Integrated Impact Analysis of Yellow-dust Storms: A Regional Case Study in China

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ABSTRACT

The dust storm is a meteorological event that is caused by strong winds and proceeds from arid and semi-arid regions, transporting a thick cloud of fine sediments. In China, the sediments of dust storms mainly come from the desert and thus are called "yellow-dust storms." Although these storms can disrupt socioeconomic activities widely and pose hazards to human health as well as to the ecosystem, no one has made a systematic socioeconomic analysis of yellow-dust storms.

I provide an integrated regional socioeconomic framework to quantify the impacts of yellow-dust storms, as a conceptual model and a demonstration of applicable methodologies. I conduct a case study using 2000 Beijing data, mainly applying input-output analysis, dose-response analysis, and a benefit-transfer approach, and test my results with sensitivity analysis. I demonstrate that the economic impacts of yellow-dust storms have reached all sectors of the regional economy, and that their delayed impacts were more significant than the immediate impacts. Further, I clarify the extent of the economic impacts of yellow-dust storms by both backward and forward linkage analyses. On the basis of both quantitative and qualitative analysis results, I discuss the policy implications of yellow-dust control and show that water-resource planning is critical both for the prevention and mitigation of yellow-dust storm problems.

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I dedicate this thesis to my parents, with my deepest gratitude and love.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

METRIC CONVERSIONS

Currency

1 US dollar = 8.3 RMB (2000)

1 US dollar = 5.5 RMB (1992)

Length

1 kilometer = 0.62 mile

Chapter 1
INTRODUCTION

The dust storm is a meteorological event that originates from arid and semi-arid regions and transports fine sediments along with strong winds. In China (People's Republic of China), the sediments of dust storms mainly come from the desert and thus are named as "yellow-dust storms." Numerically, the China Meteorological Administration (CMA, 2003) defined the dust storm as a situation in which visibility is less than one kilometer. Although Dong (2002) surmised that the yellow-dust now occurring in northern Asia is likely to have begun along with the advent of Earth, its incidence and intensity have increased significantly in recent decades, especially in the latest five years. Evidence indicates that dust storms originating in Mongolia and Northern China have been transported to Southern China, Japan, Korea, and even North America. In all these affected regions, dust storms have widely disrupted socioeconomic activities, such as precision-equipment manufacturing, transportation, agriculture, communication, and tourism. In addition, dust storms have posed hazards to human health and the ecosystem.

Increasingly severe problems of dust storms within the last decade have created many studies on the causation of yellow-dust, source areas, transportation trajectories, and physical damages as well as some plausible benefits (Lin, 2001; Lin, 2002; Jie, 1999; Kim and Park, 2001; Lu, Wang and Zou, 2001; Gao, Shi, Ha and Peil, 2002; Wang, Chen and Qian, 2000; Zhu and Zhang, 1994). In contrast, socioeconomic-impact evaluation of dust storms, either quantitatively or qualitatively, is apparently missing.

Analysts find two major reasons why socioeconomic-impact evaluation is a challenge. The first reason involves the properties of yellow-dust storms. They are transboundary, showing a variety of impacts both negatively and positively, but usually not immediately as evident as other disasters, such as earthquakes, fires, and floods. Even in developed countries with detailed data and advanced economic techniques, researchers have failed to find a satisfactory approach to evaluate such natural disasters (NRC, 1999b). Second, problematically, data inadequacy diminishes the possibility of quantitative analysis. Although yellow-dust storms can cause significant monetary or physical losses to a regional economy, scientists, more often than not, have excluded the dust storm from the list of natural disasters. In China, statistical officials have not compiled any systematic statistics of yellow-dust storms up to the present. For example, the China Meteorological Administration, State Forestry Administration, State Environmental Protection Agency, Ministry of Internal Affairs, and several newly founded agencies all have the function to analyze the information regarding dust storms and to manage the problems they create. Even so, none of the individual agencies actually has a database for yellow-dust storms; consequently, analysts do not have easy access to the available information to quantify the impacts of yellow-dust storms. These different agencies collect data in disparate ways that do not supplement each other well.

My objective is to conduct a quantitative analysis of the impacts of yellow-dust storms and evaluate the comprehensive impacts in economic terms. Such a study is urgently needed for several reasons. First, a systematic study of the impacts of dust storms may help statistical officials identify the necessary, but missing, information and enhance the effectiveness of data compilation and analysis. Second, with information of economic impacts of dust storms available, policy analysts may gain more reliable reference for a cost-benefit analysis of investment on disaster mitigation and control than is available at present for decision-making. Third, a systematic analysis and a uniform research approach will enable analysts to conduct further studies to record, track, and compare similar environmental problems (such as acid rain, hail, and snowstorms). Subsequently, scientists may apply such a systematic database to predict future yellow-dust occurrences and strengthen risk-management strategies.

For an integrated economic-impact analysis of dust storms, I focus on answering three core questions: (1) how can economic, environmental, and social impacts of yellow-dust storms be integrated into a one-dimensional framework? (2) to what extent have yellow-dust storms affected a regional economy in China? (3) what are possible policy implications of the quantitative analysis results? Targeting these questions, I start with an overview of the yellow-dust storms in China, by reviewing their causes, summarizing their impacts, and analyzing their properties in Chapter 2. Here, I use "impacts" for a general description of all the impacts, including economic, environmental, and social aspects. In contrast, I define "impacts" throughout Chapters 3 to 6 as all the impacts that can be reflected in socioeconomic activities. I admit that not all the impacts can be reflected in socioeconomic activities, and some may be inappropriate to be evaluated in economic terms. However, since monetary value is the measurement most commonly used and is necessary for regional planners to make investment decisions, I endeavor to integrate environmental and social impacts into economic analysis, in order to evaluate all the impacts in a standard dimension.

In Chapter 3, I introduce methodologies that are applicable to evaluate the economic impacts of yellow-dust storms. I divide the methodologies into two parts: categorization methods and evaluation methods. I first discuss current research gap of impact categorization across disciplines and propose an integrated research framework to evaluate the economic impacts of yellow-dust storms. To quantify the impacts in my proposed research framework, I summarize and discuss the available techniques, generally including regional-economic techniques, environmental-economics techniques, benefit-transfer approach, and sensitivity analysis. I apply both my research framework and these applicable methodologies in my case study in

Beijing (see Chapters 4 and 5). In Chapter 4, I explain the considerations of my case selection in Beijing. Based on background information of Beijing, I introduce my research design, including a list of economic impacts to be evaluated, calculation procedures, and general assumptions. I show my calculations in Chapter 5, in which I divide my calculations into three parts: evaluation of the economic impact on an individual-sector basis, evaluation of the total economic impacts caused by inter-sectoral interactions, and a sensitivity analysis. Based on my calculation results, I conclude my study and propose policy implications and further research areas in Chapter 6.

By conducting the case study in Beijing and testing all the calculations, I propose a conceptual model and feasible methodologies, rather seek precise numerical results for academic studies. Thus, policy analysts may use and further improve my research framework to evaluate the comprehensive impacts more accurately, or to measure the economic impacts of other problems with similar properties. My calculation results and policy-discussion analysis may also be a reference for regional planners, for reasonable and effective planning for water resources and disaster preparedness.

Chapter 2
AN OVERVIEW OF YELLOW-DUST STORMS IN CHINA

To evaluate their comprehensive impacts accurately, I start with a literature review of yellow-dust storms in China. First, I briefly introduce the causes of yellow-dust storms. Then, I summarize the recorded impacts of yellow-dust storms in recent years and compare the characteristics of yellow-dust storms with those of other natural disasters. Based on the discussions of the comprehensive impacts of dust storms, I indicate the current research gap of economic-impact analysis of dust storms in China at the end of the chapter.

2.1 Causes of Yellow-Dust Storms

Analysts (e.g., Gao, Shi, Ha, and Pei, 2000; Zhu and Zhou, 2002) agree that yellow-dust storms can only occur with the co-existence of three factors: (1) strong winds that are sustained enough to pick up the particles and carry them into the atmosphere; (2) a source of sand, which usually comes from areas that are deserts; and (3) thermally unstable air. They also agree that atmospheric conditions, topography, global climate, and stocks of water resources influence the formation of a yellow-dust storm. Meanwhile, scientists maintain that human activities have recently significantly intensified the yellow-dust storms. Excessive exploitation of natural resources, including over-grazing on grasslands, depleting forests for lumber production, and converting natural lands into agricultural fields, have dramatically increased desertification and water-resource shortages. In addition, intensive infrastructure construction and maintenance in the open air have provided more sand and dust sources susceptible to wind. Therefore, the exacerbation of yellow-dust storms involves both natural and human influences. The causes of yellow-dust storm cannot be effectively controlled locally. The key reason is that a dust storm is a transboundary environmental problem: the affected regions may not necessarily be the source of yellow-dust storms, and the source region may not bear all the impacts of a particular yellow-dust storm. An analyst likewise confronts difficulties in capturing all the impacts of yellow-dust storms with data from a single region.

2.2 Recorded Historical Impacts of Yellow-Dust Storms

Given that a yellow-dust storm is an environmental problem with manifold impacts, I believe that the impacts can be captured best by reviewing the environmental factors characterizing a yellow-dust storm; namely, severe winds, high concentration of particulates, and dry and cold air. Because environmental conditions influencing the formation of yellow-dust storms vary from region to region, the economic impacts on different sectors in each region also vary. I will present an example with actual numbers in my case study of Beijing (see Chapters 4 to 5). In this section, I give only a general summary of the impacts, which may not prove exhaustive as scientists gain more understanding of yellow-dust storms.

2.2.1 Impacts of Severe Winds During Yellow-Dust Storms

Wind intensity in pastures and deserts is generally higher than in urban areas during dust storms. The average wind velocity during a yellow-dust storm usually exceeds 11 meters per second (m/s) and can be as high as 25 m/s in pastures, which is strong enough to knock down trees, pick up cattle, and even destroy houses.[1] Severe winds in a dust storm commonly damage farming facilities, electricity pipelines, houses, livestock, and trees. Severe winds also have strong disruptive impacts on socioeconomic activities. Some typical examples include interruption of construction and mining and interference with outdoor activities such as commuting, shopping, dining, and traveling.

