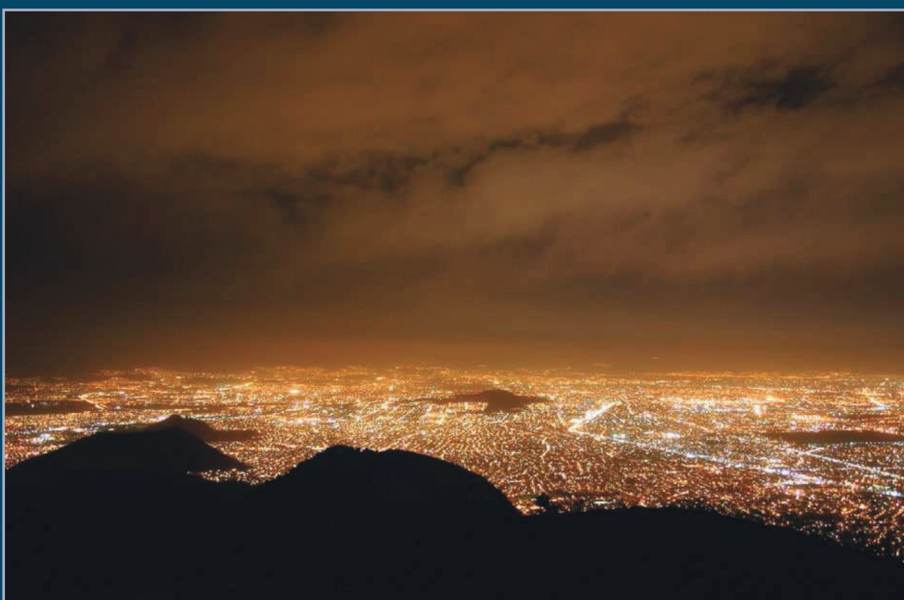
ADVANCES IN GLOBAL CHANGE RESEARCH

HACIA EL FUTURO:
ENERGY, ECONOMICS AND THE ENVIRONMENT IN 21ST CENTURY MEXICO

MARIA EUGENIA IBARRARÁN AND ROY BOYD

PREFACE BY MARIO MOLINA,
NOBEL LAUREATE IN CHEMISTRY, 1995



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HACIA EL FUTURO

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HACIA EL FUTURO

Energy, Economics, and the Environment in 21st Century Mexico

by

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To Karla, Sara, Sharon, Jerónimo and Gustavo

PREFACE

The past 25 years have witnessed an increasing worldwide concern over the issue of climate change and the specter of immense environmental and economic damage which would accompany unmitigated global warming trends. National governments in the industrialized world along with numerous multinational organizations have made a strong case for curbing the use of fossil fuels as an energy source, and agreements such as the Kyoto Protocol have come about largely due to their efforts. Many groups of researchers in both the natural and social sciences have made great strides in understanding this complicated issue. To date, however, the vast majority of climate change literature has addressed the topic from a European, North American, or global perspective, and the implications for developing countries have largely received only cursory treatment.

This book represents a major step forward in addressing the issue of climate from the perspective of a country in the developing world. It highlights the climate change concerns for a particular developing country – Mexico, and analyses the economic impacts of different policies designed to mitigate the use of fossil fuels in the context of economic development and growth. The effects of energy pricing policies, technological change, carbon sequestration, and tradable permits are all economically modeled and discussed at length by the authors. Of particular interest are the issues that these authors raise for policy makers, such as the tradeoffs between environmental concerns, economic growth, and income distribution. The discussion here is exhaustive and sometimes quite technical. It never lacks clarity and insight, though, and the authors do not lose their focus on the big issues involved. It is important reading for analysts and policymakers alike, along with anyone with an interest in economic development, the environment, and climate change issues.

Mario J. Molina
Nobel Laureat in Chemistry, 1995.

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This project is the culmination of research that has been ongoing for a number of years. It would have been impossible to complete without the help of many individuals in academic institutions, government agencies, and international organizations. We would like to thank the following people who have given us so much help but to emphasize that any errors committed, opinions expressed, or conclusions made in this book are solely our own and do not necessarily reflect the views or positions of any other individual or agency.

First of all we would like to thank Julia Martinez, Adrian Fernandez, Carlos Muñoz, Jose Carlos Fernandez, Sara Avila, Claudia Octaviano and all of their colleagues at INE and SEMARNAT for their help in identifying and presenting the detailed information on climate change impacts on Mexico presented in this book. We would also like to thank Jorge Chavez Presa and his staff at Secretaria de Energia for there assistance in sorting out the energy issues currently facing policy makers in Mexico.

We benefited greatly from comments made by various participants at the Mexican-U.S. Economic and Environmental Modeling Workshop of July 11-12, 2005 in Mexico City sponsored jointly by Battelle National Laboratory and the Centro Mario Molina. We wish to especially thank Michael Shelby and Jane Leggett of EPA, Ron Sands of Pacific Northwest National Laboratory, Jayant Sathaye of Lawrence Berkley National Laboratory, Luis Miguel Galindo of UNAM, and of course Mario Molina himself for their insightful and helpful comments on our work. We also benefited greatly from the help and encouragement provided by Onno Kuik and Reyer Gerlach of Vrije Univertiteit in Amsterdam, John Reilly of MIT, and Robert Bacon, Masami Kojima and Juan Carlos Belausteguigoitia of the World Bank.

We have received a great deal of help from our colleagues, students, and the administrative staff at both Ohio University and UDLA. In particular, we would like to thank Ariaster Chimelli, Marcelo Delajara, and Samuel Freije for reading large portions of the manuscript and providing critical information on the environment and economies of Brazil, Argentina, and Venezuela. We would also like to thank our research assistants Ivan Rodriguez, Misak Avetisyan, Haewon Chon and Garth Lobello, and our administrative staff for their many hours of assistance in preparing the programs, tables, and text of this book. Leslie Flemming, K. Doroodian, Carlos Ibarra, and Matthias Ruth were instrumental in providing us office space and extended periods of time to work together on this project. The generous financial support of CONACYT is also gratefully acknowledged.

We would be remiss if we did not thank those individuals that taught us the modeling techniques used in this analysis. Both GAMS and MPSGE play a large role in the results obtained in chapters 7, 8 and 9, and Thomas Rutherford, Miles Light, Mustafa Babiker, and Christoph Böhringer were the ones primarily responsible for teaching us these programs and familiarizing us with their use. We are deeply indebted to them for all of their help in this respect. So too are we indebted to Carol Dahl for her help in understanding energy markets and, more generally, for teaching us to be effective researchers in the area of environmental and research economics.

Finally we want to offer our deep thanks to our families without whose support the whole enterprise would have been impossible.

M.E.I.
R.B.

CONTENTS

PART 1

CHAPTER 1

INTRODUCTION

The issue of climate change and global warming has been a great concern of academics and policy makers worldwide since the early 1970's. Indeed, climate change is a truly worldwide issue in the sense that carbon emissions, regardless of where they take place, will affect conditions everywhere. An alteration of the world climate, in turn, will change local weather conditions as well, and thereby change agricultural productivity and possibly production costs for producers in other related economic sectors. Consumers everywhere will have to adjust to these new circumstances because of different weather patterns. They will have to deal with an increase in vector diseases, the increasing cost of protection from extreme weather conditions, and the higher aggregate costs of goods and services. Facing this problem requires coordinated commitments from all emitters of greenhouse gases and there has been intense ongoing international debate as to how, when, and how much specific countries should cut back on their aggregate level of carbon emissions. These debates, and the drive to find an international compromise on emissions cutbacks, culminated in the Kyoto agreement of 1997. Since that time most developed nations including Canada, Japan, Russia, and the countries of Western Europe have ratified this treaty while the U.S. and Australia have yet to agree to its terms. The countries of the developing world are not required by Kyoto to adhere to any specific cutbacks, and, consequently, though many developing countries have ratified the Kyoto Treaty, none to date have actually agreed to any emissions reductions.

The central focus of our analysis in this book is with the country of Mexico. The goal is to analyze Mexico's position regarding the international debate on emissions reduction, as well as the economic implications of adopting a range of policies to mitigate climate change.

Although negotiations are still ongoing, enforcement of the Kyoto Protocol formally went into effect in February 2005. A critical issue yet to be dealt with, however, is that without emission reduction commitments by developing countries, there is little chance that climate change trends will be significantly altered in the long run. Currently developing countries emit about half of annual global emissions with China, India, Brazil and Mexico being the top four emitters. The fact that these countries have yet to commit to emissions reductions is frequently mentioned by opponents of carbon emissions reductions in the United States and used to justify continued resistance to U.S.

ratification. At the same time, they also argue that carbon commitments by developed countries such as the US would lead to higher production costs and have a negative impact on the competitiveness of U.S. exports (Jotzo, 2005).

Nevertheless, a number of developing countries have played a significant role in shaping the Kyoto Protocol. Mexico, Argentina, Chile and Brazil are all actively involved in the ongoing Kyoto process. The main negotiation block formed by developing countries is called the G-77, and this group, along with China lobbies on behalf of its members on many international issues including climate change. Its effectiveness is somewhat limited since the interest of the individual member states of this group is quite diverse.

As mentioned above, our main goal is to study the case of Mexico, that is, a developing country with a large land mass, a delicate climate, a growing population and immense energy reserves. These attributes combine to make it unique among developing countries in terms of its sensitivity to both the costs and the benefits of CO_2 emission reduction policies. More specifically, because of its climatic vulnerability, Mexico is likely to suffer the adverse physical effects of climate change such as a loss of land to rising sea levels, increasing desertification and drought, loss of arable land, and a serious spread of vector diseases. Furthermore, in light of its large energy reserves and expanding productive capacity it finds itself under increasing pressure from the United States and other developed countries to enter into negotiations to make emissions reduction commitments as part of a multilateral reductions package. Other Latin American countries such as Brazil, Argentina and Chile are in a similar position. However, none of these countries, however, have the physical proximity and high degree of economic integration with the United States as Mexico does, and hence most of them are unlikely to come under intense pressure from the U.S. to make emissions reductions. However, the overall argument for the active enrollment of developing countries in emissions mitigation is that within a couple of decades most emissions will come from developing countries and these will outweigh any effort done by cutbacks in industrialized countries alone. Given that this is a global problem, costly efforts to reduce emissions by developed countries will be for naught, and emission levels and climate change will continue along their current trend.

There are competing proposals as to the proper instruments to use in reaching international emissions targets. One proposal is to focus on implementing a harmonized tax system. If this were adopted then countries belonging to the Protocol would impose taxes on the carbon content of their own manufactured goods and impose carbon content tariffs on the imports of goods from non-member nations. There are, however, questions as to how the less affluent consumers in these nations could be fairly and equitably compensated for such a tax scheme. The other relevant proposal is to keep existing emissions trading in place and, in the future, open trade in emissions permits to more countries, both developing and industrialized.

Given that there are alternative emission reduction policies, it is very important to obtain information on the costs and benefits of all of the various alternatives since any action taken will have various strengths and weaknesses. In this book, then, we look at the different costs and benefits that specific policies have on the Mexican economy, particularly in terms of economic growth, sector-specific growth, production, consumption, and income distribution, as well as greenhouse gas emissions. This information is of high value to policy makers who have the ultimate responsibility of pondering the pros and cons of ratifying binding commitments that may eventually help Mexico and other Latin American countries, to acquire the highest level of environmental quality for a given level of natural resource use and economic growth.

A crucial issue that is not addressed in this book is how emissions, and reductions as a matter of fact, are allocated among countries. This is still an open topic that will definitely have an impact on the results presented here. For further reference on this issue, see Jotzo (2005).

1. STRUCTURE OF THE BOOK

The book analyzes the evolution of energy policy in Mexico, and to a lesser extent Latin America, in the 20th Century, and focuses on the impact of impending energy policies on fossil fuel use, environmental quality, and economic growth over the next 15 to 20 years.

In the first five chapters of the book we examine the growth of the Mexican and other Latin American countries' energy sector from the 1920s and explain how its growth has been linked to increasing levels of international trade, government revenues, economic welfare and environmental pollution. We examine the phenomenon of climate change and show how it is tied to world energy emissions in general. The scientific linkages between greenhouse gas emissions and climate change are presented along with the economic theory behind various emissions abatement strategies. We also examine the harmful effects of climate change on economic well being in the region. Against this backdrop, we explain current thinking among policy-makers in Latin America together with their proposed energy policies. In this part of the book we make reference to the role of these countries in contributing to greenhouse gas emissions as well as their own trends in energy use and their negotiating positions regarding the Kyoto protocol. In particular, we analyze historical trends in energy use in the largest countries in the region and we discuss their market structure, as a way to draw comparisons between them.

In the final five chapters of the book, we look to the future, and here our results center mainly on Mexico. We develop a dynamic Computable General Equilibrium (CGE) model of the economy, paying particular attention to the energy sector and the linkages between the energy sector and other aspects of the aggregate economy. We then use this model to forecast the impacts of various proposed energy policies on international trade, government revenue, economic growth, the distribution of income, and consumer well being up until 2020. Various scenarios are considered depending on the particular policies pursued, the level of technological progress made, the level of investment in alternative fuels such as natural gas, the structure of the labor market, and the level of international cooperation attained in emissions trading programs. As such, we look at a wide variety of alternative policies (such as investment in natural gas drilling, investment in new technology, carbon taxes and tradable permits among different CO_2 emitters) and examine a number of possible effects on individual economic sectors and agents as well as the aggregate economy. These effects are then analyzed in detail and specific conclusions are reached as to the consequences (both intended and unintended) and effectiveness of current energy proposals. We place our overall conclusions for Mexico in the wider context of the Americas, and we contrast the effects of climate change policy with that in Venezuela, Argentina, Brazil, and Chile. Finally, by employing a similar model for the U.S., we look at the possible advantages of greenhouse gas reducing permit trading programs between these two countries.

2. CHAPTER CONTENT

Chapter 2

This chapter set ups the background for our analysis of Mexico and Latin America in relation to the problem of global warming and the policies designed to solve it. As stated at the onset, for many years when discussing climate change and global warming most of the attention centered on the actions of the world's industrialized countries. However, since the 1997 world climate change conference in Kyoto, there has been increasing pressure on the world's largest and fastest growing economies also to cut back on their carbon emissions.

Latin America accounts for roughly 6% of total world emissions, with Mexico, Brazil, Argentina, Venezuela, and Colombia being the highest emitters in the region. Mexico produced 26% of total Latin American emissions in 2002, while Brazil emitted 25% of CO_2 from consumption and flaring of fossil fuels, Argentina 9%, Venezuela 8% and Colombia 4%.

Mexico is now the 13th largest worldwide emitter of greenhouse gases and the largest source of emissions in Latin America followed very closely by Brazil (UNEP, 2001). From a strategic standpoint therefore, Mexico's and other Latin American countries' decision to abide by carbon emissions restrictions in the near future is a matter of great significance. With these factors in mind chapter 2 looks at the general issues related to climate change and its regional effects.

Chapter 3

This chapter provides an account of the damage so far done by global warming, particularly in Mexico and Latin America, as well as the outlook for future climate change together with a survey of the mitigation policies and initiatives presently being discussed in different countries. Although the exact relationship between long-term climate change and specific weather events is hard to specify, recent events suggest that the physical and economic impact of climate change in the Latin American region could indeed be severe. In 1982-1983 droughts and forest fires registered in Mexico and Central America caused damages estimated at more than US $600 million. In fact, the extended drought over the past decade in Mexico seems to be the result of general climate change. Additionally, "El Niño" events have been taking place more frequently and more intensely since the beginning of the nineteen eighties. The area affected from fires from 1992 to 1996 was three times larger than the previous five year period and economic losses from those fires were estimated to be about US$230 million (IPCC, 2001). This trend continued into 1998 when a record number of 14,445 fires occurred, more than double the average of the five previous years (SEMARNAT[1], 2001).

In some places, because of variability in the weather, agricultural production has also suffered. Hydro-irregularities have occurred in coastal areas bringing severe droughts and increased desertification. Losses have also occurred because of excessive precipitation over the past 20 years. In addition, there has been a marked increase in both the number and severity of hurricanes in Mexico. It has been suggested that warmer surface conditions and colder lower stratospheric temperatures result in stronger hurricanes, and data for the Eastern Pacific region indicate that the intensity of hurricanes in the region has been increasing significantly since 1973.

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[1] For clarification purposes and consistency among citations throughout the book, in 2000 SEMARNAP was restructured and became SEMARNAT, when the Department of Fisheries (PESCA) was placed in another ministry. Other than that, SEMARNAP and SEMARNAT are the same institution.

These changes represent a major environmental threat for Mexico and the Central American isthmus due to the expected economic and human loss in the future (IPCC, 2001) and these Latin American countries need to be prepared to mitigate these possible climate change impacts. Consequently, the region is working on climate change mitigation policies in the energy, natural resources, agriculture, transport and urban sectors. In addition, various countries in the region, including Mexico, are supporting scientific research on climate change modeling to investigate future adverse environmental impacts. We address all these issues in chapter 3.

Chapter 4

In this chapter we discuss the environmental impact of economic growth in Mexico. Presently, Mexico suffers from a host of external costs, spillover effects or, as economists term them, *externalities* related to both economic growth and the use of open access resources. Here, our focus is on economic growth-related externalities, and more specifically on energy use that generates air pollution and contributes to climate change. As a way of understanding the nature of these problems chapter 4 presents Mexico's historic economic growth, past energy policy and current energy use. Some aspects of energy use and its production in Brazil, Argentina, and Venezuela are also discussed by way of contrast and comparison.

In the case of Mexico, we initially outline existing population and employment trends along with a short history of economic growth and structural change. We describe past economic initiatives in Mexico and point out their impact on energy use over the last century. Following this, we present a detailed description of Mexico's current energy situation along with current greenhouse emissions according to the economic sector of their origin. Finally, we provide a brief summary of current fiscal policy goals and energy pricing policies. In so doing we set the scene for the policy simulations conducted in chapters 7, 8, and 9.

Chapter 5

This chapter explores the link between externalities, economic behavior, and policy as a way to understand the kind of environmental degradation observed in Mexico. As we note at the outset of this chapter, the causes of global warming can only be understood by means of the natural sciences. The temperature of the Earth is closely related to the presence of greenhouse gases, and the reaction of the Earth to global warming is linked to a host of biological, chemical and geological factors. Any solution to global warming problems involving the abatement of greenhouse gas emissions, however, can only be brought about through the actions of human beings, and these actions can only be understood within the context of the social sciences. More specifically, the curtailment of greenhouse gas emissions is again a classic case of an *externality* for which remedies are needed to internalize the external costs. Building on the analysis of the previous chapter we show in chapter 5 that most types of environmental degradation in Mexico have taken place as a consequence of such externalities. Given this fact, we find it instructive here to examine in depth the efficacy of past environmental policies taken in different countries to deal with various types of environmental problems in order to understand the strengths and weaknesses of each type of abatement action available to policy makers.

Chapter 6

The objective in this chapter is to introduce the model of the Mexican economy that we use to analyze the impact of environmental policies. For the last century, most of the empirical work done in economics has relied upon partial equilibrium analysis. This type of analysis concentrates on a single market and quantifies the changes in supply, demand, prices, quantities, and welfare brought about by exogenous shocks and/or parametric changes. Studies of this kind have been well suited to markets with limited size or with weak linkages to other economic sectors.

However, many economic problems, especially those involving externalities, do not fit easily into this mold. Often, the economic sector to be studied is large and changes in that sector can have important repercussions economy-wide over an extended period of time. Such problems are more appropriately dealt with using general equilibrium analysis. Hence, in chapter 6 we outline a dynamic model we have constructed for Mexico in which all the sectors in the economy are seen as one linked system where changes in any single sector affect prices and output economy-wide. Because of the size of the Mexican economy, the large number of economic sectors and agents involved, and the long time period covered, the analysis here is quite comprehensive and numerically complicated. Hence, the model is computable in nature and solved by a software package known as MPSGE/ GAMS. In the text, we do not present the computer code itself. We however do provide a detailed mathematical description of the model to complement the intuitive explanation of the model's structure for the sake of clarity and rigor.

Chapters 7, 8, and 9

The dynamic CGE model described in chapter 6 is used in these chapters to examine the economy-wide effects of various energy policies in Mexico. The model is run first, in what is termed a "Benchmark" using an updated 2000 Mexican social accounting matrix (SAM). In the benchmark case, imports, exports, consumption, government expenditures and production in all sectors rise steadily by the initial rate of growth. In addition, income, household welfare, and the capital stock, grow by this same initial rate.

To see the effects of changes in government tax and subsidy policies as well as in investment in the oil and natural gas sector, fossil fuel depletion, and technology changes, we run the model again altering various subsidies, sector growth rates, employment and technology parameters. These changes are based on proposed tax and subsidy policies, reasonable expectations regarding changes in oil stocks, and plausible increases in efficiency in the refinery, manufacturing and electricity sectors. By running the model with these changes and comparing their results with the benchmark case, as well as with each other, we are then able to look at the economy-wide results of these changes on production, consumption, government revenue, the balance of payments, consumer welfare, and emissions of CO_2.

In chapter 7 the model's simulations are given under the assumptions of full employment, perfect competition and total clearance of markets. In chapter 8 by contrast, these restrictive assumptions are relaxed and involuntary unemployment along with the possibility of market power is introduced. Many of the same simulations are repeated and the effect of relaxing these assumptions is evaluated. Finally, in chapter 9 we augment the model to simulate the imposition of permit trading and the sequestration of carbon in Mexico's forests. Such trading is initially assumed to exist solely between sectors within Mexico. Later however the model is run in parallel to a similar model of the United States and the effect of permit trading between the two countries is evaluated and quantified. All told there are 25 simulations that we look at in chapters 7, 8, and 9

Chapter 10

In chapter 10, our aim is to tie together all the strands of the previous nine chapters and evaluate the alternatives available to policy makers in Mexico and throughout Latin America. The consequences of various policies are contrasted and the benefits and costs of each alternative are spelled out. While it is not the aim of this book to advocate any specific policy or combination of policies, we feel that a thorough understanding of the impacts and intended or unintended spillovers of the various alternatives outlined will benefit those interested in the interaction between economic growth, energy production, and the environment in Mexico as well as in other Latin American countries.

3. TO THE USERS

We believe that this book will be of interest for a wide audience in the United States, Mexico and throughout Latin America as a supplemental text in a number of different classes in Economics and Environmental Studies. First, the book will be attractive to academic economists interested in Mexican economic development, energy use, and environmental quality. The energy sector in Mexico is important for Mexican economic development. Mexico is also seen as a crucial oil supplier and prime example of a resource based economy. Hence, our analysis will be of interest for development economists, natural resource economists, environmental economists, economists and political scientists interested in the negotiation of international treaties, and economic historians interested in Mexico. Finally, executives from the energy sector in the United States, Mexico, and throughout Latin America may also benefit greatly from the lessons contained in this book.

The book can also serve as a supplemental text for courses in environmental and resource economics, development economics, and economic modeling. For a class in environmental and resource economics instructors should concentrate on chapters 2, 3, 4, 5, 7, 8 and 9. For a class in development economics instructors are suggested to concentrate on chapters 3, 4, and 10, and for a class in economic modeling instructors would want to concentrate on chapters 6, 7, 8, and 9.

CHAPTER 2

GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

The process of climate change is due to an increase in the concentration of greenhouse gases in the atmosphere. This chapter explains the phenomenon in detail and presents empirical evidence showing the variation of the Earth's temperature over time. Both in their role as consumers and producers humans contribute to the build up of greenhouse gas emissions mainly through economic activities. The emissions of greenhouse gases, however, vary widely across countries. Industrialized countries have emitted by far the most emissions historically and have the greatest emissions per capita. Developing countries, on the other hand, have emitted much less in both absolute and relative terms, but their emission levels are growing at a very high rate and will continue to do so in the future. At the same time the effects from climate change are expected to vary substantially from region to region. Finally, some mitigation policies including the elimination of existing distortions, regulation, market-based instruments, and climatic engineering are briefly discussed.

1. THE CHEMISTRY OF CLIMATE CHANGE IN BRIEF

The process of climate change can best be understood by an analogy. Assume for a minute that a person is sitting under a blanket and a powerful radiator is heating both the person and the blanket from above. As this occurs, the blanket not only keeps part of the person's natural body heat from leaving but also much of the heat from the radiator, which has penetrated the blanket. Furthermore, this effect intensifies as more blankets are added and the temperature within the blanket becomes far greater than the temperature outside. If we think of the radiator as the Sun and the blanket as the Earth's atmosphere, we can then picture how the Earth gets heat from the Sun, and most importantly, how this heat is held within the atmosphere creating conditions favorable for life on Earth.

The above explanation is a rudimentary one, and a scientific explanation of this phenomenon would be along the following lines. Our planet absorbs energy or radiation from the Sun, and while some of this energy is reflected back into space, the rest is absorbed by the *biosphere*. The reason for this is that the Earth's atmosphere is partially made up of gases that retain energy, such as water vapor, carbon dioxide, methane, nitrous oxides, and other trace gases. These energy-holding gases trap heat in a similar way to the glass panels of a greenhouse, and hence they are known as greenhouse gases (or GHGs). It is important, however, to note that while there are some gases in the atmosphere that retain energy, there are other gases such as sulfur dioxide, ozone, and aerosols that tend to *reduce* the greenhouse effect, and obviously the net outcome of these conflicting forces. It should also be noted that all of this is a natural and desirable process that allows for life on Earth as we know it. Indeed, were it not for these gases our planet would be considerably colder and less habitable.

If this is such a natural process, one may question why there is so much concern regarding it. The problem is that our atmosphere is becoming less prone to allowing heat to escape back into space and thus *the Earth's temperature has been gradually rising* (i.e., we are sitting under more and more blankets). Humans and ecosystems are particularly vulnerable to such temperature changes, which can be illustrated by two dramatic examples.

It has, for example, been argued that a turning point in evolution came about when a change in world temperature led to the disappearance of the dinosaurs. Perhaps the most widely accepted hypothesis explaining their extinction is a large meteor hitting the Earth and causing tons of dust to rise, and plants to die off. With no more food available, dinosaurs then disappeared from the face of the Earth. Temperature on Earth has played an important role in shaping mankind's history itself with the crossing of the

Bering Strait which was made possible thousands of years ago by the cold climate of the period. This crossing fostered a large migration into the American Continent from Asia, and led to the development of cultural patterns far different from what would have emerged otherwise. The bottom line here is that we, as living beings in general, and as an animal species in particular, are quite susceptible to changes in climate.

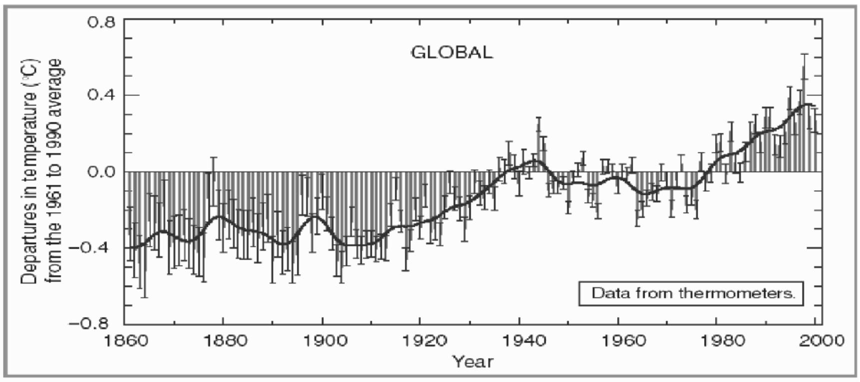
1.1 Evidence of Climate Change

In the period from 1861 to 2000 (IPCC, 2001) the global average surface temperature of the Earth increased between 0.6 ± 0.2°C. Most of this global warming occurred in the periods between 1910 to 1945 and 1976 to 2000. It is also quite noteworthy that the 1990s were the warmest 10 years during this entire 140-year period. Also, 1998 was the warmest year since 1861 (and probably among the warmest of the last 1000 years). Figure 2.1 shows these variations.

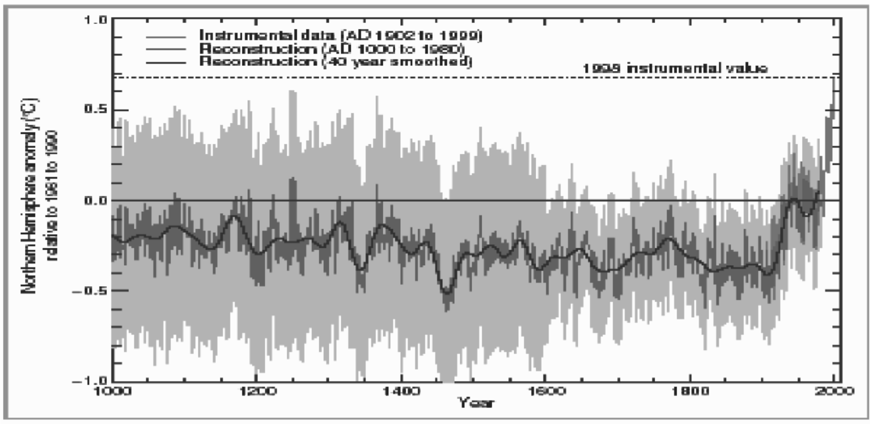
Over the past four decades temperatures in the lowest 8 km of the atmosphere have risen consistently, snow cover and ice levels have decreased, global sea levels have risen, and ocean heat content has increased. Precipitation patterns have also changed over this same period. The last few decades have witnessed an increase in cloud cover, a reduction in the frequency of extreme low temperatures, and an increase in the frequency of extreme high temperatures. Warm spells related to El Niño have been stronger and more persistent since the mid-1970s, even more than in the preceding century. Droughts in Asia and Africa have increased in recent decades (IPCC, 2001) due to these phenomena.

In spite of these changes, however, it is important to point out that a number of climate variables have remained constant over time. Several areas in the Southern Hemisphere have not warmed in recent decades, and in Antarctica, sea-ice (measured by satellite) has not experienced changes since 1978. There is no evidence of changes in tropical and extra-tropical storm frequency, or in the frequency of tornados, thunder days, or hail events throughout the 20th Century. Moreover, many of the recent variations in climate can be explained by inter-decadal to multi-decadal variation. Therefore, normal temporal patterns may then also play an important part in all of these events. However, some have suggested a link between climate change and the intensity of hurricanes (Emmanuel, 2005).

The fact of the matter is that changes in climate result from both internal variability within the climate system and from natural or anthropogenic external factors (IPCC, 2001). Climate is a byproduct of the average temperature of the atmosphere. Temperature itself largely results from three key factors: *solar radiation*, the *Earth's heat reflecting capacity*, and *the atmosphere's capability to hold heat*. The important question then is what role humans play in all of this, and how exactly human activities affect the Earth's temperature.



a) the past 140 years



Source: IPCC, 2001.

b) the past 1,000 years

Figure 2.1 Variations of the Earth's surface temperature

The first factor, solar radiation, is somewhat exogenous to human activity, since people cannot really alter it. The second and third factors, however, are directly related to land coverage (and changes in land use) as well as the composition of the atmosphere. As we discussed earlier with the help of the blanket metaphor, the higher is the concentration of GHGs, the higher the atmosphere's capability to retain heat. It is therefore likely that an increased amount of GHGs is changing the composition of the atmosphere, increasing the atmosphere's capability to hold heat, and hence, preventing increasing amounts of heat from returning to space.

It has long been known that humans directly produce GHGs and thus, it is argued, the atmosphere's capability to hold heat and thereby facilitate climate change. It has also been asserted that humans can change the Earth's climate by altering its reflecting capacity. This is because the normal activities of human beings generally produce some type of residue. Some of these residues go into the land, others into water, and the rest dissipate into the air. This is, by any assessment, a complex subject involving several issues, and thus the remaining parts of the chapter will be devoted to this topic in particular

1.2 The Source and Global Warming Potential of GHGs

As mentioned above, some greenhouse gases are part of the atmosphere. While some result from human activity, people generally produce GHGs through population growth, economic development, and agricultural and industrial activities. Carbon dioxide is the most important and most discussed of all greenhouse gases. It is released when solid waste, wood and wood products, or fossil fuels such as oil, natural gas and coal, are burned. Methane, another significant GHG, is a byproduct of the decomposition of solid organic wastes, coal mining, oil and gas production, wet rice agriculture, and livestock. The GHG nitrous oxide is emitted during agricultural activities such as fertilization, and also during the combustion of solid waste and fossil fuels. Since 1750 the atmospheric concentration of carbon dioxide has increased by 31%, methane concentration by 151%, and nitrous oxide has increased by about 17% (IPCC, 1996). Other greenhouse gases that are produced by humans include by-products of foam production, refrigeration, and certain substances used in air conditioning (chlorofluorocarbons (CFCs), hydrofluorocarbons (HCFs) and perfluorocarbons (PFCs)).

Each greenhouse gas has a different ability to retain heat in the atmosphere. HCFs and PFCs are by far the most heat-absorbent followed by methane and nitrous oxides. To accurately compare the strength of different gases, a metric that relates the force of these gases in terms of their warming potential is necessary. Hence, the concept of *global warming potential* (GWP) has been developed to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to other gases.

In computing this measure, carbon dioxide is used as the reference gas (IPCC, 1996). The GWP coefficient of a greenhouse gas is thus defined as the ratio of global warming (both direct and indirect) resulting from one unit mass of a GHG to that resulting from one unit mass of CO_2 over a period of time

(100 is conventionally used). Table 2.1 presents the GWPs for the main a GHGs (for a complete listing of GWPs, see IPCC, 1996).

Table 2.1 Global warming potential of selected GHG
(100 year time horizon)

Gas	Global Warming Potential
Carbon Dioxide	1
Methane	21
Nitrous Oxide	310
HFCs	From 140 to 11,700
CFCs	From 6,500 to 9,200
SF6	23,900

Source: IPCC, 1996.

The overall radiative effect of any given gas depends on both its GWP coefficient *and* its concentration in the atmosphere. To determine the total GWP of the Earth's atmosphere, therefore, we require not only a GWP coefficient but also an emission inventory for each and every greenhouse gas. An emission inventory indicates the concentration of all greenhouse gases as well as local and regional air pollutants in the atmosphere. Emission inventories are often calculated on a country-by-country basis, and all of those nations who have signed the Kyoto Protocol (see chapter 5) are now obliged to develop one. By analyzing these inventories, experts may draw inferences on changes in the concentration of GHG's and thereby attempt to predict future changes in world temperature. It should be noted, however, that temperature changes are very difficult to obtain directly from the atmosphere's GWP.[1]

Most of the existing academic literature surrounding GHG's focuses on carbon dioxide. This is because although not all GHG emissions are CO_2 emissions, all can be put into a *CO_2 equivalent* for computational purposes. This allows for comparisons between different countries that might have one type of emission but not the other. Largely, however, carbon emissions are the most important ones because of their large share of the total, and hence they are the ones that have traditionally received the most attention.

Finally, it needs to be stressed that climate change is itself a *global issue*, and that this environmental problem respects no state or international boundary. That is to say a GHG emitted by only one individual, company or

[1] Interestingly, as a side note, if air pollution is the main focus, inventories are sometimes used as inputs to air quality models, and to develop strategies and policies to diminish the negative effects of air pollution, as well as to establish allowable emission standards.

country may produce a temperature effect felt by many others throughout the world. Essentially, emissions will affect temperature and thus climate, but the effects on climate are by no means tied to where they occur.

1.3 Modeling the Effects of Climate Change

The concentration of atmospheric greenhouse gases and their overall global warming potential have continued to increase as a result of human activity. Indeed, the present level of carbon dioxide concentration had not been exceeded during the past 420 thousand years and probably not during the last 20 million years. Methane concentrations are currently at their 420 thousand year high. Similarly, the present concentration of nitrous oxide is quite probably as high as it has ever been. CFCs are decreasing due to the Montreal Protocol, but substitutes such as HFCs, PFCs and SF_6 (with a whopping GWP coefficient of 23,000) are all increasing. At the same time, we should note that better models have been developed to use these GHG inventories for simulating future climate changes, and so the conclusions of our simulations are becoming more and more reliable.

Modeling the climate of the future is a daunting task. Modern computers take considerable time to simulate a complete model containing all variables necessary to predict the climatic condition over the next hundred-year period. Thousands of complicated equations must be solved simultaneously to find the influence of a warmer world climate on the distribution of rainfall, sea levels, and the distribution of the food-producing regions. Nonetheless, the IPCC has obtained some interesting preliminary results, and they have been able to reproduce, with reasonable accuracy, annual global mean surface temperature variations from the 1870s to the year 2000.

Building on this recent success, researchers have now produced a number of models aimed at simulating the present trends in regional climate and temperature. The existing research on this subject employs a wide variety of approaches including time-series analysis, engineering studies, and historical analogs. The *mean temperature* is often chosen as the preferred variable to project because it is a useful index of climate change, which is highly correlated, with most of the other important climatic variables of interest.

According to the IPCC (2001), given present trends the mean global temperature could increase from 1 to 3.5º C by 2100 and the mean sea level could rise by 15 to 95 cm. Changes in spatial and temporal precipitation patterns are expected to also take place and make different regions considerably cooler, drier, wetter or cloudier than they are today. It is the case, interestingly, that while some regions could experience adverse and irreversible effects, others may indeed benefit.

Human health, ecological systems, hydrology and water resources, food and fiber production, coastal systems, and human settlements will all be affected by climate change. The IPCC is uncertain as to the exact patterns of climate change, but the overall results are quite reliable. The key question here then, is whether these changes will be beneficial or will damage human activity. Furthermore, it is important to know how these changes translate into costs and benefits both regionally and over time. It is likely that many more regional studies will be required to determine more precise impacts, and make more robust conclusions. Some initial projections of such regional models, however, can be quite informative.

It is likely that those regions that experience low rates of economic growth, rapid increases in population, and ecological degradation may become increasingly *vulnerable* to potential change. Vulnerability here is defined as the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of the system's sensitivity to changes in climate and its ability to adapt (IPCC, 1998). Furthermore, economies that count heavily on agriculture, forestry, outdoor recreation, and coastal activities are dependent upon stable temperatures and naturally occurring rainfall. The more the GNP of a nation or region relies on these sectors, the more vulnerable it is to climate change. It is easy to see then why, by and large, developing countries are the most vulnerable to climate change.

In contrast to developing countries, industrialized nations rely much less on economic sectors that have a direct interaction with climate (Nordhaus, 1993). In the United States, for example, medical services, computing, underground mining, communications, manufacturing, and other services comprise around 85 percent of GDP. These activities are not affected by climate and can generally be undertaken in carefully controlled environments. This, in turn, makes developed nations, generally, less vulnerable to climate changes.

2. ECONOMIC ACTIVITY AND CLIMATE CHANGE

Greenhouse gas emissions come from a host of different consumption and production activities. In fact, many of our seemingly innocent daily activities generate large amounts of GHG. Electricity, for example, which powers our refrigerators, is most likely to have been produced from some sort or combination of *fossil fuels*. The burning of fuels, coal, fuel oil, diesel, or natural gas generates carbon dioxide emissions and, depending on the exact source, perhaps methane and sulfur dioxide as well. Furthermore, the refrigerator itself may use CFCs for cooling purposes and these could easily leak out into the Earth's atmosphere.

While this is something to ponder the next time one opens the refrigerator, there are many other ways in which people's every day actions can and will produce GHG emissions. The movement of a country's population into previously forested areas will change the pattern of land use. Deforestation is not only a source of GHGs, but also a process that leads to many other important alterations in ecosystems. Energy use, water use and space requirements then are all connected to both daily human activity and climate change.

Indeed, *almost all economic activities* can be related to the problem of GHG production since every economic sector produces some sort of emissions. Agriculture produces methane which exacerbates global warming, even though, at the same time, it may be a receptacle for carbon dioxide. Forestry releases carbon when trees are cut down, and the heat produced for manufacturing use primarily comes from the burning of fossil fuels with high carbon content.

While it is true that *every* economic sector is responsible for at least some emissions, the extent to which they are responsible differs substantially from sector to sector. Approximately one third of worldwide carbon emissions usually come from the industrial sector, a third come from the transportation sector, 19% come from the residential sector, and 16% come from commercial establishments (EIA, 1999).

The most obvious way to cut back on GHG emissions is, of course, to reduce production, but that would only slow down economic growth and reduce economic prosperity. Individuals would have to content themselves with both less consumption and the availability of less sophisticated goods and services, which in today's consumption-driven world is unlikely to be realistic. The most obvious way to cut back on GHG emissions, then, is likely to also be the most unpopular.

Since economic activity is closely related to the use of energy and therefore to GHG emissions, an alternative to simple economic cutbacks would be to make the production process itself more energy efficient. The innovative use of technological change which initially sparked high economic growth could be employed to find more energy efficient ways of producing existing goods and services. These processes, unfortunately, are also quite expensive, and hence they are often not cost effective. To use them would require massive investments, higher taxes, and unacceptably higher prices. In dealing with climate change, it would seem, we find ourselves between the rock of cutting back growth and the hard place of higher production costs.

3. THE POLITICS OF CLIMATE CHANGE

It is not only the relationship between emissions and economic growth that create problems, but the *distribution* of both emissions and growth *between countries* that can frequently create international friction. Two questions become apparent when discussing this rather thorny issue. First, what is the relative contribution of each country, or group of countries, in terms of GHG emissions? Second, what is the expected impact of climate change on different regions? The first question is often answered by looking at the data coming from emission inventories that countries produce, while the second often relies vaguely on the output from large-scale simulation models.

3.1 The Largest Emitters

While at first glance it would seem a simple thing to identify the largest emitters of GHGs, in reality the problem is a bit more complex. Indeed, there are four alternative ways of determining just who emits the most. First, we could identify the accumulated emissions of each country over the past few decades. Second, we could discuss which country emits the most at present. Third, we could see who emits the most GHGs on a per GDP basis, and finally, we could look at which countries emit the greatest amount of GHGs on a per capita basis.

Perhaps unsurprisingly if only *past total emissions* are taken into consideration, it has been shown, that the industrialized nations of the world have tended to emit proportionately more than developing countries. The reason for this is quite straightforward. Since (1) GHGs come principally from the burning of fossil fuels, municipal solid waste, and land use change, and since (2) industrialized countries have been engaged in these activities to a far greater degree than their less well-developed counterparts, it comes as no surprise that developed countries have emitted far more GHGs to this point. Likewise, when considering the *current emissions* of GHGs, it is again the case that industrialized nations produce comparatively more harmful emissions. This is because of the close link between economic development and energy use.[2]

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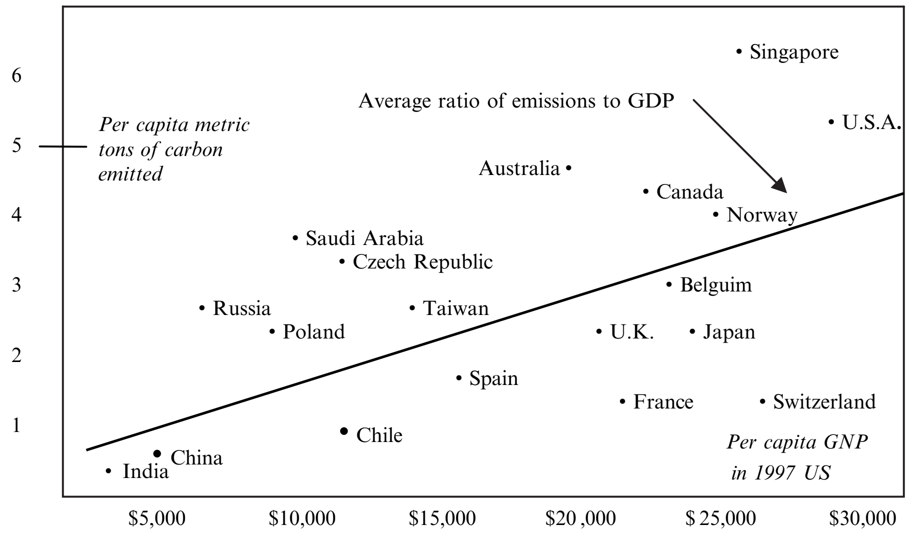
[2] As a philosophical side point consider the fact that production of goods and services for markets around the world is a "global asset". Therefore, should these countries be penalized for carrying out these activities if they enhance the world's prosperity? Another way of looking at emissions would therefore be to measure emissions on a *GDP basis*. This method of measurement still shows industrialized countries as the biggest emitters, but also takes the issue of producing goods for the global market into consideration.

Interestingly, when GDP and emissions are measured and compared on a *per capita basis*, the ranking of countries changes significantly. In figure 2.2, the line shows the average ratio of emissions to GNP. Countries above the line emit more than the average amount of carbon after adjusting emissions and the size of the economy for their population. Using these criteria, the U.S., Singapore, and Australia produce an output of carbon dioxide that is far above the per capita average. France, Chile, Switzerland and Spain, by contrast are significantly below the average in spite of having fairly high per capita growth. The U.K., Japan, Taiwan, Poland and Russia fit somewhere in between.

While most of the discussion here has centered on the overwhelming contribution of industrialized countries towards increasing GHGs, it remains a fact that *developing countries like Mexico are expected to grow significantly in the near future*, and this implies that an increasing fraction of GHGs will soon come from less developed countries. While these nations are not now obliged to comply with international efforts to mitigate climate change, their increasing participation in the generation of these gases as well as the relatively adverse effect of global warming on these regions make developing countries clear stakeholders of the evolution of climate change.



Source: CIA; Carbon Dioxide Information Analysis Center. N.Y. Times, Week in Review, June 17, 2001.

Figure 2.2 Pollution vs. prosperity among selected countries

3.2 Regional Impacts of Climate Change

The impact of climate change, although undoubtedly of global significance, is likely to have different impacts in different regions of the world as well as on individual nations within each region. A large amount of regional analysis has still to be undertaken in order for us to assess impacts directly. As a general rule, however, it would appear that developing countries stand to suffer the most from climate change. This is largely due to two factors: (1) their geographical location and (2) their relatively scarce adaptation capabilities.

The Intergovernmental Panel on Climate Change (IPCC) has identified Africa as being the most vulnerable region in the world due to its low economic growth, high population growth rates, widespread poverty, and extensive reliance and pressure on natural resources (IPCC, 1998). After Africa, the most vulnerable regions are Latin America[3], Australia, tropical and temperate Asia, and the Small Island States. While none of these regions experience the same economic costs as Africa, climate change is likely to hit their primary economic sector – agriculture – which will be adversely affected because of water scarcity and loss of land. This in turn may have a direct impact on food availability, causing socioeconomic and health problems. Other sources of income, such as tourism, might also suffer significantly due to the rise in sea level and the loss of beaches to erosion and inundation.

Europe, North America, and arid Western Asia will also incur costs from climate change. Europe particularly is likely to experience changes in precipitation patterns, droughts and river floods. North America's southern agriculture, east and mid-west ecosystems, estuarine beaches, and low cold water fisheries could all face significant damage[4]. At the same time, water and food scarcity coupled with the spread of vector diseases may seriously threaten the arid regions of western Asia.

The IPCC also predicts that some regions might actually derive partial *benefits* from a climate change. New Zealand's agricultural productivity, for example, will probably *increase* due to more favorable environmental conditions. Likewise, the northern latitudes of North America may save on heating costs as well as salting and snow clearance costs. Canada in particular could also gain due to large increases in available productive agricultural land.

Having said this, the process of climate change and the nature of its impact is by no means completely understood. Although unlikely, some

[3] Mexico is included in Latin America here.
[4] North America here includes Canada and the United States only.

extreme cases cannot be dismissed. The melting of Antarctica's ice-shelf, could, for example, increase the sea level by several meters. There could be extreme heat spells, violent storms and hurricanes reducing or weakening the North Atlantic Ocean circulation system. This could, in turn, severely alter the weather of Western Europe.

Furthermore, the gradual process of climate change may be barely perceptible from year to year or even from decade to decade. This fact may limit action towards its mitigation. To reduce the risk of severe outcomes, however, is the responsibility of the international community along with ensuring that adequate information is available and policies are in place to reallocate resources. Long-term planning and adaptation strategies are also necessary, particularly in land use policy, water supply infrastructure, and urban planning.

3.3 Overview of Mitigation Policies

Many scientists and international organizations have studied possible policies to mitigate global warming. As of yet, however, no single policy or group of policies that have been advocated fall into forum groups or categories. The first such group involves the removal of existing price distortions in a nation's agricultural, transportation, and energy sectors. This entails, among other things, the reduction of subsidies on energy use. Evidence from OECD models show that this policy could reduce CO_2 emissions between 1 and 8%. An additional policy along these lines would be to foster reforestation as a means to remove CO_2 from the atmosphere.

The second group of mitigation policies involves the enaction of stringent new governmental regulation policies on an economy wide basis. Some writers and organizations have advocated the regulation of the use of materials, buildings and products to make them more adaptable to the stresses involved in a changing climate. Still others have called for more stringent controls on the use of CFCs, HFDs and PFCs.

A third group of proposals centers on *market-based instruments* such as carbon taxes and tradable emissions permits. These instruments coupled with information and public awareness campaigns would encourage agents to change their consumption patterns and satisfy their needs with goods and services with lower carbon content.

A final category is *climatic engineering*. This primarily involves increasing the *albedo* (reflectivity) of the Earth. Many different ways of doing this have been suggested, such as injecting particles to the atmosphere to increase the backscattering and reflect incoming sunlight or stimulate absorption of carbon. Two other particularly interesting proposals include shooting smart mirrors into space with 16-inch naval rifles or possibly the seeding the oceans with iron to accelerate carbon sequestration (National Academy of Science, 1992, chapter 28).

Among the proposals suggested above, carbon taxes and tradable permits have received the most attention. Theoretically, they are equally efficient, but tradable permits have an additional advantage over taxes. This is because the efficient level of a carbon tax is uncertain, and different simulation models show different results. For example, the OECD (1999) calculated for the Annex I countries a common tax of $90 per ton of carbon ($27 per ton of CO_2) in 1995 dollars (Annex I countries are the highly industrialized nations participating in the climate agreements, listed in the appendix to chapter 5). However, if each country applies a tax of between $100 and $300, global GDP will fall anywhere between 0.1 and 0.8% (with a mean of 0.5%). We should note here that these simulations do not include the costs of relocating the labor force. On the other hand, if tradable allowances are implemented on an international basis, global GNP will only decrease by 0.4%, and this is a relatively precise figure. The implementation of these policies is quite complicated, however, and a full discussion of their relative merits is taken up later in chapter 5.

