Health Impacts from Urban Air Pollution in China: The Burden to the Economy and the Benefits of Policy

by

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Abstract

In China, elevated levels of urban air pollution result in significant adverse health impacts for its large and rapidly growing urban population. An expanded version of the Emissions Prediction and Policy Analysis (EPPA), EPPA Health Effects China (EPPA-HEC), was used to evaluate air pollution-related health impacts on the Chinese economy. EPPA-HEC, a computable general equilibrium model, was expanded to endogenously estimate the economy-wide impacts of air pollution. The effects of particulate matter (PM10), sulfur dioxide (SO2) and nitrogen oxides (NOx) were evaluated for 1970 to 2000, based on a set of epidemiological estimates of the effects of exposure to these pollutants. The estimated GDP impact to the Chinese economy of pollution levels above the WHO's recommended thresholds (ambient levels) increased from $15 ($23) billion in 1970 to $50 ($79) billion in 2000 (1997 $USD), despite improvements in overall air quality. This increase was caused by the growing urban population and rising wages that thus increased the value of lost labor and leisure. The benefit Damages as a percent of GDP decreased from a peak of 16% (10%) in 1975 to 7% (4%) in 2000 because the total size of the economy grew much more rapidly than the absolute air pollution damages.

Forward simulations considered a cap on pollution, a greenhouse gas policy, and the two policies combined. The ancillary benefits from air pollution control resulting from the climate policy resulted in an increase in China's GDP of $2.4 billion in 2010. A scenario that caps air pollutant emissions at 2005 levels results in a $3.9 billion benefit to China's GDP in 2010, and the implementation of both policies results in a $5.8 billion benefit to China's GDP in 2010. The simulations extended to 2025, and the beneficial effects of these policies increased over the period to $17.1 billion, $37.4 billion and $43.8 billion respectively. Taking both the future and the historical analyses together, it is clear that the size of the urban population, as well as the increasing value of time due to rising wages are two of the major drivers of the increasing absolute costs of pollution-related health impacts to the Chinese economy. Thus, urbanization and rising incomes and wage rates over time imply a rising marginal benefit to pollution control.

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Chapter 1: Introduction

1.1 Evaluating the Economic Impacts of Environmental Policy

China has undergone enormous growth over the past thirty years. Its real GDP has increased seven-fold between 1978 and 2000 (United Nations. Statistical Office. 2004). During the same period, the total population has grown by over 40% (United Nations. Statistical Office.), (China (Republic: 1949-). Zhu ji chu. 2001). There has been a marked increase in the standard of living as the Chinese economy has transformed from highly controlled to market driven. Urbanization, education and economic opportunities have created a large Chinese middle-class. New cities have appeared virtually overnight, as each region of the country has attempted to benefit from this period of impressive growth.

This rapid change has not come without cost. Increasing incomes have also increased consumption. Like their counterparts in the developed world, the middle-class in China have embraced all of the trappings of a successful, industrial, modern life and technology, such as appliances, automobiles, clothing, and electronics. This in turn increases the demand for electricity. In China, the vast majority of the electricity comes from relatively inefficient coal burning power plants that lack modern pollution control.

Economic growth has improved the standard of living for hundreds of millions of Chinese. Yet what effect has it had on their overall quality of life? Urbanization has resulted in growing numbers of people living in areas where pollution levels routinely exceed levels considered to be acceptable from a health standpoint. Air pollution has been a major environmental issue for more than two decades. Increases in emissions from power plants, industrial manufacturing, and automobiles have all combined to create some of the most polluted areas in the world. In some of China's largest cities, including Beijing, Chongqing and Taiyuan, levels of particulates and sulfur dioxide (SO_2) were more than double the World Health Organization (WHO) guidelines (Johnson, Liu *et al.* 1997).

High levels of air pollutants are more than a nuisance. Ozone (O_3) and sulfur dioxide (SO_2) are damaging to crops and forests. Carbon dioxide (CO_2) contributes to global warming. And many air pollutants, including ozone, SO_2, nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM) have been linked to adverse health outcomes, ranging from coughs and restricted activity to chronic bronchitis and even increased death rates from respiratory illness (Dockery, Pope *et al.* 1993; Pope, Thun *et al.* 1995; Kunzli, Kaiser *et al.* 2000; Zhang, Song *et al.* 2000; Zhang, Hu *et al.* 2002; Aunan and Pan 2004; Chen, Hong *et al.* 2004; Pope, Burnett *et al.* 2004).

These adverse health outcomes are not just quality of life issues. They incur a real cost to the Chinese economy, both in the provision of health services, and in the labor and leisure time that is lost every time an individual becomes ill. The Chinese government is not unaware of these costs. Since 1978, China has implemented a series of environmental policies aimed at curbing and reducing air pollution levels. But it is clear that the government's priority is increased economic growth, and so attempts to reduce harmful emissions have had variable levels of success. While there was a decrease in ambient levels of particulates in 40 of the 60 medium and large cities between 1991 and 1998, some of the largest cities, including Beijing and Tianjin, had significant increases in ambient concentration. More importantly, despite reductions in ambient concentrations of some pollutants, the increase in the urban population has actually led to an increase in the number of people exposed to high levels of air pollutants (World Bank. 2001).

If urban air pollution results in a cost to the Chinese economy, then any policy that addresses the problem produces a corresponding economic benefit. Yet calculating these costs and benefits is a difficult problem. Assessment of environmental externalities involves the valuation of seemingly nebulous quantities. How do you assign value to drinkable water and breathable air? But these calculations are possible if the problems are broken down into their components. It might be difficult to assess the overall value of clean air. But it is possible to calculate the economic impacts from the health effects of air pollution in different scenarios, from the clean to the dirty. This kind of analysis can enumerate the historical costs of air pollution and help to clarify the expected benefits of future policies.

A concrete cost analysis of this nature is a powerful tool. In nations where the economic bottom line takes precedence over the resulting environmental condition, the cost of environmental externalities is often omitted. Yet it is clear that addressing these externalities can have very real economic impacts. In order to create sound policies, it is important that externalities, such as health effects, are taken into account. They can help to determine the appropriate levels of control for pollution policies, since they provide information about the marginal benefits or costs of policy options. Furthermore, there are often interaction effects between different environmental policies. While urban air pollution reduction is not a primary goal of policies such as the Kyoto Protocol, which address greenhouse gas control, many greenhouse gas policies have an added benefit of reducing the levels of other air pollutants. In order to create a set of sound environmental policies, it is important for nations to have an idea of the effects of each of their policies, as well as the interactions between them, so that they can optimize across a range of options. Thus the ability to calculate these types of policy benefits has an implication beyond the immediate problem of urban air pollution. This method of analysis could also be used to influence policy decisions both domestically and internationally, and could help shape whether and how the Chinese government decides to proceed.

1.2 Research Contribution

While many methods have been attempted to calculate the economic impacts of air pollution, fewer studies (Garbaccio 2000; Yang 2004) have incorporated the economic valuation into a integrated economic model with endogenous consumer demand and preference curves. Integration into this kind of model has the advantage of capturing the effects of adverse health outcomes, such as lost labor time, increased health spending, and population reduction through mortality, on other sectors in the economy. This is important because there are feedbacks from these outcomes that eventually effect emissions levels from sectors throughout the economy. By integrating the health effects of urban air pollution into the Emissions Prediction and Policy Analysis (EPPA) model, Yang *et al.* were able to capture the stock-flow nature of pollutants, and analyze how changes in pollution levels affect the health of the population over time.

This work expands on that conducted by Yang et al, which was concentrated solely on the United States. First of all, it more fully integrates the costs of health impacts into the EPPA model. This is accomplished through the creation of an internal health module, which takes information on pollutant levels, exposure-response functions, costs of health outcomes, and urban population in order to fully calculate the number of health impacts and their costs. It is structured to take into account some of the more difficult aspects of pollution stock-flow accounting, such as the cumulative effect of pollution levels on the population, as well as the effect of a premature death on the labor force in subsequent years. The new, tighter integration of these calculations allows for the eventual feedback of predicted future emissions levels, in order to calculate the resulting health and economic impacts. In turn, these affect the emissions levels in the next period. This leads to the ability to endogenously take into account the effect of health outcomes on the preferences of the population. It also makes it possible to predict future economic, health, and emission impacts.

This study also expands beyond the United States, to consider air pollution health effects for China. There are subtle differences required in the analysis, due to differences in the health care systems (use, costs, and availability), as well as the availability of data. China, while ahead of many developing nations in terms of data measurement and availability, still presents a challenge when compared to the United States and other developed nations. Much of the contribution of this work comes from the aggregation of a great deal of data that was widely scattered throughout a series of academic articles, databases, international organizations, government reports and studies. This information was then used in the creation of the revised EPPA model, EPPA-Health Effects-China, EPPA-HEC.

Finally, this study used the EPPA-HEC model to examine two issues. The first is the historical costs of urban air pollution to the Chinese economy. Through the comparison of a number of scenarios, including the actual historical pollution levels, the pollution levels recommended by the WHO, the attainment standards set out by the Chinese government, and an entire pollution-free scenario, this study is able to give values to the benefits of cleaner air. Additionally, the new, integrated structure created to discern the health costs of each pollutant allows for an environmental accounting analysis, which can tease out the details associated with each pollutant and health outcome, including the incidences of each outcome, overall costs, and effects on the economy.

The second set of analyses concentrate on quantifying benefits that arise in the future from a variety of environmental policies. China has been traditionally reluctant to engage in efforts to reduce its greenhouse gas emissions, which it views as being costly. China's official position has been that it sees the problem as being caused by developed countries, and that it is their responsibility to bear the costs of addressing the problem (Economy 2004). However, China could derive a significant benefit from greenhouse gas emission reduction, since reductions of this type would also have a corresponding effect on urban pollution concentration. EPPA-HEC allows for the analysis of these "co-benefits" of climate change policy, and quantifies some of the benefits of engaging in such actions. It also allows for analysis of the benefits of pollution control policies, and finally of the combination of greenhouse gas and air pollution policies. This information is especially important since the Kyoto Protocol, which China has ratified, has gone into effect, and negotiations over second round commitments have already begun. Results from this work show that pollution control can have a positive effect on economic growth, and evidence of this type may help to persuade China to undertake greenhouse gas mitigation. Overall, EPPA-HEC produces a host of important data, beyond just an overall cost or benefit estimate, for the evaluation of air pollution and greenhouse gas policies.

Chapter 2 of this study reviews the history of the development of environmental policy in China, as well as the international context of this policy. Chapter 3 details the methods used to conduct an analysis of the impact of the health effects of urban air pollution on the Chinese economy. It also outlines the historical and potential future policy scenarios that were analyzed. Chapter 4 reports the results of this analysis, and details the overall economic impacts from pollution-related health outcomes, including the past costs of pollution and the potential benefits of future pollution control policies. Finally, Chapter 5 presents concluding thoughts that result from an analysis of the results, and outlines potential directions for further work in this area.

Chapter 2: China's Environmental History and Policy

In discussions about the state of China's environment, there are several statistics that are popularly quoted. One is that spending a day breathing the air in Beijing "is the equivalent of smoking three packs of cigarettes" (Tempest 1994). In that same city, the smog from particulates, sulfur dioxide and vehicle emissions is so thick, that on some days, Beijing cannot be seen by satellites in orbit around the earth (McMullen 2001). Altogether, according to the World Bank, 16 of the 20 most polluted cities, in terms of air quality, are located in China (Johnson, *et al.* 1997). There are other, similar statistics regarding the state of China's forests, its water, and its land. Environmental issues are a significant policy issue, and as China continues along its path of nearly meteoric growth, the environmental costs of decades of economically driven behavior become more and more evident. While this has led to environmental problems, it has also led to a newfound awareness in China that it cannot afford to indefinitely ignore the environmental consequences that have accompanied its economic and population growth. There is pressure domestically and internationally for China to expand its efforts to address problems of environmental degradation.

Air pollution is an issue that gets a significant amount of attention. Domestically, the air quality in many urban areas has a serious negative impact on the quality of life of urban residents. According to the World Bank, cardiovascular and respiratory diseases related to air pollution have become a leading cause of death in many urban areas. Internationally, emissions from Chinese industry are transported beyond its borders, affecting air quality in neighboring countries in Asia, and have even been traced as far away as North America. In absolute terms, China has grown to be the second largest emitter of green house gases, and is predicted to surpass the United States before the middle of the century. China is also the world's largest producer and consumer of ozone depleting substances (World Bank. 2001), which are also greenhouse gases. The Chinese government has to contend with its own citizens, many of whom are justifiably concerned that the air that they breathe is causing them to become ill. They are also facing increasing pressure from members of the international community, which realizes that future attempts to address climate change must address the fact that China, along with other developing countries, will be significant sources of greenhouse gas emissions in the future, and no agreement can be successful without their inclusion and cooperation.

The growing environmental concern in China is a new phenomenon. Historically, China has been more concerned with economic growth and development. After World War II, during Mao's tenure in power, environmental issues were not addressed beyond some early water and soil protection measures that soon fell by the wayside. Mao's massive mobilization campaigns focused on achieving modernization. His programs stressed growth and development, including population growth, increased industrialization, rapid harvesting of natural resources, and projects, such as massive dam building projects that epitomized the triumph of humans over their natural surroundings. These campaigns had serious impacts for the environment. Both the Great Leap Forward and the Cultural Revolution resulted in serious environmental consequences, so that by 1976, the few early environmental regulations had been discarded, and levels of pollution were at historic highs (Economy 2004).

After Mao's death, China underwent a fundamental shift. Deng Xiaoping initiated a series of economic reforms that opened up the country both domestically and internationally. By the early 1980's, the national slogan had become "To get rich is glorious." The period of growth that has occurred since then has been impressive. The change to a market-driven economy has resulted in an average annual GDP increase of 9.6% between 1978 and 1998. During this period, developed countries recorded annual average GDP increases of 2.2-2.4%. The economic boom helped decrease the number of Chinese living in poverty from 260 million to 42 million, while the overall population increased to 1.27 billion people. Urbanization increased rapidly, growing by 10 million per year (an annual increase equivalent to the entire population of Greece). Officially, the urban population in 1998 was 400 million; other estimates place it closer to 455 million, with growth expected to continue (World Bank. 2001).

What does this mean for the Chinese individual? While growth has been uneven, concentrated in the south, on the eastern coast, and in cities, there are currently more than 200 million fewer people living in poverty than there were at the beginning of the reform period. The increase in incomes, combined with urbanization and the availability of new goods and services has led to large increases in consumption, especially in the case of energy. Electricity demand increased by 6-9% per annum during this period (Smil 1998). Since the 1980's, the Chinese government has been increasing generation capacity by up to 9% per year (Wang 2000). This is despite the fact that China's energy intensity (the ratio of real energy consumption to real GDP) has been decreasing steadily over the same period. In the 1980's and 1990's, the energy intensity declined 70% (Fisher-Vanden, *et al.* 2004).

The increase in electricity demand has led to an increase in polluting emissions from power plants. Despite several high-profile alternative energy projects, such as the Three Gorges Dam, most of this demand has been met through an increase in coal-powered energy generation. Overall, coal use doubled between 1980 and 1999, and its share of energy production increased from 72% to 76% (Johnson, *et al.* 1997). Even with shifts to other technologies, including natural gas, it is not expected to drop below 60% anytime before 2010 (Smil 1998). This is due, in large part, to the fact that China ranks third in the world in terms of coal reserves, while it ranks 23rd in natural gas reserves, with only 0.8% of the world total (Smil 1998).

While clean-burning coal technologies are used throughout the world, much of the coal used in China is burnt in old, inefficient industrial boilers, and most plants have insufficient coal cleaning capacity. Furthermore, the coal from the reserves in the south of China is especially high in sulfur, exacerbating the air pollution problems in that area of the country (Smil 1998).

As incomes and consumption have increased, a new phenomenon has arisen in many urban areas: the advent of the private automobile as a means of transport for the middle class. For decades, the world was presented with images of Chinese transport dominated by trains, pedestrians, and bicycles. It is only recently that automobile ownership has become a possibility for more than the smallest handful of the Chinese population. Growth in automobile use and ownership has been explosive. In the 1990's, the average annual growth rate for privately owned passenger vehicles was 33%; for motorcycles, the rate was 26% (World Bank. 2001). This has several impacts. The first is an increase in motor-vehicle traffic, which has led to an impressive program of highway construction in many cities. It has also led to a dramatic increase in combustion related emissions, including CO and NO_x. This effect is compounded by the fact that Chinese cars have much higher emissions levels than their counterparts in other nations. The average car in Beijing emits four times as much CO and seven times as much NO_x as the average car in Tokyo (World Bank. 2001).