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[1] Source: Online information posted by Committee for Disaster Reduction in Jiangxi Province, China, at http://www.weather.org.cn/JX_ZHJZ/kepu/13dafeng.asp. Accessed on April 30, 2003.

Severe winds have been shown to result over time in soil erosion and corresponding decreases in crop yields. Severe winds may easily remove the topsoil, which is generally more loose and permeable to air and more fertile than deeper soil material. Most plants, including vegetable crops, grasses, and tree crops, obtain their nutrients from the topsoil. As soil erosion by wind continues, the soil therefore is degraded. [2] Zobeck and Bilbro (1999) showed numerical evidence of soil erosion by wind based on their nine-year study in west Texas in the United States. They compared the soil productivity of four plants on non-eroded and severely wind-eroded areas, while controlling other factors that may affect the productivity, and found that "the severely eroded soil produced lower yields than the non-eroded soil.... The amount of the reduction in yield varied with crop and specific yield parameters, but ranged from an average reduction of 28 percent for grain sorghum total dry matter in 1997 to an 83 percent reduction in forage sorghum grain yield in 1998. "

In addition, scientists have seen signs of impacts on biodiversity from severe winds during dust storms. In the last few years, news articles have noted that migrating geese were stranded in northwest China by severe winds and the sands after yellow-dust storms. Many geese starved to death. Possibly to avoid such risks, some migrating geese have begun to dwell in prairie lands in Inner Mongolia, rather than to migrate. [3]

2.2.2 Impacts of High Concentration of Particulates During and After Yellow-Dust Storms

Most immediately, a high concentration of particulates along with dust storms extensively interrupts outdoor activities, such as transportation, shopping, and tourism. Over time, particulates carried by dust storms have shown multiple impacts on both socioeconomic

[2] Sources: http://www.grenadianvoice.com/archives/220901/features5.htm, and http://www.agric.gov.ab.ca/agdex/500/72000002.html. Both were accessed on May 7, 2003.

[3] Many public media reported the news of the geese stranded by yellow-dust storms, e.g., Wentian Net, sponsored by China National Meteorological Observatory. Online service. www.tq121.com.cn.

activities and regional climate. These impacts are most intriguing and have attracted much attention from scientists (e.g., Zhang, Liu, Lu, and Huang, 1993; Lin, 2002; Zhu and Zhou, 2002).

A high concentration of particulates constitutes air pollution and decreases regional air visibility. According to the studies of Gao et al. (2002), from 1999 to 2000,18 out of the 43 days with serious air pollution in Beijing were related to yellow-dust storms. The decrease of visibility during dust storms increases traffic delays and accidents for both road and air transportation and generally decreases the revenue of all businesses through shorter working or business hours (Duan and Zhang, 2001, p.364).

In the long run, particulate matter (PM_{10}) can damage vegetation exposed to it by increasing disease, destroying leaf cells, and even killing the plants. Dust on the leaves of crops, trees, and shrubs inhibits photosynthesis and growth. Indirectly, particles carrying heavy metals can contaminate soil and vegetation. Once in the soil, heavy metals can accumulate to phytotoxic levels in vegetation and suppress growth. Moreover, particulate matter can scatter sunlight and cause a reduction in solar radiation, thereby affecting crop productivity.[4] In addition, particles can damage materials by providing corrosion stimulators and by accelerating the rate of degradation, thereby exerting impacts on manufacturing industries. Particles can, in some cases, also decrease the corrosion rate; "for example, basic particles may neutralize an acidic surface electrolyte" (Kucera, 2003).

Particulates' impacts on human health may be the highest among those of all the air pollutants. Studies have shown that a high concentration of particulates poses hazards to human

[4] Source: Minnesota Pollution Control Agency. Online information. "Criteria Air Pollutant: Particulate Matter (TSP and PM_{10}) in Minnesota." http://www.pca.state.mn.us/air/emissions/pm10.html. Accessed on May 6, 2003.

respiratory, cardiovascular, and ophthalmic systems, and modestly increases the mortality rate (ECON, 2000). Particulates carried by severe winds can even spread infectious diseases, such as foot-and-mouth disease (Kar and Takeuchi, 2002; Zhu and Zhou, 2002).

However, when interactions between airborne dust particles and atmospheric gases occur, these particles may show some positive impacts. Arimoto (2001) concluded that there are two major reactions of the particles: interaction with atmospheric oxidants like ozone (O_3) and interactions with sulfur (S) and nitrogen (N) cycles. Such interactions, interestingly, are shown to have neutralized acid rain in the East Asia region (Zhang, Liu, Lu, and Huang, 1993) and may repel part of the heat from the sun, thereby ameliorating global warming to some extent (Lin, 2002). In addition, by absorbing a great amount of nitrogen oxides (NOx) and sulfur oxides (SOx) emitted from vehicles, yellow-dust storms are presumed to be able to prevent the co-occurrence of photochemical smog (Lin, 2002). Dust particles containing iron (Fe) and phosphate (P) carried by strong winds in dust storms may also bring nutrition to oceanic organisms. [5]

2.2.3 Impacts of Dry and Cold Air Accompanying Yellow-Dust Storms

Along with severe winds, dry and cold air accompanying yellow-dust storms may also trigger some other disasters, such as fires and dramatic changes in temperature. In Inner Mongolia, records show that 96 fires occurred in 2001 partially because of the severe winds carrying dry air during dust storms. [6] In addition, temperature tends to change dramatically after dust storms, sometimes producing hailstones. Such temperature changes can have severe impacts

[5] Source: China Dust Storm Net. http://www.duststorm.com.cn/. Accessed on November 31, 2002.

[6] Source: http://www.enviroinfo.org.cn/Disasters/Sand_Storm/d051721.htm. Accessed on February 12, 2003.

on crops: some crops are damaged by severe winds and hailstones, while some crops are frozen, causing a severe loss of yield. [7]

2.3 Characteristics of Impacts of Yellow-Dust Storms in China

Dust storms in China have mainly occurred in the northwest, the western part of the northeast, and the north of China, which together comprise one the four biggest regions in the world affected by dust storms. [8] Although the total occurrences of yellow-dust storms have been fluctuating since the 1950s, severely strong dust storms have intensified in recent decades (Shi, Yan, Gao, Wang, Ha, and Yu, 2000; Lu, Wang, and Zou, 2001). Compared to other natural disasters, I observe that yellow-dust storms have the following characteristics that complicate the problem.

(1) Shorter occurrence length, but higher frequency.

Yellow-dust storms significantly intensify from March to May with a peak in April, as can be demonstrated by monthly records of their occurrences from 1971 to 1996 in Beijing (see Figure 2-1). Usually one dust storm lasts for only a few hours, but they may happen several times in just one day. Therefore, sometimes it is difficult to distinguish successive occurrences.

(2) Less evident socioeconomic impacts than other disasters.

Generally, yellow-dust storms result in only a few mortalities and little damage to buildings and infrastructure. This helps to explain why no official statistics exist about dust storms as natural disasters. In the long run, their cumulative effects, while not immediately apparent, may be more costly than the short-term impacts.

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[7] Source: http://www.enviroinfo.org.cn/Disasters/Sand_Storm/d041308.htm. Accessed on February 12, 2003.

[8] The other three regions locate in North Africa, Middle East, and Australia.

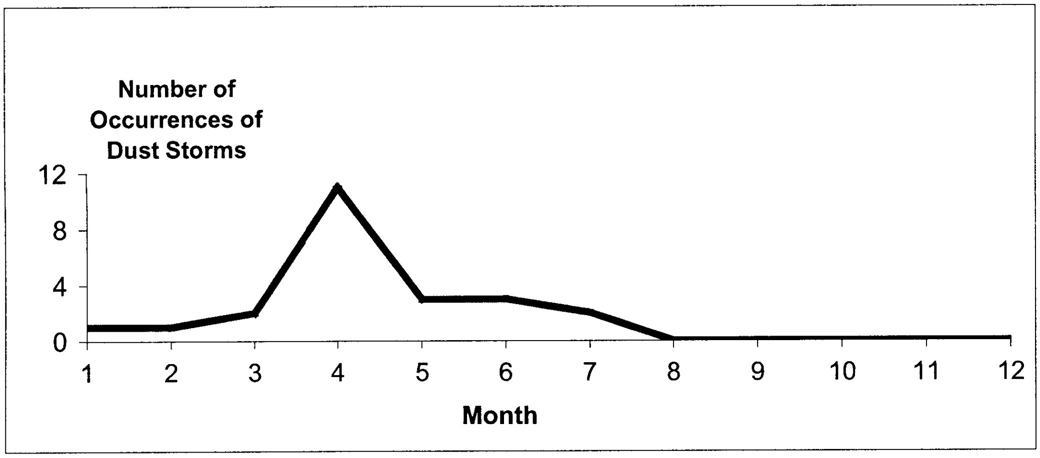

Figure 2-1 Monthly Records of Dust-storm Occurrences in Beijing, 1971-1996

Source: X.C. Liu, Y. Zeng, X.F. Qiu, and Q.L. Miao, 2002. "Sand-dust Storms Invading Beijing." *Journal of Nanjing Institute of Meteorology*, Vol. 25, No. 1. p. 120.

(3) Long-distance transportation and transboundary influence.

It seems that yellow-dust storms originating in Asia have longer transportation distances than most other disasters in the world. Domestically in China, it is recorded that there have been 17 provinces affected by yellow dust. [9] Internationally, their effects have reached Japan, Korea, Mongolia, and even North America. There are great uncertainties about how yellow dust is transported and about how its effects vary among the affected regions.

(4) Manifold impacts.

Although public attention has commonly focused on the negative impacts of dust storms, quantitative studies have revealed some positive effects, such as neutralization of acid rain, absorption of part of the heat from sunshine, and prevention of the occurrence of photochemical smog (Lin, 2002; Zhang, Liu, Lu, and Huang, 1993), as mentioned in the previous section.

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[9] Source: China Dust Storm Net. http://www.duststorm.com.cn/script/ReadNews.asp?NewsID =204&BigClassID=23&SmallClassID=72.

Because these positive benefits are likely to offset some of the losses from dust storms, I have integrated both positive and negative impacts in my analysis, rather than following traditional disaster analysis by merely focusing on economic-loss estimation.

(5) Unknown human behavioral responses.