Unfortunately for policy makers, uncertainty is present in most discussions involving policies to mitigate climate change. Besides, mitigation is costly, so some form of foreign aid will have to flow from industrialized to developing countries. Those resources, however, have a clear opportunity cost: enhancing the quality of life of people now vs. the future. There is no question, however, that if those resources are used now to support current economic growth in vulnerable countries, these countries will become stronger and possibly much more adaptable to climate change (Schelling, 1997).

4. CONCLUSIONS

This section has presented a summary of the scientific and economic issues related to global climate change. The magnitude and regional patterns resulting from climate change are relatively well understood by the scientific community. The fact is however, that most countries will be affected negatively, but regional effects are by no means uniform.

Latin America contributes through its growth and its economic activity to the climate change process, but only accounts for 6% of world emissions and the largest emitters in Latin America are by far Mexico and Brazil. Even though they are not among the primary emitters worldwide, their sheer size and expected development make them important actors in terms of the policies they might adopt. Overall, Latin America will need additional energy sources, and unless technological change is available together with accurate pricing policies, emissions of both global and local effects, will continue to grow, having negative effects on national and global well-being.

The next chapter follows up on the forecast of the expected impacts of climate change. Selected Latin American countries' actions to mitigate climate change are also presented, among them Mexico. This will allow us to set the scene to discuss Mexican energy use and possible mechanisms to modify it in the future.

CHAPTER 3

FORECASTING THE IMPACT OF CLIMATE CHANGE

Although the exact relationship between long-term climate change and specific weather is hard to specify, recent events suggest that the physical and economic impact of climate change could indeed be severe. Thus, controlling emissions that enhance climate change is of utmost importance. In 2002, emissions from Latin America represented less than 6% of world greenhouse gas emissions. However, the growth rate of Latin American greenhouse gas emissions is doubled the growth rate worldwide. Emissions are highly linked to economic activity, and most come from the burning of fossil fuels. Countries in the region, however, face different risks. The Caribbean holds the highest stakes due to a possible rise in sea level, and the region's agriculture, water resources, coastal zones, and forestry are at great risk. By 2050, Mexico will witness the effects of climate change at both the national and regional level. Agriculture will also be hurt, since there will be a significant reduction in arable land suitable for growing corn, the basic staple; about 50% of forest ecosystems will be forced to grow dryer climate vegetation; and desertification and drought will be high to very severe in approximately 80% of Mexico's growing regions.

1. EMISSIONS FROM LATIN AMERICA

Latin America's share in total world carbon emissions has grown substantially over the last 25 years. In 1980, Latin America had 4.7% of overall global emissions, and by 2002, this share had grown to 5.6%. Thus, its share in total emissions has grown at an average annual rate of 0.8%. Ceteris paribus, this means that Latin America is set to double its share in total emissions by the year 2066. In table 3.1 we present carbon emissions from fossil fuel consumption and flaring during the 1980-2002 period for the largest the region's emitters. For comparison purposes, world emissions are also reported.

Table 3.1 Carbon emissions from fossil fuel consumption and flaring, selected Latin American countries (million metric tons of carbon dioxide)

Country	1980	1985	1990	1995	2000	2002	Percentage Change (1980-2002)
Mexico	237	274	308	319	376	363	52.9
Brazil	191	190	253	302	338	346	81.6
Argentina	95	96	104	122	135	120	26.7
Venezuela	96	95	110	123	133	143	54.2
Colombia	40	44	41	53	59	59	48.9
Chile	24	20	32	40	55	54	125.0
Cuba	32	35	36	30	33	34	4.5
Pto Rico	28	22	20	24	27	35	21.2
Peru	23	23	20	25	29	28	22.6
Latin American Total	876	897	1041	1188	1358	1368	56.2
World Total	18636	19628	21638	22107	23891	24533	31.6

Source: EIA, 2002.

As can be seen, the country with the highest *emissions* is Mexico followed closely by Brazil. The highest growth *rates of emissions*, however, are found in Chile, followed by Brazil, Venezuela, Mexico, and Colombia. The lowest growth rate belongs to Cuba, due to its relatively low level of economic growth. Interestingly, the growth in emissions from 1985 to 1990 is not consistent among Latin American countries, due to their varied growth patterns, the composition of their production, and the fact that economic crises occurred in different years in different countries. Finally, it is important to notice that the growth rate of emissions in Latin America is almost double that for world emissions during that same period. This, to some extent, re-enforces the position taken by policy makers in developed nations like the U.S. The U.S. believes that, because developing countries are rapidly growing, they represent a substantial portion of total world emissions already. Hence if they do not curb their emissions level, total world emissions will rise in spite of cutbacks from the developed countries.

2. EMISSIONS AND ECONOMIC ACTIVITY

Latin American nations are Non-Annex I countries and hence they cannot be forced by the Kyoto Protocol to take action to mitigate climate change (see chapter 5). Mexico, however, is the largest emitter of GHG within Latin America, and the 13th worldwide (UNEP, 2001), and its sheer size in terms of its economy, population, and emissions make it vital to determine the actions it will undertake towards reducing its GHG emissions. Fortunately, all Latin American countries have signed and ratified the Kyoto Protocol. Among other things, this commits them to participate in the negotiations and produce periodical emission inventories of their greenhouse gases.

Mexico reported its efforts to mitigate climate change as part of the Fourth Conference of the Parties held in Buenos Aires. Current Mexican policy focuses on shifting historic trends of environmental deterioration towards clean, sustainable development. The Mexican economy optimally should grow at a rate higher than that of its population, and such growth depends crucially on energy availability. This implies, barring the unlikely event of a major technological breakthrough, that Mexican GHG emissions will rise in the immediate future.

Over the last forty years, Mexico has experienced significant industrialization, and today ranks as one of the most industrialized economies in the developing world. Additionally, since the mid-1980s it has become an open economy, signing trade treaties with North and Central America, the European Community, and Asia. Moreover, Mexico has a reasonably well-diversified economy. Indeed, only 5.9% of its national GDP comes from agribusiness, while 28.8% of total output is produced by the industrial sector, and 65.3% comes from the service sector. During the last 20 years, Mexico has had an average annual growth rate of 5%, which is expected to continue (with some slackening) into the future. More importantly, from the standpoint of this study, such growth entails changes in the use of energy and shifts in land use, both of which are important sources of greenhouse gases.

One must be cautious, however, in forecasting the environmental consequences of these trends since both per capita and total emissions in Mexico are still far from excessive when compared with most developed countries. Today, total emissions from Mexico are only 6.3% of those produced by the United States and 1.4% of total emissions worldwide. In terms of per capita GDP ratings, Mexico does not even make the top-70 list. Indeed, its CO_2 emissions now stand at just 0.96 tons per capita, far below the world average of 3.46 tons per capita.

Table 3.2 Source and distribution of GHG emissions for Mexico 1998 (Gg)

GHG	**CO_2**	**CH_4**	**N_2O**	**NOx**	**CO**	**SO_2**	**HFCs**
Total emissions	394,725	8,060	47	1,151	5,928	1,167	1
1. Energy (combustion + fugitives)	350,380	2,634	11	1,133	5,604	1,157	
A. Fuel combustion	350,380	81	11	1,133	5,604	1,157	
1. Transportation	104,592	24	8	615	3,864	51	
2. Industry	62,407	2	0	76	482	364	
3. Power Industries	47,300	1	0	66	12	60	
4. Power Generation	101,343	1	0	313	19	638	
5. Residential	22,579	51	0	46	1,223	8	
6. Commercial	6418	0	0	9	1	17	
7. Agriculture	5738	0	0	5	1	17	
B. Oil, natural gas and coal production	2,552						
2. Industrial processes	44,345	4	0	5	90	10	1
A. Mineral products	18,225				0	9	
B. Chemical industry	2,721	4	0	5	15	0	
C. Metal production	23,399			0	75	0	
D. Others				0	1	2	
3. Agriculture	2,059	36	13	232			
A. Fermentation	1,972						
B. Handling of manure	60	0					
C. Rice crop	14						
D. Agricultural soil	35						
4. Solid waste	3,362						

Source: INE, 2001.

Mexico's emissions inventory was developed using the methodology proposed by the IPCC. Greenhouse gas emissions in Mexico come from combustion of fossil fuels, changes in land use, industrial and agricultural production, and waste decomposition.

In 1998, Mexico's methane emissions were 8 thousand Gg. Of this a total of 42% came from solid waste, while oil, natural gas and coal production accounted for 32%, agriculture and livestock contributed 26%, and fuel combustion by households made up just 1% (INE, 2001). If we consider that CH_4 (methane) heats the atmosphere 21 times more per unit than CO_2, then we can view methane emissions as equivalent to 14% of carbon dioxide emissions – a very significant share. Table 3.2 shows the source and share of all GHG emissions for Mexico.

3. POSSIBLE EFFECTS ON MEXICO

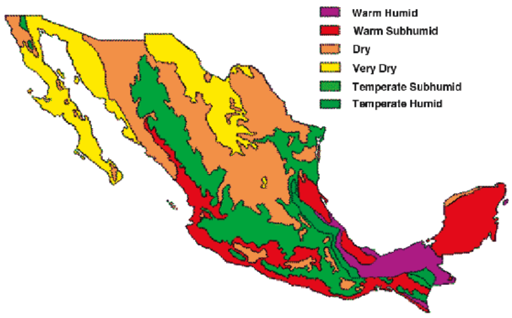
Overall, Latin America, and particularly the Caribbean, is extremely vulnerable to climate change. Many Latin American island states are at great risk, and throughout the region, there is a significant threat of deforestation, desertification and drought. Agriculture throughout Latin America is also widely believed to be vulnerable to alterations in world climate. Taken as a whole, the changes brought about by global warming have potentially grave consequences for Mexico. To assess this with greater precision, vulnerability studies were carried out by various Mexican government agencies to determine the possible effects of climate change on agriculture, human settlements, coastal regions, forest ecosystems, and water resources, energy, and industry. Most countries are highly vulnerable in many of these categories (IPCC, 2001).

While Mexico's absolute GHG emissions and their impact on local and global air pollution are important *per se*, it is also essential to look at the way climate change might affect Mexico. Recently, the National Institute of Ecology (INE) in Mexico produced a country study comparing today's climate conditions with future scenarios that may result from a doubling of carbon dioxide emissions from their pre-industrial levels. They employed two models to compute their results, the General Circulation Model (GC Model) and the Canadian Climate Center Model (CCC Model).

Overall, their results show that as the result of CO_2 doubling, rain patterns may be altered and, in particular, that the humidity in soils and in the atmosphere could change significantly and damage water deposits. The analysis by INE also suggests that desertification could occur and severe droughts may take place. This would quite likely modify the ecology of both temperate and tropical forests leading to a rise in forest fires. Such fires, in turn, would increase deforestation, erosion, carbon dioxide liberation, and cause a loss of biodiversity. Finally, INE's analysis predicts an increase in flooding, and a rise in the sea level, causing changes in seashore and deep-sea ecosystems.

3.1 Regional Impacts

Mexico has an area of 1,96 million km^2 with a wide diversity of climate zones. As shown in figure 3.1, within Mexico 23% of the surface is hot and sub-humid, 28% is dry, 21% very dry, and 21% warm and sub-humid. Because most of the population lives in the center, north and northwest where water is scarce, economic activities and human settlements are unevenly distributed with respect to water availability. Consequently, all vulnerability studies examining a doubling of atmospheric CO_2 produced to have suggested different effects on each of the country's regions.



Source: Mexico Channel, 2005.

Figure 3.1 Mexico's climatic regions

The Northern region of Mexico is comprised of the states of Baja California, Baja California Sur, Sonora, Sinaloa, Chihuahua, Durango, Coahuila, Zacatecas, Nuevo Leon, Tamaulipas, and San Luis Potosi. Here it is expected that with climate change dry weather will increase while cold weather will almost completely disappear. The CCC Model predicts that in this region the area potentially affected by droughts will increase by 36%. At the same time, however, the sea level could increase up to 2 meters and seriously damage the Lagoon of Rio Bravo, Tamaulipas. Water scarcity may then cause problems for hydroelectric and thermoelectric power plants as well as water-dependant industries such as mining and smelting. While most of the population settlements in the North are somewhat vulnerable to this type of climate change, they are already quite arid and hence far less vulnerable than the other areas to the south. The study finds the least vulnerable states to be Sonora, Chihuahua, Durango, Zacatecas, San Luis Potosi, and Baja California.

The Central region is comprised of the states of Nayarit, Jalisco, Colima, Michoacan, Aguascalientes, Guanajuato, Queretaro, Hidalgo, the State of Mexico, Distrito Federal (Mexico City), Morelos, Tlaxcala, Puebla, and Veracruz. This is believed to be one of the most vulnerable areas due to the high concentration of urban population and the large amount of economic activity. The INE model suggests that warm, humid, and semi-humid weather could disappear if climate change occurs. Likewise, the study suggests that desertification and droughts will most likely increase and water scarcity will become a problem. It predicts that industrial centers will be the most vulnerable, and that part of Veracruz could face a sea level increase of approximately two meters, eroding away much of its coastline.

The Southern region includes the states of Guerrero, Oaxaca, Chiapas, Tabasco, Campeche, Yucatan and Quintana Roo. The main consequence of climatic change here will be the sea level increase along the coast of the Gulf of Mexico and of the Caribbean. Interestingly, if this occurs, those places where oil is extracted (i.e., off the coast of Tabasco) will then be the hardest hit. Under the CCC Model, Tabasco, Campeche, Oaxaca and Chiapas will probably become drier. The GC Model, on the other hand, predicts no change in those states. Both models do agree, however, that water will probably not be scarce in this area and that the level of precipitation will not change drastically.

3.2 Specific Vulnerability

As discussed by IPCC (2001), those sectors whose preservation and welfare are given the highest priority in Mexico are agriculture, water resources, human health, forests, and biodiversity. With this in mind, in this section we summarize the main results of those studies led by the INE and the secretariat of Natural Resources and Environment (SEMARNAT) for Mexico. More specifically, we look at the results of the two General Circulation Models, the CCCM models (mentioned in the previous section) and the Geophysical Fluid Dynamics (GFDC) model. All of these models were used by the INE and SEMARNAT to study the impacts on these “high priority” sectors under a variety of possible scenarios.

Results from these models indicate that there will be a substantial modification of overall rainfall patterns, and hydrological catchments. Aquifer recharging will decline, and droughts as well as desertification will increase. Regional ecosystems will be significantly altered and there may be drastic reductions in both tropical and temperate forests. The industrial and energy sectors face potential damage throughout the country but they will be most vulnerable in the Central and Northern parts of the country as well as the coasts of Tabasco (Gay, 2003).

Agriculture

Studies based on general circulation models and crop models in Argentina, Brazil, Chile, Mexico, and Uruguay project decreased yields in several crops such as corn, wheat, barley, and grapes. It is likely that increases in temperature will reduce crop yields in the region by shortening the crop cycle (IPCC, 2001). However, the lack of consistency in the various models' precipitation scenarios make it difficult to precisely predict crop production under climate change, even when the relationship between precipitation and crop yields are well known. Increased temperature, ultraviolet radiation and rising sea levels may also threaten food production. Furthermore, climate change may reduce forestry yields as a result of reduced water availability during the dry season (IPCC, 2001).

Global warming and CO_2 fertilization effects on agricultural yields vary by region and by crop. Under certain conditions, the positive physiological effects of CO_2 enrichment could counter the temperature increases and changes in precipitation, as well as keeping crop yields fairly high. Overall, however, the effect of climate change on agriculture will be negative due to the reduced availability of water.

SEMARNAP (1997) estimated the vulnerability of Mexico's corn production due to climate change. The outcome of that study shows that the areas of land not suitable for non-irrigated corn production would increase from about 60% to approximately 70% of the country's total land area. Indeed, the areas with average suitability for non-irrigated corn production may drop from 33% to somewhere between 8% and 22% of the total land area. Certain areas of the Northern region of Mexico may become unsuitable for growing non-irrigated corn crops, and the arable land in the central zone could become unsuitable too. The area of arable land suitable for growing non-irrigated corn would disappear in the Southern and Southeastern regions. Furthermore the coastal strip, which is not suitable for the cultivation of corn, would extend itself toward the interior. A forecast of where land may be suitable for corn production is shown in figure 3.2.

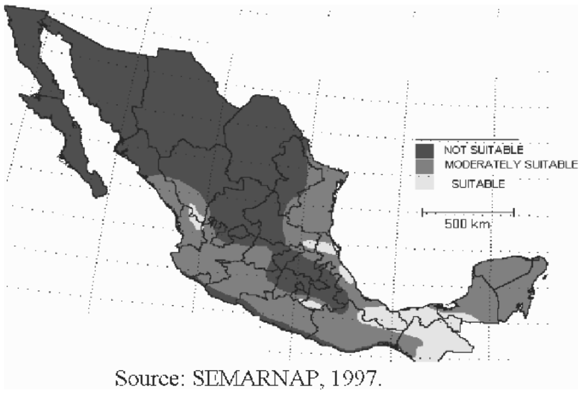


Figure 3.2 Corn production scenario

On average, over all simulations, more than 90% of the total losses in Mexican agriculture due to climate change would be caused by drought. It has been estimated that potential evaporation may increase by 7-16% and that the annual soil moisture deficit could increase by 18-45% in the important corn growing regions in Eastern Mexico. On the other hand, rising levels of CO_2 can have the greatest beneficial impacts when water is limited. Therefore, rising CO_2 may be expected to have a significant positive impact because a large portion of all Mexican crops are water-limited and rising CO_2 enhances water-use efficiency (IPCC, 2001).

Forest Ecosystems

According to climate change projections, approximately 70% of the current temperate forest area in Mexico could be affected by climate change. The vulnerability of Mexico's forests ecosystems is shown in table 3.3. Close to 50% of Mexico's vegetation may suffer, and the most vulnerable will probably be the forests in temperate areas. Arid and semi-arid climates in Northern Mexico will expand, while semi-cold regions will disappear. About 10% of the vegetation of forested ecosystems in the Northern zone will be damaged due to drought and hot weather. Large extensions of pasture land and temperate forests will also be hurt by warmer temperatures, and the extension of dry and very dry tropical forests may increase, as well as shrub growth in the deserts. In all likelihood, the most damaged forest ecosystems in Central Mexico will be those with temperate and humid forests (SEMARNAP, 1997).

Table 3.3 Change in selected ecosystems by climatic region

Type of vegetation	Climate type	Current*	CCCM Model *	GFDL Model *
Thorn woodland and xerophytic shrubland	Hot and dry	11.00	18.10	18.38
Xeriphytic shrubland and thorn forest	Semi-hot and dry	10.50	21.96	15.68
Deciduous tropical forest and tropical sub-perennial forest	Hot and semi-humid	17.70	20.20	22.80
Conifer forest	Semi-cold	2.31	0.00	0.00
Xerophytic shrubland	Arid and semi-hot	11.37	1.58	0.51
Pasture	Arid and temperate	4.72	0.00	0.00

* Percentage of the countrie's surface ($2x10^6$ km^2) covered by vegetation type.
Source: SEMARNAP, 1997.

Migratory species may be especially vulnerable to these changes because they require separate breeding, wintering, and migration habitats. In many cases, one or more of these habitats could be at risk because of climate change and other habitat loss factors. For example, a large portion of the Eastern population of the monarch butterfly winters in a small region of warm temperate dry forest in Mexico. With climate change, this area is projected to contain trees that are more typical of a subtropical dry forest. As a consequence this area will be unsuitable for the monarch butterfly (IPCC, 2001).

The IPCC report found that projected impacts of climate change will most likely result in expansion of some rangeland systems into currents moist forest areas in Mexico. These impacts, however, are likely to be relatively minor compared to the conversion of forests into grasslands, which would be suitable mainly for cattle ranching. The areas most vulnerable to climate change damage will probably be those in the Northern and Western regions of the country. Similarly, those forests most likely to face the most severe damage are those located in the west. These changes suggest that life zones which sustain temperate deserts, warm temperate deserts, and cool temperate wet forests may be severely reduced or disappear altogether. As a consequence, some industries such as cellulose and paper production will be at risk because of their dependency on forestry production (IPCC, 2001).

Desertification and Drought

Taken as a whole, Mexico is highly vulnerable to the effects of desertification. Even though only 0.2% of Mexico's land area, located in arid, semi-arid, dry, and sub-humid zones, is classified as highly susceptible to desertification, the remaining 97% of the land remains quite open to the environmental damages brought about by drought and a relatively more arid climate (SEMARNAP, 1997). Indeed, over 68% of the land in the states of Baja California, Coahuila, Jalisco, Nayarit, Queretaro, Guanajuato, Michoacan, Sonora and Hidalgo and is highly vulnerable to desertification (Gay, 2003). Low vulnerability, on the other hand, is projected for 2.5% of the country's land with most of this land situated in the states of Tamaulipas, Veracruz, and Campeche, as shown in figure 3.3.

In the Southern part of Mexico, the highly vulnerable regions are those where agriculture and livestock production are practiced with inadequate attention to soil conditions. On the other hand, in the Central region, humid temperate and sub-humid temperate climates will disappear, being replaced by dry and hot climates. Drought and desertification may intensify in these areas, thereby further exacerbating the already critical shortage of water (IPCC, 2001).

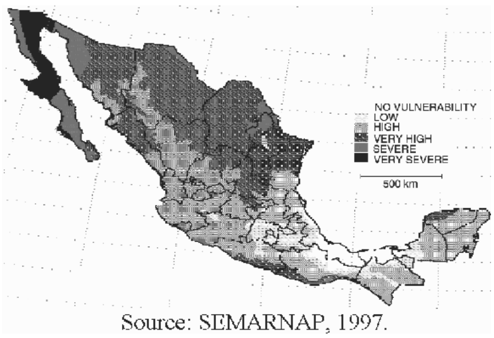


Figure 3.3 Desertification scenario

In all of these studies, over 70% of Mexico's total land area was found to have high to very high rates of vulnerability to the effects of drought and desertification. The most vulnerable areas were found to be in the North, along the entire Pacific coast and in the Central region. In terms of our national maps, this means that the Northern half of Sonora, all of the states of Jalisco, Michoacan, Guerrero, and Oaxaca are vulnerable to meteorological drought. At the same time, 75% of the states of Campeche, Chiapas, and Quintana Roo are also vulnerable to such a drought.

Hydrology

The regions in Mexico most susceptible to the ravages of long-term drought are the Central area, the Lerma-Chapala-Santiago Basin, and Baja California (given its already low level or water run-off). The country's most densely populated regions are also highly vulnerable to the effects of climate change, as shown in figure 3.4 (SEMARNAP, 1997).

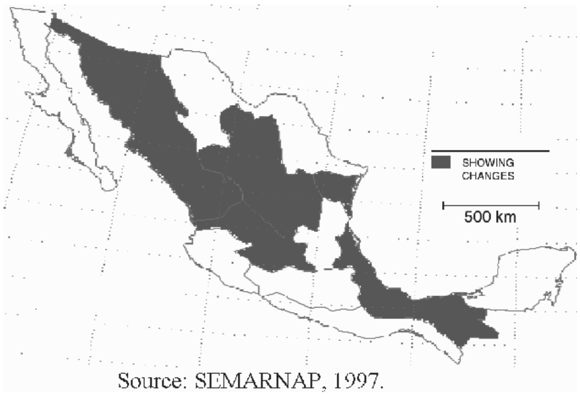


Figure 3.4 Drought scenario

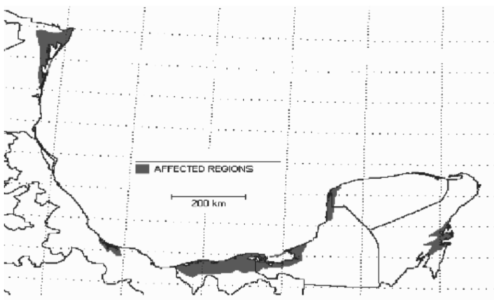
The SEMARNAP scenarios suggest that the general climate in Mexico will be drier and warmer so that several hydrological regions are likely to experience decreased precipitation and higher temperatures. Estimates of water availability in Mexico and Central America indicate that about 70% of the population in those countries will live in regions with low water supply as early as the first quarter of the 21st century. IPCC, using its climate scenarios found that decreasing precipitation in Mexico and El Salvador can decrease Summer runoff by 5–7% but that in the Winter runoff decreases by only 0.2–0.7%. For that reason, potential changes in temperature and precipitation might have a dramatic impact on the pattern and magnitude of runoff, soil moisture, and evaporation, as well as the aridity level of the various hydrological zones in Mexico (IPCC, 2001).

Coastal Zones

A major concern about global warming is that it will lead to a worldwide rise in sea levels. In Mexico the impact of this rise is expected to be highest in the coastal areas of Tamaulipas (the Bravo River and the Panuco

River delta), Veracruz (Laguna de Alvarado, and the Papaloapan River), Tabasco (the Grijalva-Mezcapala-Usumacinta deltaic complex), Yucatan (the Petenes), and Quintana Roo (Sian Kaan Bay and Chetumal). This is due to the fact that most of Mexico's coastal regions are lowlands which rarely rise over one meter above sea level. As mentioned before, in the most vulnerable areas, the rising sea would cover up to 40 to 50 km of coastal lands, (for example in the Mezcapala-Usumacinta River region, as shown in figure 3.5 (Gay, 2003). These impacts will have major effects on the abundance, distribution, and life cycle of fish and shellfish (IPCC, 2001). Impacts on fisheries may be particularly harmful if natural declines in productivity occur without corresponding reductions in exploitation rates.

In the Gulf of Mexico, variations in the freshwater discharge from streams and rivers could decrease the harvest of some commercially important species. This is because the projected changes in sea level have the potential to alter coastal and marine ecosystems through transformation in coastal habitats, upwellings, temperature, and salinity. Such changes, in turn, reduce the abundance and alter the spatial distribution of species that are important to commercial and recreational fisheries (IPCC, 2001).



Source: SEMARNAP, 1997.

Figure 3.5 Sea level rise scenario

Human Health

Extreme climate events appear to affect the incidence of allergies in Mexico. Some economic and health problems could be exacerbated in critical areas, fostering migration from rural and small urban settlements into major cities and giving rise to additional stress at the national level. This could even adversely affect international relations between neighboring countries such as the U.S. Tropical diseases, which only flourished within small eco-zones (such as the dengue fever), could become much more widespread. Hence, the increased risks for human health in Latin America due to climate change are a very real concern and need to be seriously evaluated when looking at the cost and benefits of GHG abatement policies (IPCC, 2001).

The impact of climate change on mortality in Mexico may also be significant. The population in urban areas may be especially vulnerable because some groups of people may not have the economic resources to adapt to extreme heat waves. Additionally, large cities such as Mexico City already have a serious problem with air pollution, and these problems will intensify with desertification, floods and storms. Unfortunately, the poor have fewer resources available to them when adapting to those problems, and will no doubt suffer more. Indeed, during the past decade, as much as 35% of the resources lent to Mexico, earmarked for infrastructure development, were diverted to pay for the costs incurred by natural catastrophes, making large groups of the population more vulnerable and less prone to escape from poverty (IPCC, 2001).

3.3 Policy Responses to Threats from Climate Change

As discussed above, all countries of the region have signed and ratified the Kyoto Protocol, and they have all taken steps towards reducing emissions and increasing energy efficiency. Most countries have made statements regarding the need to accelerate the use of clean energy and improve the level of technology. Their concrete actions may differ from country to country, but in general, they all follow the same pattern as those undertaken in Mexico and described in detail here.

Mexico's Responses

One of the most important steps in Mexico's attempts to mitigate climate change came about in April 1997, when the Inter-Ministry Committee on Climate Change was established. This committee was formed under the direction of the Ministry of the Environment (SEMARNAT, formerly SEMARNAP), with the cooperation from the ministries of Energy, Trade and Industry, Rural Development and Agriculture, Communications and Transports, International Relations, and Social Development. Among the features of this committee is that it now includes a bureau which studies climate change and investigates the viability of joint policies to be adopted on a national scale to deal with the effects of harmful emissions. As a result, many suggestions have been advanced to both curtail emissions and mitigate their effects. First, policy makers are looking at ways to promote energy efficiency. Second, they are trying to modernize the industrial sector with new emission reducing technologies. Third, they are trying to foster more efficient land use by designing strategic urban development policies, and also are attempting to modernize the transportation sector to be cleaner and more fuel-efficient. Finally, efforts are being made to protect the forest from fires, erosion and desertification.

In the energy sector, policymakers in Mexico are focusing on substituting natural gas for fuel oil, and on making efficient use of energy. At the same time, renewable power sources of energy are being promoted by developing hydroelectric and geothermic plants and encouraging the use of solar and wind energy.

Dealing with industrial emissions lie at the heart of any serious effort here, and Mexico's industrial energy policies to reduce climate change concentrate on using energy efficiently and cutting back on industrial pollution. Cleaner materials and fuels are being introduced, and authorities are encouraging the recycling of products and residuals. The institutional framework has been streamlined to guarantee competitive conditions for national producers, and tariffs on imports of pollution abatement technologies are being lowered or eliminated. Environmental regulation of industry is concerned with the adoption of clean technologies, the development of environmental controls to improve air quality, and the use of economic incentives that reduce emissions beyond the current standards. Finally, policymakers have enacted regulations NOM-085 and NOM-086 in order to (1) provide for the efficient substitution of cleaner energy sources such as natural gas and (2) to establish effective maximum emission allowances for sulfur dioxide, nitrogen oxides, total suspended particles, and carbon monoxide.

The second most important sector directly related to GHG emissions is transport (INE, 2001) and here again the government has been playing a positive role. New policies have been established to improve transportation conditions, design and use of roads, and to develop infrastructure that efficiently links ports, roads and trains. Design improvements to increase the efficiency of internal combustion engines are being promoted, and policies are being developed to shorten transportation distances and thereby reduce total emissions.

Due to Mexico's high reliance on fossil fuels, however, many of these policies may run counter to the country's short-run interests. Currently 7% of Mexico's total exports earnings and 33% of government revenues come from oil, and hence domestic and international agreements to cutback on the use of oil could hurt the Mexican economy substantially. On the other hand, Mexico may benefit from the Clean Development Mechanisms which allow Annex I countries to invest in GHG reducing projects in non-annex I countries (see chapter 5 for list). The ultimate impact of all these policies on economic welfare in Mexico then is ambiguous and will depend on both local energy sector reform and international trade and politics.

4. CONCLUSIONS

Climate change is expected to have negative impacts on a wide array of fields. Latin America in particular is likely to face further water scarcity, droughts, and higher temperatures. These events together with a rising sea level and a change in rain patterns will definitely have an impact on food production. Models also show reduced forestry yields because of changes in water availability during the dry season. It may also have a direct impact on other forms of vegetation that may suffer damage. Coastal areas may also be affected due to the rise in sea level.

At the same time, Latin America has to grow to satisfy the increasing needs of its population. Further growth will require additional energy resources, and it will probably generate more GHGs and promote further land use change. Finally, there is increasing pressure from industrialized nations, particularly the U.S., for developing countries to take a stand regarding international agreements on climate change and commit to emissions cutbacks. Could Latin America in general, and could large developing countries such as Mexico, Brazil, Argentina, Venezuela, Colombia, and Chile in particular find it viable to opt for emissions cutbacks, and what would such cutbacks imply in terms of its future growth and economic well-being? These unanswered questions are the focus of this book and will be addressed in our modeling effort presented in chapters 6 through 9.

CHAPTER 4

ENERGY USE IN MEXICO

Energy has traditionally been linked to economic growth, industrialization, and urbanization. Thus, as countries advance, they tend to increase their energy consumption. This chapter explores Mexico's energy use and attempts to explain why it has had very poor energy efficiency, produced rather energy intensive goods, and had fairly high levels of energy related environmental problems. We then examine the similarities between Mexico's experience and that of other Latin American countries, by comparing the energy situation in Mexico to that in Brazil, Argentina, and Venezuela.

1. INTRODUCTION

In chapters 2 and 3 we described the natural causes of global warming and examined the possible consequences of climate change for the world in general and for Mexico in particular. As we have seen, these consequences could be quite costly, and it is these potential environmental damages that have spurred the world community to adopt a series of climate change treaties. To look solely at the damages of global warming, however, is to miss half of the problem. When nations strive to alter their energy policy and cut back on the effect of greenhouse gases they incur costs as well, and these costs could be substantial. Indeed the model that we construct in the second half of the book is designed to calculate these and other costs associated with energy policy.

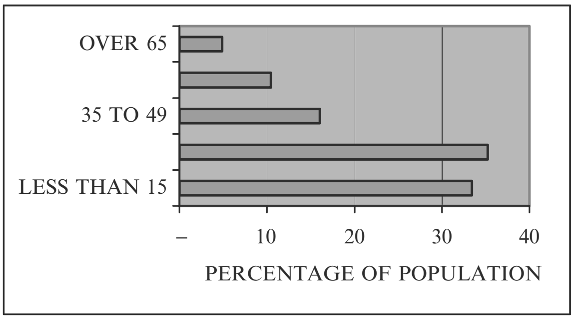
Before we begin our modeling effort though we must take a closer look at the country we are modeling. Mexico is endowed with substantial labor and natural resources. It has a rapidly growing labor force and large energy reserves. The combination of these has been responsible for rapid economic growth over the last several years. In this chapter then we take a look at the changing demographics in Mexico and explain how its growing population has led to urban pressure, economic expansion, environmental degradation, and energy exploitation.

We begin by looking at Mexico's expanding population and the ways in which population growth has led to increased urbanization, more widespread environmental pollution, and a higher level of GDP. We then connect this to its expanding energy needs and explain how Mexico has used energy as a means to satisfy the increased demands of its consumers and investors. Energy, as we shall see, contributes significantly to every sector of the Mexican economy but in fundamentally different ways. Mexican energy policy too will be examined, and we will look at the impact of energy pricing policy on both economic welfare and environmental quality. Finally, we will see how similar Mexico's energy experience has been to other Latin American countries, by comparing the situation in Mexico to that in Brazil, Argentina, and Venezuela.

2. DEMOGRAPHY AND URBANIZATION

There are three demographic trends of importance to our study of Mexico. First, there is the size of the population, second, its growth rate, and third, its age distribution. Indeed, all of these factors explain a different aspect of the way population dynamics may affect economic growth and thereby increase energy use.

Mexico presently has a population of approximately 105 million. By the year 2020, total population is expected to be 122 million (CONAPO, 2000). This represents a 1.1% annual growth rate, as opposed to 2.6% in previous decades. Overall, the Mexican population is very young with 33% of all citizens less than 15 years of age (figure 4.1). This yields an age pyramid with a broad base and a smaller width as higher age cohorts are reached.



Source: INEGI, 2001.

Figure 4.1 Age structure of the population

The age structure of the Mexican population means that there will be increased demand for final goods and services as the population ages and consumes different kinds of goods and services. Many of these goods and services are energy intensive, which means in particular that the age structure and the growth rates of the population will lead to higher demand for natural resources in general, as well as for energy.

At the same time, investment will be required to cover the basic needs of the existing population in terms of infrastructure such as housing, sewage, electricity, and transportation. This, in turn, may accentuate environmental problems if the policies undertaken do not consider their possible negative externalities on basic life support systems like clean air, land, and water.

Energy-related problems will be particularly acute in Mexico's larger cities. Studying energy use in cities is important in and of itself because urban energy production and consumption are commercial activities, and therefore, market-based policy actions are a viable option for environmental management. The study of energy use can then help to facilitate the way in which policymakers use market incentives to protect the quality of the environment. The main three uses of urban energy are typically fuel for cooking and heating, power for energy and lighting, and petroleum products for transportation.

Mexico is a relatively urbanized country. About 61% of its population lives in areas with more than 15 thousand inhabitants (INEGI, 2001). The high demand in the residential, commercial, industrial, and public sectors located in the urban areas means that total per capita energy consumption is significantly higher in the cities than in rural areas (Leitmann, 1997). Concentration of people and economic activities in urban areas also means that energy-related problems such as air pollution are most acute in cities. In fact, not only are the absolute levels of population and economic activity larger in cities, but their growth rates are also larger than that seen in rural areas.

Additional problems arise from an uneven spatial distribution of the population. According to migration theory, large cities attract larger numbers of migrants because their size tends to reflect greater employment opportunities, typically an attractive factor for new comers. This magnetizing effect is illustrated by dissimilar rates of population growth among localities of different sizes in Mexico for the period between 1970 and 2000 (table 4.1).

Presently, 45% of the population lives in localities with historically high growth rates. The highest growth rates have occurred in small and medium size cities (that range from 100 thousand to one million inhabitants). Population growth has not been accompanied, however, by the development of infrastructure and regulations designed to prevent environmental degradation. In the future this will undoubtedly lead to increased demand for a cleaner environment in urban areas.

Table 4.1 Distribution of the population by size of locality

Size of locality (inhabitants)	Percentage of Population in 2000	Population Growth rate 1970-1990	Population Growth rate 1990-1995	Population Growth rate 1995-2000
Total	100.0	2.6	2.03	1.54
1 – 2499	25.3	0.8	0.7	0.4
2500 – 4999	5.6	0.6	1.5	1.8
5000 – 9999	5.1	0.6	1.9	1.4
10000 – 14999	3.0	0.7	2.5	1.2
15000– 49999	9.0	0.8	3.5	1.7
50000 – 99999	4.7	2.5	2.4	1.2
100000 – 499999	21.0	6.0	0.8	1.4
500000 +	26.3	6.0	5.5	2.0

Source: Censo General de Poblacion y Vivienda. INEGI, 2001.

We see that for the 1970-1990 period, population growth was greater the larger the initial population in the city. For the 1990-1995 period population kept growing faster in the cities with more than 500 thousand inhabitants, but had an inverted-u shape for the other size of cities, (i.e., population growth is faster for localities with less than 50 thousand inhabitants but grows at a slower pace for cities with a population between 50 and 500 thousand inhabitants). For the last period, between 1995 and 2000 we see that all localities grew at a fairly uniform rate, which was higher than 1% per annum.

Urban population is concentrated in five major metropolitan areas: Mexico City, Guadalajara, Monterrey, Puebla, and Leon. The largest waves of urban migration took place during the 1950s and 1960s, and after 1970 the growth rates of these cities decreased. Even though these cities vary considerably in size, their growth rate between 1970 and 2000 is fairly similar (table 4.2).

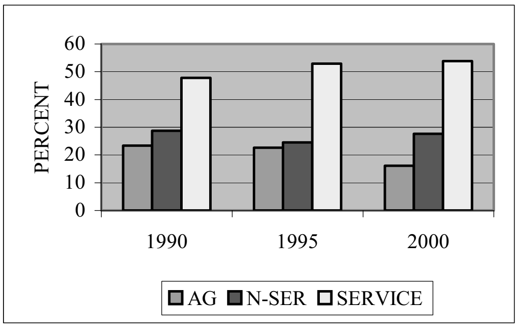
Table 4.2 Population and growth in the main metropolitan areas (1950-2000)

City	Population 1950 (millions)	Population 1970 (millions)	Population 1990 (millions)	Population 2000 (millions)	Growth rate 1950-1970	Growth rate 1970-1990	Growth rate 1990-2000
National	25.8	48.2	81.2	97.4	3.2	2.6	1.85
Mexico DF	3.1	9.0	15.0	17.8	5.4	2.7	2.3
Guadalajara	0.4	1.5	2.9	3.7	6.3	3.2	2.1
Monterrey	0.4	1.2	2.6	3.2	6.3	3.6	2.3
Puebla	0.3	0.6	1.2	1.6	3.9	3.0	2.7
León	0.2	0.5	0.8	1.2	4.8	2.3	2.4

Source: INEGI, 2001.

A final reason for growth of urban areas is the change in the type of activities in which the population is involved (figure 4.2). As of now, the largest share of the population is employed in the service sector with labor moving away from non-service activities (N-SER) such as manufacturing and into the retail and transportation sectors. In contrast to the manufacturing and service sectors, the percentage of the population working in the agricultural sector (AG) (i.e., agriculture, fishing, and forestry) has not experienced great changes and has remained fairly constant between 1990 and 1995 (though it did decrease somewhat in 2000).

Recent trends in population growth, the age structure of the inhabitants, and urbanization all suggest that energy consumption in Mexico will continue to grow in the near future. The change in the structure of the economy (i.e., the fact that people are moving into the service sector) will also continue to compel people to settle in urban areas and thereby increase their energy consumption.



Source: INEGI, 2000.

Figure 4.2 Distribution of occupied population according to economic sector

3. ECONOMIC GROWTH AND STRUCTURAL CHANGE

Much of the increase in Mexican energy use can be attributed to the industrialization and development reflected in urbanization. These processes together with government policies that have fostered economic growth, have to a large extent determined the pattern of energy use in Mexico. This section reviews the general development trends in the Mexican economy, concentrating on government industrialization policy and the growth of the transportation sector.

Mexico has adopted various policies to promote growth over the last 60 years or years (Solis, 1970). In the 1940's, economic growth was largely based on agriculture and the export of agricultural products, with a very open export-oriented policy further encouraging this activity. Initially this policy saw success, and between 1935 and 1956 foreign sales of agricultural products increased at an 8.9% annual average rate. However, growth of this sector stopped when the government's development policy shifted its emphasis to the industrial sector.

During the so-called period of *stabilizing development*, which occurred from the late fifties to the late seventies, growth was led by the industrial sector. Growth of GDP, price and exchange rate stability as well as limited export and agricultural growth were also important policy goals during this period. However, a rather conservative trade policy was adopted, and import quotas, high tariffs, fiscal exemptions to new enterprises, and preferential interest rates to specific industries promoted the substitution of imports and protected the industrial sector.

During this period of *import substitution,* private entrepreneurs took an active part in the economy, while the state had a somewhat secondary role in economic matters, engaging in other matters not necessarily related to production. Private capital was concentrated in the industrial sector, and public investment financed the growth of a productive infrastructure, particularly in the transportation and energy sectors. Monetary policy was primarily used to support investment in the industrial sector. This type of growth caused structural problems for the economy though. These problems included insufficient job creation, a balance of payments problems, and an increasing deficit in public financial accounts.

During the 1970s, economic development in Mexico became heavily dependent on the exploitation of oil. The discovery of large oil reserves allowed the Mexican government to incur debts, to increase public expenses, and to expand domestic credit. This time is now commonly known as the period of *shared development*. The chief goals of the government during this period were enhanced economic growth and a more equitable distribution of income. The policies adopted were expected to reduce protection and eliminate any bias against exporting while at the same time promoting industrial efficiency and international competitiveness. The aim of all this was to obtain a lower level of domestic indebtedness, and to adopt fiscal reforms to redistribute revenues. The government was not able; however, to adjust public financial accounts and this failure led to a higher level of both domestic and foreign debt. The lack of any meaningful tax reform during this same period made true improvement in income distribution impossible. In the early 1980's the public deficit was financed through an expansion of the monetary base and an increase in debt. The lack of domestic financing, successive devaluations, and an annual inflation rate of almost 160% led, in turn, to the economic crisis of 1987.

In table 4.3 we see that the growth rates of different sectors waxed and waned according to the particular development policies in place at that time. Between 1950 and 1981, the rate of agricultural growth declined as oil extraction, manufacturing and construction actively increased. Activity in the service sector grew substantially, and the electricity sector's growth rate increased as well. Indeed, with the exception of the five years from 1976 to 1981 the electricity sector had the highest rate of any sector over this entire 30 year period of time. During the late 1980s, a deep crisis occurred, and even though a stabilization process was quickly initiated, it did not yield positive results until the early 1990s.

In the beginning of the nineties real growth was re-established. The impetus for this growth was the liberalization of trade and investment. At the same time, the macroeconomic objective of price stability was attained, the fiscal deficit was reduced, and the economy was opened to inflows of foreign capital. From a microeconomic point of view, increased competitiveness and economic efficiency in both domestic and foreign markets was accomplished through deregulation, privatization and trade liberalization.

Table 4.3 Real growth of output (1950-1989)
(annual growth rates)

Sector	Imports Substitution	Imports Substitution	Imports Substitution	Oil-lead Growth	Crisis and Stabilization
	1950-60	1960-70	1970-76	1976-81	1981-89
Agriculture	5.0	4.3	3.2	3.9	–0.2
Mining (oil)	4.3	4.9	5.9	14.9	1.3
Manufacturing	6.6	8.6	6.4	9.3	1.3
Construction	7.3	8.3	6.8	9.9	–4.1
Electricity	11.5	11.9	10.2	8.6	3.6
Services	5.5	6.7	6.9	7.5	0.8
Total	5.9	7.2	6.3	7.5	0.8

Source: A. Ten Kate, 1993.

The National Development Plan (1989-1994) was designed specifically to stabilize the economy, increase the availability of resources for productive investment, and modernize economic institutions. The overall goal of this plan was to generate employment and well-being for the population through high rates of sustained economic growth. This required the State to reduce both its size and deficit and also redefine its role in the economic process. The financial system was restructured and liberalized, the economy became more open in response to trade liberalization, and the agricultural sector and education system went through important reforms. Economic production underwent structural changes which resulted in an increase in efficiency through an increase in the global productivity of labor and a rise in real average wages. The stabilization process achieved a reduction in inflation to single digit rates by 1993, and the GDP growth rate between 1989 and 1993 was greater that the growth rate of the population.

After a serious economic crisis in 1995, real GDP experienced overall growth above 5%. The growth rate within the energy-intensive sectors was also impressive. In the first years of the 21st century, however, growth rates have been considerably lower, following world trends.

Since the opening of the economy to trade, exports have led growth to a significant extent. Over the past ten years, both exports and imports of capital goods have increased as well. Domestic demand has also contributed to GDP growth. The output of the service sector has increased and economic growth has helped reduce unemployment. Inflation has followed a downward trend, achieving a rate lower than 5% in 2002, while price and financial market stability have stopped the deterioration of real wages. This has allowed for higher wages and provided a basis for sustained economic growth in both output and employment. Finally, as a result of the better economic situation, imports of capital goods have increased, leading to a reduction in the capital account surplus (table 4.4).

Table 4.4 Macroeconomic framework (1995-2002)

Concept	1995	1996	1997	1998	1999	2000	2001	2002
GDP (real annual growth rates)	–6.2	5.1	6.8	4.9	3.7	6.6	–0.3	0.9
Exports (real annual growth rates)	33.3	18.7	17.5	11.3	14.6	18.7	–3.0	0.4
Imports (real annual growth rates)	–10.1	27.1	32.5	5.5	17.9	14.4	–10.7	8.3
Rate of open unemploym.	5.5	4.1	2.8	2.6	2.0	2.4	2.4	2.1
Inflation (% change)	52.0	27.7	15.7	18.6	12.3	8.9	4.4	5.7

Source: INEGI, 2003; ALADI, 2001.

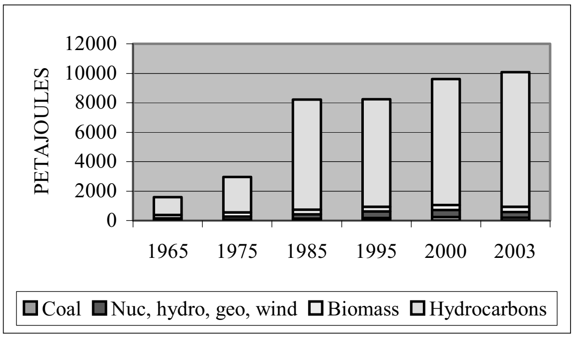
In short, recent economic policies have led to relatively high economic growth. However, changes in the level of development have led to the expansion of more energy-intensive activities in the non-service and service sectors, and this will definitely put pressure on resource and energy use in the future.

4. BRIEF OVERVIEW OF ENERGY USE

Trends in economic growth, as shown above, have had a significant impact on the energy sector. In fact it is impossible to talk about the history of the energy sector without relating it to underlying economic forces. In this section then, we describe how such energy use has evolved over time and how it has evolved within specific economic sectors.

Energy use in Mexico increased almost four-fold between 1965 and 2000 with economic growth as the driving force in this process. Domestic primary energy supply increased from 1500 petajoules in 1965 to approximately 6000 petajoules in 2000, with hydrocarbons being the most important energy source (figure 4.3).

The share of primary energy produced from hydrocarbons (i.e., oil and natural gas) increased substantially over this period while the share produced by coal increased only slightly. Hydropower remains an important source of primary energy used to produce electricity, and accounts for almost the entire amount listed in figure 4.3 under the heading of nuclear, hydro, geothermic, and wind energy (since high costs have made use of other methods economically prohibitive).

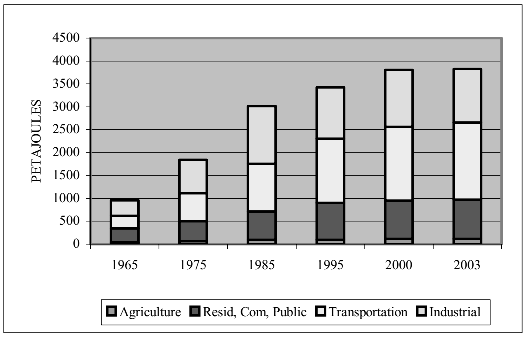


Source: Secretaria de Energia, 2005.

Figure 4.3 Primary energy supply by fuel type

During the process of economic development, the type and mixture of fuel use changes dramatically. As income and urbanization expand, the share of traditional fuels like wood and biomass diminish, while the consumption of fossil fuel consumption increases. Because of this, the share of biomass in the total production of energy has decreased in Mexico over time.

Over the past 40 years energy use itself increased significantly in *every* sector of the economy. Final energy consumption in the residential sector tripled, and the use of energy in the transportation sector increased five-fold. Industrial energy consumption quadrupled, and agricultural use increased almost three times (figure 4.4). The share of energy used by each sector also changed, and the relative share of the residential, commercial, and public sectors decreased a bit. Transportation, on the other hand, increased its share of final energy consumption substantially while agriculture and industry kept their same relative shares throughout the period.

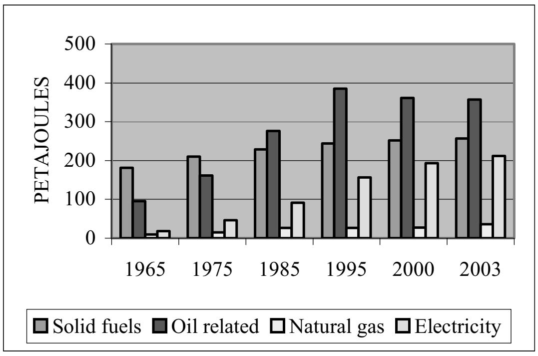


Source: Secretaria de Energia, 2005.