Increases in emissions from energy production, industrial growth, and automobiles have negatively affected the quality of air in many Chinese cities. Poor air quality has in turn led to an increase in pollution-related illnesses. A World Bank study in 1997 estimated that if China met its own air quality standards (which are roughly analogous to World Health Organization recommended levels) for NO_x, SO_2 and PM_{10}, it would have avoided, among other adverse health outcomes, 6.77 million emergency room visits, 1.76 million cases of chronic bronchitis and 178,000 premature deaths. The estimated costs for all health costs related to urban air pollution was $20 billion dollars a year, or nearly 3% of the Chinese GDP for that year (Johnson, Liu *et al.* 1997).

The economic and social costs of growth-related environmental degradation have helped to shift the Chinese government's position on environmental issues. This has been evidenced both domestically and internationally, as China has strengthened its own, internal environmental protection apparatus while simultaneously becoming more actively engaged in international efforts, including the ratification of the Kyoto Protocol on Climate Change.

In the early 1970's, there was very little attention paid to environmental issues in China. The position of the Chinese government was articulated by its delegation to the first ever UN Environmental Conference, the 1972 UN Conference on the Human Environment (UNCHE). The delegation saw the issue as a conflict between the developing world and the superpowers. They put forth ten principles for inclusion in the conference's final declaration, the central one being the "right of developing countries to develop first and address the environmental challenges one by one (Economy 2004)."

The policy of concentrating on development over environment had considerable staying power in Chinese politics. Despite increasing environmental awareness during the period of economic reform, it continued to be frequently articulated by both the political leadership and the media well into the 1990's. A shift in this mentality began after the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro. At this conference, the Chinese delegation once again articulated positions similar to those it had twenty years earlier at UNCHE, and was seen by most as an inflexible obstructionist.

Economy (2004) asserts that at UNCED, China was exposed to several new concepts. The first was the idea of "sustainable development," which advocated the inclusion of environmental factors into development decisions while still recognizing the importance of economic growth. The second was the concept of market based environmental regulations, such as emissions trading, which differed from the costly command-and-control regulations that were traditionally disliked by the business community. The final concept was the importance of involvement by non-government actors in addressing environmental challenges. China was embarrassed to not have a single Chinese non-governmental organization (NGO) represented at the conference. It became clear that these organizations were important for the transfer of technology, knowledge, and capacity building, and that bilateral and international governmental linkages alone were insufficient. In 1993, China allowed the formation of its first NGO, the Friends of Nature, which opened up a new political space for public participation in environmental issues.

These new concepts in environmental governance resulted in changes to China's domestic environmental protection system. The essentially toothless (Alford 2001) Air Protection Prevention and Control Law (APPCL) was updated in 1995. In 1998, during a central governmental reorganization that saw many cabinet-level ministries demoted and combined, the National Environmental Protection Agency (NEPA) was actually promoted to a cabinet-level ministry, and renamed the State Environmental Protection Agency (SEPA).

This institutional reorganization helped change the tenor of both domestic and international environmental debates. Those in favor of increased environmental action had an increased voice within the government. The new structure made it possible for SEPA to turn proposals into legislation much more rapidly than in the past. For example, the APPCL was once again restructured in 2000 to address many of the shortfalls of the 1995 version. Many of these were the result of NEPA's relative lack of power, and dependence on other ministries for funding and political support (Alford 2001). Changes that SEPA, with its newly elevated status, were able to incorporate included actual pollution reduction targets and increased power for enforcement.

The promotion of NEPA to a cabinet-level agency also had an impact on the local environmental protection boards (EPB). Policy decisions and enforcement are highly decentralized, with national legislation often serving as guidelines, but with many particulars left to local decision makers. The EPB's are responsible for enforcement of policies, the setting of local pollution standards, investigation of environmental accidents and the mediation of environmental disputes. Their status within the local bureaucratic hierarchy has a significant impact on their ability to perform their role effectively (Jahiel 1998).

At both the national and local levels, administrative superiority rankings and financial control determine how agencies can wield authority. Government offices assigned a lower rank have no power to compel compliance from those ranked above it, or from those to which it is ranked equal. Rankings of agencies and bureaus at the local level are partly a reflection of the national rankings of the parent ministries and agencies. But rankings are also affected by the local perception of relative importance. Changes in status at the national level are important because they impact the authority and function of corresponding local agencies (Jahiel 1998).

The effectiveness of local EPB's is ultimately an important component of the success of any national environmental policy. From 1982 until the early 1990's, as counties began to first establish local EPB's, they were almost always placed beneath the local Construction Commission. This was a reflection of the fact that at the time, environmental issues were a part of the mandate of the Ministry of Urban Construction and Environmental Protection. The problem with this set-up was that the environmental apparatus was of relatively low-status, and had no authority to compel compliance from the higher-status construction and planning related bureaus, whose interests were centered on growth and development for industry. Local governments were reluctant to support activities that might harm their industries, and thus negatively affect the area's economy. This is especially true in many areas outside of large cities, where the major industries are often township-village enterprises (TVE) that are controlled by the local governments. In many cases, these TVE's are a major source of jobs and revenue, and thus power. A conflict of interest arises, and governments often act as facilitators for these industries, instead of acting as regulators (Jahiel 1998). It was very difficult for local EPB's, who were dependent on local governments for funding, to engage in enforcement of environmental standards.

The situation improved with national administrative changes that created NEPA, which, though not first-tier in the national bureaucracy, was at least an independent entity. The subsequent creation of SEPA was a signal to local bureaucracies that the environment should be one of their top priorities. This increased the authority of many local EPB's, augmenting their ability to effectively regulate pollution and respond to national mandates.

There were also changes to China's position in regards to international environmental commitments. In the late 1980's, China had resisted signing onto the Montreal Protocol for the control of ozone depleting substances (ODS). At the time, it had contributed only a small part to the problem. However, it was also estimated that by the beginning of the 20th century, China would be a leader in the production and use of ozone depleting substances, mostly refrigerants. China was induced to sign the Protocol in 1991 based on financial arguments. Signatories of the Protocol, which included most of China's major trading partners, were forbidden from purchasing products containing ODS, which would have a negative effect on sales from appliances manufactured in China. So when financial support and technology transfers from a multinational fund were finally offered, China assented and signed on to the Protocol (Economy 2004).

This process, which occurred in the early 1990's, was evidence of continued commitment to the concept of development first. This was also the case in the debates surrounding the Kyoto Protocol on Climate Change. Economy (2004) documents that throughout the 1990's, the Ministry of Foreign Affairs and the State Planning Agency (SPA) determined China's negotiating position. Their chief concerns were economic development and national sovereignty. They saw that participation in greenhouse gas emissions reduction could have a significant negative impact on the Chinese economy, as it would require a restructuring of industry and the energy sector in particular. Their position was that developed countries should clean up their own mess, and not turn to developing countries as a less expensive alternative solution. As such, China refused to accept any emissions targets or timetables. They also declared that they would not take part in joint implementation (JI) and clean development mechanism (CDM) projects that allowed developed nations to meet their targets through projects that reduced emissions or created emissions sinks in developing nations (Economy 2004; The Shaw Group 2005).

After the ascension of SEPA to ministerial status, new voices entered the climate change debate in China. A new group of politicians, concerned that China was missing important opportunities for technology transfer, international goodwill, and improved environmental conditions, experienced important improvements in their status. As a result, in 2002, at the UN World Summit on Sustainable Development in Johannesburg, the Chinese delegation announced that China had finally ratified the Kyoto Protocol. Instead of rejecting CDM projects, there are now several underway, including a leachate evaporator system on the Anding Landfill near Beijing (The Shaw Group 2005).

China's continued participation in international climate change agreements is crucial to the ultimate success of international greenhouse gas mitigation. When the United States declined to ratify the Kyoto Treaty in 2001, it cited the lack of emissions reduction targets for China and India as an element of its rationale. The current Kyoto agreement only goes until 2012, and negotiations for the next phase are already underway. Significant pressure is being placed on China by developed nations to adopt a more aggressive strategy in regards to emissions reductions.

Despite the increased status of environmental concerns, China is unlikely to agree unless it sees significant benefits for its population. While the past two decades of development have been striking, there are still large numbers of Chinese living in poverty. China has announced a new campaign to focus on the economic development of the less prosperous western provinces. Any international agreement that hampers progress in this effort has only a minimal chance of being accepted by the Chinese delegation. This is especially true for climate change, where the expected impacts are highly uncertain on a number of fronts, including the costs, the magnitude of the impacts, and the time frame in which they will occur.

While there is a new strength to environmental action, concern for Chinese growth and development is still strategically important. The demonstration of benefits, both economic and social, greatly increases the resiliency of a policy to the internal political process. This is the reason why the incorporation of health benefits into air pollution and climate change policy analysis has become an important area of research.

Since the involvement of China is imperative to the long-term success of climate change policies, it is important to elucidate not just the potential costs, but also the potential benefits of both air pollution control and greenhouse gas mitigation policies. In this regard, China's history of environmental neglect presents opportunities not available in more developed nations with a stronger history of environmental consciousness. In places such as the United States, many of the lower-cost options to reduce emissions of air pollutants have already been taken. This means that greenhouse gas policies may not have a huge impact on the level of other air pollutants. It also means that the imposition of stronger air pollution controls can be very costly. In China, however, many more low-cost, high-impact options still remain. In some cases, there is an added benefit that the same actions that will help reduce greenhouse gas emissions can also have a large impact on overall air quality.

For example, the use of more efficient, cleaner burning coal boilers would not only increase overall energy efficiency and reduce the greenhouse gas emissions per unit of coal burned, but there would also be reductions in other pollutants, such as NO_x, SO_2

and PM_{10} that pose serious health risks to the population. The same is true for shifts in the energy sector towards other options, such as natural gas, oil, and alternative technologies. Measures to promote energy conservation and efficiency will help to reduce energy costs, while at the same time decreasing emissions. Efforts to address the size, composition, and fuels used in the transportation fleet will also have an effect on these pollutants, as well as others, such as ozone and CO, that are becoming increasingly problematic. The creation of carbon sinks, through programs such reforestation to control dust storms, can also have a positive impact on the overall air quality.

There is a distinct possibility that while adherence to a program to reduce greenhouse gas emissions could have a significant cost when examined in the context of China's growth, there is also a possibility that the same policies have benefits that often go unaccounted for, such as the impact on health. Such green accounting, which takes environmental costs and benefits into account, is increasingly popular worldwide. SEPA is currently beginning a program to calculate a "Green GDP," which includes a valuation of the environmental costs of growth. And in the area of environmental policy, and especially for climate change, there have been significant efforts to quantify benefits of policies, as well as their interaction effects with other environmental policies. It is important to be able to quantify how domestic and international policies will interact to produce environmental and economic benefits.

As bargaining for the second commitment period of the Kyoto protocol commences, it is important that China and other developing nations understand the cost and benefit implications of participation in greenhouse gas mitigation agreements. In nations that are still trying to meet development goals, and where the provision of basic welfare and services remains an issue, it is important that the benefits of environmentally responsible action are well quantified and understood. For China, if adherence to carbon emissions standards will have a range of benefits, and pressure for action is not just an attempt by more developed nations to transfer the burden of the global warming problem to the developing world, then the chances of active participation are improved. While China's environmental history has not always been a positive one, it has realized the seriousness of the environmental challenges that it is facing, and its government has shown itself to be willing to give environmental issues a new level of priority.

Chapter 3: Methods

3.1 Introduction Outline of Methodology

Analyzing the economic impacts of pollution-related health outcomes on the overall economy has five main "steps." The basic methodology requires: (1) Identification of key pollutants and the health effects of them. (2) A set of epidemiological results that relate exposure to the health effect. (3) Relationships that translate the health effect to a change that we can model in the economy (labor, leisure, and demand for health services). (4) Development and benchmarking of the CGE model to make use of these data. (5) And, finally conducting counterfactual simulations of the Chinese economy based on different levels of pollution exposure of the population.

This chapter works through this methodology. It begins with the description of the economic framework used to simulate the Chinese economy over time with different levels of pollution exposure. Then it describes the data sets for the epidemiological relationships that relate pollution exposure to health effects. After this, the other necessary data inputs, including pollution levels, health care costs and demographics are presented. Finally, it describes the scenarios to be analyzed, both for analysis of the historical costs of China's urban air pollution, and for the potential future benefits of pollution control.

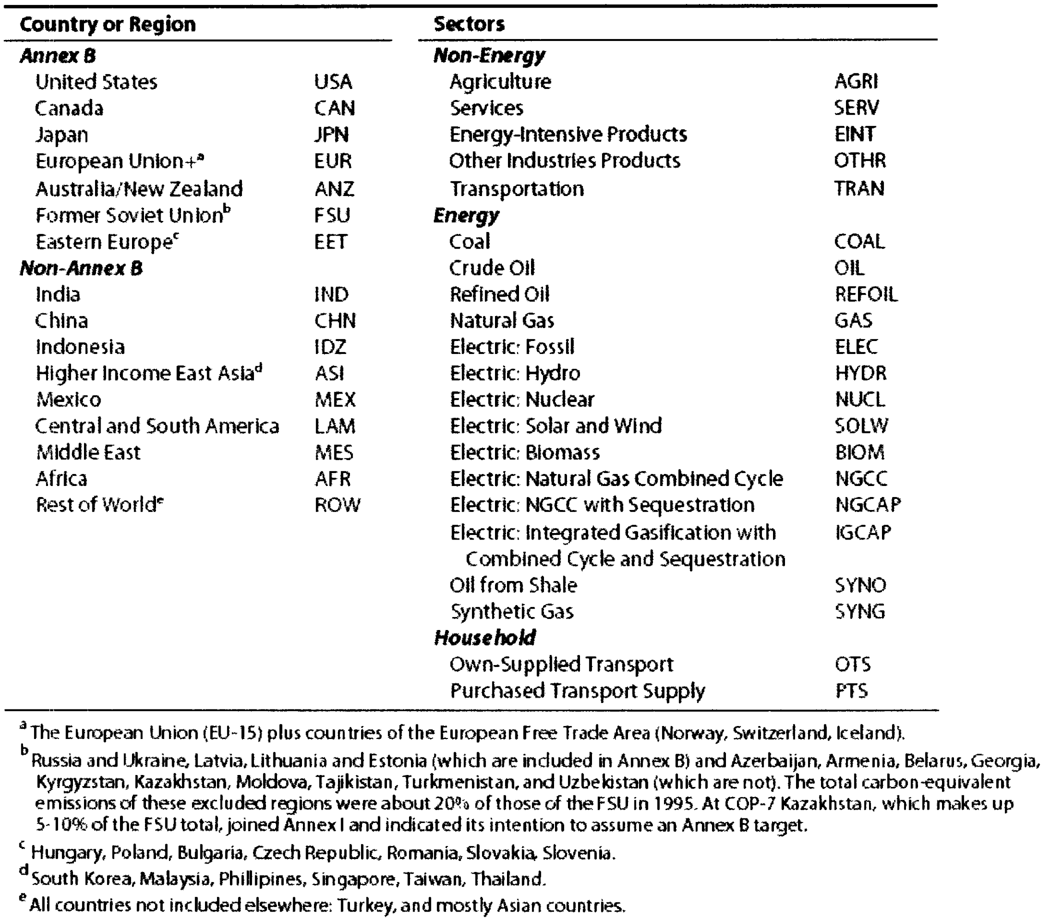
3.2 Economic Modeling Framework

In many studies, valuations of health impacts are done using point estimates of costs. These estimates attempt to take into account both the market and non-market effects of a health outcome, and they are derived from gross production/consumption loss or willingness to pay surveys. While this partial equilibrium approach is sound, it does not take into account the interactions that occur within the overall economy. The use of health services or the loss of labor time to deal with an illness has effects throughout the larger economy. A general equilibrium model, which takes into account the broader economic interactions, allows for the construction of a richer picture of the costs of urban air pollution.