Although dust storms tend to affect human behavior and decisions regarding shopping, transportation, cleaning, traveling, and so on, there are no records indicating how the public and private sectors respond to yellow-dust storms. Because the use of hazard insurance is underdeveloped in China, neither is there any information on the expenditures induced by yellow-dust storms at a regional level.

In conclusion, an integrated economic-impact analysis of yellow-dust storms demands a large variety of statistics, which cover everything from the ecological environment to socioeconomic activities. Unfortunately, systematic information in China is far from adequate, which helps to explain the research gap of economic-impact analysis of dust storm, as I discuss in the methodology section.

Chapter 3
METHODOLOGIES FOR ECONOMIC-IMPACT ANALYSIS OF DUST STORMS

I divide the methodology of my impact analysis into two parts: (1) categorization of comprehensive impacts of dust storms, and (2) evaluation of those impacts in economic terms. I first discuss current research gap of impact categorization across disciplines and propose an integrated research framework to evaluate the economic impacts of yellow-dust storms. Then, I summarize and discuss the available techniques to quantify the impacts in my proposed research framework.

3.1 Categorization of Impacts of Yellow-Dust Storms

Both the methods of categorizing information and the selection of the impact categories themselves may directly influence the accuracy and correctness of the results of economic-impact analysis. I elaborate on categorization issues mainly out of two considerations. First, because yellow-dust storms have shown diverse and manifold impacts (as I discussed in Chapter 2), categorization methods are especially important for further quantitative analysis. Second, scholars in different disciplines do not have a uniform framework of disaster categorization, which prevents me from doing a simple summation of different types of impacts in economic terms. I find the following five challenges most problematic for a systematic impact analysis.

First, analysts in different disciplines emphasize different aspects of impacts and correspondingly exclude some aspects of the impacts. Although each analyst covers a portion of the impacts, total impacts are not a simple summation of the impacts examined in different disciplines.

Second, for the same impacts, analysts in different disciplines may analyze from different perspectives and with different implications. In the case of yellow-dust storms, analysts in different disciplines may treat the expenditures on the prevention of air pollution in different ways. Environmental economists regard the increases in expenditures as costs to both households and the public, but regional economists may view the expenditures from a regional perspective and count them as increases in sales and investment, consequently as increases in regional output. Because different analysts emphasize different impacts in line with their own research needs and interests, there is no single standard by which to judge among the categorization methods. In other words, an analyst needs to clarify his/her research objectives before adopting a categorization method.

Third, seemingly similar concepts with different definitions across disciplines further complicate transboundary impact analyses. Two of the most obvious examples are definitions of "direct impacts" and "indirect impacts." First, regional-economic analysts regard investment in dust-storm control as "direct impacts," but scientists in other disciplines either treat it as "indirect" or exclude it from the impact evaluation. Second, regional-economic analysts specifically define "indirect impacts" as the impacts resulting from economic sector interaction, namely, inter-industry transactions, while in other disciplines, analysts define "indirect impacts" as covering all the impacts resulting from direct impacts. Moreover, only regional economists distinguish the impacts on households (as "induced impacts").

Fourth, not all impacts can be quantified accurately, such as frustration and anxiety during dust storms, changes in migration patterns of geese, and the nutritive elements brought by dust storms to ocean organisms. Even for quantifiable impacts, different analysts may use different metrics to quantify them. The measurements can be dollars, or workday losses, or concentration of atmosphere pollutants. To integrate all types of impacts, an analyst primarily needs a uniform measurement, such as a monetary economic measure.

Fifth, analysts do not provide a uniform definition for the time span of the impact analysis in order to separate short- and long-term impacts. In other words, analysts do not agree whether one day, one year, one decade, or even longer after a dust storm is "long-term."

These five problems are likely to result in mistakes easily being made by analysts when they borrow others' results, and they are also likely to lead to duplicate work by researchers in different disciplines. To mitigate these problems, analysts first need to identify the focus and objective of their impact analysis and select a key approach. Second, analysts should incorporate currently available classifications to the greatest extent possible, rather than coin many new terms, in order to define a visually simple, but complete, categorization framework and to facilitate further data sharing within one discipline or across several.

To measure the comprehensive impacts of dust storms in economic terms on a regional economy, I have adopted regional economic-impact analysis as the key approach and extended my evaluation of impacts by integrating other approaches when possible. I present my proposed economic-impact categorization framework in Table 3-2, and compare each category with that in other disciplines. I also summarize all the impacts (covering economic, environmental, and social aspects) that I can quantify in my economic-impact analysis, and those I cannot capture at this moment.

In my economic-impact categorization framework, I mainly follow the economic-impact definitions in regional-economic analysis, which include direct, indirect, and induced. Under the category of direct impacts, I have further classified the economic impacts into "immediate impacts" and "delayed impacts" in terms of occurrence time. I define immediate impacts as those occurring during dust storms and delayed impacts as those existing (or even strengthening) after a period of time subsequent to dust storms. With such definitions and categorization of direct impacts, I can extend traditional economic analysis by integrating several aspects of environmental and social impacts when quantifiable.

Corresponding to the definitions of immediate impacts in regional economics, I can include acute environmental impacts of yellow-dust storms, such as pollution in the air and water, and subsequent social impacts, such as eye-infection-related diseases. For delayed impacts, theoretically, they should include impacts happening over an infinite time; however, due to the constraints of the static input-output technique that I employ for my calculations, I limit the delay impacts in my analysis to one year. Within the one-year study period, I can include cumulative environmental impacts, such as soil erosion, reduction in nitrogen oxides (NOx) and sulfur oxides (SOx) in the atmosphere, and equipment corrosion. Also, I can integrate the impacts on health into my economic-impact analysis. For other intangible impacts, I may not be able to capture them within a one-year study. One example could be preference changes in travel and investment, because I predict that in the springtime, travelers may consider changing their itineraries to more southerly cities where dust storms are less severe, and investors may choose other places with better environmental conditions to hold conferences or set up new branch offices. Such changes, if they exist, may have sizeable impacts on regional economies. Thus, I would be able to evaluate the delayed impacts more accurately if I extend this to a dynamic input-output analysis when additional data are available. In addition, because many environmental resources are not tradable in commercial markets, such as migrating birds, I will only be able to quantify the parts of the economic impacts that can be reflected in the market. Therefore, I assume that yellow-dust storms tend to have greater delayed or cumulative impacts than immediate impacts, and the results from my study tend to be underestimated results.

So far, my analysis has focused only on the economic-impacts reflected on each sector. To capture the impacts caused by inter-sector interactions, I also examine “indirect” and “induced” impacts as commonly examined by regional input-output economists. “Indirect impacts” refer to effects resulting from the sectors’ purchasing and selling interactions with directly affected sectors. “Induced impacts,” in my study, refer to household expenditure changes due to both direct and indirect impacts. Quantitative analysis of indirect and induced impacts may provide an accurate basis for tangible indirect losses and intangible losses as used in natural disaster assessment.

By setting up the research framework above, I regard it as the currently best solution to quantify the comprehensive impacts accurately, without duplication and with the least omission of impacts. I continue with a discussion of multidisciplinary methodologies, in particular for mitigating the challenges in inadequate data and diversified impacts.

3.2 Economic-Impact Evaluation Techniques

I conduct a literature review of the available techniques analysts have developed to measure economic, environmental, and social impacts. I discuss the applicability of these techniques to yellow-dust storms by reviewing them from two perspectives: a regional- economic perspective and an environmental-economic perspective. I apply the regional- economic-impact analysis as the main technique in my study and select appropriate environmental-economic techniques to supplement the traditional economic analysis and provide the numerical data required for regional-economic-impact analysis. In addition, I introduce a benefit-transfer approach and sensitivity analysis methods to mitigate the problems caused by inadequate data and information.

3.2.1 Regional-Economic-Impact Analysis

Regional economists have commonly agreed that input-output models are the core technique for regional-economic-impact analysis, and recently they have developed several modified models based on traditional input-output analysis. I focus first on the input-output models that I use for my economic-impact analysis case study, and then I briefly discuss other modified models. In this section, I mainly focus on their applicability for impact evaluation of yellow-dust storms, while introducing the basics of input-output models in Appendix A.

3.2.1.1 Input-Output Techniques

Wassily Leontief developed the input-output model in 1936 (Lewis, J. A., 1988, p.172), which disaggregates the economy into individual sectors, and traces detailed statistical information of the flow of goods and services among the producing and purchasing sectors in input-output tables. Also reflected in input-output tables are intermediate transactions among different levels of producers and purchasers (Bendavid-Val, 1991, p. 88; Polenske and Fournier, 2002, p. 205). Thus, analysts can measure the economic impacts on a regional economy caused by inter-sectoral interactions using the numerical information in an input-output table.

Analysts commonly trace economic impacts on a region's output based on the basic relationship in an input-output model:

$$AX + Y = X \qquad (3.1)$$

After transformation of Equation (3.1), analysts can derive the Leontief input-output relationship as below:

$$X = (I-A)^{-1}Y; \text{ or, } \Delta X = (I-A)^{-1}\Delta Y \qquad (3.2)$$

where:

A = matrix of direct-input coefficients (a_{ij});

$(I\text{-}A)^{-1}$ = Leontief inverse indicating input-output relations among sectors;
X = matrix of total output of every sector;
ΔX = changes in total output;
Y = matrix representing the final demands for all the sectors; and
ΔY = changes in final demands.

That is to say, analysts may trace the economic impacts by examining changes in final demand, as generated by demand-driven effects, or what analysts call backward linkages. Numerically, analysts may derive the economic impacts on each sector as well as the whole region's output (X), by multiplying the Leontief inverse matrix $(I\text{-}A)^{-1}$ by the changes in the final demand matrix Y.

To derive the total economic impacts caused by forward linkages among sectors, I derive the equation from the vertical relationship in an input-output model. Namely, total inputs are the sum of intermediate inputs and primary inputs (value added).

$$F^T X + V = X \tag{3.3}$$

where:

F = the matrix of f_{ij} ($= x_{ij}/x_j$) or each element of the intermediate inputs divided by the row sum;
X = the matrix of total output of every sector;
V = a matrix representing the value added of every sector.