Figure 4.4 Total final energy consumption by sector

4.1 Residential, Commercial, and Public

Within each sector, total energy consumption is essentially derived from four sources: solid fuels, oil-related fuels, natural gas, and electricity. In the residential sector, the use of solid fuels decreased their relative use share by half (figure 4.5), as people began substituting fuel for wood when cooking on their stores. As a consequence of this, oil, natural gas, and electricity use increased.

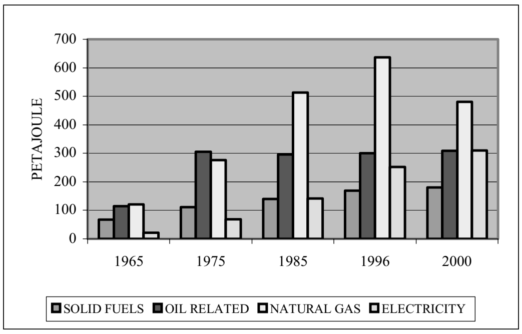


Source: Secretaria de Energia, 2005.

Figure 4.5 Fuel use in the residential sector

4.2 Industry

The trend of fuel use here is similar to that described above in the residential sector (figure 4.6). While the share of solid fuel in total energy use decreased slightly, the use of natural gas increased significantly. Most importantly, the share of electricity more than tripled.



Source: Secretaria de Energía, 2001.

Figure 4.6 Fuel used in the industrial sector

Within the industrial sector, mining, construction and electricity have been the fastest growing industries. Construction has grown at a fast rate during sustained economic growth but has fallen in recent years as the rate of economic growth declined. Several factors are expected to lead to growth in the Mexican industrial sector. First of all, industrial output needs to expand in order to accommodate a growing population with increased income and consumption levels; and second, overall output needs to increase in response to higher demand for Mexican products from abroad as free trade expands.

4.3 Transportation

In Mexico, as in most countries, transportation is the sector that is both the fastest growing and the one which consumes the highest share of fossil fuels. The transportation sector is highly reliant on gasoline, diesel, and jet fuel, and the potential for diversifying to other sources of energy is extremely limited. Today the transportation sector consumes approximately 40% of all energy used as fuel in Mexico. Of this total 60% comes from gasoline and 30% from diesel.

The length of roads built between 1989 and 1994 totaled some four thousand kilometers. This, in turn, led to a 25% increase in the flow of products transported by road vehicles. At the same time, the number of vehicles circulating throughout the country grew by 36% while the importance of rail transport declined due to its inefficiency. On the other hand, the lack of an efficient public transportation system has increased both private car ownership and fuel consumption.

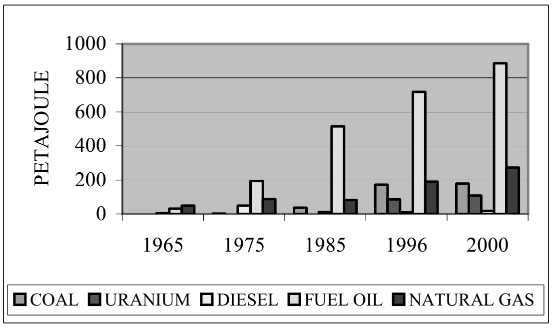
The transportation sector is expected to grow as car ownership expands and as higher income and development levels are attained. Economic growth and recent trade agreements will most likely increase commerce, requiring further expansion and modernization of the transportation system. Another factor expected to increase energy use in this sector is poor gas mileage of the automobile fleet. Attempts to increase average mileage of the fleet have been made but there is a huge economic incentive to smuggle cheap fuel inefficient used cars from the United States for use by those in the lower income groups. The average age of automobiles in Mexico is significantly higher than in the U.S. and this is expected to remain the case for some time to come.

4.4 Agriculture

In agriculture petroleum-derived fuels remain the most important sources of energy, although electricity has recently become increasingly important. At the present time, fuels derived from petroleum account for over 70% of total energy use while the remainder largely comes from electricity.

4.5 Electricity

Installed electricity generation capacity increased eight-fold from 1965 to 1999, but its composition changed somewhat over that same period (figure 4.7). In 1965, more than half of all the installed capacity came from hydropower while the remainder came from thermal plants. Today, by contrast, 60% of all electricity comes from thermal plants and roughly 30% from hydropower.



Source: Secretaría de Energía, 2001.

Figure 4.7 Fuel use for electricity generation

5. ENERGY PRICING AND FISCAL POLICY

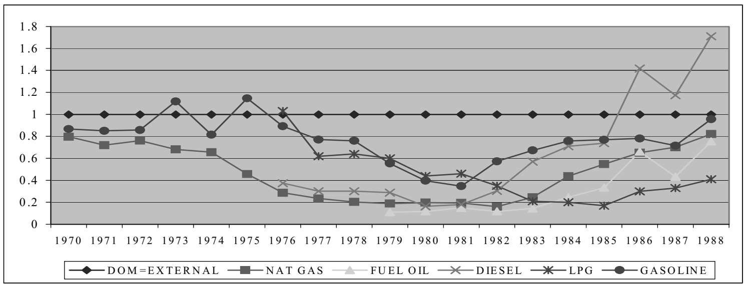
Without a doubt, one of the leading causes of high energy intensity (energy consumption per dollar of GDP produced) in the Mexican economy is low energy prices. This section describes the trends in fuel and electricity prices. Additionally it discusses, quite broadly, the general aspects of Mexico's fiscal structure. Both of these themes, (i.e., prices and fiscal policy), are important elements used in the simulations presented in the latter part of the book.

5.1 Energy Prices

The prices of fuels supplied by the state-owned monopoly PEMEX (Petróleos Mexicanos), have not corresponded to world prices. For several years the real domestic prices of several important petroleum products set by PEMEX, were declining. State intervention generated a non-transparent energy-pricing rule. Subsidies granted by the government to consumers and producers blocked any efficiency gains that may have occurred if economic agents were exposed to international fuel prices. Indeed, the increase in energy intensity in a number of economic sectors in Mexico are due to low energy prices, as well as existing subsidies on oil, electricity, fertilizers and credit (Ten Kate, 1993).

A large portion of the energy produced in Mexico comes from state-owned enterprises, namely PEMEX for oil derivatives and CFE (Federal Commission of Electricity) for electricity. The electricity-generating sector is in the process of being deregulated, and privatization of all the non-strategic sectors of PEMEX is now occurring. State-owned enterprises are under political control, and do not necessarily minimize production costs. In many cases, in fact, the selling price of energy is actually lower than its production costs, creating a highly inefficient allocation of resources.

As we have seen, industrialization over the past 30 years increased the demand for oil and electricity, and while a large part of the oil produced was exported, domestic consumption also increased significantly. Between 1970 and 1990, energy pricing policies led to an annual implicit subsidy for energy products (petroleum fuels, gas and electricity) of between \$8 and \$13 billion dollars per year, or between 4% and 7% of total Mexican GDP. Low energy prices encouraged industrial development from the 1960's to the 1980's but these low prices did not lead to the adoption of efficient production technologies.



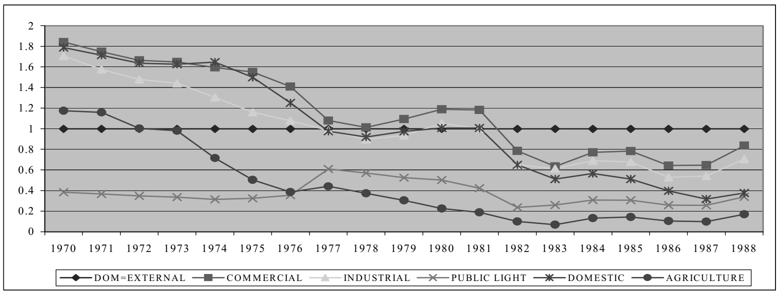
Source: CFE, 1990.

Figure 4.8 Relation between domestic prices and opportunity costs or external prices for petroleum fuels and natural gas (1970-1988)

To compare the sales price of different types of fuels to final consumers, a ratio of the domestic price to the relevant foreign price was calculated for each fuel (figure 4.8). If this ratio was greater than 1, then domestic prices were higher than the corresponding international price. If, on the other hand, the ratio was less than one, this implied that there was a subsidy to the domestic consumer for that specific source of energy.

Looking at figure 4.8 we see that over the 1980s the domestic price of natural gas fell relative to that of imported natural gas. The lowest ratio occurred in 1980, when the domestic price stood at 22% of the world price. Later this trend reversed itself and by 1990, the domestic price had risen to the international price level. This same general trend was also true for diesel and most other fossil fuels including gasoline.

Because of differential subsidies to promote equity, the prices of electricity have historically varied according to the user (figure 4.9). As can be seen, after 1970 there was a sharp decline in domestic electricity prices in Mexico, and by 1988 all electricity rates were below those in the U.S. The sectors receiving the highest subsidies were agriculture and public lighting. Commercial and the domestic rates remained higher than international prices until the early eighties when they fell below the rates charged in the U.S.



Source: CFE, 1990.

Figure 4.9 Comparison of electricity rates between Mexico and U.S. (domestic rate/US rate)

Due to industrialization policies and low energy prices, energy intensity in Mexico increased between 1970 and 1990, while, at the same time, it was significantly decreasing in other OECD countries (table 4.5).

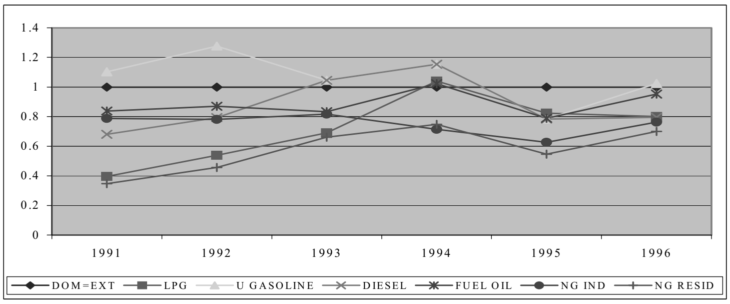
In these other OECD countries, this decrease in energy intensity has been attributed almost exclusively to technological change in almost all industries, and not to structural changes in the bundle of goods produced by the most energy intensive sectors. This is not; however, the case in Mexico where low energy prices have been responsible for increased energy intensity.

Table 4.5 Intensity of industrial energy use (energy/GDP, index (1970 = 100))

Year	Fossil Fuels		Natural Gas		Electricity		Total	
	Mexico	OECD	Mexico	OECD	Mexico	OECD	Mexico	OECD
1970	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1971	97.0	97.4	101.7	103.4	105.1	110.0	100.6	99.9
1975	123.5	91.3	92.3	100.0	105.9	112.4	103.6	97.7
1980	94.1	78.7	100.6	92.4	108.2	107.5	99.4	88.0
1985	117.3	52.8	108.3	75.6	136.9	104.2	114.4	68.8
1990	124.5	44.1	84.6	78.6	159.2	102.0	105.7	67.4

Source: A. Ten Kate, 1993.

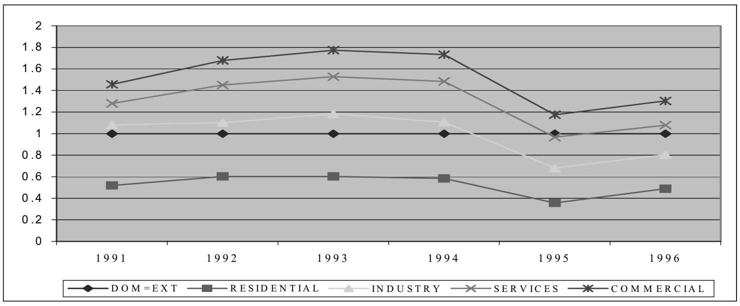
In more recent times things have begun to change in Mexico. Comparing the domestic price of selected fuels in Mexico to those of the U.S. (figure 4.10) for the 1991-1996 period, we see that Mexican domestic prices have been fluctuating around the U.S. rates. In fact, after a slight dip in prices from 1994-95, all prices again increased toward U.S. price levels.



Source: Secretaría de Energía, 1996.

Figure 4.10 Recent trends in fossil fuel prices: comparison of Mexico and U.S. rates (1991-1996)

In 1996 the average price for electricity was 3.7 cents/kwh in the industrial sector and 4.1 cents in the residential sector (figure 4.11). At that same time, the rate of electricity for commercial purposes was a bit higher in Mexico than in the U.S., while the residential price in Mexico was significantly lower than the residential price in the U.S.



Source: Secretaría de Energía, 1996.

Figure 4.11 Comparison of electricity rates in Mexico and in the U.S.

Low prices of electric power do not necessarily translate into improvements in equipment and services to customers however. Artificially low prices give rise to excessive demand. They also may reduce the ability of the utilities to expand their production capacity since funds for capital investment expansion are often lacking. Additionally, and very importantly, state ownership of electric utilities and under-pricing has reduced the incentives for Mexican investment in newer and cleaner technologies due to a lack of existing economic incentives (World Bank, 1992).

Both low energy prices and subsidies have a direct impact on the environment. The more polluting a fuel source is and the higher the subsidy it receives, the worse the impact on the environment. Subsidies therefore play a significant role in limiting energy efficiency and increasing energy use. The present energy pricing policy must first be examined before policy makers further distort the energy market with fiscal instruments such as environmental taxes. First and foremost among these changes will have to be subsidy removal, and indeed the first steps towards the removal of energy subsidies has already begun. If this process is allowed to continue and domestic energy prices are allowed to rise to the international equilibrium level, then a crucial step will have been taken to both enhance economic efficiency and stem environmental degradation.

5.2 Fiscal policy towards the energy sector

For Mexico, oil income represents roughly a third of total government revenue. Additionally, all revenues from PEMEX and CFE are subject to the corporate income tax, and in the particular case of PEMEX, this tax is levied at a much higher rate than the rate applied to other firms. At the same time, due to constitutional restraints, there are practically no investment flows into the sector, since private investment – domestic and foreign – is banned. This has had deleterious effects on the sector which is also harmful for the macro economy. Indeed, this particular fiscal policy has led to massive under-investment in the energy sector, to an increase in production costs, and a high level of debt for PEMEX. A reform in the fiscal policies applied to the energy sector and in rules applied to energy investment has long been sought, but existing political opposition makes it infeasible for meaningful change to take place in the short and medium term.

The Mexican government has traditionally used energy pricing to stem inflationary pressures. Thus, the government without regard to market forces fixes energy prices. In December 2004, for instance, President Fox announced a reduction in electricity tariffs starting in January 2005, with the not-explicitly-mentioned objective of reducing inflation.

The combination of low prices and high production costs then led to increasing deficits in the two state-owned energy enterprises, CFE and PEMEX. Consequently, the Mexican economy lost much of its competetiveness on the world energy market. Such fiscal dependence on oil income and on oil related taxes, combined with a fall in prices, then has reduced both the incentive to enhance energy efficiency and the incentive to reduce environmental degradation.

6. ENERGY IN OTHER LATIN AMERICAN COUNTRIES

The story of energy use and prices described above for Mexico is common for many, if not all, Latin American countries. Almost all Latin

American countries have rapidly growing populations and economies requiring increased use of energy. Most of these countries experienced a rapid urbanization process, and the primary sector was all but left behind. In most cases, this meant an increase in energy demand, since cities are far more energy intensive per capita than rural areas. At the same time, most Latin American countries were industrializing through the same process as Mexico, and they began to experiment with import substitution in their international trade policies. This industrialization process required, among other things, vast amounts of energy, and energy prices were generally held down to keep their energy intensive exports competitive on the world market.

Figure 4.12 shows energy consumption in the major Latin American countries. As can be seen there, Brazil is the largest energy consumer in Latin America, followed by Mexico. Venezuela uses about half of the energy Mexico uses, and Argentina behaves, all in all, much along the same lines as Venezuela. Colombia ranks fifth among energy consumers in the region and Chile (not depicted in the graph) lags even further behind.

Low energy prices in Latin America have kept per capita energy consumption high throughout the region and significantly higher above the level seen in the developed countries. Energy intensity is high in Venezuela, and it has been on an upward trend for the last two decades. This is largely due to subsidized energy prices, since Venezuela, like Mexico has a relative abundance of oil and fossil fuels. Figures show, that total energy use depends as much on population as per capita energy use. Brazil, the largest consumer, is fourth in terms of per capita consumption, and only Colombia has a smaller per capita usage. Argentina and Mexico are close in terms of their per capita energy consumption while Venezuela has the highest ratio of per capita energy consumption in all of Latin America.

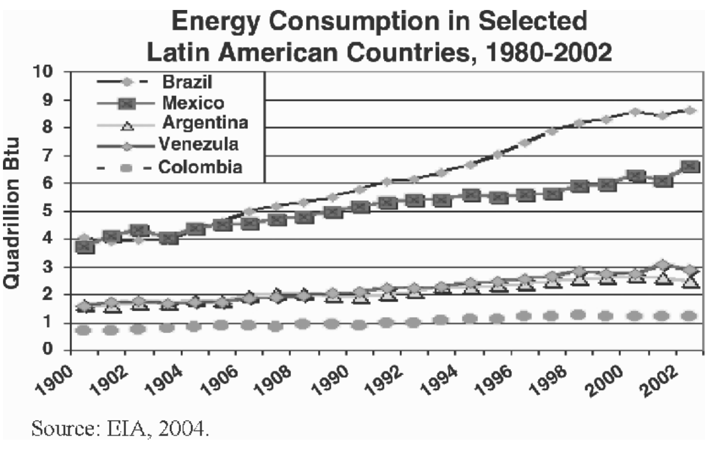


Figure 4.12 Energy consumption in selected Latin American countries

Over the years, a number of justifications for low energy prices and high-energy intensity have been given. First, it has been argued that the industrialization process based on import substitution policies requires low energy prices in order to reduce production costs and allow domestic firms to flourish in highly competitive international markets. Second, proponents of low prices have asserted that subsidizing energy is necessary to correct the inefficiencies caused by the existence of monopoly power and under-production in the state owned energy sector. Such subsidies, it is argued, are necessary to increase energy use and thereby reduce social welfare loss. Finally, low energy prices have been promoted as a short-term policy to control inflation[1]. It bears noting, however, that none of these arguments takes account of the external environmental costs incurred by increased natural resource use.

Given this historical context, in this section we take a more detailed look at the situation in of Brazil, the largest energy consumer in the region, as well as Venezuela, the largest oil producer, and Argentina, an important player in the regional energy market. Brazil has added importance since its level of total GHG emissions is second – and a very close second at that – to those of Mexico. Venezuela is not a high emitter of GHG's, but its energy intensity per capita is the highest in the region. Argentina's energy consumption (in absolute terms) is as high as that of Venezuela, and its energy use, in per capita terms, is similar to Mexico, and significantly above that of Brazil.

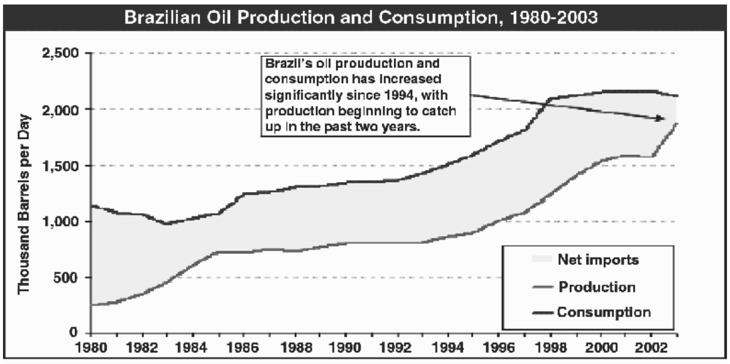
6.1 Brazil

Having a population of 175 million and an annual population growth rate of 1%, Brazil is the largest country in Latin America. Also it is the largest energy consumer in the Americas after the United Sates and Canada. Total primary energy consumption in Brazil increased at an annual rate of 3% between 1992 and 2002 (EIA, 2004) and in 2000 its total oil energy consumption stood at 1.9 million barrels per day.

Oil production in Brazil is carried out through Petrobras, a monopoly that is 51% government-owned. Due to a Constitutional reform in 1995 it can contract state or privately owned companies to carry out activities in the oil and natural gas sector. However, foreign investment has not flowed as much as expected into the country due to unclear regulations and the difficulty in

[1] This last argument has been frequently used throughout Latin America as a short run justification for subsidies. Once established, however, energy subsidies have proven difficult to remove in a timely manner since eliminating them would require policy makers to take away the economic rents collected by the various interest groups who profit.

finding oil fields large enough (and with the appropriate characteristics) to commercialize. Additionally, there are fiscal uncertainties at the federal and state levels.



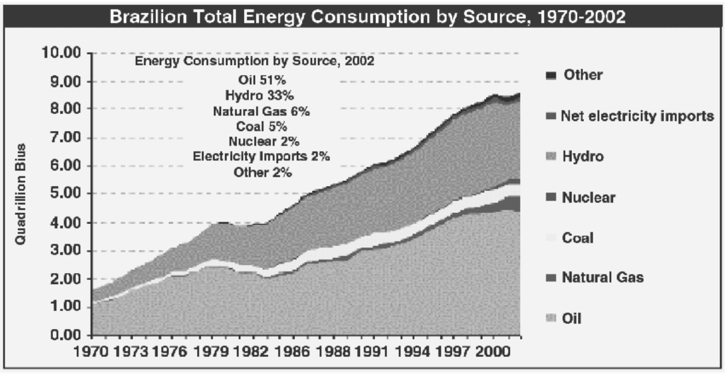
Source: EIA, 2004.

Figure 4.13 Brazilian oil production and consumption

Oil reserves in Brazil are the second largest in South America, just after Venezuela, and additional discoveries have been recently reported. The country has made a great effort to increase oil production, and by 2003 Brazil was almost able to meet its total consumption needs (figure 4.13). The goal of Brazilian policy makers is to produce 2.3 million barrels per day to be self-sufficient. New reserves may help toward that end. Analysts are not sure that the self-sufficiency goal is either desirable or sustainable given its growing population and increased economic growth.

Brazil is active in the international oil and refined products markets. Despite the increase in petroleum production, Brazil imports crude oil, mostly light crude, to mix with its own oil and then refine. It imports its oil chiefly from Africa (64%), and from the Middle East (approximately 30%). The rest comes from a host of other countries in South America, as well as Europe, and Oceania. It exports a combination of refined products and heavy crude with the latter going to China.

In terms of power, Brazil is the largest electricity consumer after the United States and Canada with most of this power coming from hydro plants. In 2002 it had an installed capacity of 76.2 GW, which has been growing at a 3.6% yearly rate. Eighty three percent of all Brazilian electricity come from is hydropower (figure 4.14). Electrobras is the state-owned electricity holding company that generates and transmits electric energy through its subsidiaries.



Source: EIA, 2004.

Figure 4.14 Brazilian Energy Consumption by Source

Due to their reliance on hydropower, many of Brazil's power generating plants, are located far from consumption centers, resulting in high transmission and distribution losses, equivalent to 15% of total domestic demand supplied (EIA, 2004). Electricity consumption has been growing at a rate of 3.2% per year, and now meets its consumption needs through the use of imports, mainly coming from Argentina.

In 2001, Brazil had to impose a rationing scheme on electricity consumption due to the lack of availability of water required to produce hydro power, as well as lack of investment in generation capacity expansion in the overall sector. Higher living standards and economic growth during the 1990s were in no way accompanied with increasing investments to meet the demand which increased by 58% in just a decade. There was therefore a need to expand capacity and to diversify Brazil's fuel mix. Lula da Silva's government has introduced regulation to the energy sector to help prevent a future power crisis. The rationing scheme ended in the Summer of 2002, and in March 2004, a new plan was introduced to ensure a reliable supply, stabilize prices for consumers and attract long-term investment to the sector (EIA, 2004).

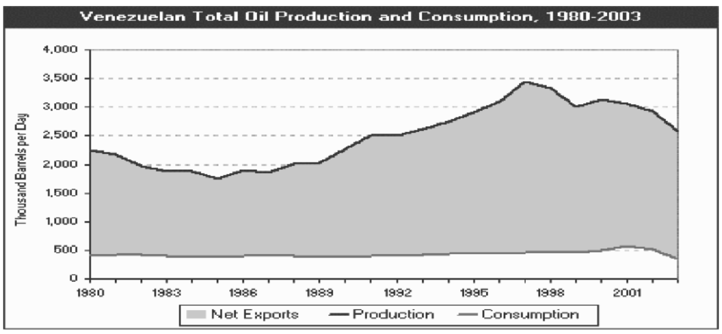
Privatization of the energy sector in Brazil started in 1995, under President Cardoso. As a result of this privatization electrical generation as well as the transmission of electricity is done by the state. The distribution of electricity, on the other hand, is performed by private firms. However, the net effects of privatization are still under discussion. Some critics charge that the process has stalled and that, at any rate, it has failed to deliver the expected results.

Finally, over the last several decades ethanol has become an important source of energy for Brazil, particularly in the transportation sector. In 1970, the government-funded program PROALCOOL was created to spearhead the production of ethanol from biomass, particularly sugar cane. The production of ethanol steady rose after that time and by 1988 it accounted for 5% of total Brazilian energy use, and 20% of all the energy used in Brazil's transportation sector. Its production has since stabilized somewhat and in 2000 ethanol accounted for 4% of total energy use and 12% of the total energy used in the transportation sector (Ministry of Mines and Energy, Brazil, 2005).

In 1985 almost 90% of all automobiles produced in Brazil were designed to run on ethanol. In the 1990s, however, Brazil experienced a deep fiscal crisis and the government was forced to remove its subsidies for ethanol. At that same time, the price of sugar increased on the international market and more of the cane crop was used in for the production of sugar rather than for the production of ethanol. Consequently, the production of ethanol cars fell to only 2% of total auto production in the early 1990s before rebounding to 20% of total production in 2000. Since that time "flex-fuel" cars were introduced into the Brazilian market. These cars run on ethanol, gasoline or any combination of the two. Production and sales of these cars are increasing rapidly, and recently the production of flex-fuel cars surpassed the production of the more conventional cars that only run on gasoline.

6.2 Venezuela

The largest proven conventional reserves of oil in Latin America are found in Venezuela. The first reserves in Venezuela were discovered in the early nineteen hundreds and since that time they have been one of the main pillars of the economy. Internationally, Venezuela is a significant player in the oil market. It is a member of the Organization of Petroleum Exporting Countries (OPEC) and among the top five oil suppliers to the U.S.

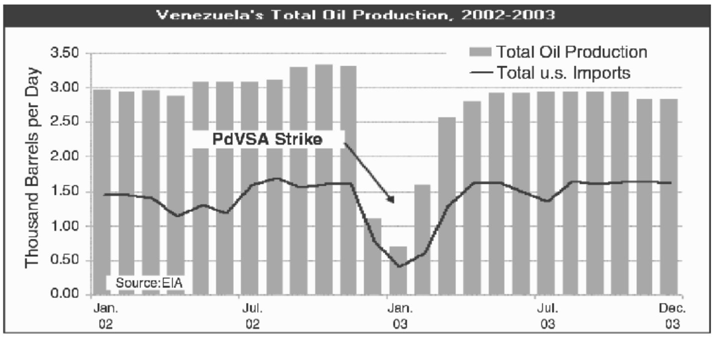


Source: EIA, 2004.

Figure 4.15 Venezuela's oil production and consumption

About 75% of Venezuela's total export revenues come from oil along with half of all its government revenues and a third of its GDP. In 2003, Venezuela's oil production was 2.6 million barrels per day (bbl/d), 10% less than the previous year due to the recession, and its consumption was 350,000 to 400,000 million bbl/d. At that same time its oil exports were 2.25 million bbl/d and 1.39 million bbl/d were sent to the U.S. (figure 4.15).

The oil industry has been at the center of the political and economic crisis faced by the administration of Hugo Chavez. The state-owned oil company, PdVSA, had to shut down its operations in 2002, and in early 2003, it lost approximately half of its personnel. This resulted in a large loss in total oil production over that period (figure 4.16).



Source: EIA, 2004.

Figure 4.16 Venezuela's oil production

Hydro, an extensive source of Power in Venezuela, makes up 62% (13.1 GW) of its installed electric capacity. In 2002 68% of all electric power came from this source. In fact, in 2001 Venezuela exported some electricity to Brazil, due to the energy crisis faced by Brazil at that time (see the previous section). Most other electrical power comes from the use of fossil fuels, with only a minor portion coming from non-hydro renewable energy sources, such as solar energy, photovoltaic cells, and wind power. Due to its reliance on water levels in damns to generate power, Venezuela, like Brazil, faced an energy shortage in 2003. This occurred basically due to low precipitation. Another important cause of recent shortages has been electricity theft. This has occurred in Venezuela for years and currently represents about 25% of total consumption.

Energy pricing is also an issue in Venezuela. High energy subsidies promote high usage. But eliminating or even reducing those subsidies would be unwise politically given the large price increases it would entail. The elimination of highly subsidized gasoline prices are said to be the origin of massive riots in 1989. In 2003, the government enacted price controls on a basket of basic goods, which included both fossil fuel and electricity prices. Furthermore, political instability over the past several years has halted the ongoing privatization processes and there are no signs that the privatization process will be revived any time soon.

6.3 Argentina

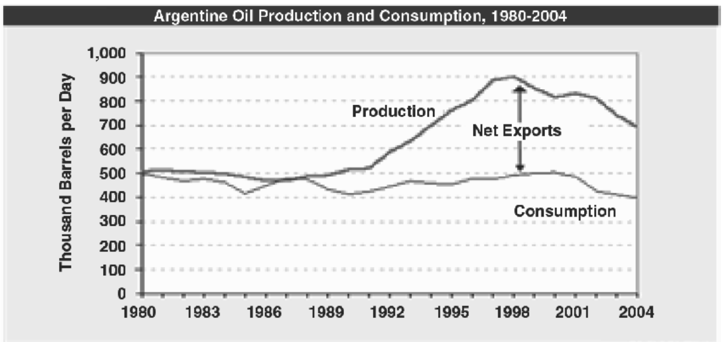
Argentina plays an important role in Latin America's energy markets both as a large consumer and also as an energy exporter to Brazil and Chile. In Recent decades, however, the Argentine energy sector as well as the Argentine economy at large has faced substantial pressures from outside forces and have been in a constant state of turmoil. During the 1990s Argentina's energy sector was subject to extensive reforms. Oil exploration and production were liberalized, the state-owned monopoly YPF was partially privatized and modernized, and new private firms were allowed to enter the market. Electricity and natural gas production, transportation, and distribution were also liberalized, and competition among private firms was promoted at all possible levels. As a result of these changes the energy sector of Argentina experienced significant gains in productivity and efficiency while consumers began to purchase energy at competitive market prices.

In 2001, following four years of extensive economic recession, the government of Argentina government finally defaulted on its international debt. This action, in turn, led to an even more severe economic crisis. In 2002, Argentina's GDP fell approximately 12%. This was the largest such decline since the 1930s and it led to the quick establishment of a new political regime. In order to stabilize the troubled economy, the new government reversed existing policy and quickly established a flexible exchange rate between the Argentine peso and all major world currencies. Given that privatized public utility tariffs were originally set in dollars the energy costs faced by Argentinean consumers were expected to increase as well. In order to calm down the social agitation produced by the effects of the economic depression, however, the government decided to control all prices and tariffs to keep energy prices artificially low.

Despite all of these financial problems the Argentine economy has shown some remarkable resiliency. Two consecutive years of more than 8% growth following the 2001-2002 crisis placed Argentina back on the road to financial solvency and economic recovery. Lingering problems with foreign debt, however, meant that financial restructuring is now of crucial importance to the success of Argentina's domestic programs as well as its ongoing infrastructure projects.

Due to the combination of a relatively quick economic recovery and artificially low relative energy prices, domestic energy demand soared above previous levels, and in 2004 Argentina went through a major energy crisis. At that time Argentina could not meet its foreign energy delivery obligations and this led to the default on its natural gas export contract with Chile. The marked increase in domestic energy demand increase also meant that Argentina found it necessary to import natural gas from Bolivia. All of these actions threatened the fledgling Argentinean economic recovery and made international relations with debt-holding countries much more difficult.

In an attempt to insulate itself against future crises, the Argentine energy sector has undertaken a series of reforms, including the establishment of a new state-owned energy company (Enarsa). In order to attract investment for downstream energy-related infrastructure the government has offered generous economic incentives, as well as future plans which call for the liberalization of most energy prices (EIA, 2005).



Source: EIA, 2004.

Figure 4.17 Argentine oil production and consumption

Argentina is the third largest oil producer in South America, behind Venezuela and Brazil, producing 629,600 bbl/d in 2004 (figure 4.17). Exports account for roughly half of the total oil production with the lion's share of this going to Chile and Brazil. In 1999, the Spanish owned firm**,** Repsol, merged with Yacimientos Petrolíferos Fiscales, the then state-owned Argentinean state-owned oil producer, and now dominates both oil exploration and oil production in the country. However, it is far from being the only petroleum producer. Other private firms such as Pan American Energy, Chevron Texaco and Petrobras Energía are also actively engaged in oil drilling and distribution activities.

Natural gas is also an important natural resource for Argentina. In fact, the largest proven reserves of natural gas in all of South America are found there. Argentine gas production increased dramatically over the last decade and surpassed that of Mexico in 2000, thus making it the region's largest producer of this important commodity (figure 4.18). While natural gas production has recently declined due to the economic crisis, its consumption has increased to such an extent that it is now the chief fossil fuel consumed. Indeed, in 2002 natural gas accounted for 45% of all primary energy consumption.

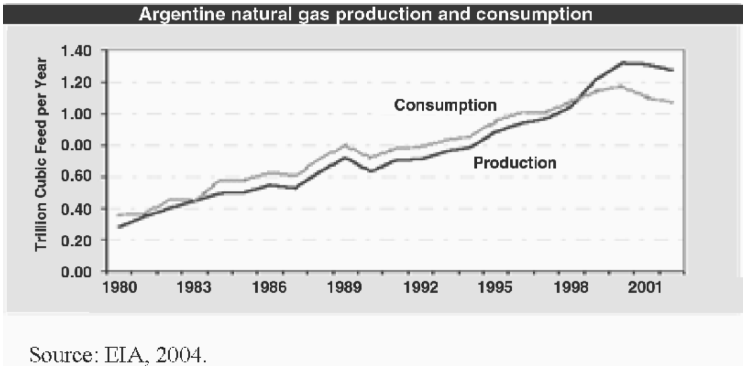
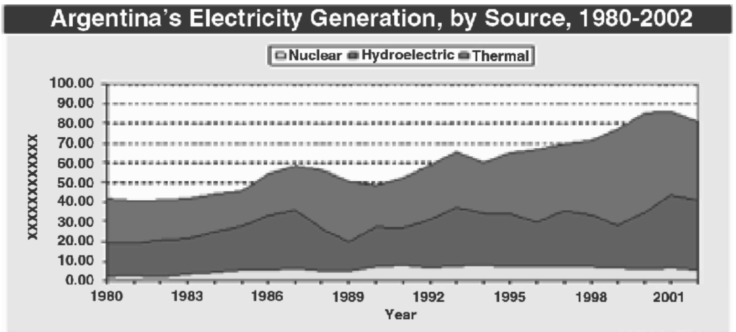


Figure 4.18 Argentine natural gas production and consumption

Repsol-YPF is by far the most important natural gas producer and upstream energy provider. Since the system was privatized in 1992, other firms, most of which have significant foreign ownership, have entered the market. The 2004 crisis made it abundantly clear that Argentina's domestic natural gas pipeline network was woefully inadequate in the face of ever increasing demand. Thus, a number of policies have been initiated to promote investment in natural gas transmission, including the removal of barriers to international capital funds. At the same time, Argentinean firms have extensive pipeline connections to Chile, Brazil, Bolivia and Uruguay, which allow for significant trade of natural gas in international energy markets.

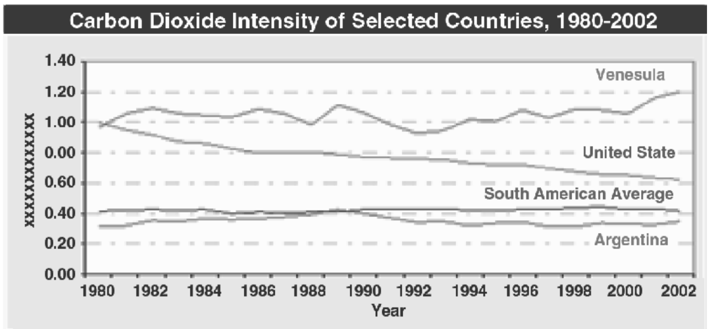
Argentina's power sector is presently deregulated. The private electricity sector operates with little restriction, and at this time both independent and state-owned companies coexist on the Argentine power grid. Most electricity is produced from hydro sources and Argentinean hydro-electric plants serve Paraguay and Uruguay as well as Argentina itself. The nation also has two nuclear power plants with a third currently under construction. All other energy sources not from either nuclear or hydro-electric power, come from thermal sources (figure 4.19).



Source: EIA, 2004.

Figure 4.19 Argentina's electricity generation by source

Given its heavy reliance on both hydroelectric power and clean-burning natural gas, Argentina is somewhat below the South American average in terms of per capita carbon emissions, and significantly below the per capita emissions level of the U.S. (figure 4. 20). Furthermore, Argentine emissions levels have been relatively stable for the past decade. Hence, energy intensity and carbon dioxide intensity are both relatively low compared to the other countries in the region (EIA, 2005).



Source: EIA, 2004.

Figure 4. 20 Carbon dioxide intensity of selected countries

7. CONCLUSIONS

Through the expansion of the industrial and transportation sector, overall economic growth has played a major role in increasing energy use as well as air pollution and greenhouse gas emissions in Mexico and Latin America. Nevertheless, development policies have also had a significant role in all of this. The most important policy employed to promote industrialization in Latin America has been the policy of import substitution in the 1960's and early 70's. Among other things this policy relied on economic incentives to develop (largely energy intensive) infant industries through commercial and fiscal incentives and subsidies.

Latin American development policies have had unintended consequences. In spite of the best intentions they did not promote internationally competitive exports, and in many cases they protected inefficiency. Artificially low pricing of energy is a major reason for increasing energy use and the price of the fuels set by state-owned monopolies rarely, if ever, followed trends in world prices. On several occasions, in fact, the real prices of fuels and electricity actually declined. The subsidies granted by the governments to consumers and domestic producers have inhibited energy savings and technological development in both energy and energy related industries. Additionally, state intervention has made the process of price determination non-transparent since the state has defined domestic prices without any clear rule to tie them to international price movements. Moreover, technological regulations have not created the incentives to adopt energy efficient processes.

The increase in the energy intensity of Latin American production can be largely attributed to inefficient industrialization, rapid economic growth of the most highly polluting sectors, and low energy prices between the late 1970s and 1980s. Much of this has, however, changed in recent years. The prices of inputs for both the industrial and the transportation sectors have tended to rise in line with international trends. Meanwhile, other distortionary policies such as subsidies have been partially eliminated. Deregulation and free trade have been extended to many sectors; state-owned monopolies are slowly disappearing and antitrust laws have been established. All these modifications have definitely provided a basis for a more efficient economy. At the same time, however, there have also been some setbacks. In the first years of the 21st century, some governments have again started to interfere with market-based prices in an effort to attain short-term political goals. This may indeed be an indication that the pro-market reforms of the early 1990's were just a transitory phase.

Mexico, Brazil, and Argentina are significant fossil fuel users and hence important emitters of greenhouse gases. They are also developing countries that may largely benefit from an environmental policy that has concomitant benefits for society. Subsidies to energy use, beside from being costly to the government, have increased energy intensity in Mexico as compared to other OECD countries. The same may be true for Brazil and is certainly so for Venezuela. Argentina also recently began controlling energy prices, for basically political reasons. High levels of air pollution and an increasing contribution to climate change are important effects of low energy costs and economic growth. Higher energy prices may help curtail energy consumption, local and global emissions, and are an essential component of any future policy to mitigate climate change.

CHAPTER 5

ECONOMIC THEORY, EMISSION CONTROL, AND KYOTO

Environmental degradation has an economic component to it, and as such, economic solutions can help solve it. This chapter reviews the economic causes of climate change, namely the fact that the atmosphere is a global common and a public good, the problem of externalities, and the fact that there are incomplete markets for environmental goods and services. Next, it discusses the Kyoto Protocol and its origins, referring to earlier environmental agreements that have been stepping stones to today's international accords. It then addresses the use of economic instruments to meet emission reduction goals of the Protocol. In particular, there is in-depth discussion of the Clean Development Mechanism, carbon taxes, and tradable emission permits. These environmental tools are then compared with respect to their effectiveness and their environmental, economic, and political impacts. Finally it discusses the position of selected Latin American countries towards the Kyoto Protocol.

1. ENVIRONMENTAL CONTROL MECHANISMS

As we have seen in chapter 2 the causes of global warming can only be understood by means of the natural sciences. The temperature of the Earth is closely related to the presence of greenhouse gases (GHGs), and the reaction of the Earth to global warming is linked to a host of biological, chemical, and geological factors. Any solution to global warming and abatement of greenhouse gas emissions, however, can only be brought about through the actions of human beings, and these actions can only be understood in the context of the social sciences. More specifically, the curtailment of GHG emissions is a classic case of what economists term an externality or an action with unintended spillover effects. Indeed, most types of environmental degradation take place as a consequence of such externalities, and it is instructive for us here to examine the efficacy of past environmental policies to understand the strengths and weaknesses of each type of abatement action.

Traditionally, policy makers in most developed and developing countries have relied on command-and-control instruments to deal with their environmental problems. Under such policies, authorities stipulate the maximum level of effluents which can be released by individual sources and often mandate the particular technologies to be used by polluters to reach those levels. Economists (e.g., Baumol and Oates, 1988; Montgomery, 1972) have often criticized command-and-control policies, and they have tended to favor market based systems such as pollution taxes and tradable emission permits. Politicians, firms, and environmentalists, however, have been disposed to favor command-and-control policies for a variety of reasons.

Firms have seen command-and-control policies as things that could be employed for their own benefit. As noted by Stavins (1998) "affected firms and their trade associations tended to prefer command-and-control instruments because standards can improve a firm's competitive position. Command-and-control instruments are inevitably set up with extensive input from existing industries and trade associations, which frequently obtain more stringent requirements for new sources and other advantages for existing firms." Environmentalists have also traditionally favored command-and-control policies albeit for a quite different set of reasons. For them, the reliance on market-based instruments was seen as giving firms the right to pollute if they paid the right price, and hence, ethically flawed. Furthermore, since damage estimates were hard to quantify, they felt that market policies shifted the emphasis to the cost of emission control without adequate emphasis on the damages due to the emissions (Kelman, 1981).

Politicians throughout the world have also seen various advantages in advocating the use of mandated regulatory policies. First of all, command-and-control policies are easily understood by the population at large and are frequently used to make popular but ineffective legislation. Often policies are announced with great public fanfare, but they are filled with exemptions, ineffective enforcement policies, and actually take effect many years after their initial passage (Stavins, 1998). Put another way, the "devil is in the details" and frequently tough sounding legislation is combined with lax enforcement policies and with little incentive for compliance.

Command-and-control policies, by their very nature are highly legalistic and require large bureaucracies to implement. More often than not, policy makers are well trained legally and are most comfortable with this type of control. Furthermore, the bureaucrats that are retained because of their expertise in this area are far more comfortable with the command-and-control policies that they are used to rather than market-based policies which shift the burden of enforcement to experts within the regulated industries themselves.

As mentioned above, when it comes to effluent abatement, economists favor the use of "market based" strategies over the use of command-and-control regulations. These types of policies, they have said, provide the least cost way of attaining a given effluent control target. Faced with the alternative of having to pay for the damages of their action, emitters, economists have argued, have an incentive not only to cut down on emissions but also to do it in as cost effective manner as possible. Furthermore, in contrast to the mandated abatement methods associated with command-and-control, the actual abatement strategies followed are up to the firms themselves, and consequently incentive for research and development (R&D) in this area is far higher under market based systems than traditional performance standards (Jung, Krutilla, and Boyd, 1996).

Although the use of market based strategies goes many years back, the Clean Air Act of 1990 is by far the most ambitious example of incentive-based environmental regulation in the United States, as well one of the most high-profile cases of such policies ever adopted worldwide. This piece of legislation was designed with the goal of reducing the nationwide emissions of sulfur dioxide (SO_2) to a level 50% below 1980 levels by the year 2000. Under this law each emitter is given allowances (or permits) to emit a specific amount of SO_2 based on its emissions during the 1985-87 baseline period. Each emitter can only release SO_2 effluents if it has sufficient permits to cover this pollution. Emitters are allowed to transfer their permits so that those polluters who find it inexpensive to cut back on SO_2 can sell their permits to those with high pollution control costs. The incentives to innovate, then, are squarely on the shoulders of the firms themselves, and thus far the results have been highly encouraging. By switching to low-sulfur coal, SO_2 emitters within the US have been able to cut their emissions to the target levels with estimated savings of $1 billion over equivalent command-and-control policies (US Environmental Protection Agency, 1997; Kennedy, 1986).

The success of the Clean Air Act of 1990 coupled with the success of similar programs has led policy-makers throughout the world to now seriously consider market based pollution control policies as a viable alternative to command-and-control strategies. In particular, authors such as Stavins (1997), and Parry, Williams, and Goulder (1997) have strongly advocated their use in the case of treaties to curb the emissions of CO_2 and other global warming gases. Given the cost effectiveness of market based instruments, most previous Computable General Equilibrium (CGE) treatments of this issue (see, for example, Böhringer and Rutherford (1996), Bernstein et al. (1999), and Jorgenson and Wilcoxen (1993a)) have assumed either a carbon tax or tradable emissions type of setup. Indeed, in our own modeling effort to be described in chapters 6 through 9 we assume market-based strategies. Hence, in the following sections, the discussion is restricted to the economic instruments in the CO_2 context, namely carbon taxes, tradable carbon emission permits, and the Clean Development Mechanism.

2. THE ECONOMICS OF CLIMATE CHANGE

Environmental issues have been on the agenda of economic research since David Ricardo, when discussing land quality. Later Pigou (1920) and Hotelling (1939) referred to issues of optimal taxation of environmental externalities and resource use respectively early last century. Since the late 1960s and the early 1970s economic theory has become more interested in issues of pollution and exploitation of the global commons (Hardin, 1968), and it was in the early 1990s that a bulk of economists started addressing global climate change from an economic perspective. The main economic arguments given for its study from this field are as follows. First, GHG emissions are a typical case of an externality, and from this view point this problem may have an economic solution. Second, economic analysis is necessary to estimate the costs that adopting mitigation policies will impose on a nation or on a worldwide basis. Third, economic incentives may lower the costs of mitigating climate change. And fourth, economic methods can also help determine the benefits from avoiding climate change (Stavins, 2000).

2.1 The Global Commons and Public Goods

Several traditional concepts can be useful to describe global climate change from an economic perspective. First, the environment is a receptacle of greenhouse gas emissions that alter the climate. Given that there is a zero price associated to its use, the atmosphere can be thought of as a *common-property* *resource,* where *property rights* are not clearly defined. Most common property resources are overused and ultimately destroyed. On the other hand, environmental quality is a *public good* in the sense that there is no rivalry in its use. This means that several individuals can benefit from it at the same time without affecting its enjoyment to others[1]. Additionally, once environmental quality is provided, it is technically infeasible or economically too costly to exclude others from using it.

The characteristics that make the global commons so unique (i.e., the fact that they are an open access resource, with unclear property rights, and that they are a public good with no rivalry in their consumption and no exclusion from their provision) make it difficult to establish markets for environmental quality there. Indeed, most environmental goods markets cannot operate because the underlying conditions do not hold (Fullerton and Stavins, 1998). Thus, market indicators such as prices convey no useful information for decision makers, and allow the overuse of natural resources to occur. Hanley et al. (1997) explain what can happen to the global commons:

> If your consumption of an asset rivals my consumption but we both have legal access to the asset, we both have an incentive to capture as many of the benefits that the asset provides as soon as possible before the other person captures them. In such cases we may overuse the asset relative to what is best for society. When overuse occurs as the result of non-exclusion the market has failed to signal the true scarcity of the asset. Non-rivalry implies that the marginal social costs of supplying the good to an additional individual are zero. Therefore it is not Pareto efficient to set prices that will exclude anyone who derives positive marginal benefits from the public good- a market failure exists since a private firm cannot profit by providing a pure public good for free as dictated by Pareto efficiency[2].

Since the Earth's atmosphere has many public good characteristics and since everyone benefits from the services provided by a public good and no one can be excluded from these benefits, people could free-ride. A *free rider* is someone who conceals his or her preferences for the good in order to enjoy the benefits without paying for it. Free-riding, reflected as a low overall willingness to pay for the public good, implies that the market will provide less of the public good than is socially desired, thereby misallocating resources away from the

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[1] This is true if there is no congestion.

[2] Pareto efficiency is reached when no other allocation of goods and services is possible without making at least someone worst off.

environmental good and towards the provision of private goods where the conditions of rivalry and exclusion hold (Olson, 1965).

2.2 Missing Markets and Externalities

Most market failures related to environmental assets can be linked in one way or another to the fact that there are some things for which there is no market. In economic jargon this is referred to as missing markets, and externalities are a classic case of missing markets for an environmental asset (Arrow, 1969). Externalities do not work through a market price, but rather through its impact on the production of utility or profit for consumers or producers. The set of markets are missing because there is no exchange institution where the person pays for the external benefits or pays a price for imposing the external costs of an action (Hanley et al., 1997).

The environment provides resources that are used as inputs in production activities (for example, oxygen for combustion processes). In so doing, however, they often combine to produce harmful by-products which are emitted back into that same environment. A good example of this is the carbon and sulfur dioxide emissions which result from the burning of fossil fuels. These greenhouse gas emissions in turn create externalities since they cause changes in the Earth's climate, and reduce environmental quality. As we have seen, there are markets for sulfur dioxide emissions, but presently, there is no market where carbon dioxide emissions can actually pay for the costs they impose on others[3]. Seen in this way carbon emissions are then a negative externality and as such they decrease the overall welfare of society[4] (Ledyard, 1987).

The presence of externalities is responsible for a divergence between the private and social costs of the firms' activities. Put another way, in undertaking its production activities a firm only faces those private costs such as the cost of labor and capital that it encounters directly. It does not take into consideration the external costs imposed on others as a consequence of its activities. If such social costs are ignored and market prices are only set according to private costs then the prices of goods produced with high emission intensity do not reflect the environmental costs that they impose on society at large. This means that the final price of goods reflects costs, but only to some extent, and that environmental costs are being left out.