MIT's Emissions Prediction Policy Analysis model (EPPA 4) is computable general equilibrium model that can be easily modified to include valuation of health impacts. EPPA 4 is a multi-region, multi-sectoral, recursive-dynamic model. It is frequently used for policy analyses, and has the advantage of being designed to simulate pollutant emissions based on economic growth. Ideally, the economic impacts resulting from the health impacts could be part of feedback loop, affecting the economy, and therefore the emission of pollutants, in future periods. EPPA is built on the 1997 GTAP dataset (B. Dimaranan 2002), with additional data for greenhouse gases and urban gas emissions (Mayer 2000). It models the consumption and production sectors as a series of nested constant elasticity of substitution (CES) production functions. It also includes Cobb-Douglas and Leontieff production functions. Both of these are just special cases of the CES. Overall, it includes 16 regions and 12 sectors (see Figure 1).

EPPA 4 performs predictive simulation with a base year of 1997. It solves recursively in five-year intervals starting with the year 2000. Typical simulations run from 25 to 100 years in length. EPPA 4 has been used for a variety of policy studies, including one of the McCain-Lieberman Proposal for greenhouse gas emissions trading

(Paltsev 2003). It differs from the previous version described in Babiker *et al.* (Babiker, Reilly *et al.* 2001) in that it has increased sectoral and regional disaggregation, integrates advanced technology options, is based on the updated GTAP 5 dataset, and includes a revision of projected economic growth and inventories of non-CO_2 greenhouse gases and urban pollutants.



Country or Region		Sectors	
Annex B		***Non-Energy***	
United States	USA	Agriculture	AGRI
Canada	CAN	Services	SERV
Japan	JPN	Energy-Intensive Products	EINT
European Union+[a]	EUR	Other Industries Products	OTHR
Australia/New Zealand	ANZ	Transportation	TRAN
Former Soviet Union[b]	FSU	***Energy***	
Eastern Europe[c]	EET	Coal	COAL
Non-Annex B		Crude Oil	OIL
India	IND	Refined Oil	REFOIL
China	CHN	Natural Gas	GAS
Indonesia	IDZ	Electric: Fossil	ELEC
Higher Income East Asia[d]	ASI	Electric: Hydro	HYDR
Mexico	MEX	Electric: Nuclear	NUCL
Central and South America	LAM	Electric: Solar and Wind	SOLW
Middle East	MES	Electric: Biomass	BIOM
Africa	AFR	Electric: Natural Gas Combined Cycle	NGCC
Rest of World[e]	ROW	Electric: NGCC with Sequestration	NGCAP
		Electric: Integrated Gasification with Combined Cycle and Sequestration	IGCAP
		Oil from Shale	SYNO
		Synthetic Gas	SYNG
		Household	
		Own-Supplied Transport	OTS
		Purchased Transport Supply	PTS

[a] The European Union (EU-15) plus countries of the European Free Trade Area (Norway, Switzerland, Iceland).

[b] Russia and Ukraine, Latvia, Lithuania and Estonia (which are included in Annex B) and Azerbaijan, Armenia, Belarus, Georgia, Kyrgyzstan, Kazakhstan, Moldova, Tajikistan, Turkmenistan, and Uzbekistan (which are not). The total carbon-equivalent emissions of these excluded regions were about 20% of those of the FSU in 1995. At COP-7 Kazakhstan, which makes up 5-10% of the FSU total, joined Annex I and indicated its intention to assume an Annex B target.

[c] Hungary, Poland, Bulgaria, Czech Republic, Romania, Slovakia, Slovenia.

[d] South Korea, Malaysia, Phillipines, Singapore, Taiwan, Thailand.

[e] All countries not included elsewhere: Turkey, and mostly Asian countries.

Figure 1 Sectors and Regions in EPPA 4

A version of EPPA 4, EPPA-HE, was modified to allow for health impact valuation in the United States, and was used to analyze the costs and benefits of the 1970 Clean Air Act (Yang 2004; Matus, Yang et al. 2005). Based on early work by Yang (Yang 2004), this involved the addition of household production to the social accounting matrix (SAM) and the inclusion of non-wage labor, or leisure. Household production provides "pollution health services," which allows for the capture of health effects, both morbidity and mortality. The result of this is a new sector, household healthcare (HH) that includes the production relationships for each of the pollutants. This new sector is Leontieff both with respect to each pollutant and with other goods and services. Leisure is added as a component of consumption, with an elasticity, σ_L that is parameterized at σ = 0.2. This value is based on a labor own-price supply, which is discussed in detail in Yang *et al.* (Yang 2004). The addition of household production to the SAM can be seen in Figure 2, and the addition of leisure and the HH sector can be seen in Figure 3.

	Production Sectors	***Household Production***	Final Consumption
Production Sectors	Input/Output ***Medical Services for Air Pollution***	Household Transportation ***Household Mitigation of Pollution Health Effects***	Goods and Services ***Pollution Health Service*** ***Leisure***
Factors	Labor, Capital, Resources	***Household Labor***	***Total Consumption = Total Factor Income***

Figure 2 Expanded SAM for EPPA-HE. Newly Added Components in Bold Italics

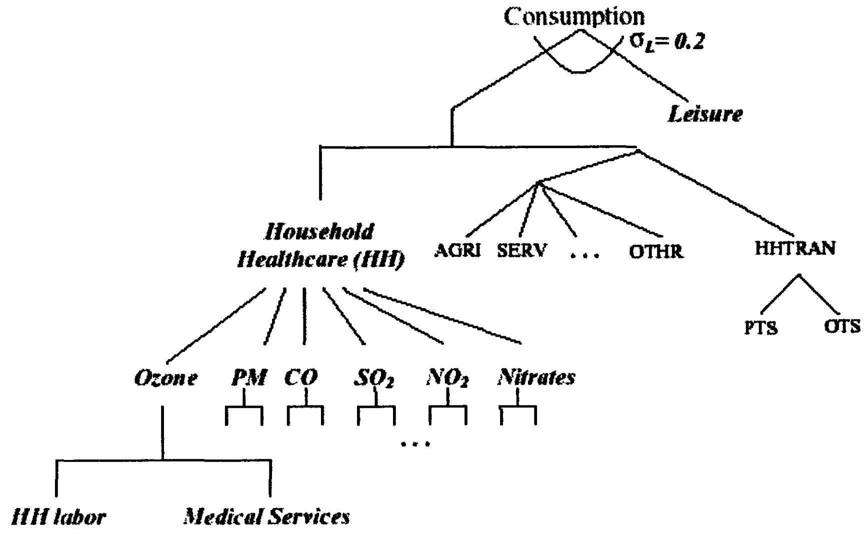


Figure 3 Household and Consumption Structure for EPPA-HE. New household activities inEPPA-HE are in bold italic. Pollutant labels (Ozone, PM, CO, SO_2, NO_2, Nitrates) are used as shorthand reference to health services used to combat various health effects from the pollutant.

EPPA-HE was also modified to have a base year of 1970, and then solve every five years. To accomplish this, the 1997 United States economy and population were scaled back by the total GDP growth between the new base year (1970) and 1997 to rebase the model to 1970. It was then simulated forward and benchmarked to historical real GDP and population growth in each period.

3.3 Expansion of EPPA-HE to Include Health Impacts

EPPA-HE was further developed for this study in order to fully integrate the valuation of the health endpoints into the model. The model retains the structure of EPPA-HE, but includes the internal calculation of the incidence and overall costs of each health outcome. This required the addition of two calculation modules, the Morbidity module and the Chronic Mortality module.

The Morbidity module is used to calculate the service, labor and leisure costs of all health endpoints except for chronic mortality due to particulate exposure. The calculations performed by this model are mathematically simple, but they generate a wealth of information. In each time period, for each pollutant, it calculates the number of cases of every health outcome, given a pollution level and the number of people exposed. Once the number of cases is known, it then calculates the cost. The cost for dealing with any health endpoint is a combination of three factors: health service inputs, lost labor, and leisure time needed to deal with the illness. The Morbidity module calculates changes in the quantity of the service input, labor and leisure. It then totals them over endpoints and pollutants. Changes in labor and leisure are then passed to the model as a change in the total amount of labor supply in the economy. The total labor supply, and changes in it, are allocated between labor and leisure depending on the specification of the labor supply elasticity and changes in the endogenously modeled wage rate. Greater (or fewer) medical service needs are treated as a reduction (increase) in the productivity of the HH sector. For example, a 5 percent increase in health service needs, is modeled as a 5 percent reduction in the productivity of the HH sector, and thus the demand for health services increases by 5 percent. Introducing these changes as shocks in the general equilibrium model makes it possible to capture the interactions that occur between the sectors. For all non-fatal health outcomes, the following calculation for the total of the inputs for each health outcome (*h*) in year *y* was used:

$$Input_{h,y} = \sum_p (ER)_{h,p} * C_{p,y} * Up_y$$

Equation 1

where $ER_{h,p}$ is the exposure-response factor specific to each health outcome and pollutant (p), $C_{p,y}$ is the annual urban concentration of each pollutant in year y, and Up_y is the urban population in year y. The service, labor, and leisure inputs were determined by multiplying the total inputs for each health outcome by the service, labor, and leisure percentages, respectively. Finally, the total inputs in each year was simply the sum of all of the health outcomes for that year:

$$TotalInput_y = \sum_h Cost_{h,y} .$$

Equation 2

The calculation for acute mortality (*AM*) differs only in that the E-R function is expressed as an increase in the mortality rate, so the calculation is for number of cases, so that

$$Cases_{AM} = \sum_p ER_{AM,p} * C_{p,y} * M * Up_y ,$$

Equation 3

where $ER_{AM,p}$ is the exposure-response function by pollutant for acute mortality, and M is the overall mortality rate for the population.

The Chronic Mortality module is of a similar nature to the morbidity module, except that it deals solely with the number of lives lost due to long-term particulate exposure. There is evidence, discussed in more detail later, that particulate exposure has a cumulative effect. Thus the likelihood that an individual will succumb to particulate related illness depends on their average exposure over their lifetime. The chronic mortality module keeps track of the lifetime exposure of each age cohort. Additionally, the premature deaths from chronic exposure have an effect beyond the immediate time period in which they occur. When an individual dies at 40 years of age, assuming that the retirement age is 65, then the economy loses 25 years worth of labor from this individual. The chronic mortality module is also able to track deaths in each period, and propagate them forward until the point where they no longer represent a loss to the economy (the year in which the individual would no longer have been part of the workforce). It also performs a similar calculation for the amount of leisure lost, assuming that the individual would have only leisure time in the period after they left the workforce and before they died. In this case, average life expectancy is 75 years of age, and it is assumed that there is no lost leisure beyond this point.

In order to keep track of chronic exposure and chronic mortality, which is age dependent, the population was divided into eight age cohorts: 0-4 years, 5-14 years, 15-29 years, 30-44 year, 45-59 years, 60-69 years, 70-75 years and 80+ years. For each year, the model can calculate the average lifetime exposure of each age cohort, and then the chronic mortalities for each age cohort can be calculated accordingly.

For each year, the number of new chronic mortalities incurred is calculated by age cohort (*g*) as follows:

$$Cases_{CM,y,g} = \sum_{PM} ER_{PM} * Up_{y,g} * M_{CP} * EX_{g},$$

Equation 4

where ER_{PM} is the exposure-response function for PM_{10} (expressed as a percentage increase in the cardio-pulmonary death rate), $UP_{y,g}$ is the urban population in year y for each age cohort, M_{CP} is the cardio-pulmonary death rate, and EX_g is the average cumulative lifetime PM_{10} exposure for each cohort.

Then, for each cohort, a summation of chronic mortalities experienced in all previous years is taken, in order to get the full effect of past mortalities as a loss of available labor in the economy. This requires not just an accounting of total premature deaths, but also a calculation of how much labor is lost for each of those deaths. Because labor productivity increases over time, the value of lost labor also increases over time. So if an individual dies five years before they would have left the workforce, they economy loses not only those five years of labor, but also extra labor that would have been available due to productivity increases. For example, if labor productivity increased by 50% for each of those five years, the total labor lost would have been just over 13 years (1 + 1.5 + 2.25 + 3.375 + 5.0625). In order to take into account changes in labor productivity, each past death is multiplied by the changes in labor productivity for each year since the death. This captures the overall labor lost due to premature death. Then the total sum of deaths across all cohorts is subtracted from available labor in the main model.

Both the Morbidity and the Chronic Mortality modules solve every year, as a preprocessing step before the main model runs. The data is then passed into the main processing step of EPPA-HE. The model still uses 1970 as a base year and solves every five years until 2000.

A specialized version of EPPA-HE, EPPA-HEC (EPPA- Health Effects China), was created to allow for analysis of health impacts in China. For EPPA-HEC, the Chinese economy and population has also been historically benchmarked in the same manner used for the United States in EPPA-HE. It is also similar to EPPA-HE in that it can be used to investigate the effects of six pollutants- ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrous oxides ($NO_{x)}$, nitrates, and particulates of 10 microns or less (PM_{10}). These six are known as the "criteria pollutants," so named because the United States EPA sets acceptable concentration limits for the six based on health impact criteria. EPPA-HEC also includes demographic, pollution, and health data specific to China.

3.4 Data and Inputs

The EPPA-HEC model requires several important data inputs in order to perform the health calculations. These are the health endpoints of concern, the exposure-response functions for each health endpoint and pollutant, the historical (and predicted) pollution levels, the costs associated with each endpoint, and demographic information for each region being studied.

3.4.1 Health Endpoints and Exposure-Response Functions

The relationship between various pollutants and associated health outcomes has been documented extensively in the epidemiological literature (Dockery, Pope et al. 1993; Pope, Thun et al. 1995; Holland 1998; Kunzli, Kaiser et al. 2000; Zhang, Song et al. 2000; Peng, Wu et al. 2002; Zhang, Hu et al. 2002; Venners, Wang et al. 2003; Aunan and Pan 2004; Chen, Hong et al. 2004; Pope, Burnett et al. 2004). In 1997, a report from the Science Research and Development wing of the European Commission compiled the strongest of the data as part of its study of the externalities of energy, ExternE (Holland 1998). The ExternE compilation focused on the data available for Europe, and when there were no European-specific studies, the authors adjusted results from other nations, mostly the United States, to reflect differences in the populations. The goal of this study was not to just choose the best exposure-response (E-R) functions out of the available literature. It was, instead, to choose for those pollutants and endpoints where a causal relationship (as opposed to just an association) is indicated, a set of functions that are reliable when taken as a whole.

The comprehensiveness of the ExternE report lends itself well to the type of analysis done first by Yang *et al.* for the United States, as well as for China. Estimated exposure-response functions differ across studies and across populations. There are not enough broad population studies in China to produce a similar set of functions covering a large range of outcomes and pollutants. A survey of the available epidemiological studies for pollutant health impacts in China indicates that the coefficients may be lower in China. One possible explanation is that the exposure-response relationship may be less steep as exposure increases. Another explanation is confounding with indoor air pollution exposure, which is indicated in several studies. This kind of misclassification of exposure will often result in lowered coefficients (Aunan and Pan 2004).

There are other reasons why these functions differ across populations. One important one is confounding factors. For example, in China, both tobacco use and indoor air pollution are significant health factors, and could effect the calculation of coefficients. Also, it is common to perform these kinds of epidemiological studies for specific groups, such as children or asthmatics. These studies have found that exposure-response functions do vary for different segments of the population. So the overall averages for any population could vary from region to region based on the specific make-up of each population, such as its age distribution and percentage of asthmatics. Finally, the Chinese studies are very local, usually in one city or region; converting these results to the entire nation could be as problematic as applying results from other countries. For China, there are not any multi-city studies such as those done by Dockery and Pope in the Six Cities Study (Dockery, Pope et al. 1993). It is likely that in a nation as large as China, there is as much internal variation between cities and regions as there is external variation between nations.

For the sake of consistency, this study followed the procedure used by Yang *et al.* which was to use the ExternE exposure-response functions reported in Holland *et al.* 1998 with only one adjustment. We replace the results for chronic mortality from PM with the more recent work of Pope, *et al.*, 2004 because there were errors discovered in the original Pope *et a.l* 1995 study. The advantage to this approach is consistency of comparison across regions and studies, since they all examine the same set of health endpoints.