Because input-output models bear the characteristics of equal total outputs and total inputs, I can derive the total changes of regional input/output caused by forward linkage effects in Equation (3.3). In other words, I calculate the changes in regional economy by examining the changes in value added in the affected sectors.

$$X = (I - F^T)^{-1} V; \text{ or, } \Delta X = (I - F^T)^{-1} \Delta V \tag{3.4}$$

where:

$(I\text{-}F^T)^{-1}$ = Leontief inverse of the transpose of the F matrix;
ΔX = changes in total output;
ΔV = changes in final demands; and
F, X, and V have the same meaning as shown in Equation (3.3).

Given the open model currently available, I extend it into a partially closed model for economic-impact analysis of yellow-dust storms. That is to say, I treat households as endogenous to the regional economy. A partially closed model with regard to households is more suitable in the case of economic-impact evaluation for two reasons. First, the household sector is one that is affected by yellow-dust storms, involving property loss, health impact and corresponding increases in expenses, and other factors. Second, from an economic perspective, the household sector plays an important role as the supplier of labor; thus, it can induce reasonable ripple effects in a regional economy. To distinguish the partially closed table from a traditional open table, I use an asterisk after the symbols of all matrixes, such as A* and F*.

3.2.1.2 Other Input-Output-Derived Techniques

Using the basic single-region input-output models, researchers have developed interregional and multiregional input-output models (Miller and Blair, 1985; Polenske, 1995). In addition, researchers have discussed input-output econometric (IOE) analyses and computable general equilibrium (CGE) analyses (Johansen, 1964) as ways to remedy the weakness of the static property of traditional input-output models (OESR, 2003). In recent years, Chen (1992) has incorporated those resources that are indispensable, but may not be directly consumed by production, such as land, fixed assets, and capital flows, into traditional input-output analysis, which he calls input-occupancy-output (IOO) tables (Chen, 1992) and many analysts refer to them as "extended input-output tables." Furthermore, he has compiled and applied the extended input-output tables in water-resources planning in China (Chen, 2000). Analysts use all of these techniques in order to identify "changes in a local economy resulting from a stimulus (positive or negative) to a particular segment of the economy" (Davis, 1990, p. 5) and to achieve more accurate results than traditional input-output analysis. However, because of the large demand for statistics, analysts have made until now only very limited application of these modified input-output techniques to economic-impact analysis.

Regarding economic-impact analysis of yellow-dust storms in North China, an integration of the extended input-output table and econometric analysis is most desirable, because yellow-dust is an historical environmental phenomenon, which involves resource issues and changes over time. However, due to the lack of systematic sets of time-series data, currently I can only implement a traditional input-output analysis, mainly targeting evaluation of sector-interaction impacts of yellow-dust storms.

3.2.2 Environmental-Economics Techniques

As I have shown, input-output techniques only accommodate information input in economic terms. They normally do not capture non-economic aspects or environmental issues or cumulative effects, such as soil erosion and climate change. To capture the environmental or intangible impacts not directly reflected in the common goods markets, environmental economists have investigated many ways to quantify environmental resources in order to incorporate them into traditional economic analysis. I summarize and divide the environmental-evaluation techniques into two categories: market-based and indirect environmental-evaluation techniques.

3.2.2.1 Market-Based Environmental-Evaluation Techniques

Analysts use market-based evaluation techniques to connect the environmental impacts and socioeconomic activities and to evaluate the impacts through examining changes in socioeconomic activities. Thus, some researchers (e.g., Freeman, 1993) also call market-based evaluation techniques “direct-evaluation methods.” Three typical market-based evaluation techniques include: dose-response analysis, market-value method, and human-capital method.

Dose-Response Analysis

Dose-response analysis is "a component of risk assessment that describes the quantitative relationship between the amount of exposure to a substance and the extent of toxic injury or disease caused by such a substance" (SRA, 2003). Scientists derive the "quantitative relationship" for a region from regression analysis of sample statistics and apply the result to estimate possible impacts of pollutants on human health. Because socioeconomic and environmental conditions (such as the utilization of energy, the composition of the stock of vehicles, the age distribution, and the overall health status of the population) are different from region to region, dose-response functions are theoretically region-specific and time-specific. Scientists thus need to adjust the coefficients when they borrow dose-response functions derived in other countries or regions (Aunan and Li, 1999; quoted from ECON, 2000).

I present a list of applicable dose-response functions of the airborne substances related to dust storms in Table 3-3. By referring to these functions adjusted by Aunan and Li and recommended by ECON, I can estimate the number of people affected by yellow-dust storms when corresponding meteorological records are available. What complicates my impact analysis and also challenges the accuracy of dose-response functions is that the effects of dust storm related air pollutants--NOx, PM_{10}, and SO_2--are chemically and biologically interrelated.[10] In addition, yellow-dust storms may result in both increases and decreases in the concentration of airborne pollutants and the co-existence of negative and positive impacts offset each other to some unknown extent (see Chapter 2). Thus, the total impacts of yellow-dust storms are not a summation of effects of all the pollutants listed in the table. My strategy is to focus on the

[10] Discussed by Aunan and Li, 1999. Quoted from "An Environmental Cost Model" by ECON Center for Economic Analysis, 2000.

dominant pollutant, and then make rough estimates of minor impacts of other pollutants. By doing this way, I can capture the most serious impacts while cancelling minor positive and minor negative impacts, thereby avoiding large biases.

In particular, I focus on particulate matter (PM_{10}) as the main medium by which dust storms affect the atmosphere negatively, because PM_{10} appears to be the dominant variable in exposure-response functions for several kinds of damage to respiratory and cardiovascular systems (ECON, 2000). For purposes of analysis, I note that particulates, NO_x, O_3, and SO_2 all show much looser numerical relationships than PM_{10} but pose similar hazards to human respiratory and cardiovascular. Thus, I assume that the effects of particulates' absorption of nitrogen (N) and sulfur (S), as well as the interaction with O_3, are minor and not significant until at least one year afterwards. Furthermore, I assume that the minor negative impacts cancel the minor positive effects of decreases of N and S in the atmosphere. Then, I can calculate the difference of negative and positive impacts of dust storms by particulate matter to derive the total impacts on human health, as I demonstrate in my case study in Beijing.

Market-Value Method

Analysts also call it as the "Changes-in-Productivity Approach." In other words, analysts evaluate the changes in environmental conditions by determining the market value of changes in productivity. For example, analysts can estimate the impacts of water pollution by calculating the losses in fishery production, or the impacts of soil degradation by calculating the changes in the yield of certain crops grown on those lands affected by yellow dust. To transform these impacts into a monetary value, analysts can multiply the losses in productivity by the market value of the crops.

In my study, I have adopted the market-value method to evaluate the impacts of yellow-dust storms on agriculture. In particular, I borrowed the relationship of crops and particulates discovered by Chameides et al. (1999). They concluded that "high concentrations of particulates are currently depressing by 5–30% optimal yields of about 70% of the crops grown in China." This finding enables me to conduct a market-value approach to quantifying the impacts of particulates carried by yellow-dust storms (see Chapter 5).

The market-value method is apparently the most straightforward approach to evaluate the value of natural resources. However, because not all environmental resources are sold in the common market, the applicability of this method is very limited for economic evaluations.

Human-Capital Method

Analysts use the human-capital method to evaluate the economic loss caused by health impacts on those working people exposed to environmental pollution. The calculation method is to multiply the number of lost working hours caused by health problems by the sum of the value the workers would have produced per hour and their health-care costs. When environmental pollution or natural disasters result in any mortality, analysts also use the human-capital method to estimate the total losses from death by calculating the potential household income in the remaining lifetime. In this regard, the human-capital method has involved the opportunity-cost approach, which measures the foregone property, resources, and human lives by the maximum value they could have produced. Thus, different people claim the value of a lost life within a broad range, which implies different ethical values.

In my study, I use the human-capital method to evaluate the economic value of workday losses due to air pollution during dust storms. Because the dust storms I evaluate in my case study did not result in any known deaths immediately, I assume that my estimation using the human-capital method will not involve a wide range of bias resulting from different valuations of human life.

3.2.2.2 Indirect-Evaluation Techniques

Although market-based techniques are intuitively easy to apply, they can only capture tangible impacts that are directly reflected in economic activities. More often than not, environmental and social impacts are intangible, and they are neither traded nor reflected in the markets for common goods. Even for tangible impacts, analysts may not always have access to quantitative relationships. Thus, environmental economists have developed several techniques based on questionnaires and surveys, which are called "indirect techniques" (Freeman, 1993). A brief list of various indirect-evaluation techniques includes:

Contingent-Valuation Methods (CVM): Analysts use surveys to induce people to express their willingness to pay (WTP) or willingness to accept (WTA); then, they determine the economic value of environmental conditions by WTP or WTA. This method is applicable for all types of environmental impacts but may involve possible biases in interviewees' responses.

Hedonic-Property Methods (HPM): Analysts collect data on housing sales prices and housing characteristics to estimate the demand function, and then they estimate the value of local environmental amenities when controlling other factors to be the same. Analysts need to confirm that the real-estate markets to be examined are active and healthy. But still, it is hard to separate other factors that may influence the prices of housing sales.

Travel-Cost Methods (TCM): Analysts collect data on visitation rates, origins, and demographic characteristics to estimate the recreational benefits of accessible resorts. Accordingly, this method is particularly and exclusively helpful to evaluate the environment at tourism resorts, and analysts may easily omit variables when setting up demand functions. Thus, the range of this method's potential application can be very narrow.

Analysts have applied these indirect evaluation techniques in many settings worldwide, and each of them has shown its advantage in certain areas. However, empirical studies have shown a wide range of results of indirect evaluations, even when applying the same technique in the same region (Freeman, 1993; Xu, 1998). More practically, these approaches require more time and resources than I have available for the impact analysis. Thus, I have not selected these indirect-evaluation techniques to quantify the environmental impacts.

3.2.3 Benefit-Transfer Approach

When there is a lack of data, scientists borrow damage-assessment data from a region where reliable statistical information is available under similar conditions for use in the study region, and then they adjust the data by the ratio of several economic indexes. This is called the "Benefit-Transfer Approach."

This technique proves helpful in the case of the yellow-dust storm impact evaluation, because in China economic-evaluation techniques are underdeveloped and only very limited economic-loss statistics are currently available. Therefore, although there is a risk that this approach may introduce inaccuracies when borrowing and modifying economic-loss data from other countries, this approach provides a reference for quantitative analysis.