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[3] Some are emerging, such as the Chicago climate Exchange, but its use is not yet widespread.

[4] Technically, an externality decreases welfare since its creation decreases the welfare of third parties in the economy. In this situation it is impossible to maintain the previous level of overall welfare, and the resulting allocation of resources is said to be Pareto inefficient.

At the present time there is absolutely no cost for using the Earth's atmosphere as a receptacle of GHGs. There is thus an overuse of the atmosphere when it comes to assimilation of GHGs and a decline in environmental quality due to climate change. Emission intensive activities are carried out beyond the social optimum since the externalities brought about by these activities do not have to be paid for.

2.3 Applicability of the Coase Theorem

The property-rights approach maintains that in many cases involving public goods, private property rights can be defined. One of the basic results of the property-rights approach to environmental allocation has been proposed by Coase (1960), who states:

> Let exclusive property titles to the environment be defined, and let them be transferable. Let there be no transaction costs. Let individuals maximize their utilities, and let them be non-altruistic. Then a bargaining solution among different users of the environment will result in a Pareto-optimal allocation of the environment. The resulting allocation is independent of the initial distribution of property titles.

In the case of the atmosphere, there are an almost infinite number of parties involved, with high transaction costs among them, and with an unclear definition of property rights on the environment. Negotiation will therefore not lead to an optimal outcome, and government intervention is required (for a deep discussion on this see Siebert, 1995).

In the end, a discussion on who owns the commons leads us back to the section on the geo-economics of climate change. All countries emit, most will be affected by climate change, but who has the rights on the atmosphere? To solve this problem from an economic standpoint, the property rights issue must be addressed.

2.4 Ownership of the Commons: Back to Geo-Economics of Climate Change

Sub-optimal competitive market equilibrium often arises when no property rights are defined. Indeed, it is essential to have markets for every transaction if a market failure is to be avoided. Simply stated, in order for goods and services to be sold in markets, they have to be owned by someone, and that owner must be entitled to transfer their possession to someone else. This well-defined property rights system represents a set of entitlements that define the owner's privileges and obligations for use of a resource or asset. Markets related to environmental goods are missing because of the failure or inability of institutions to establish well-defined property rights (Hanley et al., 1997).

Thus, efficient use of the environment or of natural resources requires clearly defined property rights, i.e. that the resource should not be provided under open access conditions because this may lead to its exhaustion and degradation. Hence, whoever is the "owner" of the environmental good or natural resources must charge others for its use.

3. CLIMATE CHANGE AND THE KYOTO PROTOCOL

The fact that climate change has a global dimension has made all nations stakeholders of this event. Currently, it has a new impulse because the Kyoto Protocol became binding for 128 nations on February 16, 2005.

3.1 Some Background

In 1979 the first global conference on climate change took place. This conference called on the governments of the world to anticipate the changes in climate caused by human activities that affect human well-being. From 1980 to 1990 the intergovernmental efforts on climate change focused on the scientific and political issues and called for global action. In 1992 the United Nations Framework Convention on Climate Change was signed. This conference took place in Rio de Janeiro and was ratified by 154 states plus the European Union. This convention, adopted in March 1994, is the centerpiece of all global efforts to mitigate climate change.

The first Conference of the Parties was held in Berlin, and in December 1997 a legal structure was built into climate change agreements through the Kyoto Protocol. The Protocol establishes quantitative targets to reduce the emission of greenhouse gases in the short run for developed nations. The industrialized nations thereby commit themselves to reduce their collective emissions of greenhouse gases by 5.2% with respect to their emissions of 1990; this reduction is expected to take place during the 2008-2012 period. The listed emissions are carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (N_2O), hydrofluorocarbons (HFCs), perfluorochemicals (PFCs), and sulfur hexafluoride (SF_6). However, commitments are generally in terms of CO_2 only. For example, Switzerland and some Central European and Eastern European nations would be expected to reduce their emissions by 8%, the USA by 7%, and Canada, Hungary, Japan, and Poland by 6%. New Zealand and Ukraine would then stabilize their emissions at their 1990 levels. Other countries could even increase their emissions, examples being Norway by 1%, Australia by 8%, and Iceland by 10%.

After the international meeting in Kyoto, the Buenos Aires conference of 1998 designed a two-year action plan while the Kyoto Protocol was placed up for ratification. This action plan called for the cooperation of the members to build policies and measures to stabilize greenhouse gases to a level that prevents damages in the climate system. For this purpose, all members, including Latin American countries, were expected to present emission inventories, as well as indicate their CO_2 absorption capacity in carbon sinks. Members were expected to work as well on developing strategies and national programs to adapt to the impacts of climate change. Their cooperation was also expected on scientific, technical and educational issues. Furthermore, they were called upon to promote public awareness, and exchange information related to climate change.

The Kyoto Protocol is technically effective because, as of November 18, 2004, Russia, which produces 17.4% of total emissions, ratified it. In December of 2004, 129 countries had ratified the Kyoto Protocol representing 61.6% of emissions. The two large outstanding countries that have signed but have not ratified the Protocol are the United States and Australia. Nevertheless, the Protocol came into effect in February 16, 2005, without the approbation of the US, the world's largest emitter.

3.2 Recent international agreements

The Conference of the Parties is the supreme body of the United Nations Framework Convention on Climate Change (UNFCCC). It includes all nations which have ratified the convention, and it meets every year to promote and review the implementation of the agreements. This body recognizes that developing countries need help to prepare their reports, to adapt to the adverse effects of future climate change, and to obtain efficient carbon mitigation technologies. Members of the UNFCCC are grouped in three blocks according to their GDP and development levels, and each group has different CO_2 reduction targets under the Kyoto Protocol. The appendix at the end of this chapter shows these groups.

Annex I Countries include most of the OECD countries as well as the Central and Eastern European nations. All of these countries are obliged to reduce their emissions. The OECD nations (except for Mexico, Turkey and the Republic of Korea) have been called upon to take strong measures, while the transition economies have been given a certain degree of freedom. We will focus on two large Parties within the Annex I countries, namely the US and the European Community.

The U.S. ratified the Convention on October 15, 1992 and signed the Kyoto Protocol on November 12, 1998. However, the U.S. has not yet ratified the Protocol despite the fact that it is responsible for 36% of the world emissions of CO_2 (UNFCCC, 2004). Its government wants developing nations to commit to actual emission reduction targets before it ratifies the Protocol. The climate policy of the United States was developed through a cooperative inter-agency process involving more than 20 agencies within the federal government as well as several entities from the President's Executive Office. It has relied heavily on voluntary instruments to reduce GHG emissions. The most important of these are research and development along with the provision of financial incentives. The United States Initiative on Clean Development Mechanism (USICDM) supports the development and implementation of voluntary projects between the U.S. and non-U.S. partners that reduce, avoid, or sequester greenhouse gas emissions.

In contrast to the United States, the European Community is among the most eager to carry out the terms of the treaty. The EU is making great efforts to convince other members of the Convention, such as Russia, to ratify the Protocol so that it is fully implemented. The European Community ratified the Convention on December 21, 1993 and signed the Kyoto Protocol on April 29, 1998. It has been at the forefront of the international efforts to mitigate climate change, and in March 2000 it launched the European Climate Change Program (ECCP). The goals of this program are to prepare additional policies, measures and an emission trading schemes, and to ensure that the EU achieves the 8% cut in emissions by the 2008-2012 deadlines for which it is committed under the current terms of the Kyoto Protocol.

The EU's emissions fell by 2.5% between 1990 and 1998, due mainly to reductions by Germany and the UK. Individual members of the EU must implement national climate strategies because common and coordinated policies throughout the Community are difficult to put into place. The national policies which have been proposed to date include energy taxation, the use of renewable energy sources, energy efficiency, and a cutback on total vehicle emissions. The EU strongly opposes the use of the clean development mechanism (CDM) supported by the U.S.

Annex II Countries are the richest nations among the Annex I Countries. They must fund the costs of reports prepared by the developing nations. They also help finance energy efficiency projects and technology transfer programs.

Non-Annex I Countries are basically developing nations. Their commitments are to build, analyze, and publish emission inventories. They are also required to implement national programs to mitigate, adapt, and conserve carbon sinks. The countries in this group may be asked to exchange experience and information while preparing their reports. Carbon dioxide emissions from energy use, land-use change, and deforestation are generally the primary source of emissions reported by the Non-Annex I countries (except for Uruguay for which methane emissions from livestock are the most significant). Fuel combustion, however, is the largest single source of CO_2 emissions for all reporting parties (except for Indonesia, Lesotho, Philippines, Samoa, and Senegal, where forest and grassland conversion is the main cause of higher greenhouse gas levels).

The Kyoto Protocol considers several mechanisms in order to achieve the goal of reducing emissions with respect to the 1990 level, namely, Joint Implementation (JI), Emissions Trading (ET), and Clean Development Mechanism (CDM). Among these three, only the CDM is allowed between a developed and a developing country. The other two are restricted for use among developing nations.

Other policies, to be practiced within a country, are the use of carbon taxes and emissions trading. An emission (or carbon) tax is one way of introducing a price and redefining property rights. Another would be to use emission licenses. The maximum emissions per firm could be specified by policymakers, and a secondary market for such permits would implicitly set a price on emissions. In all of these cases, the environment as a receptacle of emissions would be transformed into a private resource and its use would have a positive price. We will now focus on describing the issues related to the CDM, the taxes and the trading system, and their expected impact regarding the Protocol.

4. ECONOMIC INSTRUMENTS

The central objective of the economic instruments proposed here is to reduce emissions at the lowest possible cost. Here we discuss three options. The first one is the Clean Development Mechanism. This is one of the instruments considered under the Kyoto Protocol and its goal is "to implement projects that reduce emissions in non-Annex I Parties, or absorb carbon through afforestation or reforestation activities, in return for certified emission reductions and assist the host parties in achieving sustainable development and contributing to the ultimate objective of the Convention" [5]. The CDM is supervised by the CDM

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[5] A Certified Emission Reductions (CERs) is the technical term for the output of Clean Development Mechanism (CDM) projects, as defined by the Kyoto Protocol. A unit of greenhouse gas reductions that has been generated and certified under the provisions of

Executive Board" (UNFCCC, 2004). In terms of the Kyoto mechanisms, Mexico is eligible to participate in this. The other two mechanisms that we discuss are carbon taxes and emissions trading. None of them are considered in the Protocol: taxes are not discussed and trading is only allowed between industrialized countries, which rules Mexico out. It is important however to discuss carbon taxes and trading here as part of a complete discussion of all the options involved in combating global warming. It is also important, we would argue, to discuss the impacts of carbon taxes and emissions trading on the Mexican economy as we do in chapters 7, 8, and 9 below. This importance stems first from the fact it is essential to know the effect of such policies on Mexico's consumer welfare and economic growth if and when they are put into effect. Second, to the extent that Mexico has features in common with other Latin American and developing countries, such results take on increased importance worldwide. Finally, for the Kyoto Protocol to be truly effective the participation of the U. S. is essential and any U.S. participation will come only when other nations agree to the use of instruments such as carbon taxes and/or emissions permits.

4.1 The Clean Development Mechanism

The idea of the Clean Development Mechanism was first introduced by the Norwegians in 1992, at the Earth Summit in Rio de Janeiro, and since that time it has become the topic of heated debate between its supporters and those who remain skeptical about its usefulness. Some perceive it as a variation on the concept of tradable permits which has received considerable attention.

Basically, the Clean Development Mechanism (or CDM) calls for the establishment of a system whereby one country (usually an advanced industrialized country) invests in projects designed to curb carbon emissions in another country (usually a developing country). The idea here is that the investing country has a higher cost of curbing greenhouse gas emissions than the host country does, and that this provides a cost efficient way of cutting ambient emission levels. It, in effect, allows investor countries to shop around and find those host countries where it lowers its own abatement costs the most. The purpose of the Clean Development Mechanism shall be to assist parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments.

Article 12 of the Kyoto Protocol that addresses the Clean Development Mechanism (CDM) (http://www.cogeneration.net/certified_emission_reduction.htm).

While investors profit from CDM projects by obtaining reductions at costs lower than in their own countries, the gains to the developing country host parties are in the form of finance, technology and sustainable development benefits. The basic rules for the functioning of the CDM were agreed at the seventh Conference of Parties (COP7) held in Marrakesh in November 2001. Projects starting in the year 2000 are eligible to earn certified emission reductions if they lead to GHG reductions, which are additional to any that would occur in the absence of the CDM project. This includes afforestation and reforestation projects, which lead to the sequestration of carbon dioxide.

The eighth Conference of Parties (COP8) met in New Delhi in 2002, and had minor agreements reached compared to COP5, COP6 and COP7. At COP7 the parties adopted general rules for the CDM and established an interim executive board to get the CDM under way pending Kyoto's entry into force. At COP8 the parties only adopted rules for the executive board of the CDM, and a share of the proceeds from project activities that will be used to assist developing countries in meeting the costs of adaptation to climate change.

Advocates of CDM stress that greenhouse gases are somewhat unique among pollutants in that one ton of such gases released anywhere on Earth have the same atmospheric effect. Put another way, it does not matter if emissions are reduced in Mexico, Russia, the United States or any place else in the world. The only thing that matters is that the level of worldwide emissions declines. Both host countries and investing countries stand to benefit from CDM. Investing countries benefit from the lower cost of greenhouse gas emissions abatement abroad. These countries, as mentioned above, are generally the industrialized countries. They are the countries most responsible for worldwide CO_2 emissions, and they are uniformly worried about the impact of CO_2 abatement on their competitive advantage vis-a-vis other industrialized countries. For such countries unilateral action is impossible due to the high costs of abatement and the subsequent loss of international competitiveness that would bring (see, for example Barrett, 1995; and Jepma, 1995), and CDM offers them a lower cost alternative. From a global standpoint CDM is desirable since it leads to lower aggregate costs.

Host countries also stand to gain from CDM. First of all, and most importantly, these countries get the benefit of environmental cleanup. For many years it was thought that developing countries such as Mexico had a minimal interest in any environmental protection coming about at the expense of economic growth and development. Recent studies, however, (see for example Grossman and Krueger, 1991), indicate the presence of a so-called "Environmental Kuznets Curve". Their findings show that, as expected, environmental quality is a normal good and that after a certain level of income, individuals in developing countries are willing to sacrifice some economic development for the sake of a better environment. Interstingly this increased preference for environmental quality seems to occur at a per capita income of around $5,000 per year placing countries such as Mexico in that region where people do indeed value the environment. The critical income level depends on the type of pollutant being analyzed.

A second benefit of CDM for host countries is the opportunity it gives them to acquire advanced technology. Because of the investment from developed countries, these host countries are able to expand their economies in a fuel-efficient manner. Furthermore, in working with firms from more developed countries, workers in host countries are able to learn new technical skills and enhance their productivity. Finally, the lack of infrastructure and other protection from natural disasters makes developing countries particularly vulnerable to the ravages caused by global warming, and most developing countries realize that abatement of greenhouse gases is in their best interest.

Implementation of CDM Projects

Clean Development Mechanism projects can take several forms depending on the entities, countries, and situations involved. They can, for example, come about as the result of an agreement between two sovereign states (see, for example, Jones, 1994; and Michaelowa, 1995). Under this type of arrangement the investing country can either use a public entity or a private enterprise to carry out the CDM project in the host country. CDM projects could also be carried out by the private sector. Firms could become interested in these activities if their countries gave them financial incentives for their participation. Conversely, private corporations may want to participate in order to give themselves an environmentally friendly profile or to stave off new environmental regulations at home. Private corporations could potentially be a source of substantial funds for CDM investment projects without many of the inefficiencies associated with government sponsored investment.

Regardless of the method chosen, some monitoring agency needs to be set up to inform both countries on the progress of the project or projects being carried out. Indeed, this agency could be expanded to identify potential CDM projects and follow up on them.

Finally, as mentioned by several authors (e.g., Jones, 1994; and Michaelowa, 1995) CDM projects could be handled by an international organization, and in fact now several exist. The aim of such an organization would be to take funds from investment countries, pool the funds, and disperse them for use in projects taking place in host countries. This approach would have the advantage of being more coordinated than the former two. It would also serve to spread risk and lead to healthy competition between host countries counties for project funding.

Opposition to CDM Projects

In spite of the advantages of CDM to both developed and developing countries discussed above, it is widely opposed by a number of groups. In particular, non-government organizations or NGO's in many developing countries strongly oppose any type of Clean Development Mechanism. They see CDM as an attempt by industrialized countries to defer making the changes in their own production and consumption patterns, and letting developing countries deal with climate problems. In effect, NGO's believe that industrialized countries are using CDM as a way of buying themselves out of any responsibility for climate change. Interestingly, skepticism about CDM is shared by environmentalists in industrialized countries as well, and to be widely accepted, any CDM project will need to comply with a number of strict criteria. Indeed, the need for such criteria was seen as far back as 1992, and it was placed in Article 4 of the final draft of that convention signed by 155 countries (see, for example, Hare and Stevens, 1995; and Climate Network Europe, 1994). According to the FCCC document the criteria for CDM is to be determined by a Conference of the Parties (COP). In addition, the COP is to determine the size of the projects and the type of institutions involved.

Although no criteria have officially been established, yet various authors (see, for example, Parikh, 1995; and Loske and Obenthur, 1994) have offered some suggestion as to just what this might entail. First, they believe that any CDM projects should be done in addition to current assistance for economic development rather than as a replacement for such assistance. This is important because many developing countries will fear that the industrialized countries will use the CDM as an excuse to drop much of their traditional aid projects for economic and social development. Additionally, there is concern among those developing countries with little emissions and small GDPs that countries such as China, India, Brazil, and Mexico -with the large fossil fuel driven economies- will garner the lion's share of all CDM investment, and, that if these CDM funds are allowed to crowd out traditional development assistance, they will suffer. Hence, these authors recommend that all industrialized countries establish a policy that a certain percentage of their GDP be allocated to the traditional development projects that they are currently funding.

Second, more attention should be given to projects that curtail carbon emissions and less attention be given to projects such as reforestation which create so-called "Carbon Sinks". They argue that there exists a lot of uncertainty as to the amount of carbon actually sequestered by new forest growth. They point out that although sinks are quite cost effective they are only stop-gap measures and eventually the problem of climate change has to be dealt with by emissions reduction. Finally, they point out that there are other greenhouse gases besides CO_2 which carbon sequestration cannot alleviate.

The idea of "Carbon Sinks", however, has many defenders, and they present very strong arguments in support of their case. Sedjo (1998), for example states that the amount of carbon sequestered in trees is equal to about 50% of its biomass and is fairly easy to measure using current sampling techniques. He agrees that the potential of sinks to offset carbon emissions is "limited", but he points out that they are cost effective, and he says that "the best way to view sinks is as a temporary low-cost mitigation strategy that can buy humanity three to five decades to make more fundamental changes". Sedjo also points out that much of opposition to carbon sinks has to do with political self-interest on the part of various countries. Many countries in Western Europe, he notes, have a limited potential for additional forest growth and these countries have been the most resistant to the idea of giving countries emissions credits for projects such as reforestation. Nations such as the U.S. and Canada, on the other hand, expect their stock of managed forests to increase significantly in the early part of the 21st century, and, consequently, they have been among the most vocal advocates for the use of carbon sinks in global warming agreements. Furthermore, as Cline (1991) notes "the lowest-cost means of obtaining major initial reductions in carbon emissions is to reduce deforestation and to place new land in forests ... and [if] developing countries are expected to begin to make their own contributions to emissions restraint, reduced deforestation would be a critical component with or without special finance from industrial countries." This last point is particularly relevant to developing countries with large (potential) tracts of forests like Mexico as we shall see in chapter 9.

In the following sections we turn to other means of dealing with the GHG externality problem on both a national and international scale. More specifically we look at a tax on the emission of carbon and a system of tradable carbon emissions permits. Such an exercise as this could be questioned as irrelevant on the grounds that they are not contained in the existing Kyoto accords. While this is true such a discussion is, we would argue, very relevant. First, while instruments such as carbon taxes and emissions permits are not presently called for under the existing Kyoto framework they are not banned and countries are certainly free to employ them as domestic policies where necessary. Second, at the present time the U.S. is not a participant in the agreement, and it is unrealistic to imagine that Kyoto or any international agreement on climate change could ever be effective without U.S. participation. As policymakers in the U.S. have clearly stated, however, it is impossible to have U.S. participation without carbon taxes, permits or both as part of the agreement. Finally, Mexico has its own energy concerns and its own wish to curtail needless energy use and this too warrants a full discussion of these two important policy instruments.

4.2 Carbon Taxes on Fuels

A carbon tax is essentially an excise tax that is levied in proportion to the carbon content of fossil fuels. For any given level of energy, the most carbon intensive of the major types of fossil fuels is coal. By contrast the cleanest burning of fossil fuels is natural gas. Oil and refinery products tend to have a level of carbon somewhere between that of coal and natural gas depending on the particular petroleum product being considered. As it turns out, a carbon tax is a very cost-effective way to achieve a given level of CO_2 emissions since it is able to equalize the marginal cost of CO_2 abatement across fuels (see for example Manne and Richels, 1993; Jorgenson and Wilcoxen, 1993). Put another way carbon taxes are an efficient means of reducing CO_2 emissions because they raise fuel prices to curb general energy consumption and because they affect fuel choice and induce consumers to switch to fuels with relatively less carbon content.

The subject of carbon taxes has been treated extensively in the theoretical literature, and over the past decade, economists (Pezzey, 1992; Walker and Birol, 1992; and Poterba, 1993), have advanced certain criteria essential to the successful implementation of such a tax. First of all, they point out that if a carbon tax is to reflect the rising damage of CO_2 accumulation it should be increased gradually over time. Gradual implementation also has the practical advantage of allowing more flexibility for energy alternatives to come on line in response to the proper market signals and eliminates the need for rapid costly adjustments. Second, in order to be effective, carbon taxes must be implemented jointly by a number of countries rather than unilaterally by only a few countries. As Cline (1991) points out, there is a definite “free rider” problem since each country wants to get the benefits from global warming abatement, but every country has a strong economic incentive to avoid the costs of cutting back on their own greenhouse gas emissions. In the absence of cooperation, low-cost non-participating countries could undermine the cutbacks in the participating countries. Third, there has to be a real possibility for fuel switching and the availability of viable “backstop” technologies such as wind, solar, and geothermal power. Without such alternatives the cost of the tax could become exorbitant (Barrett, 1991). This is especially true for developing countries like Mexico and other Latin American countries where any severe cutback in economic growth could entail disastrous social and political consequences. Finally, as with any excise tax, the imposition of a carbon tax by itself entails price distortions, allocative inefficiencies and deadweight welfare losses. Such taxes, additionally, are usually introduced into an economy like Mexico’s which has many pre-existing taxes (e.g. the VAT and income tax) along with a host of subsidies and special taxes in the energy, power, and agricultural sectors. When these existing distortions are taken into account or when the revenues generated from the imposition of a carbon tax are recycled into the economy for replacing another indirect tax, second best considerations (Harberger, 1962) can cut the welfare losses of a carbon tax (see also Pearce, 1991; and Goulder, 1994)). These taxes interact in very complicated ways, however, and the size of the welfare loss is an empirical question.

Before a carbon tax is levied it is essential to determine its effect on the economic as well as environmental welfare of that country. Most taxes impose some sort of welfare loss on the economy. Economists (such as Harberger, 1964) have, however, noted that a tax levied on an economy may interact with existing taxes to actually create a welfare gain. In this spirit, some (e.g., Lee, Misiolek and Pearce, 1991; Goulder, 1995) have long noted the possibility of a so-called "Double-Dividend" from a carbon tax. The first dividend, it is argued, is the environmental dividend that comes about through the reduced emissions of greenhouse gases, and the second dividend is the reduction in overall economic cost due to raising government revenues through a "Green Tax" which is less distortionary than the sales and income taxes which it replaces.

In his study, Goulder (1995) makes a further distinction between a "weak" double dividend and a "strong" double dividend. A "weak" double dividend occurs because the revenue gained from the implementation of a carbon tax allows policy makers to reduce highly distortionary taxes like the value added tax (VAT). This, in turn, leads to an overall increase in economic welfare over the original situation. A "strong" double dividend occurs when the non-environmental economic benefits of a carbon tax are actually greater than its economic costs. Most economists have serious doubts about the actual existence of a strong double dividend and simulations by authors such as Böhringer and Rutherford (1996) find little evidence of such an occurrence in modern industrialized countries. The concept of a "weak double dividend", by contrast has found more support among economists. Indeed, studies by DRI (1991), Standeart (1992), and Karadeloglou (1992) find that reducing the VAT while imposing a carbon tax tends to offset its inflationary impacts as well as its negative effect on the level of GDP. All things considered, however, the ideal of a "weak double dividend" is fairly tautological.

The extent of all gains or losses, however, depends on the types of taxes reduced as well as the responsiveness of the various agents in the economy to price signals. In the final analysis the existence or non-existence of a double dividend is an empirical question and most empirical studies of this issue have concentrated on developed countries such as the U.S., Japan, and the countries of Western Europe. Developing countries such as Mexico have been largely ignored even though their compliance is essential to the effectiveness of any worldwide climate change treaty. However, Ibarraran (1999) studies the existence of a double dividend from a carbon tax for the case of Mexico.

A second criterion to be considered before imposing a carbon tax is its equity effects on the country or countries in question. In most industrialized countries a carbon tax is generally thought to be regressive since those with the lowest incomes tend to spend a higher share of their income on energy and fossil fuel products. In a recent study, Doroodian and Boyd (2001) looked at the impact of a carbon tax (spanning 40 years from 2000 to 2039) on the distribution of income in the United States. Their results show that the poorest third of the population spends 1.35% more of their total yearly income on energy, while those in the middle third would pay 1.29% more on energy, and those in the highest third would pay 1.18% more on energy. Hence, although the differences are small, those in the lower income groups would be hurt relatively more by such a tax while those in the higher income groups would be hurt relatively less by the tax. A study by Smith (1992) comes to similar conclusions about the distributional effects of an energy tax in the UK.

Authors such as Shah and Larsen (1992) have cautioned that results like these from developed countries cannot be immediately generalized to developing countries. They have pointed out that any carbon tax in developing countries could be affected by institutional factors such as price controls, import and export quotas, rationed foreign exchange and the presence of black markets.

The case of Mexico, however, is quite different from that of most other developing countries. Mexico is a net exporter of oil, and the abundance of oil in Mexico combined with subsidies on fuel and electric power (see ESMAP, 2001) have made energy relatively accessible to lower income consumers. Indeed information reported by INEGI (2000) indicates that energy consumption does make up a substantial portion of the budget of consumers in the lower income groups. As with economic efficiency, the impact of a carbon tax on equity in Mexico is ultimately an empirical question.

Authors such as Cline (1991), however, have pointed out developing countries need not rely solely on the revenues of their own carbon taxes. Since such taxes would only be levied in conjunction with similar taxes in developed countries, the revenues from taxes from the EU and the U.S. could be used to finance more fuel efficient energy and manufacturing industries in countries such as Mexico. These funds could also be used to cut down on deforestation and assist reforestation efforts in the third world through the Clean Development Mechanisms suggested in the Kyoto Protocol, discussed above.

The final thing to be considered when assessing both the short and long term viability of a national carbon tax is the effect that this tax will have on a nation's competitiveness in the international arena. Because a carbon tax raises the prices of both energy and energy intensive goods it can hurt the ability of a country to sell its goods in international markets. This is especially true if such a tax is unilaterally imposed by one country or a small group of countries. Even if an action like this is taken as part of a global effort, certain types of countries may be more apt than others to suffer in terms of their exports. Put another way, a worldwide carbon tax may produce "net losers" and "net winners" when it comes to their international competitiveness. Mexico, for example, is a net exporter of petroleum. Furthermore, because of its relative abundance of energy much of Mexico's exports such as chemicals, petrochemicals, and refined goods are high in energy content. Following a global tax on carbon Mexico might be faced with declining demand for one of its main exports, crude oil, and this, combined with the increased prices of its other exports could lead to serious trade losses. Compensatory mechanisms at the international level are an object of ongoing research and we will offer some observations on these issues further on.

Aside from international losses, certain industries within a country can be expected to be hurt relatively more severely by a carbon tax than others, especially in the short term. In response to such concerns the Commission of the European Communities (i.e., CEC) issued a report in 1992 suggesting that the European community exempt certain critical energy intensive industries from all or part of this tax. These industries are (1) iron and steel, (2) cement, (3) glass, (4) nonferrous metals, (5) chemicals, and (6) pulp and paper. Obviously, such actions reduce the effectiveness of a carbon tax to cut back on greenhouse emissions. The idea here, however, would be to slowly remove these exemptions over time and give these industries a chance to adopt more fuel efficient technologies.

4.3 Tradable Carbon Emission Permits

An alternative to a global carbon tax would be a system in which carbon emission permits are issued to various countries, and those countries are allowed to buy or trade their entitlements with other countries. This idea has been around for quite some time (see, for example Pearce, 1990; and Hoel, 1991), as discussed in section 1 above. However, the recent success of programs such as the U.S. Clean Air Act of 1990 has now made the idea of tradable permits an attractive option as a means to cut back on greenhouse gases. As stated there, the idea behind such a system is simple. As long as the marginal cost of reducing CO_2 and other greenhouse gas emissions differs between countries, those countries with low cleanup costs will have an incentive to sell their permits to those countries with high cleanup costs. At the same time, high cost countries will find it less expensive to buy permits from low cost countries than to further cut their own emissions. In the end, the marginal cleanup cost will be equalized among nations and emissions will be cut back in an economically efficient way.

The first objective of an emissions permit system would be to establish a target for the level of global emissions. This target could be varied from year to year and it is generally thought that the overall target would be gradually obtained over time. This is due to the fact that alternative technologies –that are currently available but not currently economically viable on a large scale - need time to develop and that harsh emission reductions can stifle long-term economic growth. Indeed these last points are particularly relevant to countries like Mexico where technology transfer is crucial and where energy use and export is essential for long term economic growth.

After an overall emission level is set, the second problem of a permit system is how to allocate these permits among the participating countries. On this score a number of options have been proposed. First, it has been suggested that permits be issued on the basis of a country's historical level of greenhouse emissions (i.e., a grandfathering approach). Alternatively emission permits could be issued on a current GNP (or GDP) and population basis, or a uniform percentage reduction across all of the participating countries. The subject of optimal permit allocation has been treated in a number of articles (see, for example, Grubb, 1989; Rose, 1990; Hoel, 1991; Welsch, 1993; Rose and Stevens, 1993; and Larsen and Shah, 1994). There remains, however, a lack of consensus as to what rule leads to the most equitable allocation of emissions permits (Jotzo, 2005).

In his article, Welsch (1993) argues that an equal percentage cutback has the advantage of being straightforward and is based on the basic principle that all countries share the burden of cutting back to the same degree. As Rose and Stevens (1993) argue, however, such a rule ignores the fact that CO_2 is built up in the atmosphere over time and that developing countries - such as Mexico - are responsible for fewer CO_2 emissions in the past than developed countries - such as the United States. This, in effect unfairly thwarts the development of third-world nations vies-a-vie developed countries which faced no such constraint when economic expansion occurred there. From an equity standpoint, then, this criterion by itself has a host of problems, and it is hard to imagine such a strategy being agreed to by developing countries. Furthermore, these same authors point out that when the developed countries produced carbon emissions in the past that they, in effect, were ignoring an externality and producing goods in an allocatively inefficient manner. By instituting an equal percentage cutback, they then argue, policy makers are thus implicitly rewarding past inefficiency in energy and manufacturing production.

An alternative to basing cutbacks to historical emissions is to base them on the level of a country's GNP or GDP. The reasoning behind this is that, because energy is required for economic production, any severe divergence from the distribution of production could force unnecessary reductions in global output. Using GDP as the basis for quota allocation would not avoid the problem of rewarding past inefficiency in the use of energy however, and it would not avoid the problem of global inequity since current production is, by and large, concentrated in the developed countries.

The idea of grandfathering permits based on a country's past emissions of greenhouse gases or on the current levels of GNP also has its problems. Like an equal percentage cutback in CO_2 emissions, this kind of grandfathering approach would tend to favor developed countries with their high existing levels of output and fossil fuel usage. In addition it arguably gives an unfair advantage to one set of developing countries over another. If, for example, permits were now issued on the basis of CO_2 emissions, developed countries such as France which relies heavily on nuclear power would be penalized relative to countries such as the United States and the U.K. which produce most of their power using traditional fossil fuels such as oil and coal. To rectify such inequities the permit authorities could be forced to give extra permits on the basis of past cutbacks. This kind of a scheme, however, would be quite complicated, and could be perceived as too subjective.

The idea of allocating CO_2 emission permits on the basis of a country's population would be quite appealing to developing countries since generally they have a high population to greenhouse gas emissions ratio. Indeed, this kind of an allocation scheme can be seen as the ultimate equity-oriented rule. In this case, however, one would expect that this kind of system would never be agreed to. As Kverndokk (1993) has pointed out, if such a scheme were actually implemented the United States and the Western European nations would, in effect, have to transfer between 3% and 6% of their annual GDP to developing countries. The developed countries would be hard pressed to agree to this, given that none of them presently pay more than 0.7% of their national product for development assistance. In addition to these obstacles a system of emissions permits based on population may have the unintended spillover effect of creating an incentive to expand a country's population, depending on their stage of the development and their initial per capita GDP level. Obviously, this is exactly the opposite of what a climate change treaty is designed to do and would cut down its effectiveness a great deal.

Given the objections to all of these permit allocation schemes in their pure form, economists such as Pearce (1990) and Cline (1992) have advocated a combination of the different methods. According to them, the best type of allocation policy would be one where all three rules (i.e., permits by CO_2 emissions, GDP, and population) are used through a weighted average. Initially permits would be grandfathered in, but over time, the value of the permits in developed countries would decrease. In developing countries, by contrast, the value of the permits would increase over time reflecting the population criteria. The rise in permits in the developing countries, however, would less than offset the decline in the developed countries. Cline (1991) estimated that under a system of equal weights, the United States would have to cut back on emissions approximately 16% of the total world cutback. By similar calculations he finds that Japan would be responsible for 5.2% of the world's total cutback. The point of all these calculations is to show that under such a scheme the industrial countries would face substantial cleanup costs and would be forced to buy significant quota rights from developing countries such as India and Brazil.

4.4 Carbon Taxes vs. Tradable Emissions Permits

As we have seen, the purpose of both carbon taxes and tradable emissions is to minimize the overall cost of cutting back on harmful greenhouse gases. As authors such as Baumol and Oates (1988) have pointed out, since the aim of both policies is to equalize the marginal cleanup costs across emitters, the results of both should be identical in a world of perfect competition and no uncertainty. To the extent, however, that either of these is absent, the emission output levels and economic efficiency of carbon taxes and tradable permits may differ.

Over the last 10 years, economists have developed several strong arguments in favor of tradable permits over the alternative of carbon taxes. First of all, it is argued, tradable permits specify a particular level of allowed emissions, and this gives us more certainty at arriving at a specific emissions target. Carbon taxes, on the other hand, work on emissions levels indirectly through prices, and in using such instruments we run the danger of undershooting or overshooting our emissions target (see Cline, 1992). This problem with carbon taxes is further complicated by the fact that different fossil fuels have different levels of carbon content and must be taxed at various rates. Once particular tax rates have been established, as a practical matter it is a very difficult and time-consuming process to change them if they are incorrect and fail to lower emissions to the targeted amount.

Another practical problem with carbon taxes has to do with the level of the actual tax burden placed on producers. Ideally the level of carbon taxes should be set where the level of the marginal damages due to the emissions is equal to the level of the marginal benefits of emissions cutbacks. To do this requires that the level of taxes be set so that it is equal to marginal rather than average damages and, as Baumol and Oates (1988) point out, the tax levy may be so onerous that the emitters may be forced to shut down completely. From the viewpoint of aggregate economic efficiency there is nothing wrong with this result per se; as a practical, however, the prospect of having a number of businesses and power suppliers going out of business is a prospect that may be politically untenable.

A final argument against the use of carbon taxes as an emissions reductions device has to do with the level of energy taxes across countries. Because of the existence of trade barriers, taxes, natural monopolies, subsidies, and other market distortions, the price of energy varies greatly among different countries and across different fuels. The price of energy to consumers in Mexico and the United States, for example, is presently much lower than the price of energy to consumers in Europe and Japan (see for example Hoeller and Coppel, 1992; Cline, 1992; and World Energy Council, 2000). This, in effect, means that we have an uneven playing field when carbon taxes are implemented and in a world of such price distortions**,** those countries with the lowest prices would need to raise taxes the least in order to achieve any given target level for carbon emissions reductions, and this would give them free-rider benefits. Put another way, the high taxes in countries with high energy prices have already gone a long way to reducing the use of fossil fuels. To achieve any further large absolute reductions, then, these countries will have to raise taxes significantly to spur further conservation measures. Countries with low prices and taxes, on the other hand will only need modest tax hikes to realize large absolute cuts as consumers and producers reduce inefficiency and turn to relatively low priced alternatives. While this would indeed be beneficial to low energy price countries like Mexico it might make energy taxes unacceptable to the higher cost countries in Western Europe and Japan. At the very least it appears certain that any internationally run carbon tax system would have to be coupled with the removal of existing distortions in all international energy markets. Removal of these distortions, however, might be very difficult to negotiate, and this would add to the difficulty of implementing any system of carbon taxes.

Adopting a system using tradable emissions permits to curb greenhouse gas levels would avoid many of the troubles associated with carbon taxes. Tradable emissions permits, however, are not without their own problems. As discussed above, there are a variety of ways to allocate these permits and each way has its drawbacks. Indeed, if developing countries are to be persuaded to join an agreement, the allocation scheme will have to be quite flexible, and permits will have to be allocated on some basis other than the existing levels of emissions alone. On the other hand an international carbon tax system would be blind with respect to individual countries and parties while the underlying "equity" value judgment about who gets to use fossil fuels becomes explicit in the initial allocation. Indeed, the need to decide on quota allocation has been the source of many severe negotiation difficulties.

A workable system of tradable permits needs both a sufficient number of participating countries and a heterogeneous mix of countries. If the market for permits is too thin, then the participating countries have a great deal of trouble finding any trading partners. Furthermore, if all participating countries are homogeneous in terms of their compliance costs there exists very little incentive for any country to trade in order to reduce such costs. It is generally believed (Dasgupta et al., 1999) that developing countries such as Mexico have lower compliance costs than developed countries and their participation would greatly facilitate any trading permit system. Any tradable permit system would need a large number of developing country participants if it is to be politically, economically, and environmentally viable.

Some countries' participation in the permit market is crucial. For example, as shown by Böhringer and Löschel (2003), if the US withdraws from the Kyoto Protocol, the demand for permits would drop significantly and the prices of permits would fall. This would have a strong negative impact on the environmental effectiveness of this policy and severely reduce the expected revenues for both transition economies and the members of the Former Soviet Union.

Besides a large and varied group of participants any workable permit system needs an international agency to monitor and enforce compliance. There may be occasions (see Hoel, 1991) where a nation is large enough to have monopoly or monopsony power and may be able to seriously influence the price of permits. Large sellers would strive to have a higher level of emissions than would be optimal if one is looking strictly at their marginal abatement costs. Large buyers, by contrast, would try to have a lower level of emissions than would be optimal if one is looking at their marginal abatement costs. In a market with such incentives then an agency may need to intervene on occasion and stabilize the price of such permits.

There are several other reasons why an international agency is essential here. First of all, an agency has to monitor trades and enforce fair play. Market abuse needs to be penalized and only an outside force such as an international agency can do this. Second, changes in both environmental and economic conditions will make it necessary to adjust the overall level of restrictions from time to time. A downturn in economic activity and fears of recession will inevitably lead to calls for loosening restrictions while increased global temperature concerns will lead to calls for tightening things up and increasing restrictions and here again an international agency is needed to do this.

While the role of an international agency is clear the means by which it is allowed to carry out its tasks have yet to be determined. Countries, by their very nature are sovereign and very suspicious of any type of outside entity that may impinge on such sovereignty. Indeed, the objections of industrialized countries to agencies like the UN and WTO can be expected to replay themselves with any establishment of an international emissions regulatory agency. Developing countries too may feel uneasy about the kind of control such an agency may have on the freedom of their national economies. Mexico, for example, has experienced a long history of outside interference in its internal affairs, and it has responded in the past by means of both political upheaval and natural resource nationalization. Any international body which is established to regulate greenhouse gas emissions then must be perceived by all, developed and developing countries, as being both impartial and respectful of national sovereignty. A prototype for this type of agency is the Chicago Carbon Exchange, which has been established recently, and works in a manner similar to a stock exchange.

With all of this said, the question remains as to whether tradable permits are to be preferred to carbon taxes or vice versa. As we have seen, any emissions control program will require the presence of an international agency, and any program is likely to be plagued by difficulties in effective outside monitoring as well as on strong doubt about its political and financial viability. Both permits and taxes have their drawbacks with respect to economic efficiency as well. At the present time there is no clear consensus as to the extent of the long run environmental and economic damages associated with continued carbon emissions. If it turns out that there has been a serious miscalculation and emissions damages are much lower than expected then a price based mechanism such as carbon taxes is to be preferred to a quantity based system such as permits (see for example, Shah and Larsen, 1992, for a discussion on this). If, on the other hand, scientists indeed believe that there is some threshold beyond which the cost of emissions damages climb unacceptably high, then it is probably best to have a system of tradable permits (see Kägeson, 1991; and Shah and Larsen, 1992). The ultimate decision of which mechanism to use then is a complicated one, and it depends on the relative political acceptability of these two alternatives as well as the reliability of damage estimates.

5. LATIN AMERICA AND THE KYOTO PROTOCOL

Latin America is part of the Group of 77 (G-77, now made up of 133 developing countries) and China. It has been difficult for this large group of 134 nations to have a unified position regarding the Kyoto negotiations. However, within Latin America itself, there is a near consensus to have a single aligned regional position. The lone holdout is Venezuela, which, as a leading oil exporter, believes that a reduction in CO_2 emissions from the consumption and flaring of fossil fuels will severely reduce its main source of income and international exchange. Brazil, second in emissions (after Mexico), is reluctant to sacrifice economic growth to slow the buildup of carbon emissions in the atmosphere. On the other hand, Chile, Uruguay, and Argentina, together with the Caribbean and Island States, are quite eager to negotiate with a single voice.

As of this point in time, as countries within the Latin American region have adopted only the minimal actions specified for non-Annex I countries. All Latin American countries are now submitting GHG inventory reports and taking isolated actions to reduce emissions from energy use. Nevertheless, the actions being taken are largely to abate local pollution rather than to deal with climate change in any meaningful way. Up until now, no country in Latin America has voluntarily adopted emission reduction targets. Argentina had made a voluntary commitment to reduce emissions, but it withdrew its commitment in the face of heavy opposition from the other G-77 countries.

Latin American countries could potentially benefit from several of the policies established and promoted by the Kyoto agreement. First of all they could take advantage of those provisions in the Clean Development Mechanism which calls for technology transfers from developed to developing countries. Second, as discussed in chapter 9, they could realize substantial economic gains from funds to be provided by the CDM for forestation and reforestation as part of its world-wide effort to promote carbon sequestration. Finally, they could find it in their interest to engage in the trading of emission permits with developed countries such as the U.S.

Latin America is one of the most highly forested areas in the world with 88% of its total forested land located in Brazil, Peru, Mexico, Bolivia, Colombia, Venezuela, and Argentina. At the same time, vast amounts of these forests are being lost. The greatest of these losses have occurred in Brazil where 23 million hectors (or 4.2% of that country's forests) were cut down between 1990 and 2000. Over that same time period, Mexico experienced the second greatest loss of forests in Latin America. Mexico lost 6.3 million hectares of forested land over the 1990's and had an annual deforestation rate of 1.1%, almost triple that of Brazil. This is equivalent to a deforestation rate of over 800 thousand hectors per year (UNEP, 2003).

Throughout the Latin American region natural forests face great pressure from the expansion of the agricultural and urban frontiers, from the building of roads, and from mining activities. Much of this expansion is driven by government policies such as subsidies to agriculture, livestock, and urban development. The remainder of the damage is brought about by a combination of natural and man-made causes including forest fires, wood extraction, severe weather conditions, and pestilence.

There is a huge potential to use the Amazonian forest area of Brazil as a carbon sink. Indeed, this region contains the largest single tract of forested land and tropical vegetation on earth. Since the 1970's, however, Brazil has faced problems of severe deforestation due in part to the heavy concentration of Amazonian land ownership in just a few hands. Furthermore, in the wake of severe droughts in northeastern Brazil, large migratory movements to the Amazonian region have occurred. Road construction investments during that same period led to lower transportation costs and made it much easier to extract wood from the region. Finally the inflexible institutions, antiquated laws, and the perverse economic incentives of recent land reform policies have all contributed to the widespread destruction of the existing rainforest.

Instituto Nacional de Colonização e Reforma Agrária or INCRA is the chief federal government agency responsible for agrarian reform as well titling the claims of landowners in this region. In theory, it has sovereignty over the affairs in this entire region but in reality its effectiveness is limited by poor staffing and inadequate funding by the federal government. In addition to inadequate funding, many of the problems that the government in the Amazon faces today stems from conflicting laws coupled with ill-defined and insecure property rights over the land. Quite often, poor migrants from other regions of Brazil settle in the Amazonian states as squatters and claim ownership over unclaimed government land as well as “unused “private land. Although by law the state has the right to expropriate land from the individuals that are not carrying out the social function of the land, those squatters who occupy and develop private land, if evicted, have the right to compensation for improvements they have made to the land[6]. Another law defines forested (and hence protected) land in the Amazon region as those properties which retain 80% of their area in forests. Often, however INCRA interprets the observation of this law as evidence that the property is unproductive and subject to expropriation.

In the midst of this confusion, squatters have strong incentive to remove forests which are both presently unproductive and involve high monitoring costs. They also have an incentive to clear land since if they are evicted they must be compensated for their improvements. Landowners, on the other hand, have an incentive to evict squatters before INCRA and the courts get involved and they have an incentive to clear their own land as well. All of this has led to violent conflicts over land ownership and has promoted the use of deforestation as a means of reducing potential disputes for land (Alston et al., 2000).

As for Mexico, between 1940 and 1970, the agricultural sector, supported by government subsidies, had an annual growth rate of over 4%. Government assistance during this time included funds for agricultural inputs, soft loans with low payback rates, and only very limited monitoring of the adjacent forested lands. This, in effect, expanded the agricultural frontier into Mexico’s forests. At the same time, Mexico’s forests did not receive anywhere near this level of governmental support and protection. All of this had disastrous consequences for both the temperate and the tropical forests of Mexico (Moran

[6] The *social function* of the land includes, among other things the rational use of the land as well as the preservation of the environment.

and Galleti, 2002, in UNEP, 2003). Forested areas, in effect, had no value to their owners, given that crops and livestock were much more attractive from an economic point of view, and this, in turn, led to the rampant destruction of woodlands.

In Mexico then, as in Brazil, uncertain property rights combined with perverse economic incentives has led to widespread deforestation. Faced with these disturbing trends in Latin America and elsewhere, the authors of Kyoto's Clean Development Mechanism have sought to introduce reforestation into these affected regions. The goal of the CDM project is quite simply to introduce mechanisms to give economic value back to the forests, so that their owners have incentives to protect them instead of cutting trees to grow food, raise livestock, or produce lumber.

In addition to the CDM, the Kyoto agreement calls for a tradable emission permit program which includes the forestry sector. This would, in theory, allow for a market price on the environmental services that forests carry out such as carbon sequestration, habitat for biodiversity and protection of water resources. These services do not presently have a market price, and indeed, such a market price would be difficult to estimate with any precision. When a cap is placed on emissions by the energy and manufacturing sectors, however, the price of these permits will be determined by the interaction of supply and demand in the permit market.[7] This price, in turn, will reflect the willingness of net emitters to pay for carbon sequestration in order to generate an additional unit of carbon dioxide or its equivalent. The tradable permits program will have a side benefit for the forestry sector itself since it will help siphon resources towards that activity, and it may prove beneficial in the fight against poverty. World-wide, of the 1200 million people who live in extreme poverty, 90% depend in some way on forestry resources to survive (World Bank, 2005).

Rescuing forests from the destruction then is crucial from both an ecological and an economic standpoint. If current trends continue into the future, forests and grasslands will eventually disappear worldwide. This could lead to effects such as widespread erosion and drought, water pollution, and the loss of biodiversity. In addition, it could contribute to the buildup of greenhouse gases and exacerbate the daunting problem of climate change which is the focus of most of our attention here in this book.

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[7] These manufacturing and energy sectors may be located in the developing countries where the forests are or alternatively in the developed countries who wish to purchase carbon sequestration for their own emissions activities. These issues will be taken up again at great length in our simulations in chapter 9.

6. CONCLUSIONS

In this chapter we have seen that economic incentives are needed to have any cost-effective program of emissions abatement policy. We have also seen the types of economic policies available to policymakers and examined the pros and cons of each. In all of this, however, it is important to recognize the political dimension of any agreement that is to be reached, and to be aware of the numerous problems involved in any international action to be taken. It is generally recognized that some type of carbon tax or emissions permit trading arrangement must be present at the national level if carbon emissions are to be reduced in a timely and efficient way. Furthermore, it is generally agreed that some type of emissions trading at the international level is essential if costs are to be contained when developing countries seek to limit their carbon emission levels. Nonetheless, any viable policy must be seen as equitable if it is to be widely accepted and, as we have seen, the concept of equity varies widely among countries with different income levels and at different levels of growth. In particular Latin America, as most developing regions, will only pursue that energy plan that is felt to be in its national interest, and any carbon abatement strategy that it undertakes must be seen as contributing to its sustainable development.

With these cautionary thoughts in mind we now proceed to chapter 6 where we provide a framework for the intersectoral computer modeling simulations to be done in the remainder of the book.