The ExternE study is also divided into two sets of impacts (Holland, *et al.* 1998). The first set is health impacts for which the epidemiological data indicates a solid causal relationship between the pollutant and the health outcome. The other set is the health impacts for which the causal relationship is less certain. The second set is most useful in sensitivity studies, to help establish an upper bound of economic impacts. These impacts are not considered in this analysis, due to the high level of uncertainty associated with their exposure-response functions. However, previous work (Matus *et al.* 2005) has shown that these impacts can have significant additional economic impacts. In both sets of impacts, many of the endpoints are also population specific in that they affect children or the elderly differently than adults. There are also some endpoints and E-R functions specific to asthmatics. This group is especially vulnerable to respiratory ailments, and airborne pollutants will affect them differently than the general population. The health endpoints by pollutant and affected population group, along with the associated E-R factors, are listed in Table 1 and Table 2. All of the E-R factors for non-fatal outcomes are reported as the number of cases due to exposure to $\mu g/m^3$ ambient levels of the pollutant per year. Impacts that result in mortality are reported as the change in the annual mortality rate due to exposure to $\mu g/m^3$ per year.

For EPPA-HEC, the assumption was made that the E-R functions are linear with no threshold, and that they are independent. There are indications that some of the health effects may be a result of multi-pollutant exposure. However, that possibility is not taken into account in this study.

Pollutant	*SO2*		
Outcome	*Affected Population*	*ER Factor*	*Source*
Respiratory Hospital Admissions	All	2.04E-06	Ponce de Leon 1996
Acute Mortality	All	0.072%	Anderson et al 1996, Touloumi et al 1996

Pollutant	*NO2*		
Outcome	*Affected Population*	*ER Factor*	*Source*
Respiratory Hospital Admissions	All	1.40E-06	Ponce de Leon 1996

Pollutant	*PM10*		
Outcome	*Affected Population*	*ER Factor*	*Source*
Respiratory Hospital Admissions	All	2.07E-06	Dab et al 1996
Cerebrovascular Hospital Admissions	All	5.04E-06	Wordley et al 1997
Acute Mortality	All	0.040%	Spix and Wichmann 1996, Verhoeff et al 1996
Chronic Bronchitis	Adults	4.90E-05	Abbey et al, 1995
Chronic Bronchitis	Children	1.61E-03	Dockery et al 1989
Chronic Cough	Children	2.07E-03	Dockery et al 1990
Restricted Activity Day	Adults	2.50E-02	Ostro, 1987
Congestive Heart Failure	Elderly	1.85E-05	Schwartz and Morris, 1995
Bronchodilator Use	Adults, Asthmatics	1.63E-01	Dusseldrop et al 1995
Bronchodilator Use	Children, Asthmatics	7.80E-02	Roemer et al, 1993
Cough	Adults, Asthmatics	1.68E-01	Dusseldrop et al 1995
Cough	Children, Asthmatics	1.33E-01	Pope and Dockery, 1992
Wheeze	Adults, Asthmatics	6.10E-02	Dusseldrop et al 1995
Wheeze	Children, Asthmatics	1.03E-01	Roemer et al, 1993
Chronic Mortality	Adults	0.25%	Pope et al 2002

Pollutant	*O3*		
Outcome	*Affected Population*	*ER Factor*	*Source*
Respiratory Hospital Admissions	All	7.09E-06	Ponce de Leon 1996
Symptom Days	All	3.30E-02	Krupnik et al, 1990
Acute Mortality	All	0.059%	Anderson et al, 1996; Touloumi et al, 1996; Sunyer et al, 1996
Minor Restricted Activity Day	Adults	9.76E-03	Ostro and Rothschild, 1989
Asthma Attack	All Asthmatics	4.29E-03	Whittemore and Korn, 1980

Pollutant	*CO*		
Outcome	*Affected Population*	*ER Factor*	*Source*
Congestive Heart Failure	Elderly	5.55E-07	Schwartz and Morris, 1995

Table 1 Extern-E Health Outcomes; ER Factors are in #cases per μg/m^3 increase for morbidity outcomes, and % increase in mortality rate for all mortality outcomes.

Source: Adapted from Holland *et al.*, 1998.

Pollutant	**SO2**		
Outcome	**Affected Population**	**ER Factor**	**Source**
ER Visit for Chronic Obstructive Pulmonary Disease	All	1.200E-05	Sunyer et al, 1993
ER Visit for Asthma	All Asthmatics	1.080E-05	

Pollutant	**PM10**		
Outcome	**Affected Population**	**ER Factor**	**Source**
Ischaemic Heart Disease	Elderly	1.75E-05	Schwartz and Morris, 1995
ER Visit for Chronic Obstructive Pulmonary Disease	All	7.20E-06	Sunyer et al, 1993
ER Visit for Asthma	All Asthmatics	6.45E-06	Schwartz, 1993

Pollutant	**O3**		
Outcome	**Affected Population**	**ER Factor**	**Source**
ER Visit for Asthma	All Asthmatics	1.32E-05	Cody,1992; Bates, 1992

Pollutant	**CO**		
Outcome	**Affected Population**	**ER Factor**	**Source**
Ischaemic Heart Disease	Elderly	4.17E-07	Schwartz and Morris, 1995

Table 2 Extern-E Health Outcomes for Sensitivity Analysis Only; ER Factors are in #cases per μg/m^3 increase for morbidity outcomes, and % increase in mortality rate for all mortality outcomes.

Source: Adapted from Holland *et al.*, 1998.

3.4.2 Historical and Predicted Pollution Levels

While the E-R functions are an important part of the calculation of the health impacts on a population, the magnitude of the impact is also directly related to the population's exposure to the pollutants. Thus determining the ambient concentration of each pollutant for each time period is a key step in the analysis. This exercise is not too onerous in places like the United States and the European Union, which have extensive and long-standing monitoring programs for criteria pollutants. However, developing nations such as China present a greater challenge.

In China, monitoring efforts are relatively recent. Some cities began monitoring around 1980 and 1981, when the first provisional Environmental Protection Law went into affect. However, it was not until the 1990's that a general monitoring program was implemented for cities nation-wide. Furthermore, unlike the United States, which tracks levels of all six criteria pollutants, China only engages in systematic monitoring of SO_2, NO_x and TSP (total suspended particulates, which can be used to estimate PM_{10} levels). There are no comprehensive time series available for CO and O_3; and the little data available is from single city studies ranging from a few months to several years.

Two strategies were used to deal with the paucity of available data on historical pollution levels in China. The first was to limit the main analysis to the three pollutants for which time-series data was available- of SO_2, NO_x and PM_{10} . The other three- CO, O_3 and nitrates were set to the levels recommended in the WHO air quality guidelines (Europe 2000). Sensitivity studies were performed with the levels of these three set to natural background levels (no pollution), as well as to values reported from single city studies.

The second strategy was to make a simplifying assumption in order to deal with the lack of any particulate data before 1980. The study assumes that at the end of World War II there was only a minimal background level of particulate matter in the cities. From 1950 until 1980, the particulate levels increase linearly until they reach the measured levels at the beginning of the time series. While the reality was certainly more complicated, this assumption is reasonable for several reasons. First of all, until the late 1970's, China underwent very slow growth, with a focus on agriculture as opposed to industry. Secondly, urban populations actually decreased during some parts of this period, so the growth in particulate levels would have been gradual, especially in the early years of the People's Republic and during the Cultural Revolution. Finally, the importance of having a long time series of historical data available for PM is due to the fact that the Chronic Mortality associated to particulate matter is related to average lifetime exposure. Thus, in order to calculate the increase in mortality for any age cohort in a given year, we need to know what their lifetime exposure has been. The linear assumption allows a decent first-order approximation for lifetime average exposure for that part of the population born before 1970 and exposed through the study period.

The time series data available for China's three regulated pollutants, TSP, NO_x and SO_2, was the annual average measured concentration by city. Most cities were missing measurements in at least one year; many smaller cities had no measurements prior to 1991. In order to deal with the large quantities of missing data, several criteria were established. Only cities of more than 1,000,000 inhabitants were included, since these were the only locations where measurements dated back to 1981. Any city missing four or more measurements, or more than two consecutive measurements was also eliminated. The remaining missing data was filled in by linearly approximating given the values for the year before and after the missing measurement. Finally, an annual average was calculated by taking the weighted average (weighted by population) of the cities for which data was available. This method was developed in order to minimize large fluctuations in the average that occur because of flaws in the data set (such as a missing measurement from a large, highly polluted city for one year), as opposed to fluctuations that are the result of real trends in the measured concentration levels.

3.4.3 Future Concentrations

The prediction of future concentrations of pollutants also presents a methodological challenge. EPPA-HEC calculates urban emissions for each time period, but these are not converted to concentrations. For some pollutants, such as ozone, the relationship between emissions and concentrations are very complex, since the pollutant is the result of secondary reactions in the atmosphere. In order to be done effectively, the calculations require a fully integrated urban model that can properly allocate regional emissions to urban areas, and then perform a series of calculations based on known chemical interactions in order to arrive at annual mean concentrations. At this time, EPPA does not include such an urban model, so a different method of calculating future urban concentrations was required.

First, in order to simplify the analysis, only PM_{10} concentrations are be taken into account for predictive scenarios. Since historical analyses (Yang 2004; Yang, *et al.* 2004) have shown that particulates account for by far the largest share of pollution-related health costs, an analysis of particulate health effects will give an effective lower bound on the potential future benefits of policies.

The first step was to look at a three-dimensional interactive aerosol-climate model, which provided black carbon (BC) mean annual concentration with 2.8° x 2.8° resolution (Wang 2004). Wang has shown that this model correctly replicates BC concentrations to within a factor of two when compared with observed data; the difference between the model and observation can be as high as a factor of 10 for areas with BC levels similar to those measured in many Chinese cities (Wang 2004; Yu, *et al.*

2004). The use of this model allows for the calculation of a zonal average concentration for the entire China region. The 3D model provided a zonal annual mean for 1995, which is the base year for the pollution calculations.

The next step is to calculate how this zonal mean changes as a result of emissions changes. Future scenarios run through the IGSM provide output for concentrations by longitudinal band. The zonal BC mean from the 3D model was indexed to the BC and SO_2 concentrations reported in the appropriate zonal bands. As the longitudinal values changed over time, the zonal BC carbon was adjusted proportionally. This creates a future pollution path.

All of the calculations so far involved adjustment of BC. But BC is only one element of particulate matter. There are two possibilities for the calculation of the actual urban particulate concentrations. The first is to do a direct conversion between BC and particulates, using studies that calculate the BC content of particulates in Chinese cities, as well as the relationship between concentrations of $PM_{2.5}$ and PM_{10} in these studies. With these values, BC concentration can be converted to PM_{10} concentration. However, these studies show that particulate composition differs by city. The BC content in Beijing ranged from 7-8% (He, *et al.* 2001), while in Shanghai the range was 10-12% (Ye, *et al.* 2003). Local variations in particulate composition make this calculation much more complex; furthermore, the data is only available for a few studies, and there is no data on what the composition ranges are on a national scale.

Since the desired value is a national annual mean, the second option is to treat the BC concentrations as an index. This assumes that the general composition on particulates on a national scale remains constant, and that any change in BC concentration results in a corresponding, proportional change in the PM_{10} levels. Future concentration levels are obtained by multiplying the 1995 base-year observation by the BC index. This approach makes similar assumptions to the direct calculation methods, but avoids difficulties presented by local differences in particulate composition. In the end, it produces a concentration path for each scenario.

Ultimately, the best way to approach the question of urban concentrations of pollutants for future scenarios is to construct a more complex urban chemistry model that can be integrated into EPPA, and can convert emissions into concentrations. This is a complicated endeavor that includes detailed demographic, spatial modeling, as well as complex climate and chemical interactions, and was thus beyond the scope of this work.

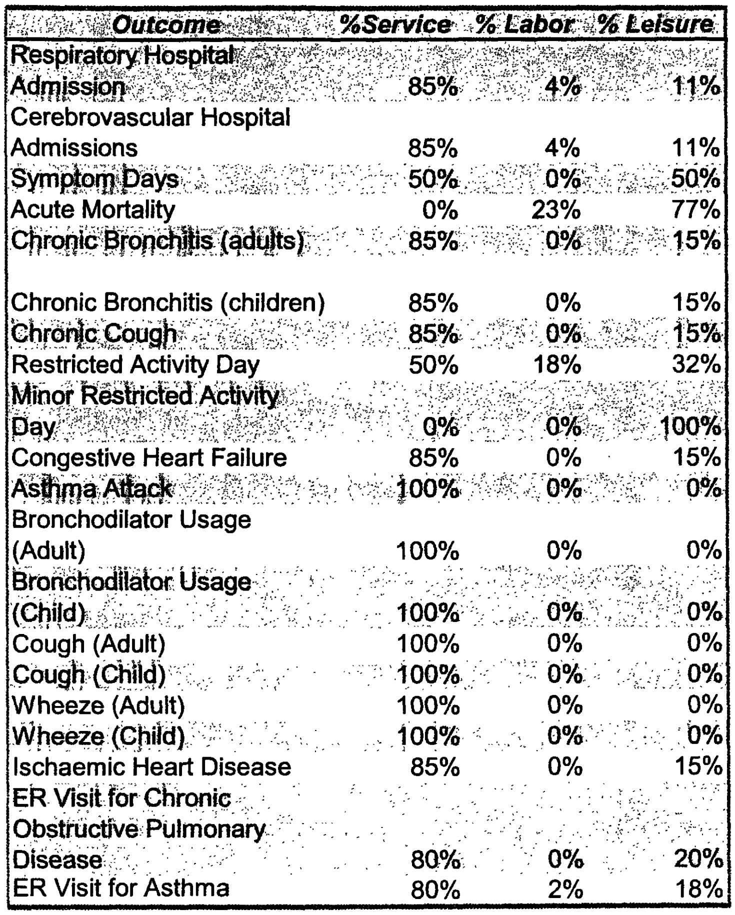
3.4.4 Health Care Costs and Utilization

Another challenge comes from the need to associate a demand for health services to each health endpoint. In this case, data from the ExternE study would not be appropriate, due to the very large differences between the European and Chinese health care systems. A World Bank study in 1997 calculated the costs of the endpoints using a willingness-to-pay, as well as a human-capital approach. The willingness-to-pay approach has become the more popular of the two methods. This method uses surveys and market data to determine what people are willing to pay to avoid injury or death. The human-capital approach only looks at the productivity and wages lost when an individual dies or is incapacitated. The debate over which is the more appropriate measure is especially acute in the case of putting a value on human life.

In this case, the values for morbidity (non-fatal) outcomes are the same for all endpoints except for chronic bronchitis (see Table 3). For chronic bronchitis, we chose the human-capital approach as being the most consistent with our analysis. For acute mortality, the deaths not attributable to chronic exposure, it is assumed that the individuals would have died within that period, with no loss of wages or productivity, so the associated costs stem from any medical services that they were provided. After taking these numbers, we assumed that the cost of any different outcome is the sum of three underlying factors- the cost of medical services, the cost from lost labor time, and the cost from lost leisure time to deal with the illness and procure health services. The breakdown differs between outcomes (see Table 4). Some outcomes, such as bronchitis, require a combination of medical services, labor and leisure. Others, such as cough or restricted activity day do not incur a service cost, but do result in lost labor and leisure.

Outcome	Cost (1997 $USD)
Respiratory Hospital Admission	284
Cerebrovascular Hospital Admissions	284
Symptom Days	0.6
Acute Mortality	60000
Chronic Bronchitis (adults)	8000
Chronic Bronchitis (children)	13
Chronic Cough	0.6
Restricted Activity Day	2.32
Minor Restricted Activity Day	0.6
Congestive Heart Failure	284
Asthma Attack	4
Bronchodilator Usage (Adult)	0
Bronchodilator Usage (Child)	0
Cough (Adult)	0.6
Cough (Child)	0.6
Wheeze (Adult)	0.6
Wheeze (Child)	0.6
Ischaemic Heart Disease	284
ER Visit for Chronic Obstructive Pulmonary Disease	23
ER Visit for Asthma	23

Table 3 Cost of Health Outcomes (1997 $USD)



Outcome	%Service	% Labor	% Leisure
Respiratory Hospital Admission	85%	4%	11%
Cerebrovascular Hospital Admissions	85%	4%	11%
Symptom Days	50%	0%	50%
Acute Mortality	0%	23%	77%
Chronic Bronchitis (adults)	85%	0%	15%
Chronic Bronchitis (children)	85%	0%	15%
Chronic Cough	85%	0%	15%
Restricted Activity Day	50%	18%	32%
Minor Restricted Activity Day	0%	0%	100%
Congestive Heart Failure	85%	0%	15%
Asthma Attack	100%	0%	0%
Bronchodilator Usage (Adult)	100%	0%	0%
Bronchodilator Usage (Child)	100%	0%	0%
Cough (Adult)	100%	0%	0%
Cough (Child)	100%	0%	0%
Wheeze (Adult)	100%	0%	0%
Wheeze (Child)	100%	0%	0%
Ischaemic Heart Disease	85%	0%	15%
ER Visit for Chronic Obstructive Pulmonary Disease	80%	0%	20%
ER Visit for Asthma	80%	2%	18%

Table 4 Service, Labor and Leisure Breakdown by Health Outcome

One important detail is the pattern of utilization of health services in China. Only a part of the population has any sort of health insurance, and for many, medical care is very expensive compared to their income. China's most recent healthcare study found that in urban areas, people sought medical care in only 50% of illness, relying instead upon traditional or other remedies, or leaving their conditions uncared for (Ministry of

Health 1999). For this reason, the overall service cost in each period is decreased by 50% to reflect the reality of the Chinese healthcare system.