For example, I concluded after investigation that there are no cost data for traffic delays in China. After reviewing relevant studies in other countries, I noticed a statistic in the United

States: “the cost of a diverted flight can be as high as $150,000 and a cancellation close to $40,000” (Irrgang and McKinney, 1992, quoted from an online article by Qualley W.L.). As a follow-up, I located the data for value added of transportation sectors in China and the United States in 1992, the currency exchange rate, and the China Price Index from 1992 (the year with estimated data) to 2000 (the year I examine), and then conducted numerical calculations.

Another possible application of the benefit-transfer approach is as a calculation method for indirect impacts. In previous statistics, most indirect losses are recorded not as numerical data but in words, because researchers do not agree on a uniform boundary for indirect impacts nor on an appropriate methodology to evaluate them. Some researchers derive monetary values for the impacts through multiplying direct losses by a coefficient. For instance, under the circumstance of an earthquake, Grigg suggested that such a coefficient could range from 0.3 to 0.5 (Wang 1997). In other words, if the direct impacts of an earthquake were one million dollars, then the indirect impacts could be between 0.3 million and 0.5 million dollars. It is evident that such results may vary greatly when different researchers estimate indirect losses using different coefficients. If we were to apply such coefficients to evaluate the impacts of yellow-dust storms, it would seem to be too vague and unpersuasive. Hence, I do not adopt such coefficients for my study.

3.2.4 Sensitivity Analysis

Rather than evaluating any certain type of impacts, sensitivity analysis (SA) “aims to ascertain how the model depends upon the information fed into it, upon its structure and upon the framing assumptions made to build it" (ISIS, 2003). In other words, sensitivity analysis (SA) can predict how the variation in the output of a model varies dependent of different sources of variation. I believe that it is particularly helpful to remedy the extensive uncertainties of yellow-dust storms and therefore enhance the reliability and accuracy of my calculation results. Thus, I have conducted a sensitivity analysis in addition to my current estimates in my case study, indicating both lower and upper range of the results. However, my sensitivity analysis is limited to an evaluation of those impacts that can be quantifiable or that I can locate evidence to make estimates. This would still exclude impacts such as biodiversity or human psychological changes. Thus, my upper estimate in the sensitivity analysis may still underestimate impacts of yellow-dust storms.

Because each of the techniques I have discussed above has its unique advantages and limitations, I need to combine the most applicable techniques in my integrated-impact analysis. One example is that I will combine dose-response analysis and human-capital method to derive economic implications from environmental indicators. In this way, I can determine the economic implications of environmental and social aspects and measure them in one dimension as I show in the research framework in Table 3-2 and I calculate in my case study in Chapters 5-6.

Table 3-1 Comparisons of Different Approaches for Economic-Impact Analysis

Approaches	Categories	Sub-categories	Definitions	Examples	Comments
Social Science-Natural Disaster Assessment of Economic Aspect	Tangible Direct Losses	Primary Losses	Immediate physical destruction of property and loss of life.	Collapse of buildings, farmhouses.	Most easily captured and calculated.
		Secondary Losses	Instant and direct outcomes of primary effects.	Fire or diseases after a hurricane.	In some analyses, secondary losses are identified as indirect losses.
	Tangible Indirect Losses		Long-term economic impacts on the region that occur as a result of direct economic losses.	Changes in unemployment or sales. Changes in number of economic immigrants.	1. Considerable variation, especially in the estimation of indirect costs, exists in the methods used to estimate past disaster costs. 2. No simple relationship exists between indirect and direct costs of a disaster. Previous disaster reports indicate that, as a broad estimate, indirect costs are usually in the range of 25 to 40 percent of direct costs (Gentle et al., 2001).
	Intangible Losses		Captures all the other losses that are either tangible or embodied with market value.	Visitors' preferences for traveling to a city.	There are very few methods for the estimation of intangible costs.

Table 3-1 Comparisons of Different Approaches for Economic-Impact Analysis (Continued)

Approaches	Categories	Sub-categories	Definitions	Examples	Comments
Regional Economic-Impact analysis	Direct Economic Impact		Initial, immediate effects caused by a specific activity, subsequently initiating iterative rounds of income creation, spending, and re-spending.	Expenditures on investment associated with an activity.	
	Indirect Economic Impact		Effects that result from the actions of the processing sectors to produce the direct impacts.	Changes to production, employment, and incomes caused by new investment.	Indirect and induced impacts are derived from an input-output model by inputting direct impacts.
	Induced Impact		The effects of spending by the households in the regional economy as the result of direct and indirect effects.	Changes in the earnings and spending patterns of the households caused by the direct and indirect changes.	

Table 3-1 Comparisons of Different Approaches for Economic-Impact Analysis (Continued)

Approaches	Categories	Sub-categories	Definitions	Examples	Comments
Environmental-Impacts Scientific Assessment	Acute Environmental Impact	Air Water Noise Soil	Immediate and direct effects on the ecosystem and on public health.	Air and water pollution after an earthquake.	
	Cumulative Environmental Impact	Air Water Noise Soil	Long-term and accumulating effects.	Infectious diseases transported by a hurricane.	Hard to capture and perceive.
General Impact Assessment	Local Effects		Effects that occur only in local areas.	Pollution caused by solid waste.	
	Regional Effects		Effects that may extend through out a region or to multiple regions.	Pollution caused by acid rain.	
	International Effects		Effects that have influences beyond one country or even worldwide.	Climate change.	

Source: The author, based on literature review.

Table 3-2 Categorization Methods of Impact Analysis of Yellow-Dust Storms

Regional Economic Impacts		Corresponding Social Impacts	Corresponding Environmental Impacts	Impacts to Be Monetarized	Impacts Not Able to Be Included
Categorization	**Sub-categorization**				
Direct Impacts (Individual Sector Analysis)	Immediate	Tangible Primary Losses	Acute Impacts	Damage to crops, animals, infrastructure, and plants.	Psychological impacts.
				Disruption of socioeconomic activities.	
				Diseases due to acute environmental pollution.	
	Delayed	Tangible Secondary Losses	Cumulative Impacts	Health impacts.	Regional atmospheric changes.
				Wind erosion and soil erosion.	Influences on biodiversity.
				Material corrosion by particulates.	Any other direct-economic impacts that fall out of one-year range.
Indirect and Induced Impacts (Inter-Sector Analysis)		Tangible Indirect Losses and Intangible Losses		Changes in business and employment through inter-sector interaction.	Any other indirect and induced economic impacts that fall out of one-year range

Source: The author.

Table 3-3 Dose-Response Functions for Impacts on Health from Air Pollution[11]

Response	Indicator	Percentage of Annual Increase Rate per $\mu g/m^3$	Threshold ($\mu g/m^3$)	Source (Secondary)
Mortality rate	PM_{10} SO_2	0.04 (0.00-0.6) 0.12 (0.09-0.16)	0 50	PM_{10} coefficient combines acute (short-term) and chronic (long-erm) effects. SO_2 is acute, but high compared with most studies. Acute coefficients from Aunan and Li (1999). Chronic coefficient from EC (1998a). Impacts on child mortality included in the estimate.
Hospital admissions	PM_{10} SO_2	0.11 (0.07-0.14) 0.21 (0.0-0.34)	0 50	Aunan and Li (1999)
Hospital admissions for respiratory disease	PM_{10} SO_2	0.25 (0.13-0.38) 0.25 (0.13-0.38)	0 50	Aunan and Li (1999) Note: This is a subgroup of hospital admissions.
Hospital admissions for chronic obstructive pulmonary disease	PM_{10} SO_2	0.07 (0.0-0.13) 0.04 (0.0-0.08)	0 50	Aunan and Li (1999) Note: This is a subgroup of hospital admissions.
Emergency room visits	PM_{10} SO_2	0.011 (0.003-0.02) 0.037 (0.023-0.052)	0 50	Aunan and Li (1999)
Hospital outpatient visits	PM_{10} SO_2	0.054 (0.023-0.086) 0.021 (0.0018-0.024)	0 50	Aunan and Li (1999)
Work day losses	PM_{10}	0.4 (0.2-0.6) (days)	0	Aunan and Li (1999)
Symptom days	O_3	0.033 (days)	120	EC (1998a)
Asthma attacks	PM_{10}	0.06 (0.03-0.20)	0	WHO (1999a), Aunan and Li (1999)

Source: ECON Center for Economic Analysis, 2000. pp. 21-22.

Note: O_3: ozone;

PM_{10}: particulate matter less than 10 but larger than 2.5 micrometers in size;

SO_2: sulfur dioxide.

[11] This is an abbreviated list of the coefficients recommended by ECON Center for Economic Analysis, 2000, commissioned for the World Bank. I based the list on ECON's recent literature review on health impacts from pollution, compiling the research results by Aunan and Li (1999), the European Commission (EC, 1998a), the World Health Organization (WHO, 1999a) and the Asian Development Bank (ADB, 1996).

Chapter 4

CASE SELECTION OF BEIJING IN 2000 AND RESEARCH DESIGN

To analyze the economic impact of yellow-dust storms, I decided to conduct a case study of Beijing in 2000. In this chapter, I briefly explain my reasons for this case selection, considering location, time period, and scope. Then I demonstrate and discuss the data availability for a regional economic-impact analysis of yellow-dust storms in Beijing, as a basis for my quantitative analysis in Chapter 5.

4.1 Considerations in Case Selection

I have selected Beijing as the domain of my regional case study for two reasons. First, and the key point, is the constraint of data availability. Because policy makers have not regarded yellow-dust storms as disasters until recently, even now they exclude dust storms from the *China Disaster Statistics Yearbook*. Consequently, I cannot find adequate data for a national or multiregional analysis. For any quantitative analysis in a single region, I can rely only on individual scientific studies for second-hand data. As the national capital, Beijing has attracted many scholars' attention regarding dust-storm problems, and scholars have accumulated more information than for any other region in China. The advantage of data accessibility in Beijing determined my case selection. My other concern is the scope of the economic impacts. Beijing may not have suffered as much as Inner Mongolia and Gansu province in agriculture; however, I regard Beijing as a good case for analyzing all kinds of economic impacts of yellow-dust storms. As a metropolis with a dense population and fast-growing socioeconomic activities, Beijing is more vulnerable than other less-developed regions to natural disasters, including yellow-dust storms, and is affected in more ways. As an empirical analysis covering all these economic impacts, my study can serve as a good reference for further economic-impact analyses, either for Beijing or for any other regions in China.