APPENDIX - List of countries under the Kyoto Protocol

Annex I Countries	Annex II Countries	Non-Annex I Countries				
Australia Austria Belarus Belgium Bulgaria Canada Coatia Czech Republic Denmark Estonia European Economic Community Finland France Germany Greece Hungary Iceland Ireland Italy Japan Latvia Liechtenstein Lithuania Luxembourg Monaco Netherlands New Zealand Norway Poland Portugal Romania Russian Federation Slovakia Slovenia Spain Sweden Switzerland Turkey Ukraine United Kingdom United States of America	Australia Austria Belgium Canada Denmark Finland France Germany Greece Iceland Ireland Italy Japan Luxembourg Netherlands New Zealand Norway Portugal Spain Sweden Switzerland Turkey United Kingdom United States of America European Commission	Afghanistan Albania Algeria Angola Antigua and Barbuda Argentina Armenia Azerbaijan Bahamas Bahrain Bangladesh Barbados Belize Benin Bhutan Bolivia Bosnia and Herzegovina Botswana Brazil Burkina Faso Burundi Cambodia Cameroon Cape Verde Central African Republic Chad Chile China Colombia Comoros	Congo Cook Islands Costa Rica Côte d'Ivoire Cuba Cyprus Democratic People's Republic of Korea Democratic Republic of the Congo Djibouti Dominica Dominican Republic Ecuador Egypt El Salvador Equatorial Guinea Eritrea Ethopia Fiji Gabon Gambia Georgia Ghana Grenada Guatemala Guinea Guinea Bissau Guyana Haití Honduras India	Indonesia Iran (Islamic Republic of) Israel Jamaica Jordan Kazakhstan Kenya Kiribati Kuwait Kyrgyzstan Lao People's Democratic Republic Lebanon Lesotho Liberia Libyan Arab Jamahiriya Madagascar Malawi Malaysia Maldives Mali Malta Marshall Islands Mauritania Mauritius Mexico Micronesia (Federated States of) Mongolia Morroco Mozambique Myanmar	Namibia Nauru Nepal Nicaragua Níger Nigeria Niue Oman Pakistan Palau Panama Papua New Guinea Paraguay Peru Philippines Qatar Republic of Korea Republic of Moldova Rwanda Saint Kitts and Nevis Saint Lucia St Vincent and the Grenadines Samoa San Marino Sao Tome and Principe Saudi Arabia Senegal Serbia and Montenegro Seychelles	Sierra Leone Singapore Solomon Islands South Africa Sri Lanka Sudan Suriname Swaziland Syrian Arab Republic Tajikistan Thailand The former Yugoslav Republic of Macedonia Togo Tonga Trinidad and Tobago Tunisia Turkmenistan Tuvalu Uganda United Arab Emirates United Republic of Tanzania Uruguay Uzbekistan Vanatu Venezuela Viet Nam Yemen Zambia Zimbabwe

Source: http://unfccc.int/parties_and_observers/parties/non_annex_i/items/2833.php

PART 2

CHAPTER 6

THE DYNAMIC GENERAL EQUILIBRIUM MODEL

This chapter sets up the computable general equilibrium (CGE) model used for the simulations of the Mexican economy reported in subsequent chapters. Within the framework of this model all sectors of the economy are linked and changes in any one sector affect prices and output economy-wide. The model is dynamic in nature and runs for twenty one time periods. It is based on previous work first initiated by Harberger in the 1960s and continued more recently by authors such as Shoven and Whalley, Goulder, and Rutherford. The model contains nine producing sectors, seven consumption goods, four income groups, a foreign sector and a government sector. The model is calibrated to a 2000 data set with pertinent information coming from a variety of sources. In the appendix, other recent energy and environmental modeling efforts are enumerated and briefly discussed.

1. THE GENERAL EQUILIBRIUM FRAMEWORK

Over the past 100 years most of the empirical work done in economics has relied upon partial equilibrium analysis. This type of analysis concentrates on a single market and quantifies the changes in supply, demand, prices, quantities, and welfare brought about by exogenous shocks and/or parametric changes. This type of analysis has been well suited to markets with limited size or with weak linkages to other economic sectors.

However, many economic problems are not conducive to analysis within such a simplified framework. Often, the economic sector analyzed is large and changes in that sector can have important repercussions throughout the economy. Such problems are more appropriately dealt with using general equilibrium analysis. In this type of analysis all the sectors in the economy are seen as one linked system where a change in any part affects prices and output economy-wide.

Mathematically, an interlinked economy cannot be described in one or two equations, but rather by a large system of simultaneous equations. More precisely in an economy with N markets, we require $N-1$ equations to solve for all of the prices and outputs in the system. Needless to say, while the theory behind general equilibrium can be described fairly easily, the computations involved in solving such a system are quite complex and have proved to be fairly difficult to solve. Indeed, it wasn't until the advent of high-speed computers and efficient solution algorithms that large economy-wide general equilibrium problems could be solved at all.

In a simple static model, the actual solution of a general equilibrium problem requires the modeler to construct a Social Accounting Matrix or SAM. In this SAM all production in all markets, all tax revenue of the government, all foreign transactions, and all consumption by all consumers for a specific base year have to be first replicated exactly. Hence, for a country like Mexico one must specify the amount of manufacturing, agricultural, energy and service outputs along with all other sectoral outputs which actually occurred during that particular base year. Supply and demand elasticities must also be specified, and the model calibrated through constants in each equation so that each consumer group is assigned the amount they actually consumed in that year. The equations are then solved and the results checked to see that the base year is indeed replicated. At this stage, the model is then run under a counterfactual scenario. Here a particular sector's supplies, demands, taxes or technology levels are altered, and the results from re-solving the model are compared with the original benchmark to show the changes in prices and output in each of the model's many sectors. In both runs, the total level of consumer welfare and GDP are also calculated and the two are compared to see what impact changes of these exogenous factors have on these economy-wide measures.

The use of general equilibrium analysis to calculate the impact of various economic policies dates back to the early work of Harberger (1962, 1964). Such analyses, however, were generally limited to two or three sectors until the advent of the more complicated computable general equilibrium (CGE) models in the early 1970's. The policies that have been analyzed through these models include changes in various kinds of taxes and tariffs, technological change, natural resource policy, and employment policy. Both efficiency and distribution impacts are presented in these studies (for the main features of the above models, see Shoven and Whalley, 1992) [1].

The extension of a static CGE model to a dynamic one is fairly straightforward. Although computationally more complex, a dynamic CGE model differs from its static counterpart only by the inclusion of a driving force to move the economy from period to period. In most dynamic models this force is provided by the growth in the underlying labor force and/or a change in the level of technology in one or more sectors of the economy. These changes are facilitated by new investments and the growth of the capital stock in the economy.

As with the static model the actual output for each sector in a specific base year is replicated through the calibration procedure. In addition, the economy is now expected to grow, and in the initial benchmark has to be run with all sectors, quantities, and factors of production, each of which are required to grow at the same steady state rate. When a counterfactual shock is then given to a dynamic CGE model two things occur. First, the affected prices and quantities traverse to a new growth path in the years following the shock. Second, the new growth path itself returns to a steady state but with economic variables at a level different than they would have been at in the benchmark case. Generally, the interest in these dynamic models is on that new path and how much higher or lower it is than the original benchmark path.

Analytical treatment of aggregate economic growth has its origin in the work of early theorists such as Ramsey (1928), Solow (1956), and Koopmans (1965). Nonetheless, due to their heavy computational requirements, true dynamic extensions of computable general equilibrium models are a fairly recent development. In the past few years, authors such as Summers

[1] Cornerstone works related to taxation models include Shoven and Whalley (1972), Whalley (1975), Shoven (1976), Ballentine and Thirsk (1979), Keller (1980), Piggot (1980), Slemrod (1983), Serra-Puche (1984), Pigott and Whalley (1985), and Ballard, Fullerton, Shoven, and Whalley (1985).

and Goulder (1989), Jorgenson and Wilcoxen (1990), and Rutherford, Montgomery and Bernstein (1997) have begun to use dynamic CGE models to explore a variety of policy issues using a single consuming agent.

New models have been developed to address the issue of energy policies and carbon taxes to prevent global warming. A comparison of many of these models is found in Goulder (1995b). They all estimate the economic impact of imposing a tax on carbon emissions. Most of these models have been applied to the United States (see, for example Goulder (1995a and 1995b), and Jorgenson and Wilcoxen, (1995)) and other industrialized nations. However, there are also some applications to India, Indonesia, and Pakistan (Shah and Larsen, 1992)[2].

2. RECENT MODELING EFFORTS [3]

Some researchers have studied the impact of environmental taxes in Mexico. Romero (1994) and Fernández (1997) have studied the impact of an environmental tax reform using static computable general equilibrium models. In his study, Romero found that under a 20% *ad valorem* carbon tax scenario, total emissions decrease by 13%. However, the effect on the consumer price index is very small and for the year 2001 GDP is only 0.6% lower than under a no-tax scenario. The sectors harmed most by a carbon tax are oil, mining, construction, and chemicals. The long-run demand of oil in each sector declines by 13% as a response to such a tax, and the long-run capital stock falls by almost 1%, even as the price of capital goods increase slightly, and the return rate to capital increases. The wage bill drops from 1 to 2% overall, but there tends to be a high variation among sectors. Wages drop by 14% in the transportation sector and 18% in the chemicals sector, but increase by 23% in the mining sector due to increased hiring. The tax policy analyzed in Romero’s study is however, not revenue-neutral (that is, the total tax receipts are allowed to vary from the base case).

Fernández (1997) introduces an environmental tax to the manufacturing sector and evaluates the policy outcome both with and without revenue neutrality.

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[2] Other important studies on this topic may be found in Nordhaus (1993), Bovenberg and Ploeg (1994), Bovenberg and de Mooji (1992 and 1994), Poterba (1991 and 1993), and Manne and Rutherford (1994). Boyd, et al. (1995) have also developed a model to analyze the net benefit of energy taxation and energy conservation as policies to reduce reduce CO_2 emissions.

[3] The only models considered here are top-down CGE models in the tradition of the dynamic CGE model which we developed. For a more thorough discussion of some of the most recent energy models developed for Mexico please see the appendix at the end of this chapter.

The baseline case considers a maximum tax of 5% on the most highly polluting manufacturing industries, that is, basic petrochemical products. The remaining tax rates for the rest of the industries within the manufacturing sector are then defined as depending on the pollution intensity of each sector relative to the heaviest polluter. His results indicate that the introduction of an environmental tax on manufacturing reduces pollution significantly, decreases output of the heavily polluting sectors, and reallocates resources from the private to the public sector.

3. OVERALL STRUCTURE OF THE PRESENT MODEL

Our model is here disaggregated into nine producing sectors, ten production goods, four household (income) categories, seven consumption sectors, a foreign sector, and the government (see Tables 6.1 and 6.2).

Table 6.1 Classification of sectors and goods

Producing Sectors	Production Goods	Consumer Goods and Services
1. Manufacturing	Manufacturing Goods	1. Food
2. Coal Mining	Coal	2. Energy
3. Chemicals and Plastics	Chemicals and Plastics	3. Autos
4. Agriculture	Agricultural goods	4. Gasoline
5. Services	Producer Services	5. Consumer Transport
6. Transportation	Transportation for production	6. Consumer Services
7. Electricity	Electricity	7. Housing and Household goods
8. Oil and Gas	1. Crude Petroleum	
	2. Natural Gas	
9. Refining output	Refined output	

Table 6.2 Household categories based on income

Category	Income
Agent 1	Bottom 2 deciles: 1-2
Agent 2	Deciles 3-5
Agent 3	Deciles 6-8
Agent 4	Top 2 deciles: 9-10

The economic variables determined by the model are investment, capital accumulation, production by each sector, household consumption by sector, imports and exports, relative prices, wages and interest rates, government budget expenditures and revenues, and total wage income. The level of depreciation and the initial return to capital are taken as exogenous, as is the rate of labor force growth.

This particular model is designed to focus primarily on the workings of the energy sector in Mexico and to show that sector's linkages to the economy as a whole. Hence, it contains some special features not commonly found in country-wide CGE Model. Fossil fuel production is disaggregated to include coal mining, oil and gas extraction and refinery output. Furthermore, output in oil and gas extraction is broken down into its constituent parts, namely crude oil production and natural gas production. These two outputs often occur jointly in nature but do not necessarily occur in fixed proportions. Hence, in our model the extraction of the two can be altered according to an elasticity of transformation. The oil and gas outputs, in turn, are used as inputs in other production and consumption sectors, and are sold to foreign consumers as well.

3.1 Production

The production portion of the model is built upon information from a balanced data set that is flexible with regards to the substitution between both the primary factor inputs (capital and labor), and the material (semi-finished) inputs from other production sectors.[4] The material inputs enter in a manner similar to that of an input-output model except that their substitutability can differ from zero. Technologies are represented by production functions which exhibit constant elasticities of substitution. Technical progress is taken as exogenous to the model.[5]

Production in each sector for every time period is represented as a constant elasticity of substitution (CES) function of capital, labor, and material inputs where the elasticity of substitution can vary from zero to infinity.[6] Hence,

$$V_t = \phi_t [\, \delta_L L_t^{(\sigma-1)/\sigma} + \delta_K K_t^{(\sigma-1)/\sigma} + \delta_M M_t^{(\sigma-1)/\sigma} \,]^{(\sigma/\sigma-1)} \qquad (1)$$

[4] The input-output table used is an updated version of the 1980 table. The update was performed with information provided by SEMARNAP.
[5] For endogenous technological change, see Romer (1990). Another good reference is den Butter, Dellink, and Hofkes (1995).
[6] Substitution elasticities between capital and labor for agriculture and manufacturing were derived from case studies (Hueter, 1997 and Skuta, 1997 respectively); (Wylie, 1995); the elasticities of substitution for petroleum were US estimates since no appropriate Mexican estimates were found, except for gasoline (SEMARNAP, 1995).

where V_t is value at time t[7], σ is the elasticity of substitution between inputs that is estimated econometrically for the different sectors, ϕ_t is an efficiency parameter for the entire production function, L_t is labor at time t, K_t is capital at time t, M_t are materials at time t, and the δ′s are the share parameters defined so that,

$$\delta_L, \delta_K, \delta_M > 0 \text{ and}$$
$$\delta_L + \delta_K + \delta_M = 1$$

The materials input, M_t, does not represent a single factor input but rather a host of inputs from the various production sectors. Hence, in our model M_t is a composite input produced by a nested CES production function whose arguments are the actual inputs from the model's production sectors. All of this is depicted in Figure 6.1. In the diagram the total output of a generic production good, V_t, is shown at the apex of the figure. The labor, capital, and composite materials inputs are placed at the second tier, and each of the individual materials inputs are placed at the third tier. Besides being more flexible, this setup has the distinct advantage of allowing the elasticity of substitution between materials inputs to vary from the elasticity of substitution between the primary inputs.

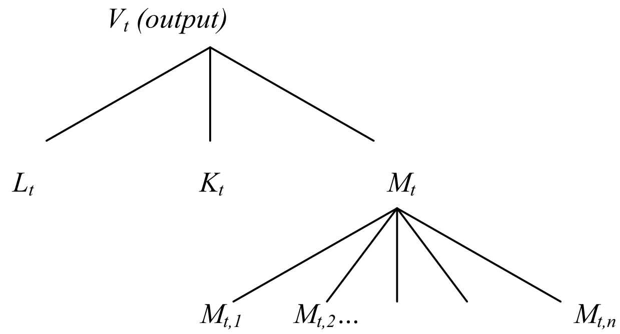

Figure 6.1 Nested production function of a generic good

One central characteristic to the model is the use of nested functions to the production side of the economy as well as to the production of final consumption goods and services. This allows for different degrees of substitution for the inputs considered. In the particular case of production, it allows for substitution between labor, capital, energy, as well as non-energy inputs. It also allows for interfuel substitution.

[7] Since initially we set the real price of all goods at 1 for purpose of simplification, V_t here refers both to the quantity of output and the value of that output.

In each time period producers maximize profits in a competitive environment. Output and input prices are treated as variables. Taxes are also included with producers facing tax exclusive prices and consumers (and input consuming firms) facing the tax inclusive prices. Profit maximization, based on the described production technology, yields output supply and factor demands for each production sector and factor market in the model. Chapter 7 presents results for simulations using perfect competition as described here, and chapter 8 includes monopoly power in the energy markets, as well as sticky wages brought about by non-clearing labor markets.

It is important to note that the goods produced in the model's production sectors are not the same final goods consumed by consumers. Agricultural products, for example, must be combined with transportation services, manufacturing, and chemicals before they can be consumed by individuals as food. Hence, in our model we use a matrix (referred to as a *Z* matrix by Ballard et al. (1985)) to map from the vector of production goods to the vector of consumption goods. More specifically this matrix assigns output to each of seven consumer goods categories in direct proportion to the amount of value added that is given to that good by each of the nine production sectors.

3.2 Labor Market

The equilibrium in the labor market is endogenous with a single wage rate clearing the market. The firms in the model pay out a wage gross of all labor taxes while the consumers in the model receive a wage net of all labor taxes. Demand for labor is determined by the firms as a result of their profit maximization process. The growth of the labor force is determined exogenously, but the supply of hours from this is determined by the labor-leisure choice, subject to the constraint that 60 hours per week is the maximum available. This labor-leisure choice is made by individuals (in this case by the income groups) depending on the marginal tax rate on income. The higher this marginal tax rate, the less labor supplied and the more leisure consumed. Effective labor supply grows at rate γ, the exogenous rate of population growth plus technical progress. This, in effect, means that the underlying growth in the model has two components and depends on both Mexico's growth in population and its rate of technical progress.

In our initial set of runs we assume that the aggregate Mexican economy operates at full employment and that wages are fully flexible in both directions. Indeed such an assumption is commonly made and is standard practice for most CGE applications. A large body of literature (see, for example Ball and Romer (1990) and Lebow, Sacks and Wilson (1999)), however, suggests that union power and other forces may cause workers to refuse lower wages and for aggregate wages to be "sticky" downwards. The presence of sticky wages, in turn can lead to long term unemployment and affect both aggregate economic output and the distribution of income. In several of our later runs then we constrain aggregate wages to stay above or equal to some predetermined level and measure the impact of this on sectoral output, employment levels, and consumer income.

3.3 Consumption

On the demand side, the model reflects the behavior of domestic consumers and foreigners (who can also invest through their savings), as well as that of the government. Domestic consumers are assigned to four groups (agents) according to income and a demand equation is specified for each. Each group has a different consumption bundle depending on its income. All four groups are endowed with labor. Since only the wealthy actually have (formal) savings in Mexico, we assume here (in accordance with the latest data from INEGI) that only the top two groups (agents 3 and 4) own capital. These resources are rented out to firms in order to finance the purchase of domestic or foreign goods and services, save, or pay taxes to the government.

For each household c total utility is modeled by the function,

$$U_c = \Sigma_t \, U_{c,t} \, (X_{c,t}, R_{c,t}) * (1+\rho)^{-t} \qquad t = 1, \ldots, n \tag{2}$$

where U_c is household utility over all n time periods, $U_{c,t}$ is the utility derived from the present period consumption of goods and services, $X_{c,t}$ (a seven-dimensional vector) and leisure $R_{c,t}$, and where ρ is the discount rate (time preference).[8] Each U_c is taken to be a (nested) CES utility function defined over all consumer goods as well as all time periods.[9] The value of household utility is given by the addition of the value of consumption plus the value of leisure (Ballard et al., 1985), which is equal to the number of hours devoted to leisure multiplied by the net wage per hour worked; the latter represents the price of leisure (foregone wages).

[8] To rule out the possibility of a Ponzi game it is assumed that the credit market puts a limit on the amount of consumer borrowing. This is specified by the constraint that the present value of the assets owned by the consumer must be non-negative.

[9] For the purpose of this analysis, all consumers have a constant intertemporal elasticity of substitution (CIES) utility function, and we use values for this elasticity which are consistent with the empirical literature.

Each consumer's expenditure constraint can be written as,

$$\sum_{t=1}^{n} (TG_{c,t} + TF_{c,t} + (P_{L,t} * L_{c,t}) + (r * K_{t} * S_{c,t})) =$$

$$\sum_{t=1}^{n} ((INV_{t} * S_{c,t}) + (P_{I,t} * X_{c,t}) + (P_{L,t} * R_{c,t})) \qquad (3)$$

where endowments are given on the left-hand side of the equation and expenditures are placed on the right hand side. $TG_{c,t}$ and $TF_{c,t}$ represent the transfer to the consumer from the government and from the foreign agents, $P_{L,t}$ is the tax exclusive price of labor and r is the rental rate of capital. K_t is the level of capital stock in period t, $S_{c,t}$ is the share of total capital owned by consumer c, INV_t is the total investment in time period t, and $P_{I,t}$ is the tax inclusive vector of prices for consumer goods. Thus, transfers to consumers both from the government and the foreign sector (i.e., net income from abroad) plus income from labor and capital earnings are used towards savings, consumption of goods and services, and consumption of leisure. Theoretically households can borrow with the interest being, in essence, collected by themselves. In this particular model, however, there is net savings and it is used to build up the value of the capital stock through investment.

Maximizing the nested utility function (2) with respect to the expenditure constraint (3) simultaneously determines the consumption level of the seven consumer goods and services, the amount of labor supply, and the consumers' level of saving and investment in each of the n time periods.

3.4 Government

The government sector is treated as a separate agent (Ballard et al., 1985). The government agent is modeled with an expenditure function similar to the household expenditure functions (i.e., based on a CES utility function). Revenues derived from all taxes and tariffs are spent according to an expenditure function. Within this expenditure function the government spends its revenues on goods and services from the various private production sectors discussed above. The government also spends its revenues on labor. Together these arguments represent the government purchases and payment of government employees necessary for it to carry on its work. The government also separately redistributes income through exogenously set subsidies and transfer payments, and all revenues are spent.[10] Its function is,

[10] Hence there is no elasticity of substitution between government expenditures and payroll expenses on the one hand, and subsidies and transfer payments on the other.

$$G_u = Ax_1^{\alpha_1} x_2^{\alpha_2} x_i^{\alpha_i} x_n^{\alpha_n}$$
$$\sum_i \alpha_i = 1 \tag{4}$$
$$E = \frac{1}{A} \prod_{i=1}^{n} P_i^{\alpha_i}$$

where G_u is the Government's utility and α_i represents the producer goods' factor shares. The x_i*'s* are the units of producer goods purchased by the government. E is total government expenditures; A is a scale parameter; and P_i are the market prices of production goods purchased by the government.

However, it should be pointed out that it is assumed that the government sector does not save as such and there is a zero surplus in the government account[11]. Hence the government does not own capital, and the capital needed for government provided goods such as education is rented from the private sector.

Taxes in the model are expressed *ad valorem* and include personal income taxes, labor taxes, capital taxes, property taxes, revenue taxes (such as payments from oil and gas activities), value added taxes, sales taxes, import tariffs and export taxes. As stated above, in the initial calibration of this model, taxes are calculated in such a way as to exactly reproduce the amount of revenue generated in Mexico in 2000. The taxes on final goods such as gasoline differ from other consumer goods because of special taxes levied on them by the government. By the same token final goods such as electricity differ in treatment due to existing government subsidies. When applicable, taxation is based on marginal tax rates. To capture the incentive effect of the tax system, the highest marginal rate is levied on the relevant revenue base. Since this procedure results in over taxation, the difference between the revenue generated by the highest marginal tax rate and the average tax rate is rebated to consumers as a lump-sum transfer.

Subsidies in the model are essentially treated as negative taxes and in these cases the government transfers funds back to a sector in proportion to that sector's output. Thus, if these subsidies are abolished, the government has more revenue. To keep aggregate revenues equal to aggregate expenditures the government will increase spending on all items in proportion to existing government expenditures on the different goods and services. This assumption may then be relaxed later if desired.

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[11] Interestingly in the 2000 base year used, government revenues were quite close to expenditures and the balanced government assumption actually fits quite well.

In most CGE applications it is appropriate to represent all government income equivalent, regardless of the source, and to send it directly to the government sector for spending without differentiating between sources. In this analysis however, it is important to distinguish those funds that come from PEMEX, those that come from CFE, and those that come from all other sources throughout the economy. To do this we construct two "Dummy" sectors in the economy. The purpose of these sectors is to collect the funds from PEMEX and CFE and then transfer them on to the government general fund. By so doing we are then able to obtain an accurate measure all of government revenues derived from CFE and PEMEX.

3.5 Income Distribution

Consumers in this model are divided into four groups according to their level of income. Agent 1 consists of the lowest two deciles in terms of income. Agent 2 is made up of the next three deciles. Agent 3 consists of the following three deciles, and Agent 4 includes the top 2 deciles. The gross income of each group rises by the rate of population growth plus the rate of technological change which is taken as capital augmenting. As indicated above, all groups are taxed at their marginal rates and the choice for the group between labor and leisure depends on their relative price. Under steady growth the proportion of time spent in leisure activities is assumed to remain constant.

Various forces affect the distribution of income within this model. In the 2000 base year the distribution of income depends on the actual factor payments going to each agent during that 12-month period. Furthermore, in the initial benchmark run there is no change in distribution since all components of income grow at the same rate, and all relative prices of all goods in the model are constant. In subsequent counter-factual scenarios, the distribution of income may change if: (1) capital grows relative to labor; or (2) the relative price of various consumption goods changes. It is not, however, affected by government spending and tax revenue since transfers are divided between groups on the basis of their values in the year 2000.

3.6 Trade

International trade within the model is handled by means of a foreign agent. Output in each of the producing sectors is exported to the foreign agent in exchange for foreign-produced imports. Under this setup the aggregate level of imports is set and grows at the steady state level, but the level of individual imports may change in response to changes in relative prices. Exports are exogenous as well and are assumed to follow a constant growth path. They are, however, responsive to changing prices, and can change as individual sectors are shocked. Transfer payments, on the other hand, are endogenous and act so as to clear the model. Price-dependent import supply schedules are derived from elasticity estimates found in the literature[12].

In specifying the substitutability between foreign and domestically produced goods we replace the classic Heckscher-Ohlin assumptions and rely instead on the Armington (1969) assumptions. Under these assumptions foreign imports and domestically produced goods are considered to be imperfectly substitutable goods (as opposed to Heckscher-Ohlin where foreign and domestically produced goods are considered to be perfect substitutes). Armington postulates that domestic and foreign goods are both inputs in a CES production process, the output of which is a combination of the two. It is this combined good that is consumed domestically. The benefit of such a setup is that a country can both import and export goods from the same industrial sector. Furthermore, under these assumptions domestic prices can differ from world price levels, but the more closely substitutable the foreign and domestic goods, the closer the two prices are to each other. Under the Heckscher-Ohlin assumptions, by contrast, all goods are prefect substitutes and foreign and domestic prices must be equal.

The balance of trade relationship is given by,

$$\Sigma(P_{m,t} * IM_{j,t}) = \Sigma(P_{j,t} * EX_{j,t}) + \Sigma TF_{c,t} \qquad t = 1, \ldots, n \qquad (5)$$

where $IM_{j,t}$ is a (nine dimensional) vector representing the quantity of each of the producer goods imported, $P_{m,t}$ is the vector of imported goods prices, $EX_{j,t}$ is the vector of producer goods exported, $P_{j,t}$ is the tariff inclusive vector of producer goods prices, and $TF_{c,t}$ is the level of foreign transfers which can be positive, zero, or negative. Because of the Armington assumptions, as stated above, the import prices are not required to equal their domestic counterparts, and the more highly substitutable foreign and domestic goods are, the closer their prices will be. The prices of exports are identical to their domestic price (adjusting, of course, for any export taxes). For each time period, the value of total imports is equal to the total value of exports plus foreign transfers. Since these transfers are used to finance domestic investment this relation provides the closure rule, namely, that investment is equated to domestic savings minus net exports. This, of course, includes balanced trade as a special case.[13] Certain goods, such as transportation and electricity are strictly produced for domestic consumption and enter into the model as non-tradable goods. This

[12] See, for example, Serra-Puche (1981), Romero (1994) and Fernandez (1997), and Wylie (1995).

[13] Capital flows are the remainder of the exports minus imports, or net exports, since the deficit in the current account must be made up for by a surplus in the capital account.

serves to make the model a more accurate description of the Mexican economy. It also serves to give us a measure of the real exchange rate which is defined as the price of tradables over the price of non-tradables.

In this model we assume that Mexico has no market power in the world petroleum market. Hence we treat the international price of oil as given and Mexican oil producers as price takers in the market. Consequently, when the Mexican government institutes investment policies to increase aggregate oil output, the domestic price drops as output increases and more is exported as the international price increases relative to the domestic price[14].

3.7 Labor Growth and Capital Formation

Growth within our dynamic CGE model is brought about by the changes over time in both the labor force and the capital stock. In keeping with the theoretical underpinning of the Ramsey model (1928), we model the changes in the population as exogenous and constant over the time period considered. More formally, the growth in the effective labor force over time is given by the equation,

$$L_{t+1} = L_t(1+\gamma) \tag{6}$$

where γ is the composite of the growth rate of population over time and the growth in the effectiveness of the typical worker; it is assumed that this rate remains constant in all periods of the analysis. In the absence of any perturbation, the Ramsey model predicts that the economy will grow at the labor supply growth rate in the steady state. The labor supply function is then determined by the effective labor force times the hours- supplied function per worker, which reflects the willingness to offer more hours as the net of income tax rate changes, as modeled by the consumer choice equations.

In the model we assume that there is only one type of raw capital good, which goes into the various sectors. In addition, to add realism we assume that the capital, which does go into a sector**,** works like putty and clay. More specifically, we assume that capital which is new can be readily combined with other inputs to produce outputs. Over time, this capital becomes locked into an older technology (i.e., clay) and has a harder time combining with other inputs. In the growth literature this is also known as "vintage capital". This is plausible as illustrated by sectors such as electricity production, which has been subject to a great deal of technological change over the years.

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[14] Domestic and international price of oil may differ due to quality and transportation costs.

The capital growth rate is modeled in accordance with capital theory and is represented by a system of three equations. For each time period t we have,

$$P_{A,t} = P_{k,t+1} \qquad t = 1, ..., T \qquad (7)$$

where $P_{A,t}$ is the weighted (aggregate) tax exclusive price of consumption, (i.e., the weighted average of the $P_{l,t}$'s) and $P_{k,t+1}$ is next year's tax exclusive price of capital. This says that the opportunity cost of acquiring a unit of capital next year is a unit of consumption in the present period. We also have

$$P_{k,t} = (1+r_t)\ P_{k,t+1} \qquad t = 1, ..., T \qquad (8)$$

meaning that the price of capital in this period, $P_{k,t}$, must be equal to the coming period's rental value of capital, $r_t{*}P_{k,t+1}$, plus next period price of capital, $P_{k,t+1}$. Finally, we have

$$K_{t+1} = K_t(1\text{-}\Delta) + INV_t \qquad t = 1, ..., T \qquad (9)$$

where Δ stands for the rate of depreciation and INV stands for gross investment. This states that the capital stock in the next period must be equal to this year's capital stock plus net investment. Taken together, equations 7-9 insure that economic growth will be consistent with profit maximizing behavior on the part of investors.

The actual process of calibrating a dynamic CGE model requires the use of exogenous estimates for technology and population growth γ, the return to capital r, and economy-wide depreciation Δ. Hence, we obtained estimates of these for Mexico from the literature (see below) listed in table 6.3. Given these three values, our program solves for the unique value of ρ, the discount rate. This rate of time preference is then in turn used to discount all prices and values in all time periods subsequent to the benchmark year for Mexico[15].

3.8 Terminal Conditions

One potential drawback of a computable model, such as the one employed here, is that it can only be solved for a finite number of periods. Consequently, a few adjustments are necessary to design a model that, when solved over a finite horizon, approximates infinite horizon choices. First of all, to keep consumers from consuming all of the remaining capital in the final period we, in essence, "trick" them in the model. We endow them with capital in the initial period. Then in the terminal period we take away all capital from

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[15] For more on calibration see Barro and Xala-i-Martin, 1995.

the capital owning agents preventing them from consuming it all in the final period of the analysis.

Following Lau, Puhlke, and Rutherford (1997) we divide the problem into two distinct sub-problems, one defined over the finite period from $t = 0$ to $t = T$ and the second the infinite period from $t = T+1$ to $T = \infty$. Hence, the first problem is

$$\text{Max} \sum_{t=0}^{T} \left(\frac{1}{1+\rho}\right)^t U_{c,t}(X_{c,t}, R_{c,t}) \tag{10}$$

subject to

$$\sum_{t=0}^{T} P_{A,t} X_{c,t} = \sum_{t=0}^{T} P_{L,t} \overline{L}_{c,t} + P_{k,0} K_{c,0} S_{C,t} - P_{k,T+1} \overline{K}_{c,T+1} S_{C,T+1} \tag{11}$$

and

$$\overline{L}_{c,t} = L_{c,t} + R_{c,t} \qquad \text{for all t = 0, 1, ... T} \tag{11a}$$

and the second problem is

$$\text{Max} \sum_{t=T+1}^{\infty} \left(\frac{1}{1+\rho}\right)^t U_{ct}(X_{c,t}, R_{c,t}) \tag{12}$$

subject to

$$\sum_{t=T+1}^{\infty} P_{I,,t} \cdot X_{c,t} = \sum_{t=T+1}^{\infty} P_{L,t} L_{c,t} + P_{K,T+1} \overline{K}_{c,T+1} S_{c,t+1} \tag{13}$$

$$\overline{L}_{c,t} = L_{c,t} + R_{c,t} \qquad \text{for all t = T+1, ...}\infty \tag{13a}$$

where ρ is the rate of time preferences, r_o and $K_{c,o}$ refer to the rental value of capital and quantity of capital before the terminal period, r_{T+1} and $\overline{K}_{c,T+1}$ refer to these variables after the terminal period, and $\overline{L}_{c,t}$ is total labor plus leisure for each agent in the t[th] time period. $P_{K,t}$ stands for the tax exclusive price of capital, and, as before, $P_{I,t}$ and $P_{L,t}$ stand for the tax inclusive price of consumer goods and the tax exclusive price of labor respectively.

We then need to specify an equation or specific value for $\overline{K}_{c,T+1}$. At first glance it might seem best to impose the long-run steady state level, but then the model horizon would have to be sufficiently long to eliminate terminal effects. As an alternative, we include the level of post-terminal capital as a variable and add a constraint on investment growth in the final period. Thus we have

$$INV_T/INV_{T-1} = Y_T/Y_{T-1} \quad (14)$$

where Y_T gives GDP at time *T*. This constraint imposes a balanced growth in the final period, but does not require that the model achieve steady-state growth. The advantage of this approach is that it alleviates the need to determine a specific target capital stock or a specific terminal period growth rate. In the particular model that we employ in our simulations in the next three chapters we set the terminal time at 2020 and hence T= N = 20.

3.9 Depletion

All of the meaningful runs of the model assume that oil resources in Mexico are finite and that they are subject to depletion after some point in time. Thus, in most of the model's runs we restrict output to some exogenous level. In some cases this means that output is held at some pre-determined level while at other times the level of oil output is reduced in line with existing depletion estimates.

At the same time that we are restricting output through depletion we are also increasing investment and thereby output via the government. In some of our scenarios we are assuming that the government makes major investments into PEMEX and CFE in order to improve energy output and foreign exchange earnings. In the model we handle this new investment by equating it to a government subsidy and thereby assuming that capital earnings increase by the amount of the government subsidy. This subsidy also serves to increase the overall level of the capital stock and to decrease the amount of funds that the government can employ elsewhere.

4. CALIBRATION AND DATA

The model is calibrated to a 2000 data set with these data coming from a variety of sources. Benchmark year (2000) data were obtained for income and expenditure for each of the income categories. Data on consumer expenditures on final goods by income category are from the *Encuesta Nacional de Ingresos y Gastos de los Hogares*, 2000, published by the Instituto Nacional de Estadística, Geografía e Informática (INEGI). Data on imports and exports are from *International Financial Statistics*, various editions, published by the International Monetary Fund (IMF), *The Mexican Economy*, 2000, published by the Banco de México, and the *Anuario Estadístico de los Estados Unidos Mexicanos*, 2000, published by INEGI.

Data on inputs, outputs, and use of labor and capital by production sector comes from data compiled by INEGI and supplied by the Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). This same source along with the *Anuario Estadístico de los Estados Unidos Mexicanos* were used to calculate the transformation matrix as well as to find investment levels by sector. All results on fossil fuel consumption (both aggregate and sectoral), fuel prices, fuel imports and exports, and government consumption of various fuels were provided by the Secretaría de Energía (SE), PEMEX, and INEGI.

Table 6.3 Basic parametric assumptions

Elasticities of Substitution, σ, between capital, labor and materials by production sector	
Manufacturing	0.98
Coal Ming	0.64
Chemical and Plastics	0.98
Agriculture	0.96
Services	1.0
Transportation	1.0
Electricity	0.4
Oil and Natural Gas	0.4
Refining Output	0.8
Labor growth Technical Progress	1.3% per year 2.4%, 3.9%, 4.9%
Depreciation Δ	5% per year
Return to Capital r	21%
Calibrated discount rate ρ	14%

Source: Own estimates. See text for specific references.

Tax levels and rates were calculated from the input-output tables as well as from *El Ingreso y el Gasto Público en México*, 2000, by INEGI. The latter document along with *The Mexican Economy 1995* and *Encuesta Nacional de Ingreso y Gasto de los Hogares* 2000 were also used to obtain data on government expenditures and transfer payments. Finally, data on interest rates, capital earnings, and depreciation were obtained from *The Mexican Economy 1995* as well as from Barro and Sala-i-Martin (1995). Substitution elasticity between capital and labor were taken from Heuter (1997) and Skuta (1997)[16] and import demand elasticities were taken from Wylie (1995).[17]

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[16] As noted above Heuter (1997) and Skuta (1997) were responsible for most of these. Where necessary these were supplemented by Tarr (1988) and Ballard et al (1985) estimates for the U.S.

[17] Wylie (1995) obtained estimates on various imported items.

APPENDIX

The model described above is, of course, not the only one that has been developed to study the energy sector of a given country in the context of its larger economy. We believe that the disaggregated nature of our model along with its emphasis on energy and GHG emissions and its ability to compute changes in consumer welfare among various income groups over time makes it ideal for our analysis here. Nonetheless, several different types of models have been developed to study energy use and determine the economic impact of various countries' energy and environmental policies. Additionally, some of these models have been used to analyze the economic cost of mitigating the impact of environmental agreements related to global climate change. Hence in this appendix we would like to briefly categorize and discuss other models to see where our particular model fits in with other modeling efforts that the reader may encounter in the literature.

Generally speaking, there are top-down and bottom-up models. Top-down models are more macroeconomic-oriented, while bottom-up models are more closely related to engineering data on sector by sector energy use. Bottom-up models quantify the total amount of energy consumed in each sector according to end-uses and these consumption numbers are summed to obtain total energy demand; first by sector and then for the whole economy. Top-down models, on the other hand, start from aggregated figures of economic activity, such as GDP of each sector, and then estimate future demands according to expected economic growth using relatively fixed energy coefficients by sector.

There are a large number of models used to represent the energy sector and its economic and environmental impact. Some of these models are specifically related to global climate change. Of these climate change models, some are top-down and others are bottom-up. A selected set of these models is described below.

A.1 Energy and Economic Modeling: Global and Developed-Country Models

Different models have been developed to simulate the impact of the Kyoto Protocol, both at a national level (mainly for industrialized countries), and worldwide (see chapter 9). These models differ in the way they address this issue, (i.e., nationally or regionally), how they calculate costs of compliance, and also on how they model of the economy.

In general terms, these models can be classified several different ways depending on whether one is looking from and economic or an energy and emissions standpoint. From an economic standpoint, they can be divided into aggregate production and cost models, multi-sector general equilibrium models, and multi-sector macro-econometric models.

Alternatively, in terms of their treatment of energy and emissions issues, models can be classified into three broad categories, namely sector-specific fuel supply and demand models, models based on detailed energy-related technology, and models which focus on carbon coefficients. A complete listing according to these two classification schemes is given in table 6.4.

Table 6.4 Classification of models

Economic Models	Energy / Carbon Models		
	Fuel supply and demand by sector	Energy technology detail	Carbon coefficients
Aggregate production/cost function		CETA MERGE 3 GRAPE	FUND RICE
Multisector general equilibrium	MIT-EPPA WorldScan G-Cubed*	ABARE-GTEM AIM MS-MRT SGM	
Multisector macroeconomic	Oxford		

(*) Model that share properties of two or more groups.
Source: Weyant and Hill, 1999.

A.2 Aggregate Economic Models

These models consider the consumption and supply of fossil fuels, renewable energy sources, and electric power generation technologies. In these models, the output of all industries is summed, and GDP is determined by an aggregate production function which contains capital, labor and energy as its primary inputs. These models generally omit inter-industry interactions and assume full employment of capital and labor. MERGE 3 (a model for evaluating the regional and global effects of greenhouse gas reduction policies), CETA (Carbon Emissions Trajectory Assessment), RICE (Regional Integrated Model of Climate and the Economy), FUND (Framework for Uncertainty, Negotiation and Distribution), and GRAPE (Global Relationship Assessment to Protect Environment) are examples of this category (The Energy Journal, 1999, p. xix).

A.3 Multi-Sector General Equilibrium Models

An additional category of models includes multiple economic sectors within a general equilibrium framework, focusing on the interactions of the firms and consumers in each of the various sectors and industries. These multi-sector general equilibrium models tend to ignore unemployment and financial market effects. Our model developed above is this type of model in principle, but as we shall see in chapter 8, significant modifications take place regarding the treatment of involuntary unemployment. The G-Cubed (Global General Equilibrium Growth) model does consider some unemployment and financial effects and is a hybrid general equilibrium/macro-econometric model. G-Cubed, MIT-EPPA and WorldScan all include trade in non-energy goods as well as energy goods (The Energy Journal, 1999, p. xxi).

Still other models combine elements of the previous two categories of the models discussed above. These are multi-sector, multi-region economic models with explicit energy sector detail on capital stock turnover, energy efficiency, and fuel switching possibilities. Examples of this type of hybrid model are AIM (Asian Pacific Integrated Model), ABARE-GTEM, SGM (Second Generation Model) and MS-MRT (Multi-Sector Region Trade) models. These models all include trade in non-energy goods, with AIM including energy end-use detail. Both GTEM (Global Trade and Environment Model) and the MS-MRT models include some energy supply detail. The SGM model is even more detailed in this respect and considers five separate supply sub-sectors within the electric power industry (The Energy Journal, 1999, p. xix).

A.4 Multi-Sector Macro-Econometric Models

By including unemployment, financial markets, international capital flows and monetary policy, the Oxford model is the only model included with a macro-econometric orientation. The G-Cubed model, however, does consider some unemployment and financial effects, as well as international capital flows (The Energy Journal, 1999, p. xxii).

The above models have been used to determine the cost of compliance with the Kyoto Protocol (The Energy Journal (Special Issue, 1999)). They analyzed the following four alternative scenarios: (i) No trading of international emission rights; (ii) full Annex I (or Annex B) trading of emission rights; (iii) the Double Bubble, which considers separate the EU and the rest of Annex I emission trading blocks; and (iv) full global trading of emission rights. For a description of results, and further information on the models see The Energy Journal, (Special Issue, 1999.)

A.5 Modeling of Energy Consumption and Emissions in Mexico

In Mexico, both top-down and bottom-up models have been developed for the energy sector as well the overall economy. Among the more recent models are MODEMA (Model of Energy Demand), LEAP (Long-Range Energy Alternative Systems), MEEEM (Modelo de Escenarios Energeticos y de Emisiones para Mexico) and STAIR-M (Services, Transportation, Agriculture, Industry, and Residential Model for Mexico). These models have been to a great extent developed by the University Energy Program (PUE) at the UNAM, the National Autonomous University of Mexico.

These models can be classified into two groups. MODEMA[18] and LEAP are top-down models that take a given level of economic activity, and, using fixed coefficients, determine energy demand. MEEEM[19] and STAIR-M are sector-specific end use energy models that determine sector and total energy demand, and they each require a great amount of detailed technical data. None of these four models react to changes in economic variables such as fuel prices and income levels. Indeed, any such changes are assumed to be exogenous to the model itself. Furthermore, they do not show how these changes affect the use of fuels or how they impact GHG emissions.

A.6 Current Bottom-Up Models

BRUS II-M is a recent bottom-up model designed to calculate and forecast the consumption and production of energy, as well as the associated greenhouse gas (GHG) emissions. It is a long-term scenario model that estimates the consequences of various energy reforms and looks at the energy use, economic, and environmental aspects of these policies. It calculates energy consumption, emissions, and related energy systems costs including investment, operation and maintenance costs, and fuel costs. The model facilitates long-term analyses and has explicitly incorporated the important long-term factors of the energy system, such as the development of energy technologies and conservation. The results of this model's simulations give data on total energy demand (according to fuel type), investment, operation and management costs, fuel costs, and the emission levels of various types of GHGs.

The model contains a detailed description of the demand sectors: household, service, production (including agriculture and PEMEX-petrochemicals), and transport. All of these sectors are driven by demographics and

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[18] This model was developed by Mariano Bauer and Juan Quintanilla, from the Programa Universitario de Energia, UNAM.

[19] This model was developed by Sheinbaum, from Instituto de Ingenieria, UNAM.

economic development. Supply is described by three sectors: power plants, petroleum and gas. The model can be used to test a variety of specific energy policies, such as the substitution of fuels and technologies, the development of alternative energy sources, and the manipulation of the energy demand throughout changes in fuel prices. The model is aimed to carry out studies for the Mexican energy system in the medium and long term, and determine the resulting environmental and economic consequences in order to point out ways and means to conserve energy development and mitigate pollution. At the present time, however, the ability of BRUSII-M to explicitly incorporate economic variables such as prices, income, interest rates and exchange rates is fairly limited and must be exogenously entered by the programmer. BRUS II-M is currently the exclusive property of the Secretaria de Energia, in Mexico.

Recently another bottom-up type model has been developed: the Energy and Power Evaluation Program (ENPEP). This model's main goal is to provide detailed analysis of alternative government policies on the power sector, along with the oil, natural gas, coal, and transport sectors. It is presently at the testing stage and hence no results have as yet been obtained (Secretaria de Energia, 2002).

CHAPTER 7

SIMULATION RESULTS UNDER PERFECT COMPETITION

This chapter presents the results of the first set of simulations of the dynamic CGE model. These simulations assume perfect competition in all sectors. Gradually, some assumptions are relaxed so they reflect the changes brought about by various energy policies. The economy-wide effects are then simulated by our dynamic CGE model of Mexico. The benchmark case replicates the economy in 2000 and so it is used for calibration purposes. After that, oil depletion is introduced, holding constant oil production from 2004 onward. Next we simulate the effects of new capital investment in Mexico's oil and power sectors. Such investment is assumed to go into capital enhancing technological change and thereby increase the productivity of energy production. We also include simulations on energy efficient technological change. Other simulations run here include the elimination of subsidies to electricity, investment in natural gas distribution, and the introduction of carbon taxes to fossil fuels. All of these changes are introduced sequentially in our simulation runs and the results of the simulations are compared with each other in such a way to isolate the impact of each policy on CO_2 emissions, production, consumption, relative prices, welfare, government revenues, overall as well as sectoral growth, and on the trade balance.

1. FEATURES OF THE MODEL

The dynamic CGE model described in chapter 6 can now be used to examine the economy-wide effects of various energy policies in Mexico. The model is first run in what is termed a "Benchmark" using an updated 2000 Mexican social accounting matrix (SAM). In this situation imports, exports, consumption, government expenditures, and production as well as carbon emissions in all sectors rise steadily by the initial rate of growth, and all prices expressed in 2000 decline each period by the rate of discount. Put more precisely, the values of all future outputs measured in today's terms decline by the discount rate, and in our model this is accomplished by letting the current prices decline in each period after the initial period. In addition, income, household welfare, and the capital stock grow by this same initial rate. In the literature the original "Benchmark" equilibrium is often referred to as "steady state" equilibrium since in this particular case no forces act to move the economy off from this growth rate in all sectors. Such equilibrium has a number of desirable characteristics because in this situation all markets clear in all periods, there are no excess profits being made by any firm or sector, and consumer welfare is maximized given the constraints of labor, capital, and natural resources in the model.

To see the effects of changes in government tax and subsidy policies as well as in investment in the oil and natural gas sector, fossil fuel depletion, emission levels, technology changes and carbon taxes we run the model again altering various subsidies, sector growth rates, and employment and technology parameters. These changes are based on proposed tax and subsidy policies, reasonable expectations regarding changes in oil stocks, and plausible increases in the efficiency of the refinery, manufacturing, and electricity sectors. By running the model with these changes and comparing their results with the benchmark case, as well as with each other, we are then able to examine the economy-wide results of these changes on CO_2 emissions production, consumption, government revenue, the balance of payments, consumer welfare and economic growth in Mexico for the period between 2000 and 2020. All told there are 25 simulations that we look at in chapters 7, 8, and 9, but before we look at each of these we first need to describe some of the unique aspects of this particular model which makes it appropriate for our specific analysis here[1].

1.1 Growth and Technology in the Model

As previously stated, the model used here is a modified and extended empirical variant of the dynamic growth model first developed by Ramsey in

[1] These simulations include the two benchmark cases along with 23 simulations of energy markets run under various behavioral and policy assumptions.

1927. In that model the growth in output was proportional to the growth in population when the model achieved a steady state, and as a consequence, per capita GDP remained constant at that steady state. In this model, by contrast, we assume that the overall rate of output growth is proportional to the historical (and projected) rate of population growth (1.3% per year) plus an additional amount of growth due to the overall factor neutral (i.e., Hicks neutral) technological change throughout the economy (1.6% per year). Given the empirical evidence from Mexico we feel that this initial assumption conforms fairly closely to the existing empirical data.

While the 2.9% annual growth rate assumption is maintained in our initial model runs, it is modified in various ways in subsequent scenarios. In the past, augmentation of capital via technological improvements has proved to be a powerful engine of economic growth, and it is the hope of policy-makers that such change will continue into the future. Such change could be financed by direct government investment, tax breaks, or as part of the Clean Development Mechanism. Indeed, expectations regarding more efficient capital lie at the heart of both public and private investment decisions. Hence, in a number of later model simulations we modify our initial growth assumptions and exogenously accelerate economic performance in various production sectors via capital enhancing (i.e., Harrod-Neutral) technological change. We then quantify its impact on those sectors where it occurs, as well as on related production sectors, overall welfare and economic growth.

Technological change, however, is not without costs. In addition to the investment costs of implementing such change (see footnote 5 below) there is an environmental cost to increased economic output if that output is not environmentally friendly. More specifically, unchecked increases in capital productivity without accompanying clean burning technologies can have significant negative environmental externalities. Hence, we also look at *energy efficient* technological change as an alternative to *capital-enhancing* technological change and compare their relative merits in terms of sustainable growth.