For chronic mortality, each death is subtracted from the labor force, not just for that year, but for all of the years that the individual would have worked. The loss is reflected in EPPA-HEC as a reduction in productivity. EPPA models productivity as labor-augmenting and so changes in productivity and the labor force size are equivalent (Babiker et al., 2001). The overall result of the death is not just a loss of wages and productivity, but changes in consumption of goods and the availability of leisure time. In order to quantify the amount of leisure lost, the average wage rate is used to measure the quantity of lost labor in dollar terms. Leisure is valued at the wage rate, on the assumption that people equate the value of their leisure at the margin with the labor wage (Yang 2004). The loss of labor and leisure affects demand throughout the economy. Without putting an explicit value on each life lost, it is possible to see how the deaths change a nation's economic trajectory.

3.4.5 Demographics

To evaluate the epidemiological consequences of urban air pollution, it is necessary to know the number of people exposed. In the case of this analysis, we were interested in several population groups. The most important of these is the overall size of the urban population. This is the group at risk, and on whom the urban air pollution has an effect. Within this group, it is also important to know the breakdown of the population into age cohorts. Air pollution affects children, adults and the elderly differently, so a thorough analysis requires knowledge of all three groups. The population in each age cohort is also important for the Chronic Mortality Module, which tracks each group's lifetime exposure to particulate matter. The final set of demographic data required is the overall mortality rate, and the mortality rate by cause. This is because acute mortality E-R function is represented as a percentage increase in the overall mortality rate, and the chronic mortality E-R function is represented as a percentage increase in the death rate from cardiopulmonary causes. Ideally, the cardiopulmonary death rate would be available for each age cohort, since the cardiopulmonary death rate has a large variation by age group, which would have an impact on the number of chronic mortalities present in each age cohort.

This study uses data from the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, the United Nations Statistics Division, and the China Statistical Yearbook (Republic of China Zhu ji chu. 2001), (United Nations Statistical Office 2004) . Future estimates of population and urbanization are taken from United Nations estimates (United Nations. Dept. for Economic and Social Information and Policy Analysis. and United Nations. Dept. of International Economic and Social Affairs. 2002). While Chinese data is often unreliable, we judged that the sources used provided reasonable estimates for our purposes.

3.5 Evaluating Policy: Historical Scenarios and Sensitivities

The first phase of this research focused on the effects of the known, historical levels of urban air pollution. For the historical evaluations, the simulations were run using only historical data, and employed the assumptions discussed above for those pollutants for which no data was available. The historical period considered was 1970-

2000, but the period from 1980-2000 was of the most interest. This is because China's current policy track, both economic and environmental, dates largely to the late 1970's. First, the model was benchmarked to the actual economic data given the health effects estimated due to the actual level of pollution. It is then possible to estimate counterfactual cases: how much larger would the Chinese economy have been if the pollution levels had been lower.

The benchmarking scenario, *Historical,* uses the actual measured historical data where available. For those pollutants that had no widely recorded time-series data available (CO and O_3), it was assumed that ambient concentrations were at WHO guideline levels. By comparing the results with the other two scenarios, some evaluation can be made about the effects of actual urban air pollution on the Chinese economy. It also allows for analysis of current policies.

In order to evaluate the effects of past Chinese air policy, it is necessary to construct a set of policy scenarios. In this case, the analysis involved two counterfactual scenarios, each based on a basic set of assumptions. These scenarios were named *Green,* and *WHO.*

The first counterfactual scenario, *Green*, assumes perfectly clean air, with pollutants only at ambient background levels. Setting the levels of all pollutants to 1% of historical values achieves this purpose; all of the pollutants of interest have natural ambient levels in this range (Yang 2004). The *Green* scenario assumes that the dose-response relationship is linear, so that 1% of the pollution will result in 1% of the health effects, and also 1% of the costs when compared with the historical case. The number of chronic mortalities is adjusted downward to 1% of historical levels as well. The adjusted pollutant and mortality values are fed into the model in order to arrive at the values reported for the *Green* scenario. Since pollution has an overall cost to the economy, we expect that values for GNP-E and welfare to be highest in this case.

The second counterfactual scenario, *WHO*, is based on the assumption that pollutant levels increased from ambient levels in 1950 and reached *WHO* recommended thresholds in 1970, at which point they remained stable until 2000. This scenario allows for two analyses. The first is the cost to the Chinese economy of excess pollution, above these guidelines. The second is the total amount of damage that the Chinese economy incurred from air pollution for the years 1970 to 2000.

These three scenarios can be run for all pollutants, or can be run in combinations in order to determine the contributions of each pollutant to the overall impacts. For example, by setting SO_2 to historical levels, and all other pollutants to the *Green* scenario, we can calculate the costs to the economy of historical SO_2 pollution by comparing this hybrid scenario to the totally *Green* scenario. This helps to isolate not only which pollutants do the most damage, but also which health endpoints should be of the most concern. For example, are pollutants that cause low-cost but wide-spread health effects more costly than pollutants that cause high-cost health effects that affect a much smaller portion of the population? If the relative effects of each pollutant can be determined, it helps future policy makers target the areas in which control efforts will have the most positive impact. EPPA-HEC is capable of doing this, as shown in Matus *et* *al.* 2005 for the United States. However, for this study, the focus is instead on the effect of all pollutants together.

3.6 Evaluating Policy: Future Policy Evaluations

The real power of EPPA-HEC is the ability to calculate the future benefits of policies, including those that are primarily meant to address climate change. For purposes here, combinations of GHG and pollution policies similar to those studied previously by Felzer *et al.* 2005 were constructed. The GHG policies differ from that work in a couple of ways: First, Felzer at al., 2005 delayed China participation in the GHG policy until 2025. In this study, China begins participation in 2010, in order to determine the impacts on air pollution from early action. Second, emissions allowances were allocated among regions so that there was no incentive to trade. If China was either buying or selling permits this would have been additional cost (or economic benefit) from the GHG policy, thus confounding any estimate of health benefits. A policy that allocated more permits to developing countries like China would thus result in additional benefits from emissions trading. Like the work by (Felzer *et al.*, 2005) , this work looks at the potential ancillary benefits of climate change policies. Felzer *et al.*, 2005 studied ozone and its effects on the ability of plant matter to sequester carbon from the atmosphere.

The evaluation of health related benefits of future pollution climate policies required several steps. Unfortunately, the current state of EPPA did not allow for a completely endogenous calculation of pollution levels and trends. Instead, a multi-step process was used to arrive at pollution level trends for a set of policy scenarios, which were then used to calculate policy benefits in EPPA-HEC. The key problem faced was how to identify urban air pollution concentrations for China in the MIT IGSM, which is 2-dimensional, resolved by latitude and altitude but not by longitude (citation). The chemistry is resolved for urban and non-urban areas but identification of Chinese cities from other cities in the same latitude band is not possible. Thus, the future analysis is limited to particulate matter (PM_{10}). To do this, IGSM results were combined with the spatial pattern of particulate emissions as predicted by 3-dimensional model results (Wang 2004) as described in the following section.

3.6.1 Calculating Future Particulate Pollution Paths

The most important factor for the calculation of future policy benefits is the determination of actual annual urban averages for particulates. As in the historical scenarios, once these averages are known, it is possible to calculate the health impacts, and then integrate them into the overall economy. Unlike the historical scenarios, for the future benefits, these levels must be somehow calculated, based on predictions of future emissions, taking the climate and atmospheric chemistry into account. The MIT Integrated Global Systems Model, the MIT- IGSM, (Reilly, *et al.* 1999), (Prinn, *et al.* 1999) has a 2-D coupled land-ocean/atmospheric chemistry model capable of performing such calculations (Sokolov and Stone 1998).

Use of this model for this work presents two problems. First, it calculates levels of black carbon, not PM_{10}. However, black carbon is a major element of particulate matter in China (He, *et al.* 2001; Wu, *et al.* 2003; Ye, *et al.* 2003). To address this problem, an assumption was made that the black carbon is a constant fraction of particulate matter. Given this assumption, an increase in the black carbon concentration implies in a corresponding increase in the PM_{10} concentration. The second problem with using the IGSM's model for atmospheric chemistry is that it is only a 2-D model, which divides the world into 22 latitude bands. The black carbon levels are available only for these global bands, which makes it impossible to determine the levels in urban areas in China. To address this, the 2-D model results were supplemented using the spatial pattern of black carbon concentrations from a global 3-D model simulation (Wang 2004). This model breaks the globe down into a grid, with cells that are 2.8°x 2.8°. It is possible to use this model to obtain black carbon concentrations for specific urban areas for the base year in 1995.

Calculating the future PM_{10} annual urban concentrations was a multi-step process. First, it was important to quantify what data was known at the outset. The three most important factors were (1) the average urban concentration of PM10 for China (1995), (2) the modeled black carbon annual concentrations worldwide from 3D model (1995), and (3) the modeled black carbon annual concentrations from 2D model for each latitude band (1995-2100). Given this known data, a procedure was developed to estimate the particulate concentrations for Chinese urban areas.

First, the 3-D model is used to "weight" the average emissions from the 2-D latitude bands. This produced a more accurate relationship between changes in the 2-D model and changes in the urban PM concentration in China. This required identifying the grid cells on the 3-D model that fall within China and contain an urban population. The cells identified as being Chinese and urban were aggregated into groups corresponding to each of the latitude bands containing Chinese territory in the 2-D model.

The next step was to use changes in the 2-D model black to index the 3-D aggregates when the model was simulated forward. For each change in black carbon concentration in a 2-D latitude band, the change in the value for each cell was indexed by the change in the latitude band in which it is located. Once every cell was adjusted, the average of all of the cells gave the mean value for China as a whole. In this way, changes in each 2-D band were weighted by the number of cells (or the geographic area) that fell within the latitude band.

Finally, the average annual urban PM_{10} concentration from 1995 was adjusted according to the change in the black carbon annual mean. Given the assumption stated earlier that the relationship between black carbon and PM_{10} is constant, then changes in the urban annual average black carbon concentration (calculated in the procedure outlined above) will result in a corresponding change in the annual average urban PM_{10} concentration. So if in a given year the urban black carbon concentration increased by 5% from the 1995 base year concentration, the PM_{10} concentration in that year would also increase by 5% from the 1995 concentration. This procedure was used to calculate future concentration paths for all of the future policy scenarios studied.

For the calculation of policy-related benefits, four policies were chosen, based on the work of Felzer *et al.* The first policy is a business as usual, or reference case, *V-ref.* In this scenario, no policies are implemented to control either greenhouse gases or other pollutants. The second policy is a pollution control policy, *Pol Cap*, which caps pollutant gases at their 2005 levels in all regions. The pollutants capped by this policy are CO, volatile organic carbons (VOC), SO_2, NO_x, and black carbon (BC). The third policy, *GHG Cap*, is a greenhouse gas policy that stabilizes the global atmospheric carbon concentration at 550ppm in 2100. This policy is global, includes inter-regional carbon trading, and implementation begins in 2010. This policy is set up as a tax case, where carbon prices are constant across regions for any time period. Also, in order to avoid benefits from trading confounding possible benefits from pollution reduction, the constraints are set so that China does not engage in any greenhouse gas emissions trading. Finally, the fourth policy is a hybrid policy, *GHGPol Cap*, which has the same pollution caps as *Pol Cap* and the same greenhouse gas controls as *GHG Cap*.

All four policies were evaluated using EPPA-HEC through 2025. This is a relatively short time horizon for climate change purposes, but for today's policy decisions, the near term implications of control policies on air pollution are more relevant. These pollutants are short-lived and so policies that affect emissions have near-immediate effects on concentrations. Moreover, results for the distant future grow increasingly uncertain.

Chapter 4: The Economic Impacts of Chinese Urban Air Pollution

4.1 Introduction

This research culminates with two sets of results. The first evaluates China's historical situation. These results, which used observed demographic, pollution, and economic data, are useful for evaluations of the effects of China's past policies and behaviors on its population and on its economy. Historical results such as these are useful for looking at past policies, and evaluating their efficacy and their broader implications.

The second set of results examines potential future policies and effects. The results from this case provide an initial set of boundaries for the possible effects of greenhouse gas and pollution policies. These results are necessarily more speculative because they require further economic, behavioral and technical assumptions, and because the pollution concentrations in urban areas have been extrapolated from relatively coarsely resolved economic and chemistry models. While the absolute results will differ as the methodology is polished, even these first estimates can provide valuable information for policy makers, as they try to make important policy decisions that will have an impact around the world for many years to come.

Given the expanded accounting in EPPA-HEC that values leisure, the economic effect of pollution damage can be considered in terms of the impact on conventionally measured GDP and consumption, or in terms of the broader measure that includes loss of leisure. In this chapter, references to GDP refer to impacts on GDP as conventionally measured, without including the value of leisure consumption. References to welfare loss (gain) refer to the change in conventional consumption plus the change in leisure.

4.2 Historical Analysis

One important use of the economic model developed for this work is the ability to analyze historical policies, or lack thereof, and to evaluate the consequences. The EPPA-HEC model could be used to examine a variety of time periods in modern Chinese environmental history. In this case, the period between 1980 and 1995 is especially interesting. During this time, there were some nascent environmental policies in place, but environmental protection was very low on the government agenda. It was also during this period that China's economy began to grow very rapidly, as economic reforms took hold. During this time, the attitude of development first, environment later, was at its strongest. This was a period of great change, as the urban population grew significantly, which increased the burden of air pollution on the population and the economy.

Between 1980 and 1995, the measured annual urban concentration of PM_{10} actually decreased, despite the economic growth and the absence of policy. NO_x held steady, and SO_2 showed some declines (see Figure 4). Since there was actually very little government-mandated cleanup before the 1990's, the drop in pollution is mostly the result of changes in the industrial sector and of technological improvements. Evidence from the World Bank (2001) offers some explanation for this surprising drop in pollution, even though there was little attention to pollution control. For example, during the 1960's and 1970's, many of the state-owned enterprises that were a large part of China's industrial sector were concentrated in heavy industry (like paper production, smelting, and refining), which produce significant levels of pollutants. The World Bank (2001) concludes that the economic growth in the 1980's resulted in shifts away from some of the dirtiest sectors, and also led to investments in improvements in industrial technology (World Bank. 2001). There was also an improvement in energy efficiency over this time period, which means that coal use for electricity did not grow as fast as the overall economy.