Because in 2000 northern China experienced the most intensive yellow-dust storms of recent decades (Yang, 2002), studies related to dust storms in that year are particularly plentiful. Therefore, I selected the year 2000 in Beijing as the time period of my study. Furthermore, because it is difficult to separate the manifold impacts of successive occurrences due to the characteristics of dust storms (see Chapter 2), I evaluate the total impacts of all occurrences of dust storms in Beijing in 2000. I present both meteorological and socioeconomic records of all these occurrences in Section 4.3.

4.2 Data Availability for Economic-Impact Analysis of Yellow-Dust Storms in Beijing

Before evaluating the economic impacts of yellow-dust storms on Beijing in 2000, I compiled relevant information in four categories: (1) background information on Beijing, (2) meteorological records, (3) socioeconomic statistics, and (4) a Beijing input-output table for regional economic-impact analysis. I discuss data availability issues one by one below.

4.2.1 Background Information on Beijing

As the national capital, Beijing is a major hub for transportation, communication, and trade. Beijing is also a focal point for culture, tourism, education, and scientific development. It has experienced rapid development and great changes in recent decades. In 2000, Beijing's gross domestic product (GDP) was 246 billion RMB (around 30 billion U.S. dollars[12]), representing a growth of 11 percent over the previous year, 1999.[13] Construction projects were undertaken in

[12] The exchange rate of U.S. dollars and RMB in 2000: 1 USD = 8.3 RMB (source: *http://www.x-rates.com/cgi-bin/hlookup.cgi*).

[13] It is calculated at comparable prices; that is, adjusted for inflation.

an area of 70 million square meters in 2000, up 6.7 percent from 1999. Both urban and rural retail sales suggested a growth rate of around 10 percent, with sales value up to 123,110 million RMB and 21,220 million RMB (around 15 billion and 2.5 billion US dollars), respectively. In recent years, figures show that the service sector has continued to contribute the most to the city's economic development; 53.8% of the GDP is contributed by tertiary industries (service-based industries). The city hosted some 2.82 million overseas tourists and 102 million domestic tourists in 2000.[14]

As one of the most densely populated regions in the world, Beijing has been among the top cities facing a water crisis in the recent century. Since the 1990s, water resources per capita have been less than 300 cubic meters, which is only one-eighth of the national average, and one-thirtieth of the worldwide average. Scientists estimated that in 2000, there was a water shortfall of 0.4 billion cubic meters in Beijing.[15] Water shortages, especially during the spring, have contributed to the severe effects of dust storms in Beijing.

As a city undergoing dramatic development and vast infrastructure transformations, Beijing has also faced severe environmental problems. With a large amount of investment in improving environmental conditions, Beijing has shown decreases in air pollution in recent years. However, it still faces a huge burden of pollution. In addition to the discharge of sulfur and nitrogen oxides from the millions of vehicles, records indicate that the monthly dust fall per square kilometer is up to 15.5 tons in the metropolitan area, showing particulate pollution to be an important presence in the local atmosphere. [16] Moreover, thousands of open construction

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[14] Source: People's Daily Newspaper. Online news for March 3, 2001. http://fpeng.peopledaily.com.cn/200103/03/eng20010303_63990.html. Accessed on May 7,2003.

[15] Source: People's Net. Online news for June 25, 2000. http://www.peopledaily.com.cn/GB/channel1/topic1737/. Accessed on February 27, 2003.

[16] Source: The Environmental Annual Report of 2000, published by Beijing Environmental Protection Bureau online at http: www.bjepb.gov.cn. Accessed on May 7, 2003.

sites and large areas of open soil ground in Beijing also provided an abundant source of sand, generating a main local source of yellow-dust storms in Beijing.[17]

Located along the route of yellow-dust transmission in Asia, Beijing appears very vulnerable to being affected, with its dense population and socioeconomic activities. Moreover, the water crisis and the serious particulate pollution problem in Beijing may worsen the economic impacts. Given that yellow-dust storms are a transboundary problem, the impacts may be magnified locally and passed on to other regions. Thus, I assume that my regional analysis in Beijing is a typical case of examining the comprehensive regional impacts of yellow-dust storms, but it may only capture a portion of the economic impacts the storms have brought to China.

4.2.2 Meteorological Records of Yellow-Dust Storms in Beijing in 2000

Meteorological records show that there were 10 yellow-dust events in March and April in Beijing in 2000 (Table 4-1). Examining the meteorological data on all of these, I noticed that the event on April 6, 2000, had both the strongest wind and lowest visibility among all the recorded events. I located additional records showing that on April 6 the average concentration of particles (PM_{10}) until noontime was up to 1,500 micrograms per cubic meter ($\mu g/m^3$) across the city.[18] This shows a difference of as much as 1,338 $\mu g/m^3$ compared to the annual average level of 162 $\mu g/m^3$.

[17] The monitoring data from the Beijing Environmental Protection Monitoring Center show that 80% of the yellow dust currently affecting Beijing is dust elevated from the low atmosphere, while 20% is from the high atmosphere. Such information is also supported by the information in the online article at http://www.enviroinfo.org.cn/Disasters/Sand_Storm/b041306.htm.

[18] I calculated this number on the basis of the statement by Li and Gao (2001, p. 2) that "[t]he daily average concentration of inhalable particles at 12:00 pm was twice that of Grade Two in the National Ambient Standard." According to the National Ambient Standard, the concentration of inhalable particles (indicated by the PM_{10} measurement) of Grade Two was equal to 0.15 milligrams per cubic meter. Thus, I calculated that the daily average PM_{10} was around 1.5 milligrams, or 1,500 micrograms per cubic meter. Another record indicates that the concentration of instantaneous inhalable particles (PM_{10}) was up to 1,449 micrograms per cubic meter (Workers' Daily, April 7, 2000). Comparing these two data, I conclude that the peak PM_{10} occurred in the morning, and the dust storms diminished in the

It should be noted that the records shown in Table 4-1 are the daily average value of visibility and wind speed; the instantaneous value during a yellow-dust event can be much higher than the average. For example, on April 6, 2000, meteorological records indicated that instantaneous wind speed was up to Grade 9, which can destroy grass-made houses, lift house-tiles, and break trees (Xinhua Daily Telecommunications, April 10, 2000). The lowest visibility was about 300 to 400 meters (Duan and Zhang, 2001, p. 364), although the daily average recorded was two kilometers (see Table 4-1). Therefore, the event on April 6 should be regarded as a dust storm, according to the definition of dust storms (in Chapter 1).

Table 4-1 Meteorological Records of Yellow-Dust Events in Beijing in 2000

Date	Visibility (kilometers)	Wind Speed (meters/second)
March 3	4	6
March 18	8	10
March 23	10	13
March 27	10	12
April 4	8	9
April 6	2	10
April 7	8	11
April 9	8	11
April 25	7	5
April 29	10	10

Source: Beijing Meteorological Bureau. Quoted from G. Z. Wu and S. Y. Fan, 2000. "Inner Mongolia Is the Main Sand Source of Sand Storm in Beijing Region." *Inner Mongolia Environmental Protection*, Vol. 12, No. 4, p. 5.

Records for the other events are inadequate for testing one by one. I did not exclude any of these events from my dust-storm-impact analysis in 2000, because they either showed large wind speeds that were strong enough to cause significant impacts,[19] or showed low visibility that

afternoon. This conclusion supported my assumption that yellow-dust storms on April 6, 2000, only affected the city for half a day.

[19] Based on observation of the occurrence of April 6 and the meteorological information in Appendix E.

disrupted socioeconomic activities, as reported by newspapers and scientific articles during March-April 2000. [20]

4.2.3 Socioeconomic Statistics of Yellow-Dust Storms on April 6, 2000

Apart from the meteorological records, socioeconomic information on yellow-dust storms is scattered and very limited. I located applicable information only in newspapers and published reports, most of which focused exclusively on the occurrence on April 6, 2000. From my investigation, I conclude that only the socioeconomic statistics for the occurrence on April 6 in 2000 provide me with at least a skeleton for my quantitative analysis, as compiled and presented below.

On April 6, 2000, the strong wind blew down electricity lines, and it disrupted the operation of bank ATMs (*China Youth Newspaper*, April 7, 2000). Nearly 60 million square meters of construction sites shut down, and several shelters and granaries were damaged (Zheng, Wang, and Wang, 2000). Outdoor vendors closed business much earlier than usual.

At the Beijing National Airport, 48 flights were cancelled, 9 flights returned, 52 landing flights were transferred to Tianjin Binhai Airport, and 129 flights were delayed (Duan and Zhang, 2001, p. 364). More than 3,000 passengers were detained at the Beijing airport (*Workers' Daily*, April 7, 2000; quoted by NFBC, ed. 2000. *Focus on Dust Storm*). The traffic flow apparently decreased, and road accidents increased 20-30% over normal conditions (Duan and Zhang, 2001, p. 364).

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[20] Examples can be located in the book Focus on Dust Storm (NFBC, ed., 2000), which compiles information published in newspapers for dust storms in China.

People changed from bicycles to buses, subway, or taxis for commuting. Some even asked for a leave from work (*China Youth Newspaper*, April 7, 2000). There was no obvious increase in hospitalization for respiratory diseases; however, there were more patients coming in for problems related to eye infections (*Economic Daily*, April 7, 2000).

On an individual-sector basis, I summarize the affected sectors and corresponding economic impacts in Table 4-2.

Table 4-2 Socioeconomic Effects of Yellow-Dust Storms on April 6, 2000 in Beijing

Affected Sectors	Recorded Economic Impacts
Electricity Supply	Supply was disrupted by strong winds.
Construction	Many construction sites shut down.
Transportation	Many air-flights changed. Road accidents increased.
Trade/Commercial	Business was either disrupted or closed earlier than usual.
Households	People found difficulties in outdoor activities, including commuting. Emergency hospital visits increased for eye infections.

These are all immediate and tangible economic impacts after one dust storm, and they mainly involve the socioeconomic aspects in urban areas. Thus, I need to investigate other supplemental techniques and information to estimate other economic impacts when statistics are not available.

