts on energy supply and demand alone leaves out these important, broader economic impacts. In this study, it was found that little more than one-fourth of the economic losses from carbon taxes arise directly in energy markets. The remainder come about because of losses in investment and reductions in the capital stock, due in turn to the higher interest rates and increased cost of capital goods that accompany higher energy prices.

Moreover, the effects of prior tax (and regulatory) distortions further amplify the economic impacts of higher energy costs. A regulatory program that imposes higher energy costs on top of other distorting taxes or regulations imposes the same amplified deadweight losses as would a tax. Consider the graph in Figure 8-1. Suppose a regulatory program required a reduction in energy use from the level associated with the pre-existing tax (Q_p) to the level associated with the carbon tax (Q,). The deadweight loss from this measure would be A+ B, just as in the case of the carbon tax.

Implications for Measuring Impacts of Command-and-Control Regulations

Several of the discoveries made about the economic impact of carbon taxes help in interpreting the potential costs of regulatory programs. First, it was found that removing the cyclical unemployment caused by a carbon tax eliminates less than one-third of the overall GDP loss (reducing GDP loss from the $100 tax from 2.3 percent to 1.6 percent in 2010). Second, it was found that the differences between conventional measures of deadweight loss and the losses in GDP estimated for a carbon tax are largely attributable to impacts of carbon taxes in markets outside energy. Third, it was found that pre-existing tax distortions, and by implication pre-existing regulatory programs that increase the cost of energy use, amplify deadweight losses.

These findings suggest strongly that the economic impacts of command-and-control regulations that raise the cost of energy would be like those of carbon taxes, if command-and-control regulations could achieve the same emissions reductions at the same direct cost.

However, decades of research in environmental economics have demonstrated the far higher cost of command-and-control regulations compared to economic incentives. Carbon emissions are a pervasive result of fossil energy consumption. Every decision that affects energy use affects carbon emissions. No regulatory program administered at finite cost can hope to identify and change all those decisions. Any regulatory program that attempts to achieve the same emissions reductions by concentrating on a narrower set of technological options, as is typically done, will incur far higher costs for the same emissions reduction. Moreover, most command-and-control regulations provide perverse incentives for replacement of old equipment, or encourage greater utilization of equipment that has been made more efficient, and thereby defeat some of their own purpose. The result is a further increase in the cost per ton of emissions reduced. The only exception is a form of regulation that also uses economic incentives rather than specific technology and process standards, and that is the use of tradable permits.

Otherwise, command-and-control regulations can be expected to have costs at least as high as carbon taxes, once the cyclical impacts of carbon taxes have been removed. Saying more requires examination of specific proposed regulations. A full analysis of such regulations requires considerably more detail than can be included in any overall model of the economy, and is most profitably based on the kinds of detailed industry study presented for aluminum, steel, and chlorine. Costs of regulatory programs estimated through standard deadweight loss measures based on direct impacts on energy consumption are likely to seriously underestimate overall economic impacts. Since the impacts of carbon taxes due to factors outside energy markets are about three times as large as impacts due to lower energy use, a first approximation would multiply the deadweight loss of regulatory programs by a factor of four.

References

Bovenberg, A. L., and L. H. Goulder. 1993. *Integrating Environmental and Distortionary Taxes: General Equilibrium Analysis.* Conference on Market Approaches to Environmental Protection at Stanford University.

Bovenberg, A. L., and Ruud do Mooij. 1993. "Environmental Levies and Distortionary Taxation." *American Economic Review.*

Diamond, Peter, and James Mirrlees. 1971. "Optimal Taxation and Public Production I: Production Efficiency and II: Tax Rules." *American Economic Review* 61.

Goulder, L. H. 1994. "Energy Taxes: Traditional Efficiency Effects and Environmental Implications." In James M. Poterba, ed., *Tax Policy and the Economy 8.* Cambridge: MIT Press.

Hazilla, Michael, and Raymond J. Kopp. 1986. *The Social Cost of Environmental Quality Regulations: A General Equilibrium Analysis* (Discussion Paper QE86-02). Washington, DC: Resources for the Future.

Jorgenson, D. W., and K.-Y. Yun. 1990. "Tax Reform and Economic Growth." *Journal of Political Economy* 98, pp. 5151-93.

Stiglitz, Joseph E., and Partha Dasgupta. 1971. "Differential Taxation, Public Goods, and Economic Efficiency." *Review of Economic Studies* 38, No. 2.