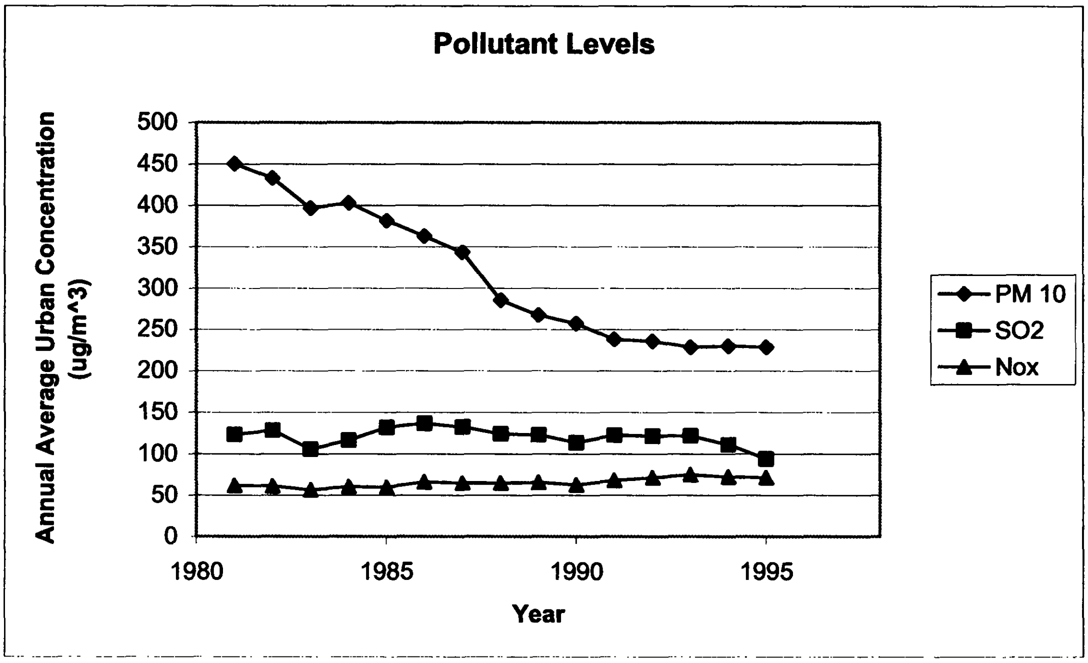


Figure 4 Measured Historical Urban Annual Average Concentrations for Pollutants in China (World Bank. and Research 1998)

By the early to mid-1990's, increasing attention was paid to the environmental costs of economic growth. While progress was made with limited central regulation, concern that this was inadequate to meet the continuing challenge of pollution control led to important changes in China's regulatory structure as discussed in Chapter 2. This included the 1995 APPCL, SEPA's promotion to a cabinet level ministry in 1998, and subsequent improvements in environmental regulation. One might conclude looking only at the trend in emissions that China was more effective at controlling pollution before these changes. However, it is likely that the flattening of the downward trend in PM_{10} and little or no additional progress has been made toward reducings other pollutants reflects the increasing difficulty and cost of reducing emissions per unit of activity still further. The reduction in pollution in the 1980's and early 1990's was mostly a by-product of economic transformation. This is reflected in the PM_{10} concentration, which begins to flatten out in the 1990's.

While China certainly underwent impressive economic growth between 1980 and 1995, results from the EPPA-HEC model indicate that this growth was tempered by the health costs incurred by the urban population to deal with negative health outcomes. The differences between the *Historical* and *WHO* scenarios shows the impact of *excess* pollution levels beyond the WHO recommended guidelines; the differences between the *Historical* and the *Green* scenarios shows the impact of the *total* urban air pollution burden.

For the overall GDP, the *Historical, Green,* and *WHO* scenarios were identical in the base year of 1970, as they also had identical pollution levels for this year. However, the two scenarios with lower pollution levels in the proceeding intervals showed greater economic growth, so that by 1975 the *Historical* scenario's GDP is $15 billion less than that in the *WHO* scenario, and $23 billion less than in the *Green* scenario (see Table 5).

	Historical	WHO	Green
1970	110.905	110.905	110.905
1975	144.283	159.336	167.015
1980	186.344	210.002	219.347
1985	315.887	348.645	360.2
1990	461.343	494.909	510.38
1995	802.123	838.264	859.326
2000	1180.734	1230.987	1260.018

Table 5 Annual GDP by Scenario (billions $1997 USD)

This results in benefits to GDP in each period in both pollution reduction scenarios, as shown in Figure 5.

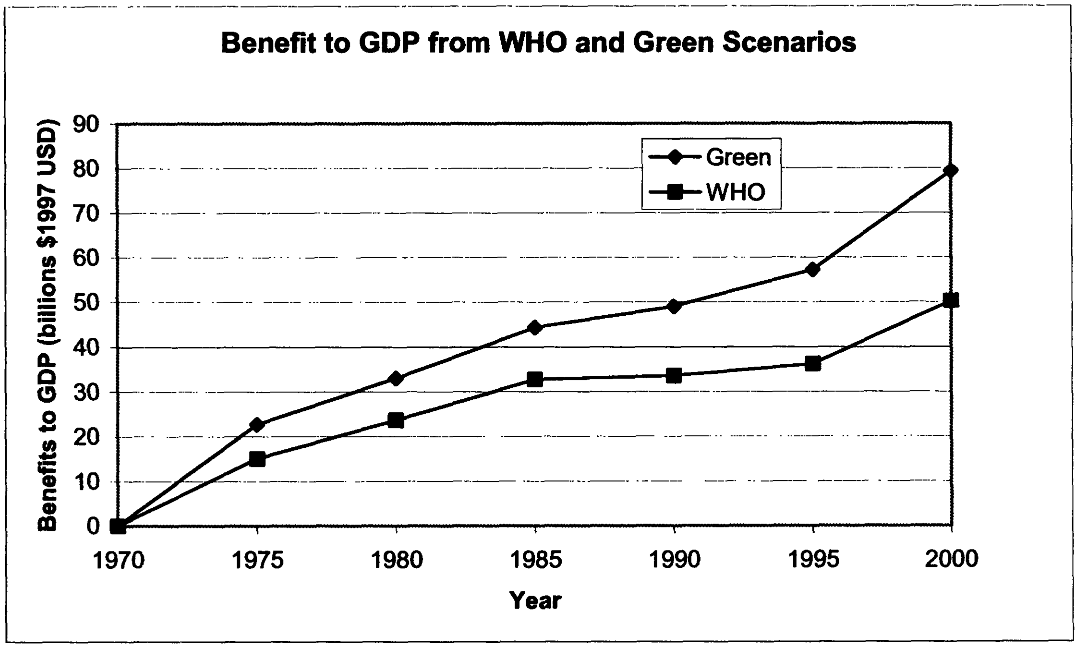


Figure 5 Benefits to GDP from Green and WHO Scenarios

Interestingly, as a percentage of the overall GDP, these benefits peak in 1980, as seen in Figure 6.

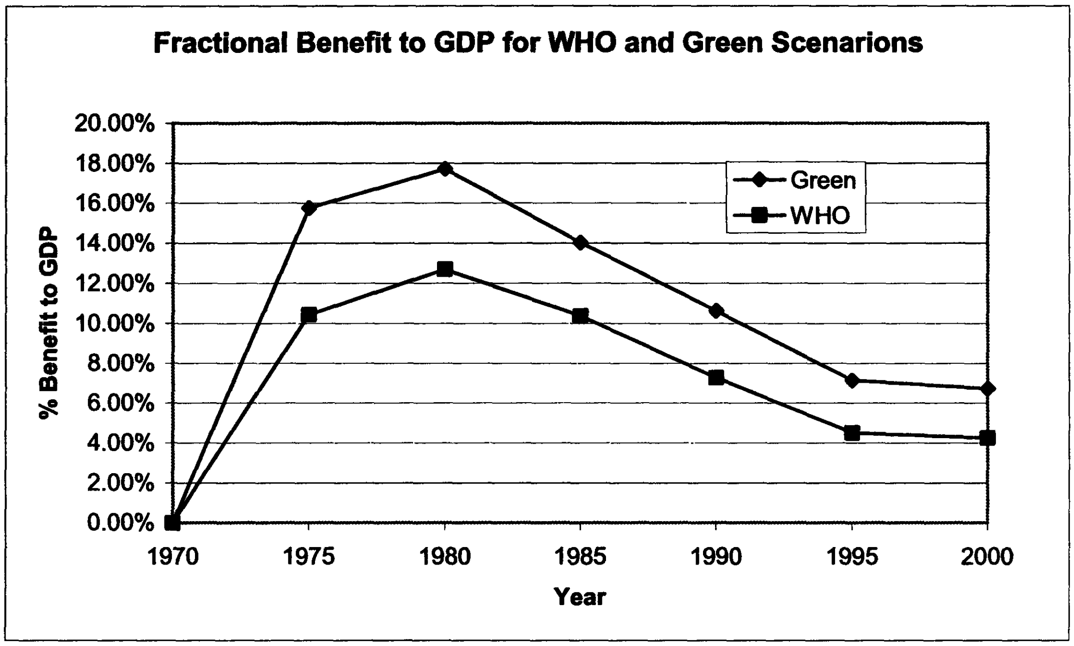


Figure 6 Benefit to GDP from WHO and Green Scenarios

They remain large throughout the 1980's, although they decrease significantly, finally leveling off between 1995 and 2000. The absolute costs of pollution can be found by looking at the differences between GDP in the *Historical* benchmarking scenario and in the two lower pollution scenarios. The difference in GDP between the *Historical* and *Green* scenarios indicates that while the absolute costs to the Chinese GDP of urban air pollution increased by nearly $24 billion dollars, and in the case of the differences between the *WHO* and *Historical* scenarios, it increased by $12 billion. However, this level of growth was not nearly as high as the overall economic growth for the same period.

Overall, the effect on the annual growth rate of the Chinese GDP is on the order of several tenths of a percent. In the *Historical* case, the annual growth rate of GDP was 8.20%, in the *WHO* case it was 8.35%, and in the *Green* case, it was 8.44%. The difference of just a few tenths of a percent in GDP growth over 30 years can accumulate to substantially effect economic well-being. This is an indicator that had China been able to effectively regulate urban air pollution more stringently during this period there would have been a considerable economic payoff.

It is interesting that this decrease in economic growth as a result of urban air pollution occurred despite positive overall trends in air quality during this period. Both PM_{10} and SO_2 concentrations decreased significantly between 1980 and 1995, mostly as a result of changes in the industrial sector away from some of the most polluting industries, as well as through improvements in technology that led to increased efficiency. Even NO_x levels, which did increase over this time, remained well below the WHO guidelines. The reason that the absolute costs of urban air-pollution-related illness increase significantly during this period is that the urban population expanded significantly. So despite lower pollution levels, a larger population was exposed, thus increasing the overall impacts. This effect was amplified by increases in overall earnings. As labor productivity, as well as earnings, increased over this period, the value of lost labor time also increased.

However, the impact of historical improvements in urban air quality is visible in a comparison of the per-period growth rates for each of the scenarios. While the *WHO* and *Green* scenarios had higher growth rates in the earlier periods, as the historical pollution levels began to drop during the 1980's, the historical rate actually catches up, and then exceeds the cleaner two scenarios (Table 6).

	Historical	WHO	Green
1975	5.4%	7.5%	8.5%
1980	5.2%	5.7%	5.6%
1985	11.1%	10.7%	10.4%
1990	7.9%	7.3%	7.2%
1995	11.7%	11.1%	11.0%
2000	8.0%	8.0%	8.0%

Table 6 Per Period Growth Rate of GDP

The increased *Historical* growth is not enough for the overall GDP to make up the losses from the earlier time periods, but they do mitigate the pollution health effect to some extent. The increased growth also indicates that decreasing pollution levels have an impact on overall economic growth.

This positive overall economic impact is most likely the result of several factors. The first is a decrease in the amount of labor lost due to pollution-related illness. Secondly, as pollution-related illness decreases, individuals can redirect their consumption towards other sectors, such as goods and services, that help to stimulate the economy. The overall increases spending for health services are driven by the growth in the size of the urban population, but for this expanding population, the per capita costs are decreasing, leaving more resources available for consumption in other economic sectors. This trend can be seen in Table 7 which shows the benefits to per-capita consumption that result from the lower pollution levels in the *Green* and *WHO* scenarios. Since overall per-capita consumption increases significantly (more than doubling in all scenarios between 1970 and 1995, as seen in Table 8), these losses, decreasing in absolute terms, are also decreasing as a percent of overall consumption.

	Green	WHO
1970	0.00	0.00
1975	133.09	87.41
1980	102.46	74.48
1985	95.06	70.49
1990	75.56	50.63
1995	77.03	47.87

Table 7 Benefit to Per Capita Consumption from WHO and Green Scenarios ($1997 USD)

	Historical	WHO	Green
1970	696.0926	696.0926	696.0926
1975	749.7001	837.1058	882.7882
1980	703.9826	778.4625	806.4434
1985	830.9706	901.4582	926.029
1990	915.703	966.3327	991.2632
1995	1334.994	1382.869	1412.028

Table 8 Per Capita Consumption ($1997 USD)

The lesson here for Chinese policy makers is that improvements in urban air quality have the potential to impact the economy in a variety of ways. Decreasing the percentage of their income that individuals must spend on health care can have a real impact on the overall economic growth. So even while overall pollution levels may remain well above optimal targets, improvements made can have a positive economic impact. This needs to be taken into consideration when the costs and potential benefits of pollution control are weighed against each other during the decision making process. Of course, not every improvement will lead to a benefit, since there is also a cost to reducing emissions that was not assessed in this analysis, and in reality both the costs and benefits would be borne by the economy.

This has important policy ramifications. First of all, population is an important consideration in the creation of pollution control policies. Reductions that affect large numbers of people will have the greatest positive effect. China is already headed in the right direction with its current APPCL, which targets the largest Chinese cities, which contain a large proportion of the overall urban population. These are areas that will receive the largest marginal benefit for any pollution reductions. Secondly, the rising absolute costs indicate that there is also a rising marginal benefit to pollution control. Continued urban growth means that absolute pollution damages to the economy will continue to rise, even for stabilizing and decreasing pollution levels. While this work does not address the cost of reducing pollution, the implication from a cost-benefit standpoint is that rising marginal costs of control are justified as income and urban population increase.

4.3 Analysis of the Benefits of Future Policies

EPPA-HEC can also be used to analyze the impacts of future environmental policies. In this case, the model was used to examine the differences between four policy scenarios. The results indicate that there are benefits to all three pollution control policies, as compared to the scenario in which no policies are implemented. The first two policy scenarios, *GHG Cap* and *Pol Cap* show the potential benefits from controlling greenhouse gases and other air pollutants, respectively. The final policy case, *GHGPol Cap* shows the potential benefits from having both kinds of policies in place. All of the benefits seen in the results are the result of changes in PM_{10}, which was the only air pollutant examined in this particular analysis.

The first policy scenario, *GHGCap*, is one example of a possible greenhouse gas policy. This particular scenario, implemented globally, results in atmospheric carbon concentrations stabilizing at 550ppm by 2100, and is designed so that there is a single global carbon price but no incentive for emissions trading. Each region is allocated emission allowances equal to actual emissions given the carbon price. This is not meant to represent a likely, or necessarily fair, allocation of the burden. Each region simply bears the full cost of reducing its emissions. This way possible benefits of emissions trading do not confound the ancillary benefits. This policy starts in 2010 and is constructed so that the global carbon prices rise at approximate 5% per year as shown in Table 9. When compared to the no policy reference case, the scenario showed decreases in the annual urban average particulate concentration, relative to the reference case, after the implementation of policy starting in 2010 (see Figure 7).

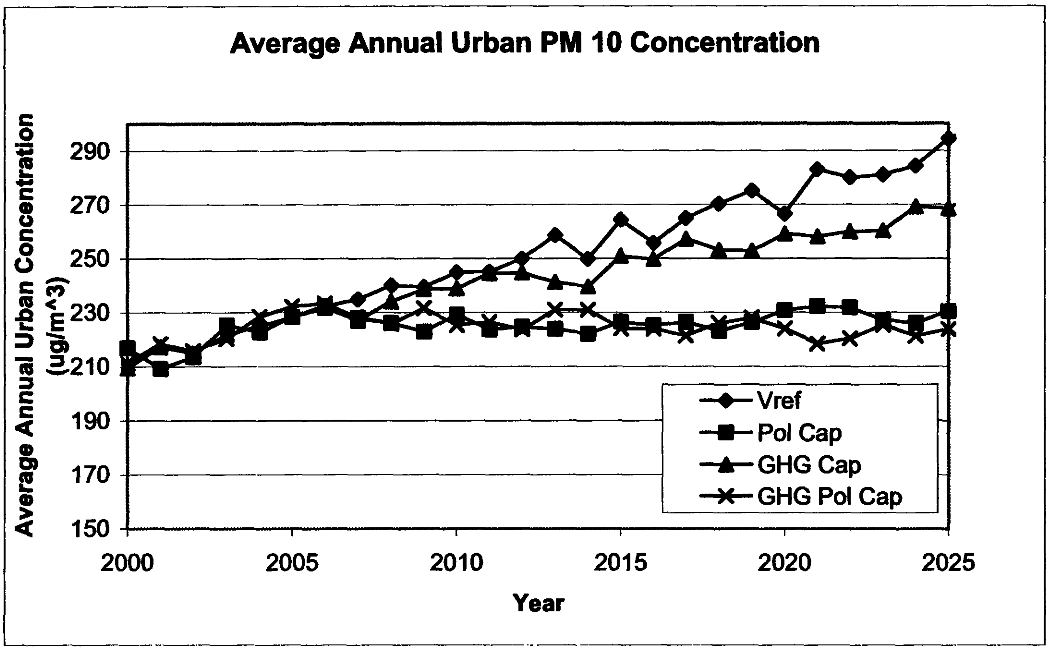


Figure 7 Annual Urban Concentrations of PM10 for All Four Policy Scenarios

Year	Carbon Tax
1997	$0.00
2000	$0.00
2005	$0.00
2010	$23.22
2015	$30.91
2020	$40.31
2025	$52.12

Table 9 Carbon Tax ($1997 USD per ton Carbon)

In terms of emissions, China's emissions of CO_2 from fossil fuels continues to increase over this period, though at a slower rate than in the reference case (see Figure 8).