4.2.4 Availability of Beijing Input-Output Tables for Economic-Impact Analysis

To evaluate the socioeconomic impacts on a regional economy in 2000, I need a Beijing input-output table of that year. In reality, the latest Beijing input-output table currently available is for 1999. It is a single-region open table including 49 sectors, treating the household sector and other components of final demand as exogenous. The table has complete statistical information for intermediate and final demand transactions; namely, information for Quadrants I and II (shown in Table 4-3). This provides me with basic requirements for input-output analysis. For other necessary information, such as labor compensation, which is supposed to be in Quadrants III and IV of the 1999 Beijing input-output table but is missing, I need to resort to other references.

Because the industrial structure did not change dramatically from 1999 to 2000, I consider it acceptable to use the l999 input-output table for my quantitative analysis of dust storms in 2000.

Table 4-3 Data Availability of the 1999 Beijing Input-Output Table

		Intermediate Demands	Final Demand	Total Output
		Sector 1 ... Sector n		
Intermediate Input	Sector 1 . . . Sector n	**II** **Intermediate Transactions** **(Available)**	**I** **Final Demand** **(Available)**	
Other Primary Input		**III** **Value Added** **(Missing)**	**IV** **Social Transfers** **(Missing)**	
Total Input				

Source: The author. Revised from Figure 3.1 by William A. Schaffer. 1998. *A Survey of Regional Economic Models* (Chapter 3, p. 2). Published on http://www.rri.wvu.edu/WebBook/Schaffer/chap03.html#Heading25. Accessed on March 11, 2002.

4.3 Research Design and General Assumptions of the Case Study in Beijing in 2000

To capture the comprehensive impacts of dust storms without limiting the analysis to those with concrete statistics, I first summarize and identify all the economic impacts to be evaluated in my case study. Then I introduce my calculation procedures to quantify all these impacts and provide some general assumptions underlying my calculations at the end.

4.3.1 Identification of Economic Impacts to be Evaluated

Drawing on both my discussions of the comprehensive impacts of dust storms (Section 2.2) and my compilation of data availability (previous section), I present in Table 4-4 a list of economic impacts of dust storms in Beijing in 2000 that I will evaluate in my case study. I summarize the information on a sectoral basis, following my impact-categorization method (see Chapter 3). Because there is a lack of quantitative statistics for delayed impacts, I resort extensively to previous studies and estimate these impacts in the case of Beijing in 2000. In other words, I have included in Table 4-4 both facts and previous research findings, which provide me with the basic information for my quantitative analysis of economic impacts.

4.3.1.1 Identification of Immediate Impacts

For immediate impacts, I have compiled information as in the previous section. I focus on the impacts on outdoor activities, including construction, transportation, trade, and catering services. I also include the impacts of losses in labor working hours due to eye-infection-related or other particulate-pollution-related emergencies. I assume that the economic value of physical damage to public facilities can be ignored compared to losses in other sectors, because there are no records showing physical damage of facilities and infrastructure after the yellow-dust storm in Beijing; neither was the wind intensity strong enough to cause serious damage to infrastructure, according to the meteorological definition of wind speed at 10 meters per second (m/s) on April 6, 2000.[21] Similarly, I had no way to evaluate the damage to crops, because neither statistics nor correlation studies between wind intensity and crop damage are available.

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[21] See Appendix F.

Table 4-4 Economic Impacts of Yellow-Dust Storms in Beijing in 2000 to be Evaluated

Categorization	Sub-categorization	Affected Sectors	Recorded Economic Impacts	Evidence for Other Economic Impacts	Notes
Direct Impacts	Immediate Impacts	Construction	Many construction sites shut down.		Exclusively negative impacts.
		Transportation	Many air-flights changed. Road accidents increased.		
		Trade	Outdoor vendors closed business much earlier than usual.		
		Households	Emergency hospital visits increased for eye infections.		
	Delayed Impacts	Agriculture		Soil erosion by wind. Damage by particulate matter. Erosion impacts by NOx and SO_2 were partly avoided.	Both negative and positive impacts.
		Manufacturing		Sophisticated-equipment erosion. Corrosion impacts by NOx and SO_2 were partly avoided.	
		Households		Hazards to human respiratory, cardiovascular, and ophthalmic systems, and modest increases in the mortality rate. Hazards by NOx and SO_2 were partly avoided.	
Indirect and Induced Impacts		All sectors			

Source: The author, based on literature review. For immediate impacts, refer to Section 4. 2. 3 for references; for delayed impacts, refer to Section 2.2 for references.

4.3.1.2 Identification of Delayed Impacts

Delayed impacts differ from immediate impacts with regard to their content and scope, showing potentially both positive and negative impacts. Negative impacts are caused by the high concentration of particulates (PM_{10}) and strong winds accompanying yellow-dust storms. Positive impacts are caused by decreases in O_3, NO_x, and SO_2 pollutants, which are absorbed by dust particulates. Drawing on my earlier discussions of methodology, I evaluate, sector by sector, the delayed impacts that yellow-dust storms may have generated. Through my literature review, I identify three sectors that were most seriously affected by yellow-dust storms: (1) agriculture, (2) manufacturing, and (3) households.

<u>Delayed Impacts on Agriculture</u>

From my literature review, I conclude that three factors may cause delayed and cumulative impacts on agriculture: wind erosion, acid-erosion amelioration, and particulate pollution.

Analysts have conducted several quantitative assessments of the effect of wind erosion on soil productivity; however, all the studies have covered a period longer than two years.[22] Thus, I assume that wind erosion does not produce noticeable negative impacts on soil productivity and crop yields within one year. I make a corresponding assumption for the effects of acid-erosion amelioration, although, in fact, decreases in acid matter in the atmosphere reduce damage to crops. Given some scientific evidence, but inadequate data, I assume that the effects of wind erosion and acid-erosion amelioration are not significant.

[22] Analysts have conducted correlation analyses of the effects of wind erosion and yield data (Fryrear, 1981 and Eck et al., 1965; quoted from Zobeck and Bilbro, 1999). Recent studies by Fryrear (1991, 1998) and Hagen (1991) have provided a direct comparison of an area with a known amount of wind erosion with a nearby non-eroded soil (cited in Zobeck and Bilbro, 1999). It is based on a two-year-long experiment, which seems to be the shortest experiment period of soil erosion. Zobeck and Bilbro show that although cotton boll and lint weights were lower in eroded than non-eroded areas, "there was no statistical difference in cotton yield between non-eroded areas and eroded areas in 1997."

Regarding particulate pollution, Chameides et al. (1999) conclude that high concentrations of particulates are currently creating yields that are 5–30% below the optimal yields for about 70% of the crops grown in China. I assume that the occurrences of yellow-dust storms in 2000 resulted in a 10% decrease in the crop yield for about 70% of the crops in Beijing.

Delayed Impacts on Manufacturing

Yellow-dust storms affect manufacturing mainly from high concentration of particulates, which increase both the rate of degradation and the rate of corrosion (Chapter 2). I assume that only sophisticated-equipment manufacturing is affected significantly. This will involve three sectors in the 1999 Beijing input-output table (49-sector aggregation): (20) Electric-equipment Manufacturing, (21) Electronic and Communication Manufacturing, and (22) Equipment and Meter Manufacturing.

Regarding the extent of impacts, I located just one article by Peng (2000)[23] with a numerical analysis, which briefly mentioned that less than 5% of the defects of products are caused by human and environmental effects. Taking additional account of possible positive effects caused by decreases in O_3, NO_x, and SO_2 after dust storms, I assume that particulates do not result in significant increases in product defects and only lead to a 1% decrease in product yield.

Delayed Impacts on Human Health

I assume that in one year, negative impacts of particulates play a dominant role, because the effects of absorption of acid matter and prevention of occurrences of photochemical smog (Lin,

[23] Source: Peng, S. E., 2000. Field Management of Microelectronic Manufacturing in Foreign Countries. *Electronic Products Reliability and Environmental Experiments.* Vol. 3, No. 105. Accessed at www.gd.cetin.net.cn/GD_Cetin/kkxhjqk/0003/20000306.htm on May 7,2003.

2002) may have some time lags. In economic terms, my assumption can be supported by the research findings in the World Bank report *Clear Water, Blue Skies*, in which the authors indicated that health costs of PM_{10} emissions made up the bulk of environmental costs in China, 83% of the total. Thus, I will assign more weight to negative impacts of particulates when combining the positive and negative impacts. To connect environmental indicators with economic terms, I rely on the dose-response functions (Table 3-3). Certainly "workday losses" is the most suitable end-point to integrate into regional economic analysis directly. Assuming that the positive effects of decreases in O_3 and SO_2 cancel some of the negative effects of an increase in PM_{10} after a dust storm, I select a lower estimation of workday losses, a 0.2% increase per $\mu g/m^3$ of PM_{10} annually in the atmosphere. That is to say, when there is one additional $\mu g/m^3$ of PM_{10} in the atmosphere due to dust storms, there would be a total of (0.2% X affected population) workday losses in one year.

4.3.1.3 Discussion of Impact Identification

Although I have tried to identify all the impacts caused by dust storms regardless of data availability, I acknowledge that my compilation of economic impacts here may be only a small portion of the impacts caused by yellow-dust storms. As humans gain a better understanding of the yellow-dust storm problem, analysts may need to consider other aspects of the economic impacts. In addition, the scope of my impact analysis is constrained by methodology and my time availability for this research as well. Theoretically, delayed and cumulative economic impacts may cover an infinite length of time; however, due to the limitation of the regional-economic model, I limit my analysis to only one year. I also exclude those economic impacts that can neither be directly nor indirectly reflected in commercial markets, such as human psychological impacts. While identifying the economic impacts to be evaluated, I stress that my analysis is only a preliminary study in economic-impact analysis. I will discuss research limitations and future research areas further at the end.

4.3.2 Research Design of Calculation Procedures

To evaluate all the impacts discussed above, I divide my analysis of impacts of yellow-dust storms into two parts: (1) individual-sector analysis, (2) inter-sector interaction analysis. I first evaluate the direct economic impacts (including immediate and delayed impacts) on an individual sectoral basis, and then input my calculation results into the Beijing input-output model for inter-sector interaction analysis, in order to derive the total economic impacts of dust storms on the regional economy.

Step One: Calculate the immediate economic impacts of yellow-dust storms on April 6, 2000, which was the only occurrence that provided me with adequate data for a quantitative analysis. I include impacts on construction, transportation, trade and catering services as well as households.