1.2 Investment and Depletion in the Model

As we also indicated in the last chapter, this particular model has been specially modified to simulate the depletion of Mexican oil reserves over time, added investment by the government in oil and natural gas exploration activities, and new capital investment into the generation and distribution of electricity production by the Mexican government.

The treatment of depletion is fairly straightforward at first glance since we only wish to cut output levels according to existing predictions after the year 2004 (see scenario 1). In reality, however, things are a bit more complicated. While we allow depletion to take its course we also let the government invest sufficient funds to allow oil production to rise to some specified level. By so doing, then, the model quantifies the investment levels and economic costs involved in raising or maintaining Mexican oil output and foreign exchange earnings over the next 20 years. There are several reasons for doing this. First we believe that any macro model which looks at non-renewable natural resources has to account for the obvious fact that these resources are finite and will be more costly to extract in the future. Second, one of the primary objectives of this model is to see exactly how carbon taxes designed to meet climate change treaty possible commitments will interact with depletion to cut down on the use of fossil fuels over time.

1.3 Government Investment in the Model

In this model, the government uses the tax and tariff revenue, which it spends on labor transfers and a variety of goods and services for use in its operations. Spending on government goods and services then can be seen as a residual between revenues from taxation and labor plus transfers. As we have also explained above, in our model's simulations, government investment is included by a capital subsidy into state owned energy companies.

In an effort to expand its overall energy capacity, as well as to provide cleaner burning alternatives for electricity, water heating and cooking, the government of Mexico has made a commitment to provide future funds for increasing both the extraction and distribution of natural gas from existing reserves. Such an outlay for new capital is treated the same by our model as a government transfer to the energy extraction sector. Insofar as such a transfer goes up while tax revenues remain the same, the spending on goods and services by the government must decline. Moreover, the spending on each sector in our model goes down proportionally. This is not unlike what could be expected to happen in the future if government transfers go up. After the financial crisis in 1994, Mexico was given aid by the U.S. and the IMF under the understanding that Mexico would be fiscally responsible, and this is precisely what the government of Mexico did. In fact, in subsequent years (after all of these loans were paid back) Mexico continued to practice restraint and cut back on its budget when the price of oil went down and projected revenues from PEMEX shrank. Expenditures were not cut proportionately per se, but the modeling of a proportionate cutback serves as a good first approximation.

1.4 Environmental Costs in the Model

While our dynamic CGE model of Mexico has been explicitly designed to measure the economic costs of implementing various energy polices (many of which are designed to cut down on aggregate emissions of greenhouse gases) it must be remembered that there are environmental costs of not carrying out such policies. Furthermore, to the extent that such environmental costs can be quantified there are substantial economic costs to letting emissions levels grow unfettered. The costs of no action at all can be placed broadly into two groups. The first of these groups are the costs to Mexico of global warming itself. In chapter 3 we looked at the possible impacts of global warming on Mexico. These impacts included a possible sea level rise, increased drought, desertification, crop loss, along with increased levels of flooding and fires. Each of these impacts would have a cost, and such costs could be expected to be substantial. The second of these cost groups are the environmental costs associated with the more "traditional" local air pollutants such as SO_2, particulates, ozone, and nitrous oxides due to fossil fuel use from both point and mobile sources. Unfortunately, however, neither one of these costs is explicitly modeled here.

The first group of costs, while important and potentially large is extremely difficult to model for a number of reasons. First of all, the impacts of global warming will only come about in a distant future period and the extent and severity of these effects are highly speculative. Second, even if the severity of these effects could be known to a given order of magnitude we would have the added problem of quantifying the adjustment costs, the medical costs, the aesthetic costs, and the cost in terms of lost or diverted work. Third, these costs cannot be fully attributed to the actions of Mexico itself but rather to the actions of *all* producers of greenhouse gases *worldwide* and we would have to ascribe only a particular portion of those costs to Mexico. Finally, even if we were able to completely quantify all of these costs they would have to be fully integrated into our social accounting matrix and this is simply not doable at this time.

Even with this high level of uncertainty, however, it is instructive to look at those estimates that have been made to at least have an idea of the magnitude of the global warming problem if no measures are taken to curb carbon emissions. In his study, Tol (1999) examines a number of studies and finds that the marginal damage costs of CO_2 emissions has been found to be anywhere from US $4 to $28 per ton of carbon emitted into the atmosphere, depending on the assumptions made in the analyses. Most of the damage in these models occurs in developing countries such as Mexico and if the assumption is made that one dollar of damage to a poor family is worth more than a dollar of damage to a rich family (the so called *equity weighted* damage measure) then these costs rise to between $28 to $64 per ton of carbon. As Tol notes, the degree of uncertainty here is large. Nevertheless they do give us an idea of the worldwide costs resulting from unabated carbon emissions regardless of the source.

The second group of costs is somewhat more tractable and has been dealt with in a number of studies from developed countries such as the U.S., Europe, Canada and Japan**.** There are a variety of costs associated with the more "traditional" air pollutants. Moreover, costs can arise from lost productivity due to sickness. There are also medical costs incurred when people affected by such pollution have to see physicians. In addition to such morbidity costs there are mortality costs if the pollution is so severe as to cause death. Crops can be damaged due to pollution, property can lose its value, and there can also be aesthetic costs. Indeed the damage due to pollution in large metropolitan areas such as Mexico City can be immense during certain times of the year. Various authors (see for example Boyd and Krutilla, and Viscusi 1995) have looked at the viability of "no regrets" policies for developed countries such as the U.S. Under such "no regrets" policies a country makes economically justifiable cutbacks in emissions to control traditional pollutants, and, at the same time, decreases the level of their greenhouse gas emissions (see for example Porter (1990) and Dahl (2005)).

Unfortunately even this kind of an analysis is not possible in the present case due to the lack of any countrywide assessment of the economic damages due to air pollution. Hence, cost estimates of even more "traditional" pollutants would be impossible to incorporate into our existing social accounting matrix of Mexico. A number of estimates of air pollution damages do exist, however, for Mexico City area and these can be helpful for the conclusions to come from our analysis. In their work "Improving Air Quality in Metropolitan Mexico City: An Economic Valuation", Cesar et al (2000) looked at the annual damage (in terms of cost of insurance, productivity loss and consumer willingness to pay) due to ozone and particulates in the Mexico City area. They then look at the benefits of reducing such emissions from between ten and twenty percent. Their results vary by the assumption made, but they range from a high of over \$1.6 billion a year to a low of just over \$150 million per year (U.S. dollars, 1999). If the environmental quality norms are observed avoided costs are in the range of \$400 to \$4 billion. These numbers include morbidity and mortality costs. Using similar data, Hammitt and Ibarraran (2005) estimate that the value of a statistical life is somewhere between \$235 and \$325 thousand dollars. Evans et al. (2002) have estimated approximately 1000-2000 cases of premature death a year in Mexico City alone. Using these estimates, the total cost of pollution solely due to mortality would lie between \$235 million and \$650 million dollars, and these numbers point to the sheer magnitude of environmental externalities when one is considering highly populated areas.

Furthermore, because these numbers are only for Mexico City, and because they only represent a small subset of all different types of pollution due to emissions, they can be taken as a lower bound to any benefits coming for carbon taxes and technological change aimed at reducing carbon emissions. While it can be reasonably argued that these values may be quite high due to the high pollution exposure in Mexico City relative to the rest of the country these overall damage numbers are assuredly less than total health damages of all of Mexico. Hence, in the analysis to follow, when we see a change downward in consumer welfare resulting from some type of emissions reduction policy it must be remembered that such numbers need, at the very least, to be balanced with the air pollution cost numbers presented here.

2. RESULTS

Scenario 0: The Benchmark Case

The first scenario run is the benchmark case. Here each equation is calibrated so that the level of each variable matches the actual level observed in hundreds of billions of 2000 dollars. In this case we assume that there is no change in policy or technology over the 2000-2020 time horizon beyond the 2.9% overall growth already described. Furthermore, we assume that the production of oil grows at the same steady rate as the rest of the economy in spite of decreasing reserves. As noted above, these results are highly predictable, and the most important are given in the summary tables at the end of this chapter[2]. It is important to note that the function of the benchmark case is to see that our social accounting matrix is balanced and to provide a framework against which other policies will be contrasted. What it gives us is what would happen if all sectors of the economy (of Mexico) were to continue to grow at a specified rate (i.e., 2.9% per year) throughout the entire period of the model simulation.

in the benchmark case we assume that the balance of trade, consumption, imports and exports, government revenue and expenditure, economy-wide savings, and the effective labor supply in hours worked all grow by this exogenously determined rate of growth. The model is then projected forward at a steady growth rate in each time period of the simulation. Accordingly, since all components of income and the amount of leisure grow at the same rate, the distribution of income remains constant while economic welfare for each group grows at a common rate. For purposes of our model here the term

[2] More detailed results are contained in the appendix at the end of this chapter where we list the values of each sector (in 2000 dollars) in 2020.

leisure is not defined in terms of time spent in leisure activities per se, but rather as the amount of money that could be earned if the laborer chose to work rather than be idle during that same period of time. As noted before, in our model we assume that a worker works 40 hours per week and has 20 hours remaining for leisure activities. Hence, the value of that leisure time is equal to one half of his or her earned income. Thus, it follows that if their income were to rise for some reason, the implicit value of their leisure time would rise proportionally.

In reality of course, though the value of income and leisure both go up with wages, the mix of leisure and labor is likely to change. Put differently, consumers make the labor/leisure choice depending on the opportunity cost of time. Labor theorists often separate an income and substitution effect due to an income change. As income increases, the relative value of labor goes up causing workers to opt for more labor. At the same time, however, the worker gets wealthier and demands more of the normal good leisure. The outcome then depends upon the strength of these two effects. For most low-wage workers it is believed that the substitution effect dominates and that the amount of labor offered increases with the wage. With higher income groups, however, theorists speculate that the income effect dominates and that the supply of labor may be backward bending over this range.

Welfare per individual grows at the rate of technical progress (the overall growth rate less the population growth rate) and hence the benchmark case entails no change in the distribution of income or the relative share of income received by any one segment of the wage-earning population of Mexico. The benchmark case may then be thought of as a “balanced growth” scenario starting in the year 2000. This means that the total production of oil starts at a level of 2.8 million barrels per day in 2000 and ends at 2020 at a level of 8 million barrels per day. In reality, such balanced growth would be impossible, given that oil is being depleted from existing reserves and the production of oil under current conditions will not rise in the foreseeable future. Put another way, what we are assuming in this initial run is that investment in the oil sector will continue at its current level while new production will not be constrained by any depletion issues. Furthermore, we assume that the world price of oil is constant and is discounted at the social rate of discount over all periods. Hence, when we are examining the effects of depletion, carbon taxes, new investment, and new technology in PEMEX, or the effects of new technology and subsidy removal in CFE, we can measure them in terms of the deviations they cause from the steady state case.

Scenario 1: Introducing Depletion

In scenario 1 the level of oil produced is allowed to rise according to the overall rate of economic growth until the year 2004, but from that time onward the amount of oil production is held constant at 4 million barrels per day. This is done because the depletion of existing stocks of petroleum will make it impossible for extraction to rise with the rest of the economy without massive investment of PEMEX in drilling and oil exploration activities. Furthermore, by capping oil production at 4 million barrels per day our model simulations correspond closely to PEMEX's current long run planning goals (see Secretaria de Energia (2000)). Holding extraction at 2004 levels then, is much more realistic than assuming that oil extraction expands as fast as general economic growth. This assumption, in turn, gives us a much more reliable benchmark with which to measure the impacts of technological change, carbon taxes, subsidy removal, and new investment in the energy sector.

The whole matter of depletion has an importance for economic modeling in general. Economic modeling can only be informative to the degree in which its underlying assumptions conform to actual physical and economic conditions. A dynamic model which contains non-renewable natural resources then, has to account for the fact that the availability and/or quality of these natural resources will decrease over time *unless* the capital and labor committed to extraction change or the level of technology in the natural resource (or natural resource using) industries rises. Consequently, any predictions of models which do not consider these factors are bound to involve serious and systematic errors.

As in scenario 0, the overall growth of the economy is set at 2.9%**.** This figure comes from the planning documents published by the Ministry of Energy in Mexico and, as such, it represents a reasonably optimistic forecast for future expansion of the Mexican economy. Further, scenario 1 assumes that existing subsidies in CFE (i.e., the national electric corporation) remain in place and that there is an increase in investment in natural gas investment consistent with what is now being proposed by policymakers. Finally, it assumes that there is no capital augmenting technological change or investment occurring by either PEMEX in drilling and oil exploration or in CFE, above that assumed in the benchmark case.

The general results from scenario 1 are given in the summary tables and contrasted to the earlier results of the benchmark case. Looking first at the aggregate natural resource use we see that, as expected, crude oil production declines substantially and drops by about 37% from its final total in the steady state benchmark case. These declines are not restricted, however, to just oil production. Because oil is the chief contributor to the generation of CO_2, its emissions decline precipitously by some 32%. Thus, the natural process of depletion can limit to some extent the emissions of greenhouse gases and failure to include depletion could possibly result in an overestimate of GHG emissions. It would be incorrect; however, to conclude that depletion alone would eventually lead to a natural solution of climate change problems worldwide since suppliers in the Middle East will not face depletion pressures for some time. Furthermore the depletion of petroleum and natural gas reserves could lead to further problems if those fuels are replaced with coal which, worldwide, is both more plentiful and more carbon intensive than either oil or natural gas.

Since crude oil serves as a direct or indirect input into other economic sectors, we see that the decline in petroleum production leads to significant declines in the production of refinery products, coal, agricultural goods, manufacturing, and chemicals. Furthermore, since oil plays such a central role in the Mexican economy there is a marked drop in GDP, the final (i.e., 2020) level of investment, and the final value of the capital stock[3]. Much of Mexico's foreign exchange is earned through its oil exports, and, as can be seen in the numbers given, the loss in oil production results in a significant curtailment of total exports and, consequently, a sizeable deficit in Mexico's balance of payments.

Boosted by significant government investment, the production of natural gas does not follow the general trend and actually increases modestly. Furthermore, since most of the natural gas extracted is used to meet Mexico's electric needs, production of the power industry also rises marginally. Natural gas, as we saw in chapter 5 (section 4.2) is cleaner burning than either oil or coal so an increase in natural gas use does not greatly boost CO_2 emissions. Oil, on the other hand releases significantly greater quantities of CO_2 into the atmosphere, and the decrease in oil extraction brought about by depletion in scenario 1 leads to a substantial net decrease in aggregate CO_2 emissions from the earlier benchmark case[4].

Interestingly, some of our results go against our *a priori* expectations. One would think, for example, that a production decrease would be accompanied by a decrease in the aggregate level of consumption. As can been seen from the summary tables, however, this is not what our dynamic CGE model predicts. The reason for this lies in the downturn in private investment. Faced with lower incomes and decreased returns to capital, all agents, and particularly agents 3 and 4 (i.e., the higher income groups who do all of the formal saving in the Mexican economy), find saving for the future to be less attractive and increase their level of current consumption.

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[3] This value along with the welfare and government expenditure numbers is discounted back to 2000 dollars for purposes of consistency.

[4] In the model results contained in the summary table total CO_2 emissions are calculated by multiplying our coal, petroleum, and natural gas output numbers by coefficients corresponding to the carbon content of their emissions and then adding the three values together.

In spite of the increase in consumption there is a decrease in welfare for all four income groups in the model. This is because welfare is a function of leisure and savings (i.e., future consumption) as well as present consumption and these are both negatively affected by the fall in the level of income. Furthermore, the decrease in the level of welfare is not constant across income classes. As can be seen in the summary tables those in the higher income classes suffer the greatest loss. This occurs because the negative effects on savings affect the highest two income groups the most. They account for all of the formal savings in Mexico, and when investment earnings go down they take the lion's share of the loss. This downturn in savings also has international ramifications since these funds are not available for foreign lending and this contributes to the downturn in the balance of payments mentioned above.

In the absence of any type of technological change, the level of oil production fails to increase and the revenues from PEMEX and CFE decline by 37% and 3% respectively. Interestingly, government revenue from sources other than PEMEX is higher than it would be in a steady state. This occurs because the declining profits in energy related industries force capital and labor resources to other sectors of the economy such as services, chemicals, agriculture, mining and other manufacturing industries. This has the effect of moderating losses in those sectors, increasing the level of taxable labor and capital outside of the energy-related sectors, and slightly increasing government expenditures.

Scenario 2: Depletion and Deregulation of Electricity Prices

The results of scenario 2 are quite similar to scenario 1 with which we contrast it in the summary tables. Here again we run the dynamic CGE model assuming a moderate rate of growth and assuming that oil production rises from 2.8 million barrels per day in the initial year to 4 million barrels per day in 2004 before leveling off. We also continue to assume that there is no capital augmenting investment in the energy sectors above that initially considered in scenario 0. The only difference here is that we now eliminate all of the 1.1 billion dollars worth of electricity subsidies which are presently in place. For a number of years CFE has given power subsidies to such sectors as agriculture and transportation. In addition it has given out considerable subsidies to low-income residential consumers as well as consumers in rural areas. There has been talk of removing some or all of these subsidies, and, in fact the government is now pressing to lower the amount of these subsidy payments. At present, these subsidies average about 20% of the value of total output in the electricity sector but, as we noted above, the government is highly selective in the industries that are heavily subsidized. Most service industries are not subsidized and the total amount of government subsidies going into the electric power sector amount to no more than 0.35% of aggregate GDP.

Hence, in the summary tables at the end of the chapter we see that if all of the present subsidies were removed there would be little economy-wide effect. When scenario 2 is compared to scenario 1 there is a slight but insignificant change in the aggregate variables. This is only one part of the story however. The power sector is not all that large as economic sectors go in this model. It is, nevertheless, an important sector since it plays a crucial role in various types of productive activity, and it is highly important for consumer welfare since consumers are dependent on power for a variety of household needs.

As expected, when the electric subsidies are removed, power output goes down somewhat as consumers cut back on nonessential energy use (see the appendix). Such cutbacks, however, are modest given the lack of viable alternatives to electricity for heat and light and the fact that we assume only limited technological change. Oil production, refining output and CO_2 emissions also decrease slightly as the demand for refined fuels from the electric power industry slackens. Thus we find clear evidence from our model's results that a policy designed to improve efficiency in the market by removing distortions in energy prices has a positive environmental impact in the sense that GHG emissions levels drop. Agriculture, transport, and manufacturing output all decline since those sectors are the major recipients of subsidized electricity. This decline is also reflected in our consumption numbers which show a decline in energy, autos, and food purchases. Faced with higher prices in these subsidized sectors, consumers cut back slightly on their purchases of these items and increase spending more on service items. Consumption expenditures as a whole, however, remain constant. Total output goes up a bit and the terminal capital stock increases slightly as well as more money is funneled into investment through saving. The balance of payments also declines modestly.

As often happens, efficiency gains come at the cost of distributional equity. Economic welfare declines for most consumers and the bulk of this decline is concentrated in the lower income groups. This is because, as mentioned previously, the subsidies are, by and large, given to the lower income groups. Indeed, almost all of the consumer subsidies are given to those in the bottom five income deciles (i.e., agents 1 and 2) and no subsidies at all are given to consumers in the top two income deciles (i.e., agent 4). Furthermore, much of the remainder of these subsidies goes to agriculture which provides staple foods to the poorer groups. Hence, in spite of its obvious efficiency and environmental benefits, elimination of distorted energy prices may cause income distribution concerns among policy makers.

Scenario 3: Capital Enhancing Investment in the Energy Sector

In scenario 3, the production of oil is held constant in a manner consistent with that described in the previous two scenarios rising from 2.8

million barrels a day in 2000 to a plateau of 4 million barrels a day in 2004, and remaining at that level thereafter. Now, however, the model allows for an increase in the production of both CFE and PEMEX as the result of increased government investment in the capital stock. In technical terms we impose what is called a capital-enhancing technological change. Under such a change the capital inputs are allowed to become more efficient but the labor inputs are assumed to remain at the same level of efficiency. Put a little differently, we assume that increased efficiency and technological improvement are brought about by the enhancement of the physical equipment used in production alone. It is very important to note that this change (which averages 3% per annum over the 11-year period from 2003 to 2020) is separate and distinct from the 2.9% improvement spoken about above. That earlier change was due to an overall increase in labor productivity throughout the Mexican economy, while this change involves the enhancement of capital in the oil and gas and electrical power industries only.

The impact of these changes on the Mexican economy is shown in the summary tables and in the appendix. Looking at the summary tables, we see that, relative to scenario 1, GDP, oil output, carbon emissions, power output, aggregate exports, and the balance of payment surplus have all risen significantly[5]. This is exactly what we would expect in the presence of technological change. Of particular interest here is the substantial increase in output experienced by the oil and power sectors. In the case of oil we have the direct effect due to increased technology in oil production, and an additional positive externality due to the fact that added investment is going into the natural gas industry. Oil and natural gas are often extracted together and the investment in one type of exploration can also be beneficial to the other. In the case of electricity, a large increase occurs because electric power benefits from technology change at several stages of the production process. First, and most obviously, electricity production increases when productivity increases within that industry itself. This increase can be thought of as a "direct effect" of technological change. Second, electricity benefits when there is an increase in productivity and a decrease in the cost of oil and gas extraction. These lower costs due to capital efficiency gains translate into lower energy input prices for CFE and cause the power industry to adapt to a more energy intensive mode of operation. This second increase can be thought of as an "indirect effect" of change in input technology. Combined, the "indirect" and "direct" effects serve to amplify the total change brought about in the power

[5] The GDP figure is a net figure since the investment funds are deducted from calculated GDP in the manner explained above in section 1.3. The amount of investment was determined outside the model by calculating the funds needed to generate the 3% technological change in the capital used in energy production. We assumed a 5% rate of return for those funds.

sector and lead to significant increases in CFE output, and these increases become quite apparent in these particular simulation results.

Furthermore, just as would be expected, there is an increase in consumption as well as in the value of the final capital stock. Curiously, we find that there is a decrease in the government revenues collected from PEMEX and CFE. This occurs because, with the advent of new technology, both CFE and PEMEX can produce the same output of their products with fewer inputs. Consistent with economic theory, the output of the industry expands as initially there is a higher return to capital and labor in the industry. The overall demand for oil and gas, however, means that as we reach a new equilibrium in subsequent years the total returns to these factors go down. Such a result is not unlike that experienced in agriculture in developed countries as technology advanced in the late 19^{th} century and early 20^{th} century. Faced with declining returns labor and capital are released from PEMEX and CFE, and capital and labor tax revenues decline in those sectors.

Boosted by higher income, purchases in every consumption category rise relative to their values in scenario 1. With the exception of refinery products and natural gas, the import purchases of most items rise. With significantly more domestic extraction of oil and natural gas fewer fossil fuels need to be purchased from abroad, and with the increase in sales of petroleum in the international market Mexico's foreign exchange receipts soar. Finally, aggregate consumer welfare goes up relative to its scenario 1 levels. Technological advancement, it would seem, has a generally positive effect on consumer well-being.

Scenario 4: Investment and Deregulation of Electricity

In scenario 4 we assume that all electric subsidies are removed as in scenario 2 but that now we also have capital enhancing technological change as in scenario 3. As before, the level of oil levels off at 4 million barrels a day in 2004. As would be expected when compared to scenario 1 the overall results of this scenario are close to scenario 3. It is, however, quite instructive to see the differential impacts of this change on the various economic sectors and agents in the model.

The results of our model following these assumptions are given in the summary tables as well as in the appendix. These tables show that almost all sectors and aggregates rise relative to their values in scenario 1 but fall relative to their values in scenario 3. The capital stock, GDP, investment, and aggregate government revenues and the welfare levels of agents 1 to 3 all go down slightly compared to scenario 3 where electricity subsidies remained in place. Interestingly, the welfare of the wealthiest consumers goes up here compared to scenario 3 since they do not profit at all from power subsidies.

Hence, when we compare scenario 4 to scenario 1 we find that all income groups experience welfare gains. Hence, according to our simulations, the combination of increased investment in energy capital and elimination of electric subsidies is both a progressive and Pareto improving move. In a wider context however, our results are not so straightforward. A quick glance at the summary tables also shows that the level of CO_2 emissions rises significantly from scenario 1 to scenario 4, and, as we saw in section 1.4, the cost of the emission externality to consumer welfare is high even without considering the global warming impacts. Hence, it is more accurate to say that in going from scenario 1 to scenario 4 all agents will experience a definite welfare gain in terms of traditional national income accounting variables, but will experience a significant decline in the welfare associated with environmental quality. The net effect on welfare, however, is extremely difficult to quantify with any accuracy.

With respect to the individual sectors in the model we find that all consumption sectors experience gains relative to scenario 1. When compared to scenario 3, however, we find that those sectors, such as energy and food, which received significant electric subsidies, go down while sectors such as services and transport which were not heavily subsidized rise slightly. Much of the same thing happens with respect to the production sectors in the model. Agriculture, manufacturing, and energy all go down slightly with respect to scenario 3 while services show a small gain. The situation in the foreign sector is essentially the same as in scenario 3. Since electricity in Mexico is a non-traded good there are no direct effects of electricity subsidy removal on imports or exports and the indirect effect on other sectors are quite small and insignificant.

Scenario 5: Energy Efficient Technological Change

Scenario 5 is very similar to scenario 4 in all respects except in the type of technological change that is modeled. Whereas in scenario 4 we assumed that investment was aimed at capital augmenting technological change in the energy sector, in scenario 5 we assume that there has been an equivalent investment in energy efficient technology among those sectors that use fossil fuels for burning. An energy efficient technological change is precisely what proponents of tax incentive programs in the U.S. and elsewhere have in mind. Furthermore, it is argued that the potential for such change is even greater in developing countries in places like Latin America with fairly old and inefficient engines, power units, and heating equipment.

The results of this scenario are given, as before, in the summary tables and the appendix. In all our tables the results of this exercise are contrasted with the results of scenario 4 above in order to see the impact of different varieties of technological change. As we see, the most dramatic effect is in the fossil fuel sectors themselves. Compared with scenario 4 oil, natural gas, and coal use drops sharply. Electricity use also declines a bit compared with scenario 4 but is significantly higher than it was in scenario 1. Net exports and the balance of payments also go down since these are driven by oil exports, and, unlike scenario 4, there is no technological change in the fossil fuel sectors per se to drive up oil and gas production.

Accompanying the decline in fossil fuel extraction there is a significant drop in CO_2 emissions relative to scenario 4. Furthermore, since the increase in energy efficiency has occurred economy-wide rather than in just a few industries, the level of GDP and the level of the capital stock increase slightly over that in the previous scenario. Economic growth occurs in a cleaner manner than before, and economic welfare is up slightly among all groups as well. As we have alluded to earlier, however, this is probably a significant understatement of welfare gains. Aggregate emissions here have dropped substantially compared with scenario 4 bringing down the medical and other costs associated with a variety of different pollutants (such as SO_2, particulates, ozone, and nitrous oxides). This kind of energy efficient technological change then has distinct environmental advantages over change solely aimed to increase capital output in one or more industrial sectors. This kind of result can be very important since policy makers often have very limited funds to direct toward competing uses and need to prioritize their investments with respect to different types of technological change.

Scenario 6: Capital Enhancing Technological Change and Carbon Taxes

The next scenario run is scenario 6. Here, all the assumptions are exactly the same as in scenario 4 except that now we levy a carbon tax on petroleum, coal, and natural gas. Since the carbon content of these fuels is different they are taxed at different rates with the highest tax on coal and the lowest tax on natural gas. More specifically over the years from 2005 to 2020 we gradually place a 50% tax on coal, a 25% tax on petroleum and a 12.5% tax on natural gas. At the same time we levy tariffs of equal magnitude on the importation of these goods and therefore eliminate an advantage that foreign producers could gain by increasing their exports of fossil fuels to Mexico. Though these taxes and tariffs could be considered a bit high they are used because they generate the cuts expected of developed countries under the Kyoto agreement (i.e. cuts of 10% from their 1990 emissions levels by 2015). Furthermore, this is only a modeling exercise and to see the direction of the changes caused by the carbon tax; the absolute rates can be lowered if necessary if they are too onerous (see scenarios 12 and 16 in chapter 8). As discussed at length in chapter 5 the idea of such a tax is to cut down on the output of greenhouse gases. While cutting down on these gases has environmental and economic benefits there are also definite economic costs, and this is what this particular scenario is designed to measure.

Looking initially at our aggregate results we see that, as expected, the aggregate level of carbon dioxide emissions drops off significantly from its scenario 4 levels. A decrease in carbon emissions is the primary goal of a carbon tax, and our modeling results here indicate that it is certainly successful in achieving this. Furthermore, this cutback in total emissions entails positive impacts with respect to local environmental quality in Mexico. There are definite costs, however, in terms of both economic efficiency and equity. The negative impacts on economic efficiency are readily apparent since GDP, investment, the terminal capital stock and the balance of payments all decline relative to their value in scenario 4. Looked at another way (again see the summary tables) we can say that for every ton of carbon emissions avoided, GDP declines by about $104 dollars. This "price of carbon abatement" derived here is potentially helpful to policymakers since it gives the opportunity cost inherent in a carbon tax. It also seems to be somewhat robust since it is similar to the results attained by other researchers (see for Fawcett and Sands, 2006). This number is fairly high with respect to other developing countries (i.e. China) and reflects the fact that Mexico has little ability to shift from high carbon content fuels (such a significant coal deposits) to fuels with substantially lower or no carbon content (such as natural gas, hydroelectric power, or nuclear power).

With respect to economic equity we see that the carbon tax is also somewhat regressive. To be more specific we see that the two lower income agents lose welfare whereas the two higher income agents gain welfare. This stems from the fact that in Mexico the lower income groups devote a higher proportion of their total income to energy expenses than the higher income groups. Furthermore, as expected, the production of petroleum, natural gas and coal drop significantly from their pretax levels (see the appendix). Manufacturing, transportation, electricity, refining, chemicals, and agriculture are all closely linked to the use of fossil fuels, and hence as energy prices rise their production declines. Services, on the other hand, require little in the way of energy and as resources are diverted away from energy intensive activities service industries are hurt less. Nevertheless, even here there is a slight net downturn of total production in the sector by the final period of the analysis.

After the imposition of a carbon tax, the consumption of energy, gasoline, and agriculture all decline as their relative prices rise. Less energy intensive categories such as housing and services, on the other hand, show slight increases. Taken as a whole, consumption in Mexico actually rises following an energy tax. This occurs because consumers, faced with higher energy bills, opt to cut down on savings, increase the level of their present consumption, and reduce their capital holdings both at home and abroad.

In terms of foreign trade, higher energy prices translate into lower export figures for petroleum, refinery products, chemicals, and natural gas. Since energy is Mexico's primary means for obtaining foreign exchange these reduced energy related exports imply that Mexico has less to spend on imports including, most importantly, manufactured items. This also means that, as a result, there is a decrease in the net balance of payments.

Scenario 7: Energy Efficiency and Carbon Taxes

Scenario 7 combines the effects of a carbon tax with an energy efficient technological change affecting all sectors. More specifically, in this model simulation we impose a carbon tax on coal, natural gas and petroleum at the exact same levels we used in scenario 6, and we levy tariffs of equal magnitude on the importation of these goods from elsewhere. In addition to this carbon tax however, we now also assume that increased investment has led to greater efficiency in burning those fuels (as we assumed in scenario 5). This scenario, then, represents a full fledged effort on the part of policymakers to cut back on fossil fuel emissions through both economic and technological means, and it is instructive to compare this scenario to the previous one where only taxation and tariffs are employed.

The results of the simulation are given in the summary tables and in the appendix. As we can see there, the combination of a carbon tax and energy efficient technological change are dramatic when it comes to emissions. The consumption of all fossil fuels declines dramatically from the levels in scenario 6 as do the emissions of CO_2. Indeed when measure the changes from scenario 7 to scenario 4 we find that the change is even more dramatic. When compared with scenario 4, the production of oil declines by over 36% and the total emissions of CO_2 decline by over 35%. Hence, if the curtailment of greenhouse gases were the only objective of policy makers this action would be quite an effective means of attaining this goal. However, when we look at the last row of summary table 3 we see that the cost of a ton of carbon emissions goes up from about $104 to over $480 a ton! When energy use becomes more efficient, the cost of added emissions abatement increases dramatically and far outweighs any potential environmental benefits. Hence, any carbon tax levied would need to be at much lower rate than that assumed here.

Looking again at the summary tables we see that GDP increases slightly with more efficient fuel use as does the terminal level of the capital stock. The level of welfare of agents 1 to 3 declines slightly, but it must be remembered that these numbers do not include the medical and other savings realized when the level of aggregate emissions drop, particularly in urban areas such as Mexico City. The level of oil exports also drops along with aggregate exports and the balance of trade, and, if maintaining a strong trade balance is an important policy consideration, energy efficient technological change would not be a good means of maintaining this.

In most other respects the results of this scenario are quite predictable. With more efficient fuel use the final consumption of gasoline and energy goes down at the same time that the consumption of all other items increases. Investment rises slightly and the productivity in the manufacturing sectors go up as well. Services initially decline a bit (not shown), but these declines are almost completely eliminated by the terminal year of 2020.

Scenario 8: Overall Technological Change and Carbon Taxes

In scenario 8 we run the dynamic CGE model with a broad-based carbon tax identical to that imposed in scenario 6. Now however we allow for a technological improvement in *all* of our production sectors. More specifically, in this simulation we impose a "Harrod Neutral" or capital-specific technological enhancement in each of the production sectors over the 20 year time horizon studied. In accordance with OECD estimates (for developing countries) the technological change for each sector was assumed to be 3.1% for the 10 years from 2005 to 2015. The results of this exercise are again given in the summary tables and the appendix.

The impact of this technological change is clear and dramatic. The balance of payments, GDP, investment, PEMEX and CFE revenue, and consumer welfare all rise significantly over their scenario 6 and scenario 7 totals. Unfortunately for environmental policy, however, the aggregate level of carbon dioxide emissions rises over 9% above its total in scenario 6 as well. Indeed these numbers clearly show the tradeoffs between environmental quality and economic growth that policy makers will face in the coming years. With other types of pollution (e.g., SO_2 pollution of the air and organic pollution of the water) technological change can sometimes act as an agent to enhance environmental change. In the case of carbon dioxide, however, output enhancing technological change can only decrease pollution to the degree that it can reduce total energy use. While this may be possible in a static setting, it becomes more problematic when economic growth is a top priority of policy makers and it needs to be targeted in the manner we saw above in scenario 7; otherwise the environmental costs are likely to be quite high.

The impact of broad technological change on consumer welfare is highly progressive with the lower income agents benefiting by much higher percentages than their higher income counterparts. In part this is due to the changes occurring in the relative prices of consumption goods. By and large, the largest portions of low income consumers' budgets are spent on basic necessities such as food, energy and housing while higher income groups tend to spend more on consumer services. In the wake of a technological change the production of food and housing climbs dramatically and their prices fall relative to the price of services. This, in turn, tends to benefit the poorest agents relatively more than the richer ones.

Wealthier agents' welfare is also more closely tied to savings and investment than those in the lower income groups. In fact, the bottom half of all consumers have no formal savings at all. Initially a technological change forces a decrease in investment and earnings on savings relative to scenario 6[6]. Eventually, this situation turns around and investment increases with respect to the earlier scenario (though the terminal level of the capital stock remains slightly below its scenario 6 level). Nonetheless, income from savings and the return to capital fall relative to labor earnings, and this again is reflected in higher relative welfare gains for agents 1 and 2.

As was previously noted, net exports and hence the balance of payments in this scenario is significantly higher than in the previous one. Significantly, these gains are due to the increased exports of the agricultural and manufacturing sectors. Traditionally, Mexico has relied on its oil and gas sector to obtain foreign exchange. In the face of a worldwide cutback on carbon use, however, other sectors gain importance and significant technological innovation in these sectors becomes critical if Mexico intends to avoid balance of payments problems.

3. CONCLUSIONS

The simulations described in this chapter are highly instructive. They illustrate the structure of the Mexican economy and highlight the linkages between all the sectors of the economy. In so doing they cast light on the options and tradeoffs focusing policy makers dealing with energy matters, and they bring out the unintended consequences of narrowly focused market interventions.

First of all, our results make it clear that discussions of energy policy have to recognize the importance of depletion and investment in the choice of energy alternatives. Policy makers cannot assume that the fossil fuel sectors will increase at the same pace as other economic sectors without significant investment. Failure to take depletion into account will lead to the over-estimation of GDP, balance of payments surpluses, consumer welfare, and

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[6] This initial decrease in investment is due to our assumption of "rational expectations" in the model. This means that if a change is to occur in a particular period, then all economic agents will be aware of that in previous periods. Hence, in anticipation of a positive technological change, investors will decrease their investment before it occurs and increase their investment spending after it occurs.

investment activity in the future. By the some token, we have seen that the increased investment in natural gas as an energy source will have positive benefits not only on that sector but on the electricity and service sectors as well. Such investment is beneficial for the environment as well since the carbon content of natural gas is significantly less than the fuel oil and diesel fuel that it would be replacing in electricity production.

Second, the results of our simulations show that a carbon tax, in spite of the significant environment benefits in terms of stemming carbon dioxide and other harmful emissions, will entail significant costs in terms of both economic efficiency and consumer equity. Because of the importance of petroleum to both manufacturing and exports in Mexico, a broad based carbon tax would significantly decrease GDP and economic growth as well as lead to balance of payments problems. Furthermore, as we have discussed, the poor use a significantly higher proportion of their income on energy products than the rich and hence a carbon tax is somewhat regressive in nature. Given these drawbacks, a pure carbon tax which was not modified for distribution of income concerns and not accompanied by financial support from developed countries (see our discussion of the Clean Development Mechanism in chapter 5) would stand little chance of being implemented.

Third, the simulations in this chapter have demonstrated the importance of technology for both the energy and non-energy sectors. We have seen that technological change is essential in restoring economic growth in the face of declining reserves of fossil fuel. Indeed, as these reserves decline Mexico will be more and more reliant on the export earnings of other industries, and new technology will be the primary means by which Mexico enhances its trade position in an increasingly competitive international market. Additionally, since technological change is most effective in energy and manufacturing related sectors it has a progressive impact on the distribution of income. The economic gains of new technology, however, must be balanced with its potential environmental costs. To the extent that new technology spurs economic growth which increases total energy use, the emissions of CO_2 and possibly other greenhouse gases will rise. The tradeoffs between GDP and CO_2 emissions can be seen in figure 7.1. Prudent environmental policy thus requires that the technological change initiated must be as “clean” as possible and enhance the overall substitution of labor and capital for energy use. Furthermore, when dealing with energy, the “cleanest” way to proceed is to invest in technological change that enhances fuel burning efficiency (and encourages alternative energy sources) rather than solely investing in technology which makes fossil fuels easier to extract or transport.

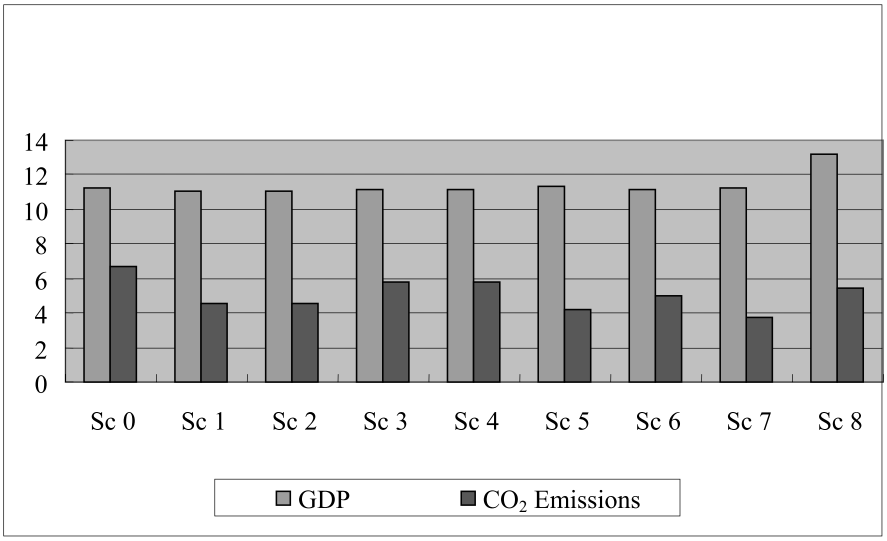

Figure 7.1 GDP and CO_2 emissions under different scenarios
(GDP in hundred billion dollars, CO_2 in hundred million tons)

Finally, our results are quite robust with respect to the parametric assumptions made. Although not shown here, each scenario was run under a wide variety of assumptions regarding the elasticity of substitution between capital and labor in production. The elasticity of substitution between fuels was also varied as was the elasticity of demand for energy outputs such as gasoline and electricity. In all of these analyses our results remained quite stable giving us reasonable confidence in the direction of the economic impacts predicted as well as the relative magnitude of the numbers obtained.

Although our analysis so far has allowed us to draw some far-reaching policy conclusions, it has ignored some rather important facets of the Mexican economy. For some time, Mexico has been plagued by significant formal unemployment. Moreover, much of this employment has been linked to structural problems such as a downward rigidity in wages and inflexible prices (primarily in the fossil fuels industries). Furthermore, the presence of large parastatal corporations like PEMEX and CFE mean that the Mexican economy is straddled with several inefficient government sponsored monopolies. To gain a more accurate picture of the challenges facing policy makers then, it is important that we run our proposed energy reforms in the presence of these economic constraints. This is what we will now do in chapter 8.

Summary Table 1A: Assumptions for Scenarios

Scenario 0: The benchmark case

Scenario 1: The benchmark case plus oil depletion

Scenario 2: Scenario 1 plus deregulation of energy prices

Scenario 3: Scenario 1 plus new investment in PEMEX and CFE producing capital-enhancing technological change in energy sectors

Scenario 4: Scenario 1 plus deregulation of energy prices and capital-enhancing technological change in energy sectors

Scenario 5: Scenario 2 plus energy efficient technological change in all sectors

Scenario 6: Scenario 4 plus a carbon tax

Scenario 7: Scenario 5 plus a carbon tax

Scenario 8: Scenario 3 plus a carbon tax and capital-enhancing technological change in all sectors

Summary Table 1B: Comparison of Scenarios

Scenario 1 is compared to Scenario 0

Scenario 2 is compared to Scenario 1

Scenario 3 is compared to Scenario 1

Scenario 4 is compared to Scenario 1

Scenario 5 is compared to Scenario 4

Scenario 6 is compared to Scenario 4

Scenario 7 is compared to Scenario 6

Scenario 8 is compared to Scenario 6

Summary Table 2: Quantities. CGE Results Data for Mexico for 2020 (hundreds of billions of 2000 dollars)

	Scenario0	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8
GDP	11.2585	11.0544	11.0614	11.1798	11.1562	11.2954	11.1348	11.2423	13.1870
Oil output	0.4304	0.2708	0.2702	0.3565	0.3559	0.2552	0.3039	0.2267	0.3217
Power output	0.1979	0.1925	0.1916	0.2226	0.2215	0.2148	0.2132	0.1862	0.2481
Consumption	7.5271	7.6342	7.6303	7.6565	7.6520	7.6821	7.6581	7.6715	8.8420
Imports	3.3175	3.3173	3.3173	3.3177	3.3177	3.3175	3.3175	3.3168	3.3155
Exports	3.6073	3.4755	3.4710	3.5567	3.5522	3.4755	3.5032	3.4424	3.7308
Exports oil	0.3899	0.2451	0.2448	0.3234	0.3230	0.2321	0.2760	0.2074	0.2803
BoP surplus	0.2897	0.1582	0.1537	0.2390	0.2345	0.1580	0.1857	0.1256	0.4154
Cumulated welfare agent 1	3.4175	3.4060	3.4026	3.4207	3.4171	3.4179	3.4147	3.4101	3.8403
Cumulated welfare agent 2	10.2034	10.1732	10.1637	10.2172	10.2076	10.2098	10.1999	10.1858	11.4841
Cumulated welfare agent 3	15.9316	15.8119	15.8026	15.8450	15.8357	15.8409	15.8387	15.8331	17.2150
Cumulated welfare agent 4	26.5939	26.3226	26.3447	26.3116	26.3335	26.3482	26.3698	26.3949	27.5731
Terminal capital stock	29.5613	28.2687	28.1667	28.5702	28.4689	29.0199	27.9907	28.1188	27.7904
Cumulated Govt. revenue from PEMEX	0.0637	0.0572	0.0574	0.0546	0.0548	0.0554	0.0524	0.0541	0.0507
Cumulated Govt. revenue from CFE	0.0080	0.0082	0.0082	0.0080	0.0080	0.0085	0.0080	0.0082	0.0097
Cum. Govt revenue from other sources	0.8367	0.8475	0.8473	0.8593	0.8592	0.8634	0.8811	0.8785	1.2762
CO2 Emissions (hundreds of millions of metric tons)	6.6766	4.5415	4.5299	5.8088	5.8016	4.1913	4.9790	3.7496	5.4411
Price of Emissions (dollars per metric ton)	-------	-------	-------	-------	-------	-------	$104.46	$480.86	$95.66

Summary Table 3: Summary CGE Results Data for Mexico for 2020 (percentage changes from respective scenarios*)

	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8
GDP	-1.81%	0.06%	1.13%	0.92%	1.25%	-0.19%	0.97%	18.43%
Final level of Investment	-11.18%	0.76%	3.75%	2.99%	4.01%	-4.32%	0.00%	19.03%
Oil output	-37.09%	-0.21%	31.64%	31.43%	-28.30%	-14.62%	-25.38%	5.87%
Power output	-2.72%	-0.48%	15.64%	15.06%	-3.02%	-3.78%	-12.64%	16.39%
Consumption	1.42%	-0.05%	0.29%	0.23%	0.39%	0.08%	0.17%	15.46%
Imports	-0.01%	0.00%	0.01%	0.01%	-0.01%	-0.01%	-0.02%	-0.06%
Exports	-3.65%	-0.13%	2.34%	2.21%	-2.16%	-1.38%	-1.73%	6.50%
Exports oil	-37.13%	-0.15%	31.92%	31.77%	-28.14%	-14.56%	-24.85%	1.55%
BoP surplus	-45.41%	-2.82%	51.12%	48.30%	-32.65%	-20.84%	-32.33%	123.72%
Cumulated welfare agent 1	-0.34%	-0.10%	0.43%	0.33%	0.02%	-0.07%	-0.14%	12.46%
Cumulated welfare agent 2	-0.30%	-0.09%	0.43%	0.34%	0.02%	-0.07%	-0.14%	12.59%
Cumulated welfare agent 3	-0.75%	-0.06%	0.21%	0.15%	0.03%	0.02%	-0.04%	8.69%
Cumulated welfare agent 4	-1.02%	0.08%	-0.04%	0.04%	0.06%	0.14%	0.10%	4.56%
Terminal capital stock	-4.37%	-0.36%	1.07%	0.71%	1.94%	-1.68%	0.46%	-0.72%
Cumulated Govt. revenue from PEMEX	-10.20%	0.32%	-4.55%	-4.22%	1.02%	-4.41%	3.19%	-3.19%
Cumulated Govt. revenue from CFE	2.33%	0.00%	-2.27%	-2.27%	6.98%	0.00%	2.33%	20.93%
Cum. Govt revenue from other sources	1.29%	-0.02%	1.40%	1.38%	0.50%	2.55%	-0.30%	44.84%
CO2 Emissions	-31.98%	-0.25%	27.90%	27.75%	-27.76%	-14.18%	-24.69%	9.28%

* See Summary Table 1B for comparison of scenarios.

APPENDIX

PRODUCTION

	*Scenario 0**	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
Agriculture	1.1569	-2.0723%	-0.7054%	1.3123%	0.5906%	1.4351%	-1.0600%	0.1319%	35.7837%
Coal	0.0195	-6.6667%	-1.0204%	2.0408%	2.0408%	-24.0000%	-11.0000%	-23.5955%	43.8202%
Petroleum	0.4304	-37.0898%	-0.2059%	31.6404%	31.4345%	-28.3029%	-14.6214%	-25.3823%	5.8716%
Manufacturing	5.1076	-3.2857%	-0.4665%	1.5989%	1.1324%	1.8042%	-1.3988%	0.1056%	31.2545%
Chemicals	0.5752	-6.3005%	-1.1034%	4.3793%	3.2414%	8.0160%	-3.0394%	4.8915%	24.9742%
Refined Products	0.2604	-14.7038%	-0.5858%	10.3766%	9.8745%	-13.5567%	-6.9307%	-19.4763%	30.0327%
Transport	0.8882	-0.2511%	-0.2098%	0.7342%	0.5244%	1.3982%	-0.4174%	0.9220%	13.3906%
Electricity	0.1979	-2.7230%	-0.4826%	15.6371%	15.0579%	-3.0201%	-3.7752%	-12.6417%	16.3906%
Services	5.7068	0.2052%	0.0780%	0.4257%	0.5037%	0.3428%	-0.0711%	-0.0841%	14.4581%
Natural Gas	0.0418	-7.5556%	0.0000%	31.7308%	31.7308%	-28.4672%	-14.5985%	-25.6410%	5.5556%
GDP	11.2585	-1.8129%	0.0630%	1.1349%	0.9215%	1.2469%	-0.1926%	0.9653%	18.4312%
Final Investment	2.8230	-11.1801%	0.7629%	3.7508%	2.9879%	4.0123%	-4.3210%	0.0000%	19.0323%
Government	0.9084	0.4910%	0.0000%	0.9976%	0.9976%	0.5846%	2.1165%	-0.0790%	41.9660%

CONSUMPTION

	*Scenario 0**	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
Food	1.9601	1.2326%	-0.2716%	0.4683%	0.1873%	0.4768%	-0.0280%	0.1683%	25.1823%
Housing	2.7933	1.5170%	0.0197%	0.1245%	0.1442%	0.4254%	0.1440%	0.3202%	12.5866%
Gasoline	0.3092	1.0216%	0.1190%	0.5354%	0.5949%	0.0591%	-0.0591%	-0.3550%	9.4675%
Automobiles	0.3301	1.4640%	-0.1110%	0.2775%	0.1110%	0.7206%	0.0554%	0.4986%	16.0665%
Energy	0.2461	1.2840%	-0.2237%	2.3863%	2.1626%	0.0000%	-0.3650%	-1.6850%	10.7692%
Transportation	0.3349	1.4428%	0.1094%	0.1094%	0.2188%	0.2183%	0.1638%	0.1090%	11.7166%
Services	1.5535	1.5791%	0.0707%	0.0353%	0.1060%	0.3294%	0.1882%	0.2701%	11.0263%
Total	7.5271	1.4222%	-0.0511%	0.2921%	0.2337%	0.3935%	0.0801%	0.1747%	15.4585%

Note: * Benchmark Scenario 0 numbers are in hundreds of billions of 2000 dollars.
** See Summary Table 1B for comparison of scenarios.