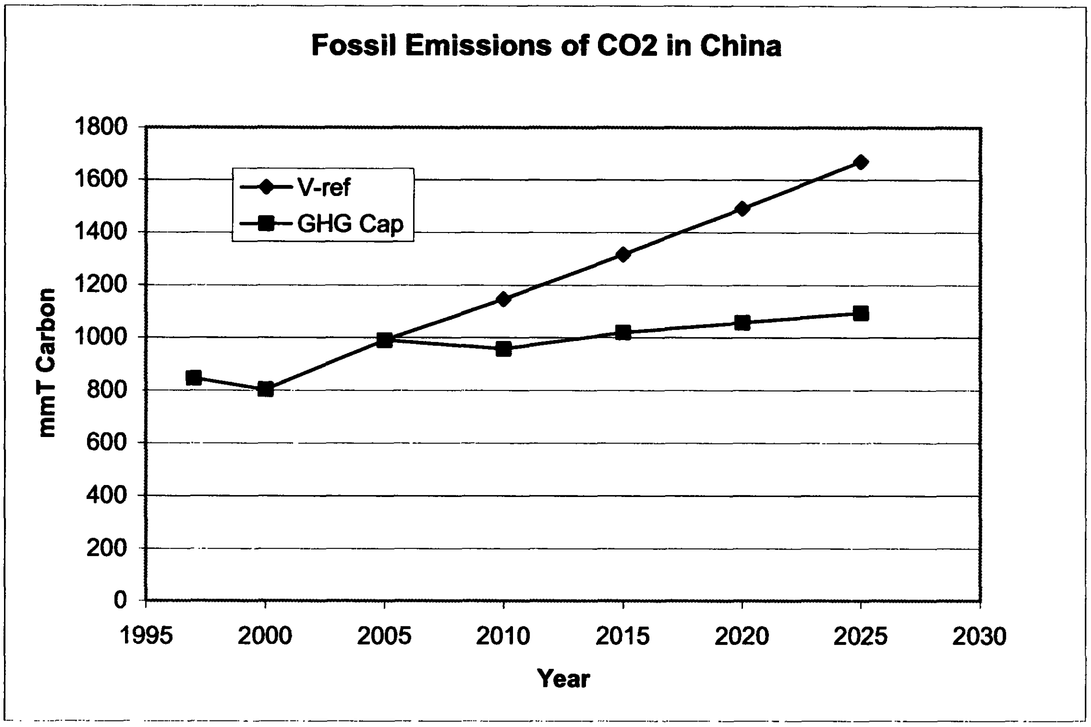


Figure 8 Fossil Emissions of CO2 for V-Ref and 550 ppm Stabilization (GHG Cap) Scenarios in mmT of Carbon

For overall greenhouse gas emissions, the trend is similar, as can be seen in Figure 9 (for the carbon tax and emissions trends through 2100, see Appendix B.

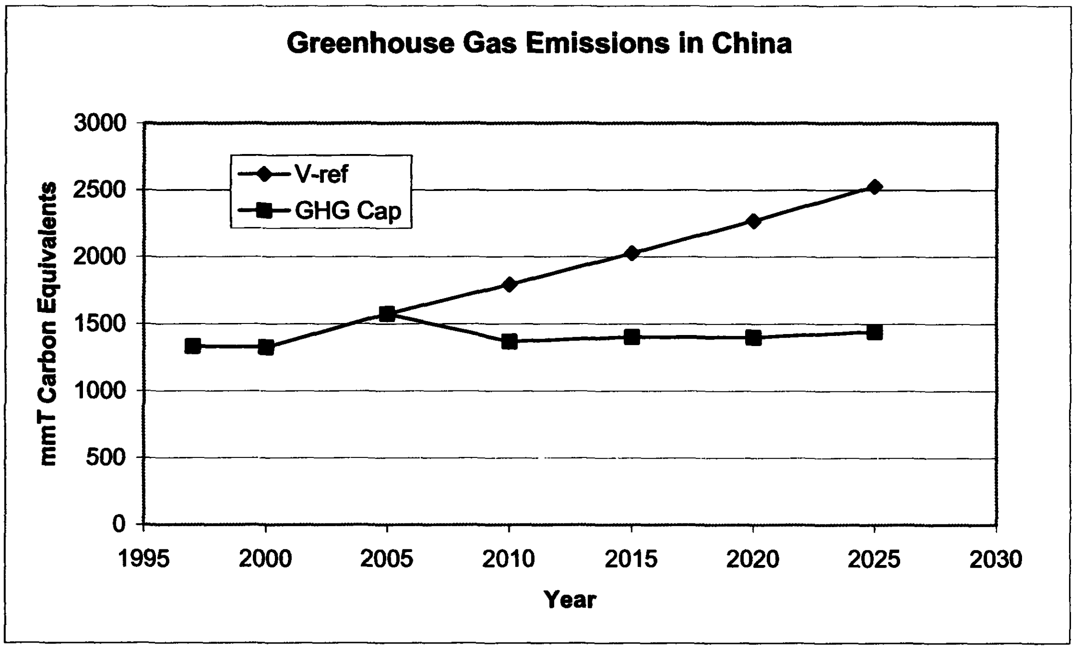


Figure 9 Total Greenhouse Gas Emissions in V-ref and 550 ppm Stabilization (GHG Cap) Scenarios in mmT of Carbon Equivalents

This lowered pollution path resulted in health related economic benefits. The benefits to GDP start out at around $2 billion (1997 USD) in 2010 (see Table 10). As pollution levels decrease, the benefit increases rapidly, reaching $11 billion in 2025. These benefits are beyond the costs of implementing this particular greenhouse gas cap, and without any policy focused specifically on the control of PM_{10}.

	Pol Cap	GHG Cap	GHG Pol Cap
1997	0	0	0
2000	0	1.607	1.34
2005	0	0.788	0.042
2010	3.919	2.386	5.754
2015	12.546	5.576	14.593
2020	16.247	5.064	20.962
2025	37.437	17.142	43.805

Table 10 Benefits of Policies to GDP (billions $1997 USD)

The second type of policy scenario implemented, *PolCap*, was a cap on air pollutants. The caps began after 2005, and benefits occurred in every time period after that year. The benefits of *PolCap* were greater than the benefits in the *GHGCap* case- $3.9 billion in 2010, growing to $37 billion in 2025, although, because the EPPA model cannot actually estimate the costs of controlling these pollutants, the *PolCap* case does not include the costs of implementing the pollution cap, and as in *GHG Cap,* the costs of the climate policy are not included. Still, overall, *PolCap* resulted in lower black carbon levels and greater benefits from a decrease in the overall health impacts than the *GHGCap* case.

The final policy scenario was *GHGPol Cap*, which combined both of the policies described above. As in the two previous scenarios, benefits began in 2010. In this case, the benefits were $5.6 billion in 2010, increasing to $82.5 billion in 2025. This third case is illustrative in that it also gives a sense of the interaction effects of policies with two different goals, but whose impacts overlap. While the benefits from *GHGPol Cap*, with both its pollution controls and greenhouse gas stabilization elements, are greater than policies that focus on only one element or the other, they are not the sum of the benefits found in the other two cases. There is an overlap in how both of the policy elements affect the levels of particulates found in urban areas.

Beyond the increasing absolute benefit to the Chinese GDP in all three cases, it is also important to see whether the absolute increase grows faster or slower than the overall economy. In all cases, the benefits grew faster than the overall GDP- the benefits, as a percentage of total GDP, increased over time (see Table 11).

	Pol Cap	**GHG Cap**	**GHG Pol Cap**
1997	0.0%	0.0%	0.0%
2000	0.0%	0.9%	0.7%
2005	0.0%	0.3%	0.0%
2010	1.2%	0.7%	1.7%
2015	2.8%	1.2%	3.2%
2020	2.6%	0.8%	3.4%
2025	4.5%	2.0%	5.2%

Table 11 Benefits of Policies as a Percentage of GDP

In the case of *Pol Cap* and *GHG Cap*, there was a slight decrease between 2015 and 2020, but this was followed by a large increase in 2025. For *GHGPol Cap*, the percentage increase was the largest, and grew in every time period. This shows that the interaction between the two policy elements leads to the largest benefits.

When comparing these scenarios, it would also be helpful to know which of these is the most cost effective. However, the model construction precludes making this determination. Further analysis that includes the costs associated with these policies would be necessary to make any determination of cost-effectiveness. As in the historical analysis, it is possible to look at the effect of policies on overall welfare, as measured in terms of consumption and leisure. All three policies resulted in a benefit to welfare (see

Figure 10). Once again, *GHGPol Cap* results in the largest overall benefits. But all three policies result in increasing welfare benefits.

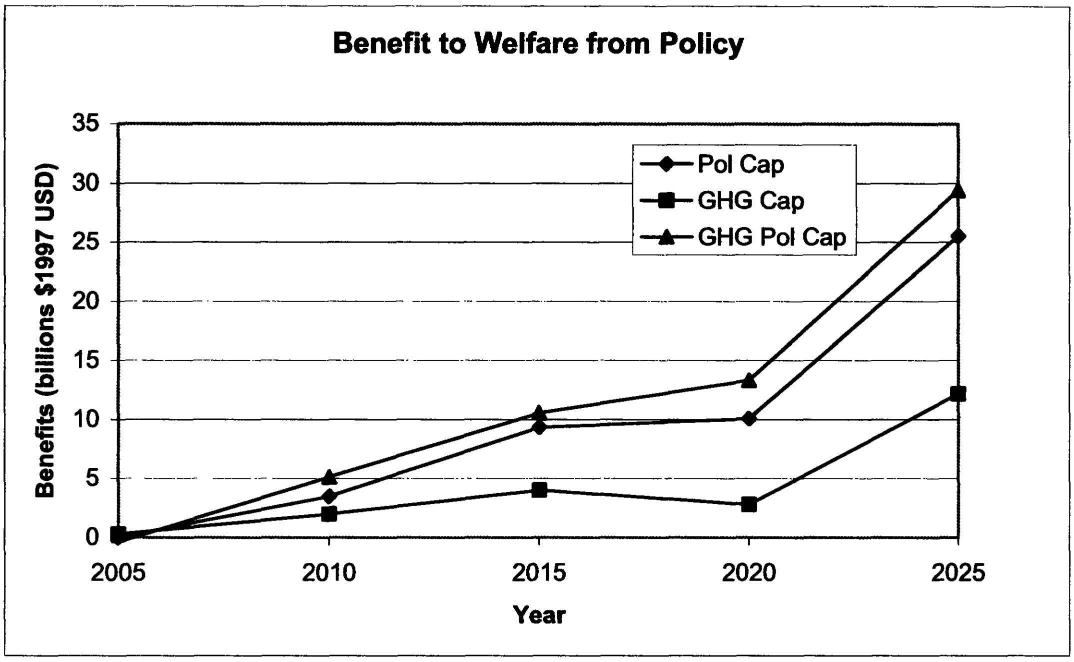


Figure 10 Benefit to Welfare from Policy Scenarios (billions $1997 USD)

Overall, these results indicate that there are economic benefits to be captured from the implementation of both climate change and pollution control policies. The large increases in benefits, both in terms of GDP and in terms of welfare in 2025 show that there are long-term returns to action. This is most likely a result of increasing urban population, combined with increasing wages, which make reductions in pollution-related illness increasingly beneficial. Furthermore, the results show that implementing both types of policies results in larger benefits than the implementation of either policy on its own. Interactions between the policies prevent the benefit from dual implementation from being the sum of the benefits from each individual policy.

It should be noted that the scenarios chosen for this analysis are purely illustrative. The 550ppm stabilization policy, or pollution caps at 2005 levels, may not be the most optimal policies, either alone or in combination. Other policies, and combinations of policies, will results in increased, and in some cases, decreased benefits. What the results of this analysis do show is how environmental policies can have tangible economic benefits simply from their ability to impact human health. Future policy proposals could be analyzed in the same way in order to determine whether they confer a health-based benefit. Menus of potential policies could also be analyzed in order to optimize across a range of options, and to help policy-makers choose which combinations would confer the largest marginal benefits.

Chapter 5: Conclusions and Directions for Future Work

Even casual visitors to China's major cities take note of the high levels of air pollution. The work presented here shows that China's urban air pollution has had a substantial impact on the economy. The impact of pollution above the WHO's health guidelines has fallen as percent of GDP from over 10% in 1975 to 4% in 2000 because pollution levels have been steady, or in some cases have fallen. But in the same period, the absolute cost to the economy has increased from $15 billion to $50 billion a year (1997 $USD), despite improvements in overall air quality. The increasing size of this urban population has been a driving force behind the increasing absolute cost of pollution-related health effects to the overall economy. As the urban population grows, more people are exposed to air pollution, increasing the total cases of pollution-related illness. The rate of urban growth is much greater than the rate of improvement in air pollution levels; absolute costs continue to rise despite positive downward trends in average annual urban concentrations. This absolute increase is amplified by the fact that China's impressive economic growth has brought with it increases in wages, so that labor and leisure lost as a result of illness become more costly over time.

Analysis of illustrative future policies indicates that there is a benefit to addressing issues of air quality. Policies aimed at controlling urban air pollutants, as well as policies aimed at combating global warming both have a positive economic impact in future years. An even larger positive impact is realized in a scenario where both types of policies exist simultaneously. This is not surprising, since China's urban and economic growth is predicted to continue well into the century. The same factors that resulted in the increasing absolute costs in the historical analysis also lead to increasing benefits in the future analysis.

Taking both the future and the historical analyses together, it becomes clear that the size of the urban population is a major factor in the creation of economically and environmentally effective policies. China has over 600 cities and towns classified as urban, however, current air pollution regulations target only 47 of these cities. At first glance, this seems like a very small proportion of China's urban areas. But these 47 cities include many of the largest and most polluted in China, including Beijing and Shanghai. They also represent a good fraction of China's urban population. The results of this analysis indicate that this policy is a sound one. By focusing on areas where large populations can benefit from changes in urban air quality, the Chinese can realize an increased marginal benefit. In high population areas, especially those that are growing rapidly, pollution control can result in benefits, even when the costs of control are high.

If China continues with a program of well-targeted, and hopefully effective, air pollution control policies, it will also see added benefits from the implementation of greenhouse gas control policies. This follows from the results of the future policy analysis, which showed that a combination of pollution control and greenhouse gas policies results in larger benefits than either policy on its own. Since China has become increasingly concerned about global warming, and has begun to be more active in international agreements and actions to address the problem, there is a good possibility that they will be able to reap some of the benefits of these policy interaction effects in the future.

The results of this study open up several interesting avenues for future work. The most interesting ones involve improving the process for modeling and evaluating future policies. First of all, it is clear that the benefits of policies are driven in a large part by the size and growth of the urban population. Currently, urban population is an exogenous variable in EPPA-HEC. Urban growth, however, is a function of many complex factors, including economic growth, income, politics, opportunity, and relative quality of life. Increases in income will often lead to increases in urban growth. On the other hand, if the cities are viewed to offer a significantly decreased quality of life, due to issues like disease and pollution, then urban growth could be slowed. Integrating an endogenous urban growth model in EPPA-HEC could give a more realistic picture of future urban growth. For example, if cities become cleaner, the urban growth rate might increase. This could have interesting impacts, since decreasing pollution levels result in decreasing pollution-related illness. However, if the population is growing at the same time, then more people are exposed to the pollution, which could lead to an increase in the absolute costs, despite improvements in the overall air quality. Capturing these interactions through better modeling of the urban population would lead to a more robust tool for future policy analysis.