IMPORTS

	*Scenario 0**	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
Agriculture	0.1195	0.0000%	0.1555%	0.1555%	0.4666%	0.1548%	-0.1548%	0.0000%	-5.4264%
Coal	0.0043	-4.3478%	0.0000%	4.5455%	4.5455%	-8.6957%	-13.0435%	-10.0000%	10.0000%
Petroleum	0.0000	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Manufacturing	2.6747	-0.2432%	-0.0279%	0.2716%	0.2438%	0.2779%	-0.1181%	0.0835%	-1.0226%
Chemicals	0.4555	0.3264%	0.1627%	-0.4880%	-0.3660%	-1.9592%	0.2041%	-1.8330%	5.4990%
Refined Products	0.0585	8.2540%	-0.2933%	-6.7449%	-7.0381%	3.1546%	4.1009%	8.1818%	7.5758%
Services	0.0020	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	9.0909%
Natural Gas	0.0030	6.2500%	0.0000%	-23.5294%	-23.5294%	-15.3846%	15.3846%	26.6667%	53.3333%
Total	3.3175	-0.0056%	0.0000%	0.0112%	0.0112%	-0.0056%	-0.0056%	-0.0224%	-0.0616%

EXPORTS

	*Scenario 0**	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
Agriculture	0.1570	0.3550%	-0.3538%	0.0000%	-0.3538%	0.3550%	0.0000%	0.2367%	12.1893%
Coal	0.0006	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Petroleum	0.3899	-37.1306%	-0.1516%	31.9181%	31.7665%	-28.1358%	-14.5570%	-24.8485%	1.5488%
Manufacturing	2.7815	0.5345%	-0.0997%	-0.0465%	-0.1462%	0.2862%	0.0067%	0.1730%	7.2807%
Chemical	0.2392	0.0000%	-0.3108%	0.7770%	0.4662%	2.5522%	-0.3094%	2.0946%	0.6982%
Refined Products	0.0329	-7.3446%	0.0000%	7.3171%	7.3171%	-2.2727%	-3.9773%	-7.1006%	-1.1834%
Services	0.0054	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	-3.4483%
Natural Gas	0.0007	0.0000%	0.0000%	25.0000%	25.0000%	20.0000%	-20.0000%	-25.0000%	-25.0000%
Total	3.6073	-3.6528%	-0.1283%	2.3368%	2.3368%	-2.1607%	-1.3812%	-1.7347%	6.4987%
BoP	0.2897	-45.4137%	-2.8202%	51.1163%	48.2961%	-32.6466%	-20.8399%	-32.3323%	123.7237%

Note: * Benchmark Scenario 0 numbers are in hundreds of billions of 2000 dollars.
** See Summary Table 1B for comparison of scenarios.

CHAPTER 8

SIMULATION RESULTS UNDER IMPERFECT COMPETITION

In this chapter we present a model that relaxes some of the main assumptions of perfect competition (i.e., that there is full employment in all sectors and that there is a competitive market structure, and therefore no monopoly power in any market). We modify the basic model slightly and re-run a number of the policy options. First, we assume that there exist sticky wages in the labor market, which leads to involuntary non–frictional unemployment. Next, we treat PEMEX and CFE as monopolies with the power to mark up petroleum and electricity prices after 2004. Using this version of the model, we test for the same policies as in chapter 7 (i.e., different versions of technological change, deregulation of energy prices, and carbon taxes).

1. INTRODUCING IMPERFECT MARKETS

In chapter 7 we used the basic dynamic CGE model to look at a host of different scenarios corresponding to various energy and environmental policies in Mexico. In performing these simulations, however, we imposed a number of serious restrictions on our model. We assumed, for example, that there is full employment in all sectors. Indeed, in our initial setup we assumed that all markets cleared, that wages were perfectly flexible, and that there are no surpluses or shortages when prices are above zero. We also assumed that there was a competitive market structure, no monopoly power in any market, and that all resources went to their highest valued use. While such assumptions are good as first approximations and make running the model more tractable, they could be a bit unrealistic in terms of accurately portraying the Mexican economy as it exists today. To begin with, both PEMEX and CFE are large state run corporations and, as they are the only suppliers of petroleum and electricity products in Mexico, they have monopoly power in the Mexican market. This means that absent effective government policy they could potentially restrict output and drive prices above their competitive levels. Second, the labor market in Mexico is not perfectly competitive, and union power along with sticky wages is a problem in several industrial sectors (IPES, 2003). This, in turn, can lead to artificially high wages and involuntary unemployment. Any comprehensive treatment of Mexican energy and environmental policy, then, should make allowances for such market imperfections.

With this in mind, in the present chapter we modify the previous model slightly and re-run a number of the policy scenarios described above under alternative assumptions. More specifically, we run variations on scenarios 3, 4, and 6 from chapter 7 under the assumption of distortionary market imperfections. First, we assume that there exist sticky wages in the labor market, which leads to involuntary non–frictional unemployment. We then see, in scenarios 9, 10, 11, and 12, how the presence of such unemployment affects our results when we have technological change as well as when we impose carbon taxes. Next, we treat PEMEX and CFE as monopolies with the power to markup petroleum and electricity prices after 2004, and run the adjusted CGE model assuming first of all in scenario 13 that there is substantial investment and technological advancement in the petroleum and electricity sectors. We then assume in scenario 14 that instead of investment into petroleum and electricity we have energy saving technological change economy-wide. In scenario 15, we run the model under the assumption of monopoly power in energy pricing but no technological advance whatsoever. Finally, in scenario 16, we impose carbon taxes, we allow for involuntary unemployment, and we assume that there is monopoly power as well as investment and technological advancement in energy and electricity. In doing all of this our intention is not to accurately forecast what will actually happen to the Mexican economy in the future but rather to discover how responsive sectoral growth, income distribution, capital accumulation, energy use, and environmental quality are to different assumptions about market structure. All of this, of course, has significant implications for policymakers and these will be pointed out at length at the end of the chapter.

2. RESULTS

Scenario 9: Unemployment and Technological Change

In our ninth scenario we take explicit account of the effect of sticky wages and labor market imperfections on the model's results. Starting again from a 2.9% base rate of economic growth, we assume that the production of oil increases from 2.8 million barrels per day in 2000 to 4 million barrels per day in 2004. We eliminate all subsidies on the consumption of electricity, and, as in scenario 4, we assume that Harrod-Neutral technological change takes place through investment in Mexico's power and petroleum/natural gas sectors. Now, however we allow for the presence of sticky wages in the Mexican labor market. Hence, labor markets no longer automatically equilibrate in response to a lowering of the wage rate, and involuntary unemployment becomes a real possibility. In essence then we run the same model as we ran in scenario 4 *except* that we now add a constraint that the 2.4% unemployment experienced by Mexico in the year 2000 was due to union power and sticky wages, and we re-run the model to see the impact on our previous results.

The results of this modeling exercise are given below in summary tables 1 through 3. Again, as in chapter 7, we include the sectoral results below in an appendix at the end of the chapter. There we see that, in this particular case, the imposition of sticky wages is not at all detrimental to the overall growth of the economy. Indeed, there is now a higher level of growth than there was earlier in scenario 4 (with which it is compared in table 3). Overall GDP grows slightly quicker than before and by the year 2020 it is about 2.4% higher than it was when we made no assumption of sticky wages. Investment, however, shows a slight decline as funds are diverted to consumption, and as a result, the 2020 level of the aggregate capital stock is about 2% less than previously in scenario 4. The overall welfare (taken over the entire 20 year period) goes up for each of the model's four agents compared to before with the lowest income agents benefiting proportionally the greatest. The level of exports and the balance of payments grow as well. At first these results appear counter-intuitive since we have allowed for the presence of involuntary unemployment. Things become clearer, however, when we realize that technological change in Mexico's capital leads to a rise in the real wage received by Mexican workers. Thus, instead of leading to increased unemployment, previously unemployed workers are allowed into the work force and involuntary unemployment completely disappears (see the terminal unemployment row in summary table 2) and productivity rises relative to the case in scenario 4 when we assumed that all workers were employed initially. In scenario 4, by contrast, we had assumed that the 2.4% level of unemployment presently experienced in Mexico is frictional in nature and that increased real wages will not pull additional employees into the work force. Hence, in the earlier scenario the size of the labor force is fixed whereas in scenario 9 it is not, and it is free to contract or expand with the real wage rate.

Our results become even more interesting and instructive when we turn to the effects on individual production and consumption sectors (see the appendix). Turning first to the production sectors we observe that with the exception of petroleum, natural gas, and electricity, all sectors experience gains throughout the 20 year period of the simulation. Oil starts to grow relative to scenario 4 after 2008 (not shown) while electricity remains slightly lower than in scenario 4 for all years studied. The explanation for the lower initial numbers in oil, gas, and electricity lies in the relative factor shares of capital and labor in those sectors. Each of these sectors is capital intensive relative to manufacturing, agriculture, and especially services. In response to higher real wages, new workers now go primarily into the labor intensive sectors and further increase the productivity of capital in those sectors. This occurrence, in turn, leads to an exodus of less productive capital in the capital intensive sectors and a decrease in those sectors output relative to the full employment case. In most cases this dip in productivity is short lived since the influx of new labor leads on increase in investment, capital stock and GDP, and these increases eventually lead to pronounced increased output in both petroleum and natural gas. In fact, during the last years of the analysis oil and natural gas experience some of the biggest percentage gains as new efficient capital comes online. Because of increases in fossil fuel extraction and use, the assumptions here lead to substantial increases in carbon dioxide emissions as well. These increases in greenhouse gases are highly significant, and, with the exception of the benchmark case, represent the highest level of CO_2 output given in any of the model simulations run in this book! Hence, the reduction of unemployment and increase in economic growth and the capital stock under this kind of scenario can have severe environmental consequences, and may seriously damage the quality of life for large portions of the urban population. For that reason, this kind of growth may prove to be unacceptable for realistic policy purposes.

Turning now to consumption, we see that our results are fairly consistent with the production results just described. When we allow for the existence of involuntary unemployment and the technology level rises, then total consumption rises as new productive workers enter into the labor force.

In fact, consumption of all categories of goods rise with the single exception of energy due to the rise in the relative price of electricity discussed before. Because of the importance of petroleum to Mexico's international trade position, the international trade results of our model in scenario 9 are driven by the performance of the petroleum sector. Since, as we have seen, petroleum initially decreases with respect to scenario 4, the balance of payments initially decreases as well. After 2004, however, the balance of payments is better than when we assumed full employment. It would seem then, when there are significant technological improvements in the energy sectors, that relaxing the full employment assumption leads to higher domeestic and international growth in our model simulations.

Scenario 10: Unemployment and No Technological Change

In this scenario we run the dynamic CGE model again assuming a 2.9% base rate of economic growth. As before, we also assume that oil production rises from 2.8 million barrels per day in the initial year to 4 million barrels per day in 2004. We also eliminate electric subsidies. As in scenario 9, we assume that wages no longer respond to downward pressure and that labor markets no longer automatically clear. Here, however, we do not increase the efficiency of the capital used in the production of petroleum and electricity. Scenario 10 then is virtually the same as scenario 9 except that now we drop the assumption of added capital enhancing technological change in Mexico's power and extraction sectors.

The importance of technological change to Mexico's economic future is nowhere more apparent than in the contrast between scenario 10 and scenario 9 given in summary table 2. The GDP numbers given in that table indicate that the failure to initiate technological change in new energy related capital leads to a significant loss in production. In fact, by the final period (i.e., 2020) of the model the gross domestic product of Mexico falls almost 25% relative to scenario 9. Investment also declines precipitously so that the capital stock ends up at only 78% of its scenario 9 level. In the midst of this decline the welfare for agents 1, 2, and 3, total government revenues, total exports, the balance of payments, and the value of the capital stock all experience significant declines. Indeed, the aggregate decline in this scenario is precipitous and affects most of the economic aggregates that we focus on in this study. Revenues to CFE go down substantially, both aggregate consumption and power output are lower than before and carbon dioxide emissions decrease by almost 38%.

The reason for these losses is quite interesting and relates to the interconnection between unemployment, GDP, the price of capital, the price of labor, and the level of new investment. When unemployment due to sticky wages occurs, two things happen. First, the fact that there are fewer workers impairs the economy's ability to produce and this directly slows economic growth. At the same time the price of labor rises relative to that of capital and this reduces the productivity and profitability of capital. Both of these serve to slow investment and this decreased investment, in turn, slows down the growth of GDP. The decrease in GDP now forces prices down, except for the price of labor. This leads to even more unemployment and the cycle continues. Gross domestic product and investment both slow further and the economy is incapable of reaching any steady state level of growth. Eventually, in the final period of the analysis (2020) aggregate unemployment climbs to a staggering 44%!

It is also instructive to look at the production of individual industries over time (given in the appendix). There we see that those industries (such as manufacturing, refining, chemicals, and mining) that are heavily dependent on new capital investment all start to shrink, especially in the latter periods of the analysis, while, at the same time, industries such as transportation and services experience much less significant losses. This is due to the heavy loss in investment funds, especially in the later years of the analysis. All areas of consumption eventually experience losses since the high employment rates cut into the funds available to make consumer purchases. In fact the only group that consumes more in scenario 10 than in scenario 9 is the highest income group. This occurs because of the heavy losses in investment. As we have seen, the richest 20% of the Mexican population is responsible for the lion's share of all domestic investment. Faced with declining returns on their investment, this group saves much less and consumes more in the present period. The increase in their consumption spending is more than outweighed by the reduced consumption of the other income groups however.

Aggregate imports in scenario 10 stay at much the same levels as in scenario 9, but we do see a significant decrease in the aggregate level of exports and this leads, in turn, to the decline in the foreign accounts balance mentioned above. Closer examination of the sectoral numbers in the appendix reveals that this decline is almost entirely due to a drop-off in the level of crude oil and refined petroleum exports. Here again, the importance of petroleum and energy policy to Mexico's international trade balance becomes highly apparent.

Scenario 11: Unemployment and Energy Efficient Technological Change

Scenario 11 is similar to scenario 9 in all respects except in the type of technological change that is modeled. As in the previous two scenarios we assume that depletion occurs, energy subsidies have been removed and the labor market fails to clear. Whereas in scenario 9 we assumed that investment was aimed at capital augmenting technological change in the energy sector, however, in scenario 11 we assume that there has been an equivalent investment in energy efficient technology among those sectors that use fossil fuels for burning. The relation between scenarios 11 and 9 then is precisely the same as the earlier relation between scenarios 5 and 4 except that now we are assuming we have persistent involuntary employment included in the model.

The results of this scenario are given in the summary tables and the appendix. In these tables the results of this model run are contrasted with the results of scenario 9 above in order to see how this difference in assumptions about technological change now affects our findings. As before, when we were contrasting scenarios 5 and 4, we find that the largest effect is in the fossil fuel sectors themselves. Compared with scenario 9 oil, natural gas, and coal use falls dramatically. Electricity use is also down by a considerable amount. Net exports and the balance of payments also go down since these are driven by oil exports, and, unlike scenario 9, there is no technological change in the fossil fuel sectors per se to drive up oil and gas production.

As when we compared scenarios 5 and 4, we find that the energy efficient technological change modeled in scenario 11 is far less polluting in terms of CO_2 emissions than the technological change modeled in scenario 9. Furthermore, since the increase in technology has occurred economy-wide rather than in just a few industries, the level of GDP, the level of the capital stock, and the welfare level of all income groups increase over their levels in scenario 9. Economic growth and the terminal level of the capital stock grow as well. Indeed, scenario 9 is unambiguously superior to scenario 11 only in the international sector where the lack of oil production associated with less energy use leads to fewer oil driven imports and a fall in the balance of trade[1]. Hence, when we drop the assumption of perfectly clearing labor markets and allow for the possibility of persistent involuntary unemployment, our basic results from before are confirmed, and we find that from both an environmental as well as an economic standpoint, a Mexican policy of energy efficient technological change seems to outperform a policy whereby energy production is the sole recipient of increased investment and new technology.

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[1] The final level of unemployment in scenario 9 is also marginally lower than that in scenario 11 but the difference here is very slight.

It remains to be seen, however, if this still holds as the assumption of no monopoly power in energy is dropped as well.

Scenario 12: Unemployment, Overall Technological Change and Carbon Taxes

The interaction of involuntary unemployment, technological change, and carbon taxes is taken up in scenario 12. In this scenario we simulate the imposition of a carbon tax on the Mexican economy and assume, as in scenarios 9, 10 and 11, that we have a 2.4% rate of involuntary unemployment in the 2000 base year. In addition to this, we assume that we have capital enhancing technological change in all production sectors, and we run the model as before, to the year 2020.

Originally, we had tried to simulate a carbon tax with no technological change. We then tried a scenario where technological change occurred only in the model's energy sectors in response to increased government investment there (as in scenarios 8 and 7 respectively). In both cases, however, the model was unable to attain a solution due to a collapse in investment and a huge drop in GDP. The reasons for this collapse were essentially the reasons outlined for reduced growth in scenario 10 above. Here, in this case, the introduction of carbon taxes drove the real wage leading to increased unemployment and driving down the productivity of capital. With this collapse in investment, growth was not sustained and the model could not reach a viable solution.

We next attempted to run the model with technological change in all sectors and applied the same carbon tax as before in scenarios 6, 7, and 8. A solution was attained but it was one that would be unacceptable for policy makers. Because of unemployment and low capital productivity, investment reached zero in the final period and all sectors were experiencing significant decreases by that time. Hence, in order to obtain something acceptable from a public policy standpoint we cut the size of the original carbon tax used in the earlier scenarios by half. This time the model not only converged but experienced fairly significant growth. The model, it turns out, is quite sensitive to the size of the carbon tax administered, and, to the extent that our model reflects the vulnerability of the Mexican economy, then the size of the carbon tax should be a prime consideration for policy makers concerned with maintaining sustained growth and, at the same time as carrying out environmental policies such as CO_2 emissions controls.

The simulation results of scenario 12 are contained in the summary tables and in the chapter 8 appendix. In these tables we contrast the numbers obtained from scenario 12 with those obtained earlier from scenario 9, and, as expected, the assumption of technological change in capital throughout the

Mexican economy leads to generally higher growth than when such changes were confined to the energy sectors alone. This result also seems to be fairly robust since scenario 12 assumes the simultaneous imposition of a moderate carbon tax on the energy use as well. The final level of GDP and the capital stock are both larger in scenario 12 than they were in scenario 9. Investment, total government welfare, employment levels and the economic welfare of all four agents are also larger than before.

Turning next to the sectoral results, we see that the increased growth noted before in connection to the economic aggregates applies to almost every production and consumption sector. The only place where growth is down from scenario 9 is in the production of oil, natural gas, and coal in the initial periods (not shown in the tables). This was, however, to be expected since the carbon tax was placed directly on these sectors. The level of CO_2 emissions is also down by over 10% and indicated that a carbon tax is relatively effective here in cutting down on the level of greenhouse gases. It comes at a relatively high price however since the cost of carbon is over \$93 per ton. Nevertheless this price is lower than the prices estimated in the previous chapter due to the lower marginal tax rate on carbon emissions imposed here. Capital and labor released from the extractive sectors to elsewhere in the economy, and the general decrease in the level of involuntary unemployment (to 1.4%) leads to further increases as the relative wage rises throughout the economy. The balance of payments here goes up relative to scenario 9, and this rise is due to an increase in manufacturing and agricultural exports. As the production of oil and natural gas goes down, more of it is diverted to local refineries and consumers. Energy use in Mexico rises when compared to scenario 9 but foreign consumption decreases. This all assumes, however, that other countries are also imposing tariffs on the importation of fossil fuels since otherwise foreign markets might be a lucrative alternative to domestic ones for Mexican producers.

Scenario 13: Monopoly and Technological Change in the Energy Sector

In the simulations we have run so far, we have made the assumption that competition held in all markets, and that none of the economic players in the model had monopoly or monopsony power. Market imperfections such as taxes, tariffs, and non-clearing employment markets have, of course, been added to the analysis and evaluated at great length, but up until this point we have assumed that no one firm had significant market power in any of our model's production sectors. There is, however, good reason to believe that in Mexico, as with many developed and developing countries, there are concentrated markets where prices are indefinitely held above their compete-tive levels. More importantly for our purposes here, both PEMEX and CFE are government owned monopolies commonly referred to as parastatal corporations. Significant market power is then a strong possibility in the very energy sectors which are the focus of our analysis, and it is important that we recognize this in our investigation and explicitly model such market power in our simulation exercises. Hence, in scenarios 13, 14, 15, and 16 we modify some of our early scenarios by introducing monopoly pricing into the oil, gas, and electricity sectors. More specifically, in scenario 13 we re-run scenario 4 and markup the prices of electricity, oil, and natural gas, by approximately 18%[2]. Our objective in this exercise in simply to find out the manner in which monopoly power would change our results and not to measure monopoly welfare loss due to PEMEX and CFE per se. These specific numbers then were chosen because they are moderate, fairly realistic, and appropriate for our present purposes, that is, to examine both the sectoral and economy-wide effects of lower energy output and higher energy prices. The exercise is repeated in scenario 14 except in that case we assume energy efficient technological change. In scenario 15 we have monopoly power but no technological change at all. Finally, in scenario 16 we rerun the scenario 12 carbon tax to see the effect of such a tax when we have both sticky wages and monopoly power in energy.

The results of scenario 13 are given in the summary tables at the end of the chapter as well as well as the tables in the appendix. The results are contrasted to the earlier results of scenario 4 and, as can be seen, they are all quite reasonable and conform to our expectations based on simple micro-economic theory. As would be expected, output in PEMEX and CFE goes down as the price of fossil fuels and electricity rise. Furthermore, the percentage decrease in CFE is larger than the percentage decrease in PEMEX, even though their prices were raised by an equal percentage. This occurs because oil and natural gas are used as inputs into electricity and hence the decrease in CFE comes both as a result of higher output prices and higher input prices. The level of GDP goes down as does the level of investment, the level of aggregate consumption, and the welfare level of all agents. In fact, not only does the level of welfare drop for all agents, but, owing to the fact that the lowest income consumers have fewer substitution possibilities, they suffer the highest percentage losses. Led by a sharp drop in the amount of petroleum sold to other countries, the aggregate level of exports and the aggregate trade balance go down as does the terminal value of the capital stock. The only positive number as far as the summary table goes is the increases in revenues coming from the government from PEMEX. This occurs because the demand for both fossil fuels is inelastic and the decline in the

[2] Monopoly power is most often introduced into general equilibrium models through the algebraic device of simple markup pricing. It is difficult to explicitly solve for a monopoly solution within a CGE context and hence authors since Harberger have relied on the use of a markup number to simulate monopoly power in an economy (see Atkinson and Stiglitz, 1980, for more information on this).

output of these sectors is more than matched by the increase in their output prices.

As would be expected, the production sectors most negatively affected by the higher energy prices are the heavy users of energy as inputs. As a result, we see that the output declines are the most severe in the energy and manufacturing sectors. This has positive implications for the environment, however, as the level of carbon dioxide emissions goes down by over 13%. The service and transportation sectors are not hit as hard but they are nevertheless negatively impacted. Likewise all consumption sectors show modest declines with the energy sector being the most severely affected. Finally, in the wake of a general economic downturn government revenues, and hence government expenditures, also decline modestly.

Scenario 14: Monopoly and Overall Energy Efficiency

Scenario 14 combines the effects of monopoly power in Mexico's energy sectors with an energy efficient technological change. In this model simulation we re-run the simulation that we ran in scenario 13 except that now instead of adjusting investment and technology to improve in the extraction and distribution of petroleum and electricity, we adjust technology so as to provide the same level of output with less use of fossil fuels. This scenario, then, represents a full fledged effort on the part of policymakers to cut back on fossil fuel emissions through technological means, given that they do nothing to change the existing imperfect market structure. Again, it is instructive to compare this scenario to the previous one where technological change was not directed towards at fuel efficiency and see the implications for environmental quality as well as economic output.

The results of this simulation are again given in the summary tables and the appendix to this chapter. As shown there, the combination of monopoly price markups and energy saving technological change are significant when it comes to the emissions of greenhouse gases. The consumption of all fossil fuels is significantly lower than in the previous scenario as are the emissions of CO_2. Consumption of all fuels also drops if we measure the changes from this scenario to scenario 5 from the previous chapter. That scenario, it will be remembered, was identical to this one except that the energy monopolies did not then employ their monopoly power to raise prices. When compared to scenario 5, the production of oil declines by over 11%, and the total emissions of CO_2 decline by over 9%. Monopoly power and the higher energy prices that it entails again serve to cut back on GHG emissions from all forms of fossil fuels.

Looking at the summary table 2 we see that, with respect to scenario 13, GDP increases slightly with more efficient fuel use as does the terminal level of the capital stock. The level of welfare of agents 1, 2 and 3 declines slightly, but again, as we stated in the last chapter, it must be remembered that these numbers do not include the medical and other savings realized when the level of aggregate emissions drop and those savings can be sizeable. Furthermore they do not include the level of welfare accruing worldwide following the slowing of climate change entailed in reduced GHG emissions. The level of oil exports again drops along with aggregate exports and the balance of trade. Aggregate consumption increases a small amount though, as consumption in all sectors, except gasoline and energy, goes up.

In most other respects the results of this scenario are quite predictable. With more efficient fuel use the final consumption of gasoline and energy goes down at the same time that the consumption of all other items increases. Investment rises slightly with respect to scenario 13 and the productivity in the manufacturing sectors go up as well (not shown). Services initially decline a bit but these declines are almost completely eliminated by the terminal year of 2020.

Scenario 15: Monopoly and no technological change

Scenario 15 is quite similar to scenarios 13 and 14 which we just discussed. Here again energy prices are marked up in accordance with monopoly power in those industries. In this scenario, however, there is no offsetting investment into the energy sectors or anywhere else for that matter (i.e., through fuel efficiency), and, as a result, the level of GDP declines relative to the previous two simulations. Even a cursory examination of the summary tables reveals that almost all of the economic aggregates go down with respect to scenario 13. Most striking are the declines in energy production, exports, emissions, and the economic welfare of all but the wealthiest consumers. Once again the importance of investment and technological change in the energy-related capital is clear.

As in the case of scenario 13, the sectoral results add little information to that already contained in the aggregate tables. Production and consumption in all sectors decrease (with respect to scenario 13) with the greatest losses in the energy and manufacturing sectors and the smallest losses in the transportation and services sectors. Again a large drop-off in fossil fuel exports leads to smaller export totals and points out Mexico's heavy reliance on petroleum as a source of foreign exchange.

Scenario 16: Monopoly, Unemployment and Carbon Taxes

In scenario 16 we combine most of the elements of our earlier simulations into one single run. The moderate carbon tax and sticky wage model simulated in scenario 12 is now combined with the monopoly power explicitly dealt with in scenarios 13, 14 and 15. The result is a simulation that shows the combined effects of carbon taxes, capital-enhancing technological change, and market imperfections on the aggregate and sectoral growth of the Mexican economy. Although care has been taken in dealing with each of these individual elements of the model, it must again be emphasized that this is in no way an accurate forecaster of future Mexican economic growth, welfare, and capital development, but rather a tool to be used when assessing the qualitative impacts of various market structures and energy policies. Thus, the most important part of our results here in this scenario is to examine how carbon taxes, sticky wages and market power interact when they occur together.

The results of scenario 16 are given in the summary tables and the appendix. As was the case above in the previous monopoly power scenarios, almost all of the economic aggregates in the summary tables go down relative to scenario 12 when monopoly power was not modeled. When monopoly power is added to the mix when we have a carbon tax and involuntary unemployment the situation gets unambiguously worse. The level of GDP, the terminal level of the capital stock, investment, energy production, aggregate consumption levels, and the level of government revenues all go down. Furthermore, the sectoral results given in the appendix all follow suit and all individual consumption and production sectors experience declines over almost all of the time period under study. On the other hand, the level of greenhouse emissions goes down by over 12% relative to scenario 12 having a positive impact on the level of environmental quality.

Finally, we see that the significant decline in oil and electricity consumption due to monopoly power not only decrease the welfare of every agent but do so in a regressive way. Clearing the economy of institutionalized monopoly in this model would not only improve the level of economic efficiency but would have small but positive impacts on the distribution of income in Mexico as well.

3. CONCLUSIONS

The results of this chapter serve to reinforce some of the results of the previous chapter and at the same time point out the importance of considering existing economic institutions, market imperfections, and alternative market structures in our analysis. As we saw in the first part of the book, Mexico is a large country with a complicated network of markets. Most of these markets are linked in some way with energy, and therefore the structure and makeup of these markets influence the effectiveness of energy and environmental policy. By the same token, the market power exercised by PEMEX and CFE can have serious consequences for related markets, and can significantly affect the balance of trade, the level of greenhouse gas emissions, the size of investment, the level of consumer welfare and the overall rate of economic growth[3].

In this chapter we have seen once again that technological change in general, and investment and technological change in the energy sectors in particular, are crucial to the growth and viability of the Mexican economy. Indeed, without sustained technological change we have seen that the presence of sticky wages or the imposition of a carbon tax can have disastrous consequences for maintaining investment and fostering continued economic growth. As in chapter 7, however, the nature of technological change is critical to the environment. More specifically we see that here again emissions of GHGs and other pollutants only decline with the introduction of energy efficiency in technology. The tradeoffs between GDP and CO_2 emissions can be seen in figure 8.1.

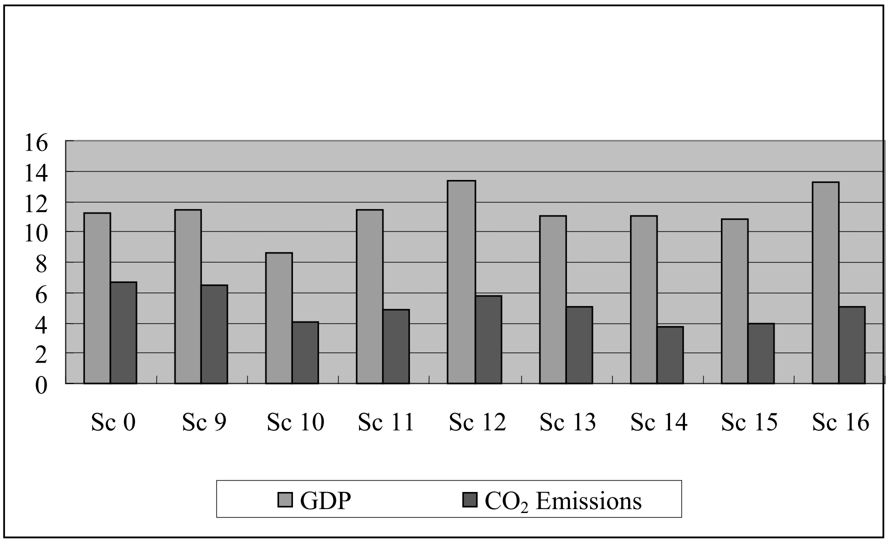

Figure 8.1 GDP and CO_2 emissions under different scenarios
(GDP in hundred billion dollars, CO_2 in hundred million tons)

[3] As in chapter 7, our results are robust with respect to assumptions regarding the elasticity of substitution between capital and labor in production, the elasticity of substitution between fuels, and the elasticity of demand for energy outputs such as gasoline and electricity.

In our analysis we have argued that the government can improve capital by the direct use of public funds, and we have assumed that this investment was both carefully reasoned and economically efficient. If policymakers have to rely on managers in PEMEX and CFE for these investments, however, the results may not be efficient at all. As monopolies, these firms are not necessarily driven to minimize their long run costs, and may have little incentive to do so. PEMEX, for example, presently has the highest debt of any petroleum company in the world ($32 billion as of 2003 (EIA-DOE, 2005)), and three fourths of its annual investment is required to service its debt payments. Furthermore, the upper management in these firms may wish to engage in other types of investments that are more in line with enhancing their prominence and national prestige such as a new headquarters building than in investing seriously in fuel efficient technology (see Galbraith, 1973). At any rate, one cannot be sure with the present market structure that the proper investment will be carried out in a timely and efficient manner.

The results of this chapter also indicate that policymakers need to be very careful when designing carbon taxes and need to set the level of these taxes at rates that will not act as an impediment to economic growth. We saw, for example, that the levying of a relatively high carbon tax combined with involuntary unemployment had a highly deleterious effect on new investment. If such situations are to be avoided then, policy makers need to have a clear view of the existing economic constraints that may limit the effectiveness of their policy and create unintended spillover effects.

Our analysis in this chapter has pointed out the importance for economic modelers to consider the implications of market imperfections carefully on a case by case basis. We found, for example, that the addition of involuntary unemployment in the model acts like a double-edged sword. When wages go up, as they do in scenario 9, this assumption leads to new employment and thereby contributes to economic expansion. When, however, wages go down, as they do in scenario 10, this assumption leads to severe economic contraction. We discovered, on the other hand, that the assumption of market power in the model's energy sectors created an unambiguous result when it comes to the economy. Whenever market power was assumed to exist in these markets it led to a loss of aggregate economic welfare and a slowdown of economic growth.

Finally, the introduction of monopoly power into this analysis has somewhat ambiguous implications when it comes to environmental quality and climate change. As Robert Solow (1974) observed over 30 years ago, when it comes to extractive industries like oil and gas the monopolist may well be the conservationist's friend. That is to say that by virtue of the fact that they restrain production, monopolists inadvertently lead to less extraction of the resource and hence to less environmental degradation. In fact, in our analysis the presence of monopoly led to a greater cut in CO_2 than a carbon tax. Four things should, however, be said about this. First, it would be wrong to rely on monopoly power for conservation since a government-run corporation may not always act as a strict profit maximizer and may produce above monopoly levels. Many government-run monopolies, including those in Latin America as we have seen in chapter 4, have traditionally been used to carry out redistribution policies by inefficiently subsidizing the provision of basic needs such as energy for lower income groups. Second, low elasticity for fossil fuels may mean that high monopoly markups are not necessary accompanied by significant monopoly cutbacks. Third, even if monopolies contribute to the reduction of an externality such as added levels of pollution, there is no guarantee that such a reduction will lead to the socially optimal level of that externality. Finally, monopolies cannot be counted upon to run efficient and clean operations and may cause all manner of other environmental waste such as high SO_2 emissions, oil spills, toxic waste dumps, and industrial accidents.

Summary Table 1A: Assumptions for Scenarios

Scenario 9 : Sticky wages in labor markets, deregulation of energy prices, and capital-enhancing technological change in energy sectors

Scenario 10: Scenario 9 without capital-enhancing technological change in energy sectors

Scenario 11: Scenario 10 plus energy efficient technological change in all sectors

Scenario 12: Scenario 9 plus capital-enhancing technological change in all sectors and a carbon tax

Scenario 13: Monopoly power in energy sector, deregulation of energy prices, and capital-enhancing technological change in the energy sectors

Scenario 14: Scenario 13 with energy efficient technological change in all sectors, instead of capital-enhancing technological change in the energy sectors

Scenario 15: Scenario 13 without any technological change

Scenario 16: Scenario 12 plus monopoly power in the energy sectors

Summary Table 1B: Comparison of Scenarios

Scenario 9 is compared to Scenario 4

Scenario 10 is compared to Scenario 9

Scenario 11 is compared to Scenario 9

Scenario 12 is compared to Scenario 9

Scenario 13 is compared to Scenario 4

Scenario 14 is compared to Scenario 5

Scenario 15 is compared to Scenario 13

Scenario 16 is compared to Scenario 12

Summary Table 2: Quantities. CGE Results Data for Mexico for 2020 (hundreds of billions of 2000 dollars)

	Scenario0	Scenario9	Scenario10	Scenario11	Scenario12	Scenario13	Scenario14	Scenario15	Scenario16
GDP	11.2585	11.4183	8.5685	11.4923	13.3889	11.0001	11.0189	10.8701	13.2270
Oil output	0.4304	0.4007	0.2611	0.3007	0.3451	0.3029	0.2264	0.2291	0.2942
Power output	0.1979	0.2173	0.1453	0.1899	0.2429	0.1825	0.1595	0.1576	0.2000
Consumption	7.5271	7.7128	7.6150	7.7453	8.9992	7.6091	7.6230	7.5871	8.9410
Imports	3.3175	3.3175	3.3173	3.3175	3.3155	3.3173	3.3172	3.3170	3.3149
Exports	3.6073	3.6080	3.4684	3.5257	3.7433	3.4911	3.4311	3.4207	3.6836
Exports oil	0.3899	0.3622	0.2539	0.2738	0.3001	0.2751	0.2070	0.2076	0.2555
BoP surplus	0.2897	0.2905	0.1511	0.2081	0.4278	0.1738	0.1139	0.1037	0.3687
Cumulated welfare agent 1	3.4175	3.4504	3.3398	3.4590	3.9481	3.4077	3.4026	3.3928	3.9360
Cumulated welfare agent 2	10.2034	10.3094	9.9745	10.3354	11.8116	10.1789	10.1643	10.1345	11.7757
Cumulated welfare agent 3	15.9316	15.9442	15.7712	15.9953	17.5564	15.8074	15.8009	15.7746	17.5157
Cumulated welfare agent 4	26.5939	26.4358	26.8247	26.5551	27.8478	26.3142	26.3384	26.3280	27.8069
Terminal capital stock	29.5613	27.8954	21.8195	29.6957	28.4527	27.9435	28.0976	27.6164	27.9805
Cumulated Govt. revenue from PEMEX	0.0637	0.0554	0.0563	0.0574	0.0519	0.0550	0.0569	0.0576	0.0520
Cumulated Govt. revenue from CFE	0.0080	0.0076	0.0074	0.0078	0.0095	0.0080	0.0082	0.0082	0.0095
Cum. Govt revenue from other sources	0.8367	0.8634	0.8356	0.8588	1.3078	0.8478	0.8458	0.8357	1.2931
CO2 Emissions (hundreds of millions of metric tons)	6.6766	6.4855	4.0689	4.8869	5.7823	5.0372	3.7971	3.9424	5.0603
Price of Emissions (dollars per metric ton)	-------	-------	-------	-------	$93.32	-------	-------	-------	$110.73
Final level of unemployment in 2020 (percentage)	-------	0%	44%	0.70%	1.40%	-------	-------	-------	1.40%

Summary Table 3: Summary CGE Results Data for Mexico for 2020
(percentage changes from respective scenarios*)

	Scenario9	Scenario10	Scenario11	Scenario12	Scenario13	Scenario14	Scenario15	Scenario16
GDP	2.35%	-24.96%	0.65%	17.26%	-1.40%	-2.45%	-1.18%	-1.21%
Final level of Investment	-4.18%	-97.81%	9.32%	8.65%	-3.95%	-7.48%	-3.98%	-2.96%
Oil output	12.58%	-34.83%	-24.95%	-13.87%	-14.88%	-11.29%	-24.36%	-14.75%
Power output	-1.93%	-33.11%	-12.57%	11.80%	-17.62%	-25.78%	-13.65%	-17.67%
Consumption	0.79%	-1.27%	0.42%	16.68%	-0.56%	-0.77%	-0.29%	-0.65%
Imports	-0.01%	-0.01%	0.00%	-0.06%	-0.01%	-0.01%	-0.01%	-0.02%
Exports	1.57%	-3.87%	-2.28%	3.75%	-1.72%	-1.28%	-2.02%	-1.59%
Exports oil	12.14%	-29.91%	-24.42%	-17.14%	-14.84%	-10.81%	-24.53%	-14.86%
BoP surplus	23.85%	-47.98%	-28.34%	47.28%	-25.91%	-27.88%	-40.32%	-13.81%
Cumulated welfare agent 1	0.97%	-3.20%	0.25%	14.42%	-0.28%	-0.45%	-0.44%	-0.31%
Cumulated welfare agent 2	1.00%	-3.25%	0.25%	14.57%	-0.28%	-0.45%	-0.44%	-0.30%
Cumulated welfare agent 3	0.69%	-1.09%	0.32%	10.11%	-0.18%	-0.25%	-0.21%	-0.23%
Cumulated welfare agent 4	0.39%	1.47%	0.45%	5.34%	-0.07%	-0.04%	0.05%	-0.15%
Terminal capital stock	-2.01%	-21.78%	6.45%	2.00%	-1.85%	-3.18%	-1.17%	-1.66%
Cumulated Govt. revenue from PEMEX	1.02%	1.68%	3.69%	-6.38%	0.34%	2.68%	4.73%	0.36%
Cumulated Govt. revenue from CFE	-4.65%	-2.44%	2.44%	24.39%	0.00%	-4.35%	2.33%	0.00%
Cum. Govt revenue from other sources	0.50%	-3.23%	-0.54%	51.46%	-1.32%	-2.04%	-1.42%	-1.12%
CO2 Emissions	11.79%	-37.26%	-24.65%	-10.84%	-13.18%	-9.41%	-21.73%	-12.49%

* See Summary Table 1B for comparison of scenarios.

APPENDIX

PRODUCTION

	Scenario 9	*Scenario 10*	*Scenario 11*	*Scenario 12*	*Scenario 13*	*Scenario 14*	*Scenario 15*	*Scenario 16*
Agriculture	3.4899%	-28.0176%	0.0788%	32.5717%	-1.6145%	-2.8135%	-1.3758%	-1.3194%
Coal	7.0000%	-71.0280%	-26.1682%	14.0187%	-3.0000%	-5.2632%	-2.0619%	-1.6393%
Petroleum	12.5849%	-34.8330%	-24.9536%	-13.8683%	-14.8825%	-11.2891%	-24.3558%	-14.7550%
Manufacturing	4.5980%	-40.2034%	-0.1174%	26.2439%	-2.0833%	-3.6432%	-1.6831%	-1.5945%
Chemicals	7.2478%	-57.6456%	3.8617%	16.9729%	-4.7094%	-7.2975%	-4.4865%	-4.2599%
Refined Products	10.8149%	-76.2887%	-18.3505%	14.7766%	-7.4638%	-13.5683%	-10.3704%	-7.0659%
Transport	2.0033%	-12.2136%	0.9411%	12.9705%	-0.7930%	-1.2554%	-0.7573%	-0.7606%
Electricity	-1.9295%	-33.1052%	-12.5749%	11.8050%	-17.6174%	-25.7785%	-13.6456%	-17.6741%
Services	1.6880%	-10.4779%	0.0223%	14.6882%	-0.6597%	-1.0570%	-0.4394%	-0.5961%
Natural Gas	12.4088%	-34.7403%	-25.0000%	-13.9610%	-10.2190%	-6.1224%	-24.3902%	-9.8113%
GDP	2.3489%	-24.9580%	0.6479%	17.2586%	-1.3992%	-2.4478%	-1.1823%	-1.2094%
Final Investment	-4.1820%	-98.0931%	9.3210%	8.6519%	-3.9506%	-7.4777%	-3.9846%	-2.9551%
Government	-6.3495%	4.1541%	7.0168%	58.5665%	-1.2094%	-1.7836%	-1.0202%	-1.0588%

CONSUMPTION

	Scenario 9	*Scenario 10*	*Scenario 11*	*Scenario 12*	*Scenario 13*	*Scenario 14*	*Scenario 15*	*Scenario 16*
Food	1.1312%	-1.8673%	0.4160%	26.5391%	-0.6731%	-0.9769%	-0.4706%	-0.7670%
Housing	0.9686%	-1.0760%	0.5574%	13.7931%	-0.3861%	-0.4888%	-0.1248%	-0.4671%
Gasoline	1.1236%	-0.8187%	-0.0585%	10.2339%	-0.5914%	-0.9456%	-0.4759%	-0.7427%
Automobiles	0.9424%	-0.1647%	0.7139%	16.8040%	-0.5543%	-0.8255%	-0.2787%	-0.7052%
Energy	-5.5474%	-2.1638%	-1.4683%	11.4374%	-3.5036%	-5.0365%	-2.3449%	-3.6061%
Transportation	1.0371%	-1.7288%	0.3782%	13.1821%	-0.3275%	-0.3813%	-0.1095%	-0.3819%
Services	0.9294%	-0.9442%	0.5129%	12.2392%	-0.3059%	-0.3635%	-0.0354%	-0.3843%
Total	0.7942%	-1.2680%	0.4217%	16.6791%	-0.5610%	-0.7693%	-0.2882%	-0.6464%

Note: * See Summary Table 1B for comparison of scenarios.

IMPORTS

	Scenario 9	*Scenario 10*	*Scenario 11*	*Scenario 12*	*Scenario 13*	*Scenario 14*	*Scenario 15*	*Scenario 16*
Agriculture	0.0000%	0.0000%	0.0000%	-5.5728%	-0.3096%	-0.3091%	-0.1553%	-0.1639%
Coal	0.0000%	0.0000%	-8.6957%	21.7391%	-4.3478%	0.0000%	0.0000%	0.0000%
Petroleum	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Manufacturing	0.0973%	-0.0764%	0.1041%	-1.1662%	-0.1946%	-0.3811%	-0.2994%	-0.2809%
Chemicals	-0.1633%	0.2453%	-1.6353%	5.6419%	0.5306%	0.6661%	0.5278%	0.6966%
Refined Products	-2.8391%	2.9221%	7.7922%	12.6623%	4.4164%	9.4801%	7.5529%	4.8991%
Services	0.0000%	0.0000%	0.0000%	9.0909%	0.0000%	0.0000%	0.0000%	0.0000%
Natural Gas	-15.3846%	-45.4545%	27.2727%	90.9091%	15.3846%	72.7273%	26.6667%	14.2857%
Total	-0.0055%	-0.0057%	-0.0001%	-0.0618%	-0.0112%	-0.0112%	-0.0112%	-0.0168%

EXPORTS

	Scenario 9	*Scenario 10*	*Scenario 11*	*Scenario 12*	*Scenario 13*	*Scenario 14*	*Scenario 15*	*Scenario 16*
Agriculture	0.4734%	-0.9423%	0.2356%	11.4252%	-0.3550%	-0.3538%	0.0000%	-0.3171%
Coal	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Petroleum	12.1404%	-29.9128%	-24.4228%	-17.1370%	-14.8446%	-10.8086%	-24.5270%	-14.8607%
Manufacturing	0.4592%	-0.9408%	0.1259%	6.5191%	-0.3128%	-0.4181%	0.0467%	-0.3172%
Chemical	0.6961%	-1.2289%	1.9201%	-0.3072%	-1.0054%	-1.4329%	-0.7813%	-1.3097%
Refined Products	3.4091%	-3.8462%	-6.5934%	-6.0440%	-4.5455%	-9.8837%	-7.1429%	-5.8480%
Services	0.0000%	0.0000%	0.0000%	-3.4483%	0.0000%	0.0000%	0.0000%	0.0000%
Natural Gas	20.0000%	83.3333%	-16.6667%	-50.0000%	0.0000%	-33.3333%	-20.0000%	0.0000%
Total	1.5695%	-3.8683%	-2.2819%	3.7499%	-1.7213%	-1.2780%	-2.0176%	-1.5937%
BoP	23.8491%	-47.9838%	-28.3418%	47.2832%	-25.9113%	-27.8824%	-40.3209%	-13.8141%

Note: * See Summary Table 1B for comparison of scenarios.

CHAPTER 9

EMISSIONS TRADING: INTERSECTORAL AND INTERNATIONAL

In this chapter we conduct simulations to test how permit trading both domestically and internationally leads to a reduction in carbon emissions. Working with a disaggregated version of our CGE model of Mexico we quantify the economic and environmental effects of a program whereby greenhouse gas emission permits are sold to CO_2 emitting manufacturers in exchange for sequestration of carbon in Mexico's forests. Simulations are first run assuming that Mexican manufacturers purchase these permits or rights. Next, using the Mexican CGE model in conjunction with a closely linked CGE model of the United States, it is assumed that U.S. firms purchase these permits. These two alternative specifications are then compared to determine which one achieves a given amount of CO_2 abatement with the lowest efficiency cost.

1. INTRODUCTION

Our modeling focus in chapter 9 is fundamentally different from the focus of the two previous chapters. In chapters 7 and 8 we used our dynamic CGE model to look at carbon abatement strategies based on investment in cleaner burning fuels and on the imposition by Mexican policymakers of a nationally administered carbon tax. While such policies can be effective, other market-based emission abatement policies can potentially be effective as well. As pointed out in chapter 5, there is great interest worldwide in tradable energy permits. In terms of their economic efficiency, such permits have a number of desirable qualities (see chapter 5). In addition these permits would serve a valuable role in attracting U.S. compliance with any future Kyoto-style agreements. In order for our modeling effort to be comprehensive with respect to carbon abatement options, we need to look at the economic effects of such policies for Mexico.

Along with the emphasis on market based pollution abatement, there is also a difference in the overall purpose of this chapter as opposed to that of the last two. In chapters 7 and 8, we were interested in looking at the economy-wide impacts of a host of specific energy policies under an exhaustive set of alternative assumptions about market structure and technological change. There, our aim was to give policymakers an idea of how policies would interact and how alternative policies would fair under various economic conditions. Here, our aim is largely to run model simulations to test how effective a particular type of permit trading is at reaching a desired level of carbon abatement. We are also curious as to what the sectoral implications of such trading might be. In other words, instead of simulating a large number of policy scenarios, here we deal with the more basic question of weather economic gains are indeed possible for emissions permit programs involving Mexico. Previous studies have suggested that the lack of low carbon alternatives to petroleum in Mexico would limit the effectiveness of permit trading there. Mexico does have large forests, however, and in this chapter we wish to explore the potential gains from the sequestration of carbon in Mexico’s temperate and tropical forests. We also wish to test for the existence and extent of any “carbon leakage” associated with a system of permit trading between Mexico and the United States.

2. BACKGROUND

In addition to the large theoretical literature on CO_2 permit trading discussed in chapter 5 there is a significant and growing number of articles, which conduct empirical investigations on the welfare impacts, and unintended consequences of various trading schemes. Along with a host of countrywide models, a number of highly sophisticated and well thought out international models using the GTAP data set have been constructed by modeling groups both in the U.S. and in Europe[1, 2]. With the use of these models, researchers have obtained important, and sometimes unexpected, results when they have examined the economic ramifications of international emissions trading policies. Furthermore, some of their findings have relevance for our analysis here. Using the MS-MRT model, Bernstein et al (1999), for instance, examined the problem of "carbon leakage." This occurs if one set of countries places restrictions on carbon use while another set of countries does not. Using their advantage in lower cost fossil fuels, the second set of countries then have the incentive to undermine the treaty's goals and increase their production of carbon intensive goods and services. In their study Bernstein et al found that leakage can indeed be a problem and warn that it can only be averted with emissions trading between developing and developed countries. Kuik and Gerlach (2003) further explore this issue and (using a GTAP-E Model) find that the problem of carbon leakage can be further exacerbated by trade liberalization. They go on to say however, that the welfare losses due to carbon leakage are generally outweighed by the welfare gains due to freer trade[3].

The general assumption that permit trading always leads to higher levels of welfare is also challenged in this literature. Employing the EPPA model, Babiker et al. (2004) discover that, under some circumstances such trading can lead to losses due to second best considerations. Those countries most at risk for such losses turn out to be countries with high pre-existing fossil fuel prices due to large taxes as well as those with relatively large international trade sectors. Based upon these considerations Mexico should not be in danger of incurring such losses when permits are traded internationally. As McKibbin et al. (1999) point out, however, (using the G-Cubed global emissions model) GHG emissions trading is more apt to lead to gains when abatement costs are dissimilar, and as Fawcett and Sands (2006) find, (using a Second Generation Model) abatement costs in Mexico are fairly similar to those of the developed countries with which it would to trade emissions permits[4]. This, in turn, casts some doubt on the size of any

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[1] See for example Bernard and Vielle (1999) on France, Böhringer and Rutherford (1996) on Germany, and Goulder (1995) on the United States.

[2] The Global Trade Analysis Project or GTAP housed at Purdue, has developed a fully integrated system of economic accounts for most of the world's economies. This, in turn has facilitated the creation of international emission permit trading models.

[3] Other good treatments of these kinds of international problems are contained in Babiker and Rutherford (2005).

[4] Second Generation Model (SGM) is a CGE model developed to analyze issues dealing with climate change.

efficiency gains from a strict emissions trading program between Mexico and developed countries such as the United States. The authors did not look, however, at the efficiency gains associated with a program whereby Mexico sequesters carbon from its forests in exchange for added emissions in the United States, and it is this kind of an emissions trading scheme that we examine below.

3. MODELING STRUCTURE

With this literature as a backdrop, we turn to the problem of implementing an emissions trading program in Mexico and modeling its general equilibrium effects. As we saw in chapter 5, there are a number of ways in which the trading of permits may be administered as well as different ways in which such permits may be traded. With regards to administration, it does not make a difference to our modeling effort here what the exact administrative makeup of the emissions trading authority is. It only matters that it is economically efficient. Hence, in our analysis we will assume that the national and/or international authorities have agreed to an equitable system whereby permits are traded among nations and economic sectors as efficiently as possible. With regards to the level at which the permits are traded we will initially assume that they are traded among different sectors within Mexico. Later on however, we will explicitly model trading of such permits between sectors in both Mexico and the United States.

As described in depth in chapter 5, there are different economic entities that may be interested in the trading of permits. Policymakers could, for example allow different businesses within Mexico to purchase the rights to emit CO_2 over some prescribed level and issue permits in such a way that the sector as a whole arrives at a prescribed emissions target level. Such a system would then be quite similar to the sulfur dioxide trading already done in the U.S. as part of the 1990 Clean Air Act (again see chapter 5). A program like this would be very difficult to simulate using our model since it would require detailed information on abatement cost at the firm level. There are other highly viable emissions trading schemes, however, which are much more conducive to our modeling efforts. We could, for example, model emissions trading between different emitting sectors such as manufacturing and electricity. Or alternatively we could model an emissions trading program whereby Mexico's emitting sectors such as manufacturing and electricity "purchase" emissions permits from the Mexican forestry sector in exchange for carbon sequestration efforts to be taken up by that sector. This second emissions trading program in particular would be highly appropriate here since it can be modeled quite accurately at the sectoral level, it impacts a large number of the environmental and energy variables, and it has readily quantifiable effects on important aggregates such as consumer welfare, GDP, and economic growth. Moreover, as pointed out by Sedjo (1998) much of the initial emissions trading will probably involve the use of forests for carbon sequestration purposes (see chapter 5, section 4.1).

In the first part of our analysis, carried out in scenarios 0P through 4P, we examine the impact of requiring Mexico's manufacturing and electricity sectors to "purchase" the right to release emission of carbon dioxide into the Earth's atmosphere. These emissions are assumed to be purchased from the Mexican forestry sector in such as way as to be used for carbon sequestration and reforestation programs in Mexico's rural areas. Any excess funds are then given to the government, which uses them to lower existing taxes. All firms are free to emit carbon up to a certain pre-determined level. Beyond a given level of CO_2 emissions, however, a certain percentage (established by the authorities) of all additional emissions must be paid for by sequestration rights and this percentage with be increased over time along with the level of reforestation and/or sequestration undertaken.

Table 9.1. Producing sectors and production goods

Producing Sectors	Production Goods
1. Manufacturing	Manufacturing Goods
2. Coal Mining	Coal
3. Chemicals and Plastics	Chemicals and Plastics
4. Fisheries	Fish and Fish Products
5. Grains	Grains
6. Livestock	Livestock
7. Other Agriculture	Other Agriculture
8. Forestry	Forestry Products
9. Services	Production Services
10. Transportation	Transportation for Production
11. Electricity	Electricity
12. Oil and Gas	1. Crude Petroleum
	2. Natural Gas
13. Refining Output	Refining Output

In order to carry out these simulations the original model developed in chapter 6 has to be augmented slightly. In that model (which we used for simulations 0-18) we divided aggregate production into a total of 9 production sectors and 10 production goods as shown in table 6.1. In the model used in this chapter, by contrast, we divide aggregate production into a total of 13 sectors with 14 production goods. In addition to the eight non-agricultural sectors from before, the agricultural sector in this model is disaggregated into livestock, grains, fisheries, forestry and “other” agriculture (see table 9.1). This was done so that we can now explicitly deal with the Mexican forestry sector and quantify its interactions with other sectors which it competes with for inputs. We need to emphasize, however, that this expanded model was extracted and calibrated from the very same 2000 database as the previous model, and that the input-output figures from all non-agricultural sectors are the same as before. Furthermore, all of the outputs and inputs in the five agriculture sectors add up to *exactly* the same totals as the aggregate agricultural sector from our previous runs. The only thing that has changed is the number of sectors to be dealt with and solved for by the model.

After investigating the effect of internal permit trading on the Mexican economy, in our second set of simulations we quantify the impacts of permit trading between Mexico and the United States. More specifically, in scenarios 5P-7P we expand our previous analysis to the international arena by allowing the forestry sector to “sell” sequestration rights permits to manufacturers in the United States in exchange for allowing them to emit carbon. This kind of program is very much in keeping with the U.S. negotiators position in Kyoto and it fits well with the goals of the Clean Development Mechanism. It is also fairly straightforward to model since it does not require extensive data on the expense of carbon emissions cutbacks for U.S. manufacturers relative to their Mexican counterparts. In order to run these scenarios it is necessary to have a dynamic CGE model of the United States as well as for Mexico. The U.S. CGE model used for this analysis is very similar in structure to the Mexican model described above making it very easy to integrate their simulation results. As with the model of Mexico, the U.S. model has 13 production sectors and 14 production goods (which correspond *exactly* to those in the Mexican model), and just as with the Mexican model, the U.S. model is calibrated to data from the year 2000. Furthermore, all its variables are assumed to grow at 2.9% rate in benchmark[5]. Both models’ results are in exactly the same units, which both facilitate the integration of the bilateral trade flows and simplify the process whereby permits are exchanged between the two countries[6].

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[5] Because its structure is similar to the model of Mexico and because its results (except for the aggregate emissions reduction figures) are not given here, the U.S. model will not be described at length in this book. Readers who are interested in the complete structure of the U.S. model may consult articles by Boyd and Doroodian (2002), which describe its workings in some detail.

[6] Data for the bilateral trade flows was obtained from the GTAP 6.2 database adjusted to fit the 2000 base year used in both models.

It needs to be emphasized that although we incorporate a U.S. model into our permit trading scenarios, the emphasis in our analysis remains on Mexico. The U.S. is primarily of interest to us due to its role as a permit-trading partner and to the extent that aggregate U.S. CO_2 emissions are reduced. Note that it is not our intention here to create a fully integrated international permit trading model along the lines of the EPPA and G-Cubed models mentioned above. Those models have reached a high degree of sophistication over many years of development and have as their goal a comparison, in terms of efficiency, of the various proposed worldwide emissions permit-trading schemes. Our purpose here rather is somewhat more modest. We are interested in examining the environmental and economic consequences for Mexico of utilizing the device of international emissions permits for improving its own forestry sector and at the same time contributing to worldwide emissions reductions. Insofar as other Latin American countries such as Brazil and Argentina, also have significant forests that can be used for a similar purpose, our results here could also have significant implications.

4. RESULTS

Scenarios 0P and 1P: Benchmark Cases for the Disaggregated Mexican Model

Just as in chapters 7 and 8 when we were dealing with carbon taxes as an emissions abatement instrument, we need to calculate the economic impacts of tradable emissions permits with respect to a "benchmark" case. In this scenario, which we label scenario 0P (for benchmark in the permits case), we run the expanded model outlined in table 9.1 under the same assumptions as those under scenario 0 in chapter 7. As with scenario 0, in scenario 0P every sector in the economy grows at the pre-specified steady state rate of 2.9% throughout the 20 years simulation period. Furthermore, just as in chapter 7 we assume that the balance of trade, consumption, imports and exports, government revenue and expenditure, economy-wide savings, and the effective labor supply in hours worked all grow by this same exogenously determined rate. However, as we noted at that time, such assumptions are somewhat unrealistic in light of oil depletion. With oil stocks shrinking over time, ever-increasing growth in the extractive industries would be impossible to sustain. Hence, in scenario 1P (just like scenario 1 in chapter 7), the level of oil produced is allowed to increase according to the economy's growth rate only until 2004. Beyond that year the quantity of oil produced remains constant at 4 million barrels per day to simulate the depletion of existing supplies of petroleum. Furthermore, it is assumed that there is investment in the extraction and distribution of natural gas in a manner consistent with the present policy of the Mexican government. Again, as with scenario 1 above, we assume that there is no technological change in either PEMEX or CFE and that there is no change in any international price including the prices of fossil fuels.

The model's results (in the year 2020) for these two initial simulations are given in table 9.2. In that table we give the numbers for GDP and consumer welfare along with the results for those economic sectors most closely linked to our permit trading exercises. These include the extractive, manufacturing and electricity sectors whose production costs rise when permits are purchased, the agricultural sectors that must compete for resources with a subsidized forestry sector, and the energy intensive chemical and refinery sectors. Greenhouse gas emission levels are given as well. As would be expected, there is no difference between the results of these first two simulations here and the results for scenarios 0 and 1 given in chapter 7. Just as before, in scenario 0P all sectors increase their output from 2000 to 2020 in a very predictable way. Our final numbers then decrease significantly form their 0P levels in scenario 1P with the decreases being most severe in the petroleum, natural gas and refinery industries. With our benchmark cases now run, we are ready to examine the impact of a market in tradable permits.

Scenarios 2P-4P: Introduction of Domestic Tradable Permits

In scenarios 2P through 4P we run the same model as in the 0P and 1P cases except now we introduce a scheme whereby emission permits will be traded between the forestry sector and those sectors of the Mexican economy which are responsible for the emissions of greenhouse gases. More specifically, what we do in these model simulations is to create a new market. The function of this market is to facilitate the trading of permits giving the owner the rights to produce carbon emissions above some specified level. The buyers in this market are the emitters in the Mexican economy and the seller is the forestry sector. We allow the forestry sector to create permits in proportion to the level of reforestation activity undertaken, and to "sell" these permits to firms in the manufacturing, electricity, and chemical sectors *within* Mexico in exchange for planting trees. The newly planted trees "sequester" a particular amount of carbon and thereby partially offset the environmental effects of the industrial carbon emissions. In essence we are enacting a system whereby emitters pay the social cost of their production to the sector responsible for ameliorating these effects. This type of a permit scheme reduces GHG's in two ways. First, and most obvious, carbon is sequestered in the form of wood and, essentially taken form the atmosphere. Second, producers have a strong incentive to cut back on emissions in order to avoid purchasing permits. In the model, GHG emitters are required to pay for an ever-increasing proportion of their emissions via carbon sequestration permits. By the final period (i.e., 2020) reforestation efforts account for 2.7

million tons of carbon or 50% of the total amount of carbon harvested as wood in the year 2000[7].

The simulation results of this exercise are listed in table 9.2. The results in the year 2020 for scenario 2P are given as changes with respect to simulation 1P, and, as can be seen, most of these results are in line with what we would intuitively expect. The introduction of a new market for emissions permits entails payments by producers for a non-consumed commodity (i.e., sequestered carbon), and, consequently, there is a decrease in GDP of about 5% or $5 billion. Aggregate welfare levels, investment and the final value of the capital stock also fall. On the other hand, the level of CO_2 emissions declines by 4.7% or 21.36 million tons and we must remember (as first pointed out in chapter 7) that there are significant positive externalities at both the national and international level associated with reduced pollution and lower GHG levels. Furthermore, these environmental benefits are not just confined to the decline in greenhouse gases. Fewer emissions also means that there will be a drop in other harmful emissions such as sulfur dioxide and nitrogen dioxide, and the associated increase in forest cover helps enhance wildlife habitat and cuts back on harmful erosion. Overall the introduction of a market for sequestered carbon is regressive as the lower income agents are hurt relatively more than their wealthier counterparts. With respect to the individual production sectors we see that permit trading leads to significant losses not only in the extractive sectors but also on energy intensive sectors such as refinery production and chemicals. Manufacturing, drops slightly since manufacturing firms have to substitute away from higher priced energy inputs, and agriculture other than forestry goes down as more resources are diverted to forestry use.

There is one result in this model simulation, however, which appears at first to be counter-intuitive and requires some additional explanation. As can be seen, the electricity sector, in spite of purchasing emissions permits, experiences an increase in production rather than a decrease. Initially, it would seem that, in light of the considerable payments made by the electric sector for the “right” to emit greenhouse gases, total production in that sector should go down. We should note however that two separate things are going on in the economy when these permits are exchanged. First, when permits are purchased by the power sector, the price of power rises. Consumers are thus discouraged from buying this electricity and are encouraged to buy substitute goods. We term this effect the “substitution” effect. Second, when

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[7] This is a very large amount of carbon sequestration and is probably somewhat greater than any sequestration program that might actually be implemented. The aggregate U.S. economy, however, is more than 16 times the size of the Mexican economy and it was felt that a sizeable program should be used in this exercise to keep the changes in the US model from being too small and possibly ambiguous.

manufacturing, chemical, and electricity prices rise, resources are forced into other sectors such as services and these other sectors expand. This increased demand for services, in turn, creates increased demand for service inputs and one of the largest of these inputs is electricity. We call this effect the "demand" effect. It is the relative strength of these effects that then determine whether the output of the electricity sector ultimately goes up or down, and in this simulation (and under these particular assumptions) that output goes up. Hence, due to the lack of good substitutes for electricity in consumer use combined with the large role that electricity has as an input in the service sector, emissions permit trading here has an unanticipated effect.

Emissions trading, if adopted, would probably take place long after electricity price supports have been removed. Hence, in scenario 3P we combine the effects of deregulated electricity prices with those of a permit market. The results of this simulation, listed in table 9.2, are qualitatively quite similar to those of scenario 2 in chapter 7 where electricity deregulation was also introduced. Here again we find that, as before, the aggregate level of welfare rises with the largest percentage (and absolute) gains experienced by the wealthiest consumers who receive the smallest subsidies presently. As expected, the production of electricity goes down along with the production of manufacturing, chemicals and agriculture. Electricity subsidies in these last three sectors are substantial so it also stands to reason that output there would decrease a bit. Oil, gas and refinery output decreases slightly as resources are diverted elsewhere, largely to the service sector. Emission levels decrease as well.

In chapters 7 and 8 we found that one of the most important components of any emission reductions program for Mexico is the introduction of energy efficient technology. With this in mind, we modify the model used in the previous simulation to incorporate such technological change (just as in scenarios 5 and 7 in chapter 7) and run it as scenario 4P. The results of this exercise are given in table 9.2 where we show the percentage changes between the two simulations. Just as before in chapters 7 and 8 GDP, investment, capital stock and the level of welfare of all consumers rise. Energy use from all sources goes down and emissions decline considerably. Manufacturing, chemicals and electricity all experience gains, and even agricultural output rises and demand for agriculture products rise in the model's other sectors.

Scenarios 5P-7P: Trading Permits with Manufacturers in the United States

Our first group of simulations dealt with a situation where carbon sequestration permits for the "right" to emit CO_2 was bought by manufacturers in Mexico itself. While it has been instructive to conduct this initial part of our experiment, the real value of this exercise comes in contrasting our results here with a situation where such rights are sold from Mexico to a developed country such as the United States. Indeed, most of the discussion in the literature and almost all of the discussion among policymakers concerned with agreements like Kyoto centers around the economic gains to be realized from a policy whereby carbon sequestration in developing countries would be secured from funds provided by the developed world. Furthermore, it stands to reason that the sale of such permits would be most effective if it were connected to emissions cutbacks in these developed countries. Hence, in our next set of simulations we have sequestration rights sold by the Mexican government to manufacturers in the United States. To make comparisons easy we simulate an identical level of carbon sequestration and aggregate CO_2 emissions as in scenarios 2P-5P above. We then compare their efficiency in terms of their cost in aggregate GDP and aggregate consumer welfare to see if there can be gains from international trade in such sequestration rights.

As mentioned above, in conducting this set of simulations two separate models were used, and working with two models rather than one necessitated some important changes in just how these simulations were, in fact, modeled and run. First, since the two models were developed separately, we needed to incorporate trade linkages between the two countries. This information was obtained from the 6.2 version of the GTAP information base developed by Hertel (1997). Trade data for the various production sectors were divided according to whether they were bilateral linkages between the two countries or linkages to third countries labeled the "rest of the world". The two models were then run separately and the bilateral trade totals (i.e., imports and exports between the two models) adjusted so that they matched[8]. Finally, transfers between the U.S. and Mexico were handled through the Mexican government sector. As in the previous case any funds in excess of those needed for reforestation were returned to the production sectors in proportion to the amount of their capital and labor taxes to keep government income neutral.

A total of three international permit trading scenarios were run. In scenario 5P, the modeling exercise described above was run assuming that the elasticity of substitution between coal, natural gas, and petroleum products was 0.5 (a common assumption used by modelers working with the GTAP data set (see Burniaux and Truong, 2002)) and that this same elasticity level held for production in both Mexico and the United States. Subsequently we

[8] Because the bilateral trade totals did not initially match, the import and export totals for each model were adjusted and both models run again. This process continued until the bilateral totals matched up to a reasonable level of tolerance. Usually, this process was not lengthy.

relaxed this initial assumption, and, in scenarios 6P and 7P we re-ran the U.S. model at alternative substitution elasticities of 0.2 and 0.8 to see how sensitive our results were to changes in this highly important parameter. In all cases the emission permit prices were adjusted so that the level of CO_2 emission reductions in the U.S. were held constant and at the same level as in scenario 2P where Mexican manufacturers were required to cut back on *their* CO_2 emissions.

The results for this final set of simulations are given in tables 9.3 and 9.4. Table 9.3 gives the aggregate 2020 totals for GDP, investment, consumer welfare and the capital stock in the U.S. economy for all the substitution elasticities considered. The aggregate CO_2 emissions levels for U.S. industry are also given along with the totals for those production sectors most critical to our analysis. The table 9.4 is divided into two parts. The first part of the table gives the aggregate 2020 totals for GDP, investment, consumer welfare and CO_2 emissions for Mexico, and the second part of the table gives the 2020 totals for Mexican exports of fossil fuels to the U.S.[9] As before, all numbers other than benchmark numbers are given as percentage changes to facilitate comparison between the various scenarios run.

Turning first to our results relating to the United States, we see that when U.S. manufacturers are required to purchase sequestration permits, the level of GDP, investment, consumer welfare and CO_2 emissions all decline as expected. What is interesting however is the relative size of that decline. As stated above in simulations 5P, 6P, and 7P we require U.S. producers to purchase sequestration rights so that their decline in CO_2 emissions exactly matches the emissions cutbacks by Mexican firms in the previous three simulations. Hence, in simulations 5P, 6P, and 7P aggregate U.S. CO_2 emissions go down by 2.136 million tons in 2020. Aggregate GDP in the United States (also in 2020), however, declines by \$600 million from the benchmark case, and this decline, while significant, is only about 12% of the loss calculated for Mexican GDP earlier in scenario 2P. Along these same lines, we find that aggregate U.S. consumer welfare goes down by about 0.0008% or \$720 million when sequestration rights are issued. Here again, this loss is only a fraction of the welfare loss experienced by Mexican consumers earlier.

The reason for significantly smaller U.S. losses viewed here is due primarily to the mix of fossil fuels used in the U.S. and Mexico. In the United States, petroleum, natural gas, and coal are all widely produced and consumed (see table 9.3). Mexico, by contrast, relies almost exclusively on its large reserves of petroleum to serve its energy needs. In the United States there is

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[9] Exports of coal and natural gas to the U.S. are not given because the level of such exports is negligible.

much greater room for interfuel substitution. When producers are forced to absorb added energy costs according to each fuel's carbon content, they have substantially greater opportunity than their Mexican counterparts to substitute low carbon natural gas for oil and coal. Thus, in table 9.3 we see that when permits are required, U.S. producers cut the usage of all fossil fuels but do so relatively more with coal and oil than on natural gas. Their ability to do this varies, and is of course dependent on the elasticity of substitution. But, even in the low elasticity case (i.e., scenario 6P) there is ample movement to higher natural gas use. Indeed, all of our results for the U.S. are quite robust with respect to the substitution elasticity chosen.

The results of U.S. producers' actions will, of course, have spillover effects on Mexico. When U.S. producers pay for the sequestration rights, those revenues ultimately go to producers and manufacturers in Mexico (in our setup here), leading to higher levels of aggregate Mexican production. This higher production, in turn, could possibly entail a higher level of CO_2 emissions as well as higher levels of energy and energy intensive exports from Mexico to the United States. This carbon leakage could be further exacerbated by increased demand for energy and energy intensive goods by U.S. importers.

Thus, in table 9.4 we list the changes in Mexican output, emissions and energy exports in scenarios 5P-7P. Our results there indicate that, overall, this permit-trading program would not create large negative spillover effects. When sequestration rights are issued to U.S. producers exports of fossil fuels from Mexico to the U.S. do not change appreciably from their scenario 1P levels. As theory would predict, the transfer of funds from the U.S. causes overall production and welfare levels in Mexico to rise slightly. This serves to further cut the aggregate welfare cost of the permit program and should be viewed as an added bonus to an international system of permit trading. Emissions of CO_2 climb as well. However, as the Mexican economy grows, this increase in CO_2 emissions does serve to dampen the intended effect of the permit program. This change is quite small though (amounting to no more than 140 thousand tons) and can be viewed as fairly inconsequential.

Figure 9.1, finally, shows GDP and CO_2 levels for Mexico under all scenarios presented in this chapter. These results are directly comparable to those in chapters 7 and 8. Values for the U.S. are not reported because the variations in GDP are very similar and CO_2 only fall 0.12% in all cases, as can be seen from table 9.3.

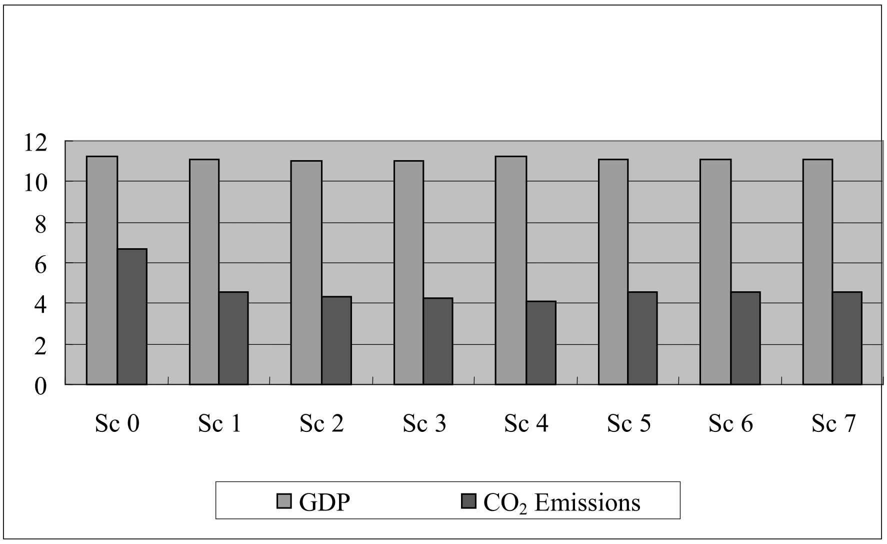

Figure 9.1 GDP and CO_2 emissions under different scenarios
(GDP in hundred billion dollars, CO_2 in hundred million tons)

5. CONCLUSIONS

In this chapter we have used our model of Mexico along with a closely linked model of the United States to examine the issues of CO_2 emissions trading and carbon sequestration in North America. The topic of emissions trading and implementation is discussed widely in the literature and has been the subject of a number of empirical studies. Fawcett and Sands (2006) suggested that Mexico, because of its strong reliance on oil and the lack of fossil fuel substitutes, has limited fuel substitution possibilities. Hence Mexico has been seen as having limited value as an emissions permit trading partner for countries like the United States. If one is considering the trading of traditional emissions permits between GHG producers in developed and developing countries such a conclusion is quite reasonable. As we have seen, however, Mexico does have large tracts of both tropical and temperate forested land, and a permit system involving carbon sequestration of those forests has the potential for efficient energy. More specifically, we have seen that if (after some level of emissions) GHG emitters are required to purchase sequestration rights for a certain percentage of their additional carbon emissions, such rights can lower GHG levels both by sequestering significant levels of carbon in carbon sinks and by reducing the level of the producers'

GHG emissions. Such gains come at relatively low costs when countries with ample reserves of low carbon fuels, such as the U.S., can participate. Moreover, as has been shown, the potential for unintended spillovers such as carbon leakage seem to be relatively small in scope and easily managed with proper policy design.

Assumptions for Scenarios

Scenario 0: The benchmark case

Scenario 1: The benchmark case plus oil depletion and constant petroleum output after 2004

Scenario 2: Scenario 1 plus internally traded carbon emission permits

Scenario 3: Scenario 2 plus deregulation of electricity prices

Scenario 4: Scenario 3 plus more efficient fossil fuel burning

Table 9.2: Changes by 2020 Domestic Trading Results for Mexico*

	Scenario 0**	Scenario 1	Scenario 2	Scenario 3	Scenario 4
GDP	11.2585	-1.8129%	-0.4649%	0.0598%	2.3406%
Agent 1 Welfare	3.4175	-0.3383%	-0.0510%	-0.0806%	0.6133%
Agent 2 Welfare	10.2034	-0.2959%	-0.0512%	-0.0765%	0.5888%
Agent 3 Welfare	15.9316	-0.7510%	-0.0006%	0.0406%	0.4707%
Agent 4 Welfare	26.5939	-1.0202%	0.0605%	0.0803%	0.1288%
Final Investment	2.8230	-11.1801%	-2.1869%	0.7858%	11.4782%
Capital Stock	29.5613	-4.3725%	-0.7508%	0.0344%	3.4821%
Manufacturing	5.1076	-3.2857%	-0.1951%	-0.1228%	4.4134%
Chemicals	0.5752	-6.3005%	-2.3113%	-1.1878%	15.9793%
Electricity	0.1979	-2.7230%	0.1420%	-1.5031%	12.1797%
Petroleum	0.4304	-37.0898%	-1.3523%	-0.3838%	-2.8073%
Natural Gas	0.0418	-7.5556%	-1.4815%	-0.3759%	-2.8302%
Coal	0.0195	-6.6667%	-10.5413%	-6.3694%	-15.3061%
Refined Products	0.2604	-14.7038%	-3.4228%	-1.9157%	0.0000%
Non-Forest Agriculture***	1.0435	-2.5615%	-0.1083%	-0.7721%	3.7665%
CO2 Emissions	6.6766	-31.9789%	-4.8009%	-0.7550%	-3.6587%

Notes

*All percentage changes are measured with respect to the directly proceeding scenario

**Benchmark Scenario 0 numbers are in hundreds of billions of 2000 dollars, except for CO2 emissions (hundreds of millions of metric tons)

***Non-forest agriculture is the sum of grains, livestock, and other agriculture

Assumptions for Scenarios

Scenario 0: The benchmark case

Scenario 5: The benchmark case plus sequestration rights sold to firms in the U.S. by Mexico

Scenario 6: Scenario 5 plus lower substitution between fuels in the U.S.

Scenario 7: Scenario 5 plus higher substitution between fuels in the U.S.

Table 9.3: Changes by 2020 International Trading Results for U.S.*

	Scenario 0**	Scenario 5	Scenario 6	Scenario 7
GDP	172.5158	-0.0035%	-0.0035%	-0.0034%
Consumer Welfare	856.1206	-0.0008%	-0.0009%	-0.0008%
Capital Stock	164.6223	-0.0109%	-0.0111%	-0.0107%
Final Investment	14.4502	-0.0336%	-0.0346%	-0.0332%
Oil	0.5750	-0.2957%	-0.3304%	-0.2696%
Natural Gas	0.6879	-0.2980%	-0.3271%	-0.2689%
Coal	0.5761	-0.5034%	-0.4513%	-0.5555%
Refining	2.8466	-0.1317%	-0.1370%	-0.1265%
Chemicals	9.7838	-0.0128%	-0.0128%	-0.0128%
Manufacturing	72.6500	-0.0119%	-0.0121%	-0.0118%
CO2 Emissions	103.1359	-0.1237%	-0.1237%	-0.1237%

Notes
*All percentage changes are measured with respect to the benchmark Scenario 0
**Benchmark Scenario 0 numbers are in hundreds of billions of 2000 dollars, except for CO2 emissions (hundreds of millions of metric tons)

Table 9.4: Changes by 2020 International Trading Results for Mexico*

	Scenario 1**	Scenario 5	Scenario 6	Scenario 7
GDP	11.0544	0.0212%	0.0203%	0.0221%
Consumer Welfare	55.7136	0.0038%	0.0036%	0.0039%
Capital Stock	28.2687	0.1503%	0.1461%	0.1545%
Final Investment	2.5074	0.4339%	0.4245%	0.4481%
CO2 Emissions	4.5415	0.0528%	0.0484%	0.0572%
Mexican Exports to US of:				
Oil	0.2178	0.0202%	0.0202%	0.0202%
Refined products	0.0183	0.0000%	0.0000%	0.0000%
Chemicals	0.1507	0.0000%	0.0000%	0.0000%

Notes
*All percentage changes are measured with respect to the Scenario 1
**Scenario 1 numbers are in hundreds of billions of 2000 dollars, except for CO2 emissions (hundreds of millions of metric tons)

CHAPTER 10

CONCLUSIONS

In addition to summarizing our previous arguments, the purpose of this chapter is to pay particular attention to the unique implications of our modeling process for Mexico while at the same time examining the more general implications it has for the rest of Latin America. After reviewing the results of the various simulations run, we evaluate various policies in terms of their environmental, equity and economic efficiency implications. We focus on the chief lessons of our analysis, such as the need for significant investment in fuel-efficient technological change, the importance of energy market liberalization, and the judicious use of market-based incentives to bring about a reduction in greenhouse gas emissions. Finally, we discuss the urgent need of adopting, financing and implementing new technologies as well as the importance of the Clean Development Mechanism and the potential benefits from an emissions trading program between industrialized and developing countries.

1. ENVIRONMENTAL AND ECONOMIC EFFECTS

In this book, we have argued that human activities dealing with the use of fossil fuels significantly increase the concentration of greenhouse gases in the atmosphere and that this, in turn, is a direct cause of global climate change. In addition to global warming such fuel combustion also releases other harmful pollutants which can generate large negative effects on health. Thus, curbing the use of fossil fuels can also lead directly to widespread improvements in public health quite apart from any discussion of climate change.

The effects of climate change have already become apparent throughout the world. While these effects, which include rising temperatures and a greater frequency of extreme weather conditions to name a few, can be more dramatic in some locations than in others, they can be felt on every continent. New meteorological studies forecast even greater changes in the years to come. These changes may still be inexact in terms of location, magnitude and timing, however, without a doubt, there is more than ample evidence to suggest that such changes *are* in fact currently in place with ever more dramatic changes yet to come.

Every nation on this planet is affected by the problem of climate change. But, it is also important to remember that each and every country, in its own way, has been responsible for it. Yet, each nation's relative contribution to climate change, their vulnerability to global warming impacts, as well as their emissions reduction costs are substantially different. Indeed, these differences make the task of negotiating an international climate change treaty so daunting. Nonetheless, many countries have participated in initiatives designed to ameliorate the impacts of climate change. On February 16, 2005 these efforts led to the adoption of the Kyoto Protocol. Due to each nation's differentiated historical responsibility and capacity to pay, however, some countries have been exempted from specific carbon reduction commitments. This exemption has been the source of tension among the participating countries and has weakened the overall strength of the Kyoto agreement. The bottom line is that emissions, and ultimately climate change, will not be significantly mitigated unless there is widespread participation by both industrialized *and* developing countries. The role of India and China is especially critical in this respect. However many Latin American nations such as Mexico, Venezuela, Argentina and Brazil also have an important role to play in the ultimate viability of the Kyoto or, for that matter, any other climate change treaty which may come about.

Over the years, a number of climate change mitigation policies have been suggested. These include the elimination of existing distortions in energy pricing, new emission regulations, various market-based instruments to limit emissions and broaden carbon sequestration, and climatic engineering.

In this book, we concentrate on the elimination of existing energy market distortions and on the use of market-based instruments such as carbon taxes and emissions trading. Worldwide, many existing distortions in markets directly or indirectly affect climate change. Policies aimed at solving specific economic and production problems, have led to significant unintended environmental side effects. This, for example, has been the case when policymakers have subsidized fertilizers to increase agricultural output and aid farmers. It also has been the case when the cost of energy to low income households has been held artificially low. In these and many other cases, prices are well below their social optimum since, even in the absence of subsidies; prices do not reflect the negative externalities inherent in the products' use and fail to include the marginal social cost of energy use.

In our model's simulations, we investigate the impact of elimination of previous distortions in energy prices. More specifically, we quantify the economy-wide effects of liberalization of electricity markets (i.e., elimination of subsidies of low cost users by CFE) and examine their impact on CO_2 levels, economic welfare and income distribution. We also include the effects of market-based policies such as taxes to the carbon content of fossil fuels and tradable emission permits.

Overall, the results show that these policies reduce CO_2 emissions with respect to a continuation of present practices. The negative economic consequences of some of these actions can be quite severe however. Carbon taxes, for example, are potentially too harmful to the economy to be enacted at anything but very modest levels. Consequently, policies like carbon taxes must be employed judiciously and in conjunction with actions such as liberalization of energy markets and technological change, which stimulate employment and increase the rate of economic growth.

Two powerful forces, oil depletion and technological change, turn out to be important to our modeling effort but serve to drive our model in opposite directions with respect to economic growth. Oil depletion is important for us to model because otherwise the natural resources of the country and their contribution to growth would be overstated and poorly depicted. Thus, adding the depletion of petroleum to the model adds to the realism of our simulations. Technological change is also crucial for us to model. It is an essential component of sustained economic growth. With respect to the environment, however its effect turns out to be somewhat ambiguous. On the one hand, technological change may improve efficiency in the burning of fossil fuels. That is, it may change the way that the inputs in the production function interact to produce lower emissions without having an impact on production or on welfare levels. On the other hand, it can also increase production, and, if nothing is done in terms of the efficiency of fuel burning, this leads to a significant increase in emissions. Therefore, for the technological change to work in the proper direction, the fuel switching or substitution effect has to be greater than the output effect, and the technological change needs to be carefully targeted towards energy efficiency.

Were not for technological change, several of the energy policies simulated would have disastrous consequences. Economic growth would be crippled, overall economic welfare would decline and the distribution of income would become even more skewed towards inequality. Indeed, in the case where a carbon tax (or equivalent regulation) is introduced into the economy in the presence of distortions in the labor and energy markets, technological change is essential for continued economic growth. Technological change then is very much a double-edged sword. On the one hand it is essential for economic growth, but environmentally it can lead to a dangerous increase in emissions since it is often true that when more goods and services are produced a greater number of (polluting) inputs are used. Thus, the type of technological change is crucial to the final environmental outcome desired.

These two features (i.e., depletion and technological change) to a large extent drive the overall results of our simulation analysis in terms of emissions. When, in scenario 1, depletion occurs in the absence of any kind of technological change, carbon emissions drop significantly since output from PEMEX and CFE falls. Environmental quality rises as both local and global pollution levels fall but this occurs at an unacceptable economic price. In scenario 2, when in addition to petroleum depletion, electricity subsidies are removed from the model, emissions fall even more as the demand for fuels to produce electricity drops as well. In scenario 3, when efficiency is introduced to fossil fuel and power production through increased investment and technological advancements, emissions increase, due to capital enhancing technological change. This trend continues in scenario 4 when capital augmenting technological change is combined with deregulation in the electricity sector. Scenario 5 introduces a different kind of technological change. Here, the emphasis is not on expanding energy use but rather in making energy use more efficient, and we see an increase in economic activity without the harmful environmental consequences.

In scenario 6, we introduce a carbon tax. As anticipated it leads to a drop in emissions but at an economic cost of some $104 U.S. per ton of carbon emission saved. Overall consumer welfare experiences severe declines and the tax itself is regressive with respect to the overall distribution of income. Scenario 7 combines the carbon tax with the kind of technological change introduced earlier in scenario 5 and this particular scenario leads to moderate economic growth combined with relatively low emissions and hence high environmental quality. In scenario 8 we combine a carbon tax with capital enhancing technological change in all economic sectors. Under this scenario, economic growth is high but the widespread technological change serves to offset the environmental gains of the carbon tax. From this analysis, we conclude that the introduction of a carbon tax (or an equivalent regulation) can lead to a severe reduction in output and reduce economic growth. Additionally, a carbon tax could also have a deleterious effect on the balance of payments since, if Mexico is the only country with such a tax, its exports would lose competitiveness in international markets. This implies that if introduced, such taxes (or equivalent policies) should be applied cautiously at low rates. An energy efficient technological change would seem to be a better alternative than a carbon tax or similar regulation, since Mexico has few alternatives to petroleum to meet its energy needs.

The scenarios in chapter 7 presuppose a somewhat simplified economy in which there is perfect competition in all sectors and all markets clear in every period considered. In chapter 8, however, we relax these earlier assumptions and introduce "real world" market imperfections into the model and re-run some of our earlier simulations to see if or how they might change. More specifically, we introduce market power in the energy sectors and allow for the possibility of non-clearing labor markets. As in chapter 7, we allow for oil market depletion and include various kinds of technological change in the eight scenarios, which are then run. In scenario 10, when electricity subsidies are eliminated, the level of harmful greenhouse gas emissions goes down, but at considerable expense to both overall economic efficiency and the distribution of income. If, however, technological change in the energy sectors is introduced, as is done in scenario 9 these results are reversed, and both GDP and economic welfare register impressive gains. In scenario 11 an energy efficient technological change policy is again introduced whereby producers in all sectors are able to produce the same amount with fewer inputs of fossil fuels. This, in essence again lets us introduce efficiency and "clean technologies" as in the previous chapter. Here, however, these technologies are introduced into an economy with non-clearing labor markets. Interestingly this does not change the general results obtained in chapter 7 and again we see there exists the possibility to have both environmental improvement and economic growth.

In scenario 12, we again introduce a carbon tax. While it does reduce GHG emissions levels it only leads to sustained growth if the rates are set lower than when we assumed clearance in the labor market (i.e., no sticky wages), and if we introduce significant technological change. Simply put, if the rates are not low and technological change is not introduced then the tax is not economically or politically viable. Scenario 13 introduces both monopoly power and technological change (but only to the energy sectors). By and large this has a favorable effect on emissions since this particular market structure limits both output and externalities with respect to the perfectly competitive case. Although the Mexican economy is worse off overall, and in terms of income distribution, the impact of market power in the energy sectors turns out to be regressive. This situation worsens even more if the exercise of monopoly power is combined with no technological change whatsoever as we have modeled in Scenario 14. Then, although emissions drop further than in the previous scenario, economic growth is stifled, investment and the capital stock decline, and the poor are hurt disproportionately.

The situation improves considerably in scenario 15 when energy monopolies choose to exercise their power at the same time that energy efficient technological change occurs. In this case not only are harmful emissions reduced, but the economy also experiences renewed economic growth. Finally, in scenario 16, exercise of monopoly power is combined with a low rate carbon tax, persistent unemployment and economy-wide capital enhancing technological change that includes monopoly. Emission levels are similar to those forecast in scenario 12 as is the impact of these factors on overall economic growth.

An overall finding of our analysis is that energy efficient technological change is of major importance if Mexico is to seriously reduce emissions without experiencing harmful effects on its economic growth and welfare. It is also essential to eliminate market distortions such as energy price distortions and labor market imperfections if policymakers want to guard against severe economic contraction when carbon taxes or other similar sorts of emission controls are introduced. Indeed, even in the absence of such distortions the economic cost of price-based carbon restrictions are high and our analysis here strongly suggests that policy makers levy carbon taxes with low rates to attain a decent level of economic growth. This is especially true if emission reducing technological change is also being used as a carbon reduction instrument. While capital enhancing technological change is an economically effective way of using investment funds, caution should be taken since increased economic activity, especially in the energy sectors, dramatically increases GHG emissions and other harmful pollutants. Finally, although the exercise of monopoly power by state owned energy producers has the potential to decrease emissions through supply restrictions, the use of such power is not to be recommended. Monopolies cannot be expected to act in either the economic or the environmental interest of the public. Monopoly production can be costly, wasteful and insensitive to environmental consequences. Monopolies, for instance, cannot be expected to introduce cleaner burning and energy efficient technologies as quickly and efficiently as competitively running industries faced with the correct incentives to reduce energy-related externalities. Furthermore, welfare levels increase when market power in the energy sector is reduced, since costs tend to fall. We advocate a policy whereby prices are liberalized and competition is introduced, and we believe that any action designed to limit both the extent and exercise of monopoly power in Mexico would be both economically and environmentally beneficial.

A number of policies then could be undertaken simultaneously to reduce energy consumption and remove harmful distortions in Mexico's energy markets (price and structure-wise), and foremost among these policies is to introduce energy efficient technological change, remove existing energy distortions, and adjust carbon prices upward to reflect its true opportunity cost. Thus, the remaining challenge for Mexico's policymakers is to find ways to finance such technology. In our analysis, we have identified several options that could potentially be potentially viable. As we stated in our conclusions to chapter 7, one such option would be to combine deregulation of electricity with economic incentives to energy using industries and a modest tax on carbon. The economic incentives to promote energy saving technological savings could take the form of direct investment from the government, government investment directed through private firms or in the form of tax incentives to private firms willing to acquire such technologies and invest in them themselves. Resources for such investment or tax cuts could come from a number of sources. It could come from the funds saved from the elimination of electricity subsidies, or from the resources saved from privatizing and operating state-owned PEMEX and CFE monopolies. Resources can also come from taxed fuels or from Clean Development Mechanism projects, as considered within the Kyoto Protocol. Another option, as we have seen, is to allow emissions trading within Mexico or between Mexico and industrialized countries such as the United States, and we now turn to the results of our modeling exercise on the impact of such trading.

In chapter 9, we introduce tradable emission permits among different sectors within the Mexican economy as well as international trading between Mexico and the United States. In our initial simulations, we introduce permit trading between the forestry sector and CO_2 emitters located within Mexico itself. We find that if permits are introduced, the emission levels of GHG's from the manufacturing and chemical sectors decline as expected, but this is not (at least initially) the case with electricity. As we have seen, a decline in manufacturing leads to relatively higher manufacturing prices, relatively lower services prices and a large transfer of economic resources from manufacturing to services. The overall level of service output increases and this increase leads to a higher demand for electricity. This increased demand for electricity outweighs any decline in electricity use brought about by substitution for other energy sources. Indeed, only if emission trading is paired with deregulation in the electricity sector is the final level of electricity production and electricity GHG emission levels comparable to the case before such permits were introduced.

Our model simulations here also show us that even though other agricultural sectors are not directly involved in permit trading, they do bear some of its indirect consequences. In particular, we see that grain, livestock and other agricultural output decrease a bit, as more money goes into the forestry sector. All of these sectors compete for scarce land and capital resources and, to some extent, the gains of the forestry sector occur at the expense of the other agricultural sectors. The losses to agriculture, however, are likely to be small and are offset to some extent by the environmental benefits involved in reducing agricultural erosion.

Finally, we consider the case where Mexico installs an emission-trading program with the U.S. Mexico's forestry sector sells emission rights while GHG emitters in the U.S. are required to purchase such rights for a certain percentage of their carbon emissions. Overall, such rights can lower GHG levels both by sequestering significant levels of carbon in carbon sinks in Mexico and by reducing the level of the producers' GHG emissions in the U.S. Such gains come at relatively low costs when countries such as the U.S. with ample reserves of low carbon fuels can participate. Moreover, the potential for unintended spillovers such as carbon leakage seem to be relatively small and easily manageable by proper policy design. Carbon sequestration, then, is another policy that could be applied by Mexico to reduce emissions and trading sequestration rights internationally could entail sizable efficency gains. This, in turn, serves to underscore a point stressed repeatedly in the literature, namely the importance of international cooperation in global warming policy and the importance of participation by both developed and developing countries.

One advantage of the model we have worked with here is that we are able to see the tradeoffs between different aspects: economic growth and productivity, the environment, and income distribution. There is no free lunch, so these tradeoffs are expected. The fact is that our model does make them explicit and allows this information to be built into the decision making process. This feature is especially important for developing countries such as Mexico where poverty and income distribution are important issues in and of themselves, and where policymakers must carefully consider distributional considerations before enacting any major initiative.

The modeling approach we have taken, however, is not without its drawbacks. As we have noted, there is considerable uncertainty both as to the value of crucial economic parameters dealing with energy substitution and demand, as well as the overall gains associated with climate change mitigation. With respect to the first drawback, we have carried out extensive sensitivity analyses to assure the robust nature of our results. Nonetheless, better estimates would be helpful in gaining a fuller understanding of the magnitudes involved when comparing the costs of alternative energy policies.

The second drawback will be harder to deal with because, in addition to the time length involved in calculating damages, modelers confront the fact that each country's contribution to those damages is global in scope and interrelated with the actions of other countries. This, however, should not deter researchers from attempting to obtain more accurate damage estimates and linking them to economy-wide modeling efforts.

2. FUTURE ENERGY POLICIES

As stated above, our general conclusions point at the need for technological change as a necessary condition to implement other energy (and environmentally friendly) policies. In the absence of such a change, policies that mitigate climate change will be too costly for any economy to phase in. The elimination of market distortions should also be seriously considered since this would improve overall economic efficiency, but this may take time due to political considerations involving equity, as has been discussed.

In the short run, there is ample room for improvement in energy efficiency and substitution through cleaner fuels and more fuel-efficient combustion. Encouraged by the economic incentives discussed above, Mexican firms and sectors would become more energy and efficient and less polluting, either by using less fuel or by switching to fuels with lower energy content, and this, in turn, will most likely lead to a decrease in aggregate emission levels. On the other hand, economic growth fostered by higher productivity (reached through technological change) will increase consumers' income and thereby increase consumers' demand for environmental quality, which is a normal good. This latter (i.e., income) effect, as we have seen in our model simulations, is strongest when technological change is directed towards capital in general and not targeted specifically to energy efficiency so careful discretion by policy makers is warranted here if policy makers are to avoid unintended consequences of well-intentioned policies. There is also a role here for a policy of consumer education and consciousness-raising within the population at large. Higher environmental quality raises living standards and the overall quality of life, and to the extent that people are made aware of their own stake in global warming and other environmental issues, they too can play an active role, as consumers, in energy conservation.

Eliminating monopoly power is also a worthy short term goal. Here too, care is needed as this may also entail unintended consequences to environmental quality. More specifically, as we observed in chapter 8 if firms now operate under perfect competition, quantity produced would increase and prices would fall, leading to higher emissions. However, if newly privatized firms face the true social opportunity costs by emission permit trading, or other similar policies outlined here, such a price drop is not likely to be much of a problem. Furthermore, eliminating market power would have the effect of increasing real income and stimulating the demand for environmental quality. Additionally, more competition among firms would lead to improvements in technology leading to greater efficiency and the use of cleaner fuels (given the proper incentive structure). Reforming the energy sector to avoid market power is a difficult political decision for Mexico, but it is an issue that needs addressing.

Generalizations for the remainder of Latin America are difficult to make given that each country is truly unique, with its own natural endowments and policymaking processes. Nevertheless, a few general observations can be made given the results of the analysis in this book. First, extreme caution must be taken with any carbon tax or other mandatory restriction limiting the use of energy in a developing country. Concerns over sustained growth and distributional equity often limit the scope of carbon restrictions until per capita national income attains some minimum acceptable level. Otherwise, any such policy is likely to be economically unwise and politically unacceptable. Second, carbon sequestration should be given high priority as an initial means of achieving climate change mitigation targets, and countries such as Brazil with large forest resources and severe deforestation problems should be encouraged to participate in sequestration "rights" trading programs such as the policy outlined above in chapter 9. Third, antiquated energy subsidy policies that distort production and consumption decisions need to be eliminated as far as distributional concerns will permit. Fourth, the diffusion of new technology promoting the efficient burning of fossil fuels and alternative energy sources should be promoted by tax subsidies, public investment and funds from the Clean Development Mechanism for *all* developing countries in the region. Finally, any global climate change mitigation program that wishes to seriously incorporate Latin America must include a comprehensive and well-designed system of tradable emission permits. Mexico and the remainder of Latin America have the potential to become effective partners in curbing the growth of climate change. They can only do so, however, when producers and consumers are given the right economic signals.

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