The analysis would also be improved through the addition of an endogenous urban climate model, which could convert regional emissions to urban pollution concentrations. Most useful would be a model that could directly calculate levels of the six criteria pollutants, without requiring conversions between TSP and PM_{10}, or the use of proxies, such as black carbon, to arrive at pollutant levels. If these concentrations are calculated endogenously in EPPA-HEC, they will allow for easier, more interesting policy analyses.

Finally, it would be interesting to investigate a broader range of pollution control and greenhouse gas policies. As negotiations for the second Kyoto commitment period get underway, EPPA-HEC could be used to analyze how various proposals would interact with current (and potential) environmental policies. Tools like EPPA-HEC would be very useful in the policy analysis that will accompany the negotiations.

As this study has shown, China has been moving in a positive direction in terms of its urban air quality. While levels remain well above recommended thresholds in some cities, in many locations, significant improvements have been realized. These improvements, the result of economic, technological, and policy changes, have all led to real economic benefits for the Chinese economy. Furthermore, future actions seem likely to have increasing benefits, given the rise in incomes and in the urban population. It will be important, going forward, for Chinese policy makers to carefully balance economic growth with the potential impacts. Increased civic awareness and environmental concern on the part of the Chinese population have brought increasing attention to achieving this balance, and hopefully this trend will continue into the future. China has much to gain through the implementation of well-thought out, carefully targeted, and economically sound environmental policies.

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Appendix A: Demographic Data

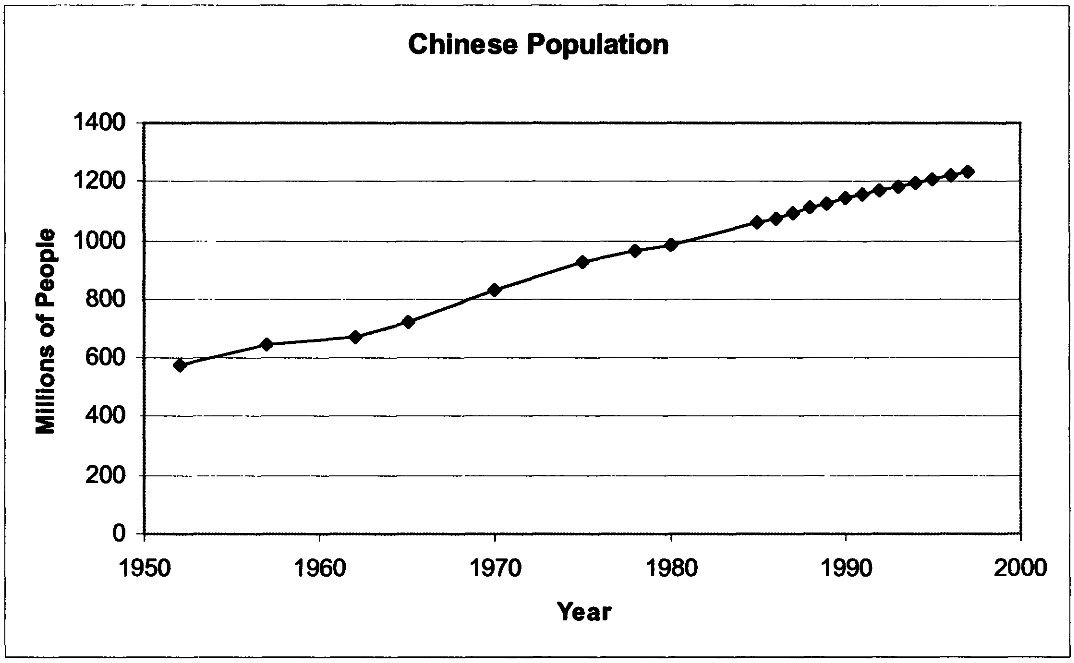

Figure 11 Total Chinese Population, from the China Statistical Yearbook, 2001

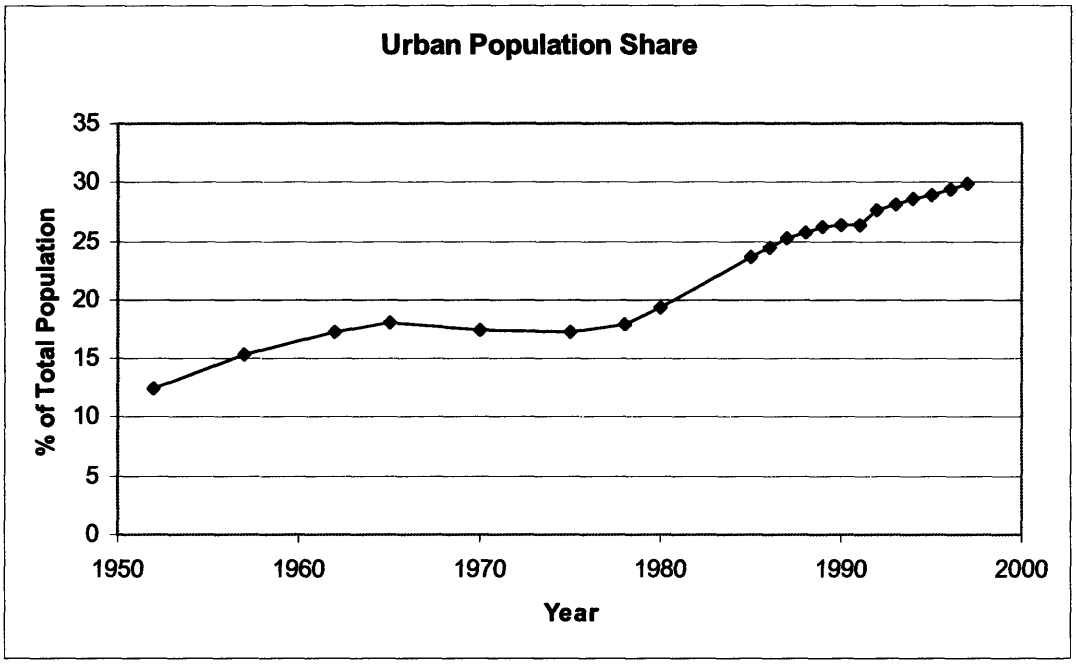

Figure 12 Chinese Urban Population Share, from the China Statistical Yearbook, 2001

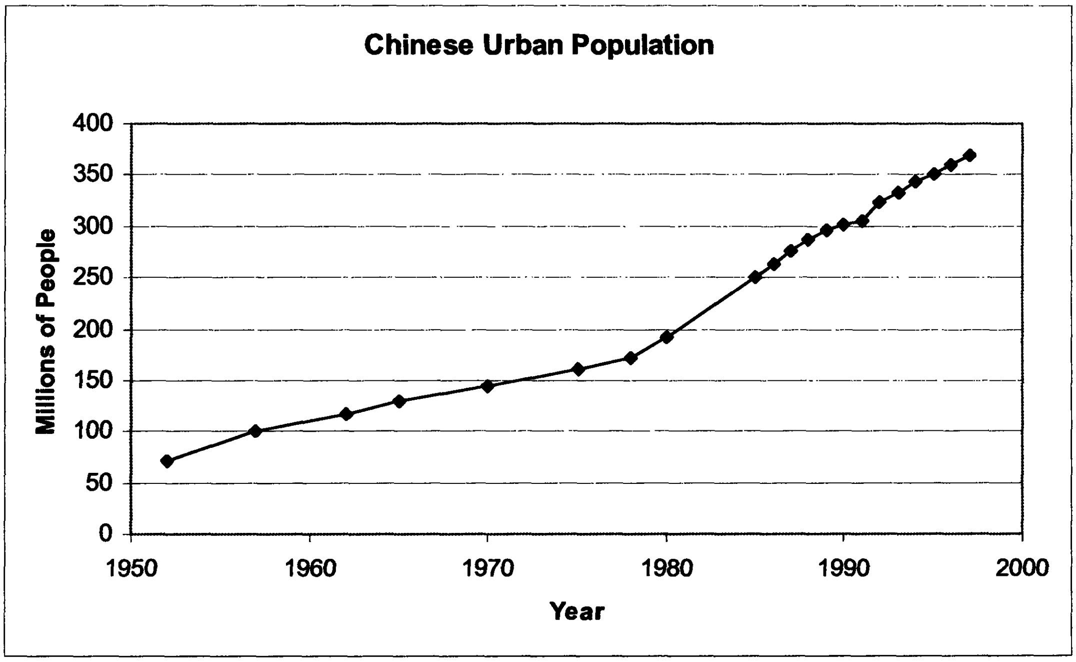

Figure 13 Total Chinese Urban Population, from the China Statistical Yearbook, 2001

Appendix B: Carbon Emissions and Carbon Tax Trends for 550ppm Stabilization Scenarios

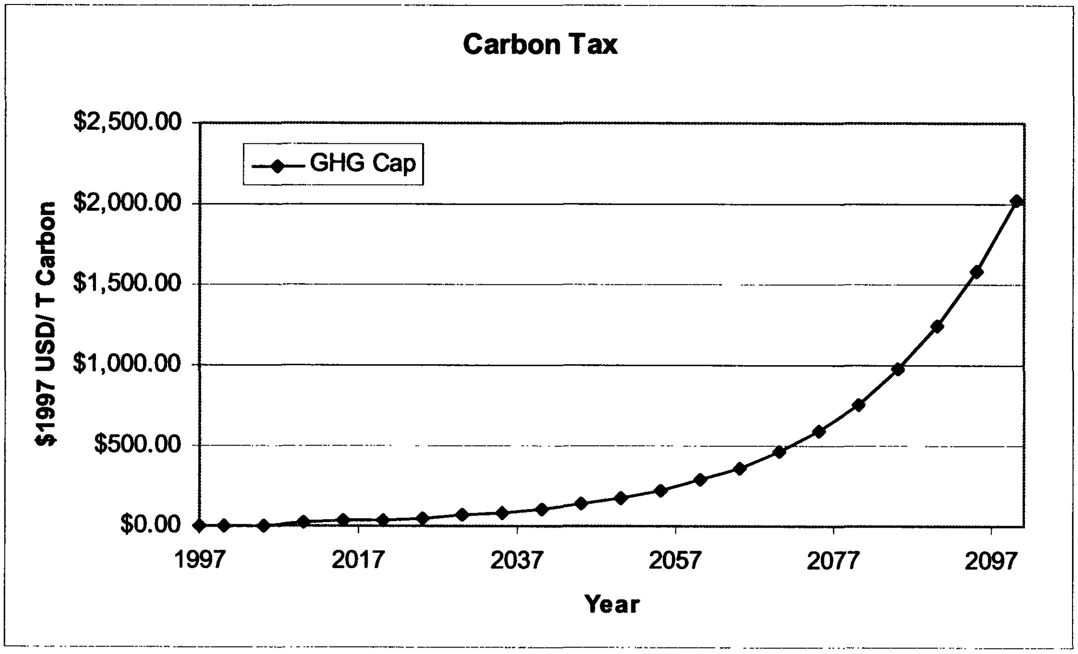

Figure 14 Carbon Tax for China with 550 ppm Stabilization Policy (GHG Cap) in $1997 USD

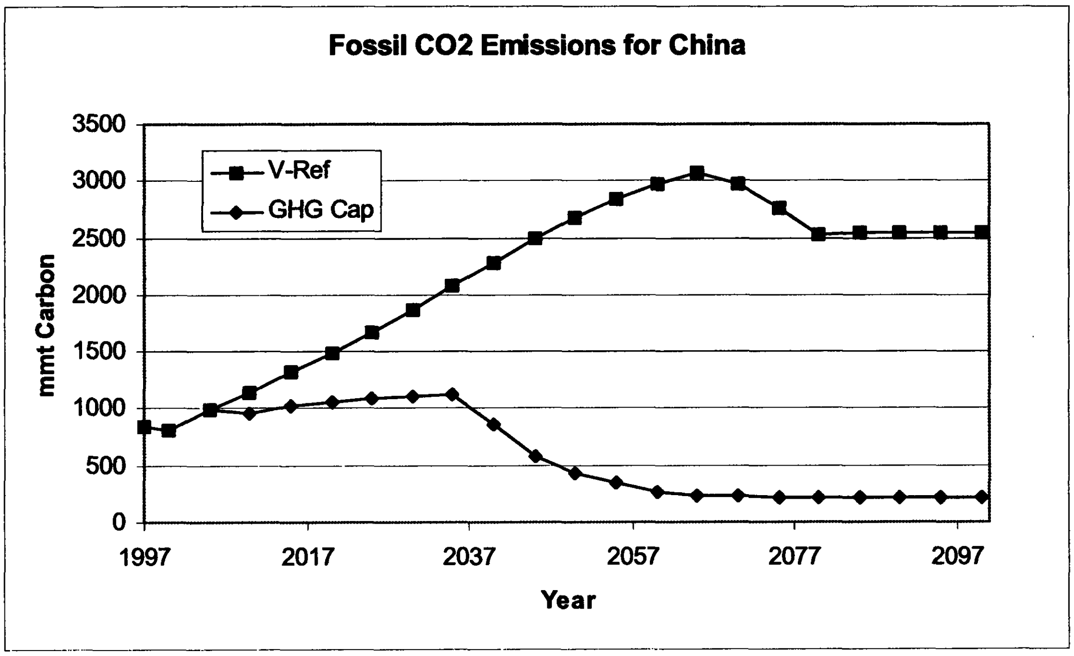

Figure 15 Total Fossil CO2 Emissions for China under V-Ref and 550 ppm Stabilization (GHG Cap) Scenarios in mmT Carbon

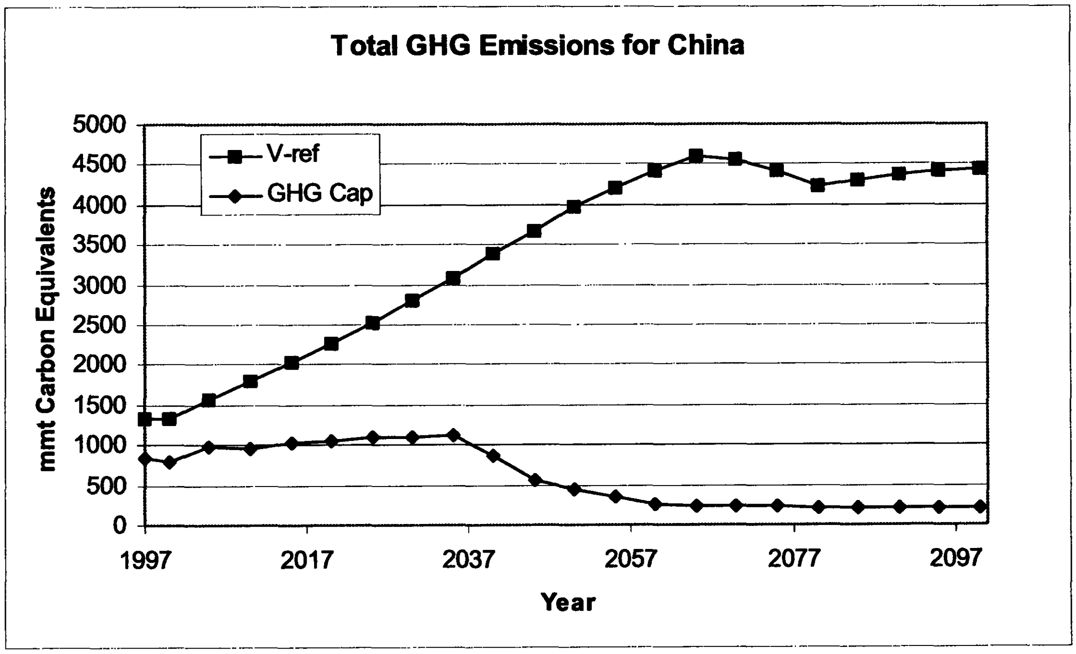

Figure 16 Total GHG Emissions for China Under V-Ref and 550 ppm Stabilization (GHG Cap) Scenarios in mmT Carbon Equivalents