Step Two: Calculate the total immediate economic impacts of the ten occurrences based on the results in Step One. With socioeconomic statistics missing for all the other occurrences, I adjust the impacts to those on April 6, 2000, using different weights derived from a visibility and wind-velocity comparison.

Step Three: Calculate cumulative impacts of all yellow-dust storms in 2000. In this step, I have extensively referred to previous studies for valid relationships between meteorological data and different types of impacts, including economic, environmental, and social aspects. Then, I estimate the impacts numerically on the basis of corresponding relationships and meteorological records.

Step Four: Sum the immediate and cumulative impacts according to different economic sectors. In other words, determine the total direct impacts on each sector.

Step Five: Based on 1999 Beijing 16-sector aggregated table, calculate total backward linkage matrix $(I-A^*)^{-1}$ and total forward linkage matrix $(I-(F^*)^T)^{-1}$.

Step Six: Backward-linkage analysis. Input the results of Step Four into the total backward linkage matrix $(I-A^*)^{-1}$ of the 1999 Beijing input-output table and derive the total impacts of yellow-dust storms in 2000 caused by backward linkages.

Step Seven: Forward-linkage analysis. Input the results of Step Four into the total forward linkage matrix $(I-(F^*)^T)^{-1}$ of the 1999 Beijing input-output table and derive the total impacts of yellow-dust storms in 2000 caused by forward linkages.

More intuitively, I have illustrated the above steps in Figure 4-1. Contents in ovals show the evaluation techniques I have adopted, and those in rectangles show the results I have reached for each step.

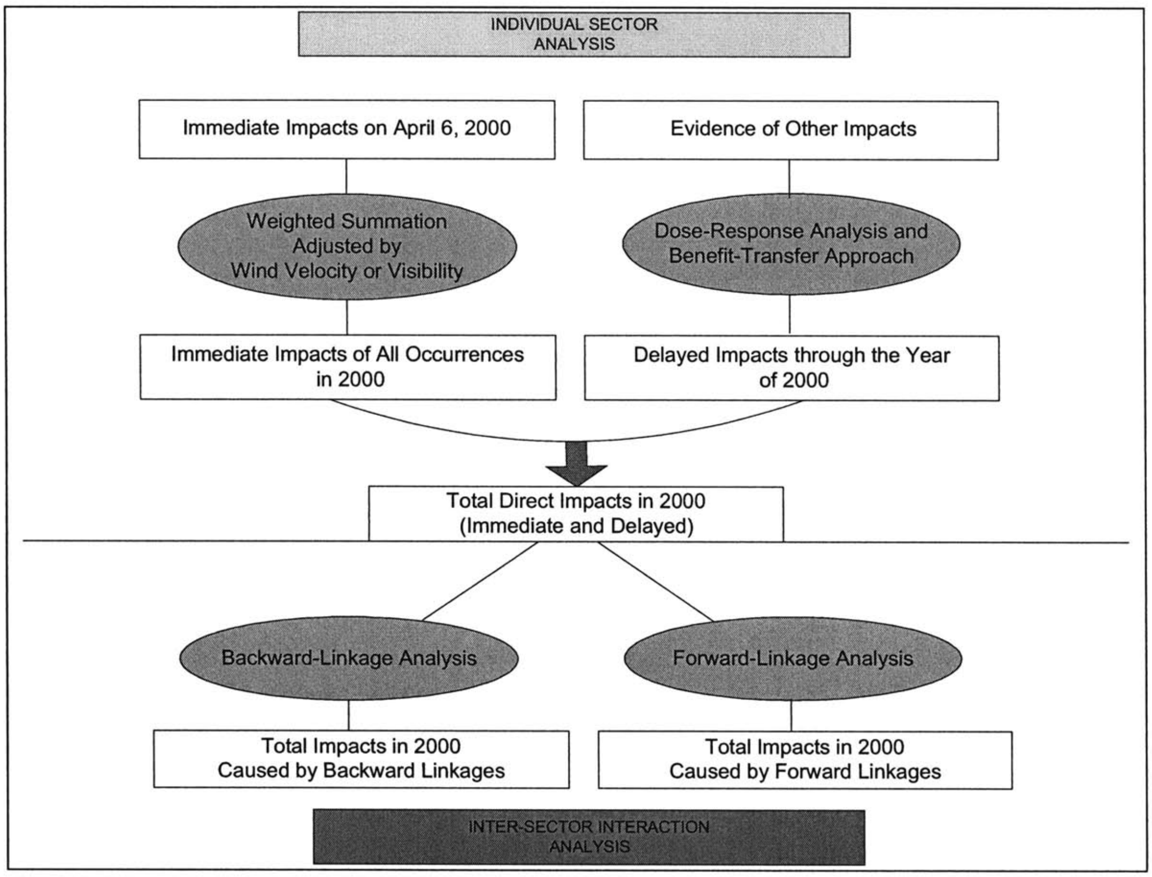

Figure 4-1 Calculation Steps for Economic-Impact Evaluation of Dust Storms in Beijing in 2000

Source: The author.

4.3.3 General Research Assumptions

Because of the limited information on economic-impact data as well as the limitations of methodology, I have had to make the following assumptions throughout my quantitative analysis. For each step of my calculations, I indicate further assumptions in each calculation process individually.

a. Different people are affected by yellow-dust storms equally and their behavior in response is the same, even though many studies suggest that women, children, elderly, minority, and low-income populations are disproportionately affected by disasters (Cutter, 2001).

b. Socioeconomic activities, such as production output and traffic conditions, are similar every day throughout the year. The daily socioeconomic activities can be reflected by the average of the annual value of corresponding indices.

c. Workday losses only result from employed workers. That is to say, I have not included the affected group of children and the unemployed people.

d. Transboundary effects of the yellow-dust storms in other regions have not significantly influenced Beijing. Thus, my case study will be a single-region analysis, and I exclude multiregional effects.

At this point, both data and methodologies are ready for my integrated economic-impact analysis of dust storms in Beijing. Referring to the information in this chapter as well as to the methodologies in Chapter 3, in Chapter 5 I do numerical calculations for Beijing in 2000.

Chapter 5
EVALUATION OF ECONOMIC IMPACTS OF DUST STORMS ON BEIJING IN 2000

As discussed in the previous chapter, my calculations of economic impacts of dust storms include two parts: (1) direct-economic-impact analysis on an individual-sector basis, and (2) total-economic-impact analysis applying input-output techniques. I show the details of my calculations and interpretation of the results in this chapter. In addition, I discuss my research's limitations and areas for further research. Finally, I present policy implications based on my study's findings.

5.1 Calculations for Direct-Economic Impacts

The goal of this part of the calculations is to quantify all the direct economic impacts listed in Table 4-4. I calculate the immediate impacts and delayed impacts, respectively, and sum them as the total direct-economic impacts.

5.1.1 Immediate Impacts

"Immediate impacts" are those occurring during dust storms (see Chapter 3). Because I only have adequate information for the dust storm on April 6 in 2000, I first calculate the immediate economic impacts of this one occurrence. Then, I estimate the economic impacts of other occurrences of dust storms based on meteorological information. I sum my estimations for the ten occurrences of dust storms to obtain the total immediate economic impacts in Beijing in 2000.

5.1.1.1 Immediate Economic Impacts on April 6, 2000

I examine the immediate economic impacts on four sectors: (1) Construction, (2) Transportation, (3) Trade and Catering Services, and (4) Households. I present the results of my calculations in Table 5-1, with a more detailed interpretation in Appendix C. My results show that the

Table 5-1 Immediate Impacts of Yellow-Dust Storms on April 6,2000 in Beijing

Affected Sectors	Facts	Calculation Results (Thousand RMB)	Calculation Results (Thousand dollars)	Notes
Construction	Nearly 60 million square meters of construction sites shut down.	23,420	2,822	1. Calculation details are shown in Appendix C-1. 2. Because a dust storm lasts only a few hours, and usually occurs in the morning, I assume that only one-half day of construction was affected.
Transportation	1. Air -Transportation 48 flights were cancelled, 9 flights returned, 52 landing flights were transferred, and altogether 129 flights delayed. More than 3,000 passengers were detained at the airport.	2,695	325	1. Calculation details are shown in Appendix C-2. 2. Opportunity cost of the detained passengers is included in the diverted- and cancellation-cost estimation. 3. Because yellow-dust storms rarely lead to overnight air-flight delays in China, I assume that the delay costs are not significant and I do not include them in the sum of the economic loss in traffic disruption.
	2. Road Transportation An increase in road accidents of 20-30% over normal conditions.	78	9	1. Calculation details are shown in Appendix C-2. 2. I have assumed a 20% increase in the number of road accidents.
	Total Impacts on Transportation	**2,773**	334	1. Calculation details are shown in Appendix C-2.
Trade and Catering Services	Outdoor vendors closed business much earlier than usual.	30,495	3,674	1. Calculation details are shown in Appendix C-3. 2. Because a dust storm lasts only a few hours and usually occurs in the morning, I assume that only one-half day of sales was affected.
Household	Emergency hospital visits increased due to particulate pollution.	136	16	1. Calculation details are shown in Appendix C-4. 2. I assume that each outpatient loses one-half workday due to hospital visits.
Total		56,824	6,846	

Source: The author. Calculation details are shown in Appendix C.

Construction sector lost 23,420 thousand RMB ($ 2,822 thousand) [24] in production activities immediately after the storm, the Trade and Catering Service sector lost 30,495 thousand RMB ($ 3,674 thousand), and the Transportation sector appears to have lost less than the other two sectors, showing a loss of 2,773 thousand RMB ($ 334 thousand). For the Household sector, 1,248 workday losses would have caused an economic loss of 136 thousand RMB during the occurrence of yellow-dust storms, for a total of 56,824 thousand RMB ($ 6,846 thousand) from the four sectors.

5.1.1.2 Total Immediate Impacts of Ten Occurrences of Yellow-Dust Storms in Beijing

Based on the calculation results for April 6, 2000, I do a weighted estimation using current meteorological conditions of ten occurrences of yellow-dust storms in Beijing in 2000. Because no socioeconomic data are available, I estimate the impacts of other occurrences by comparing the intensity of the other nine yellow-dust storms with the one on April 6, 2000.

I make four assumptions in this summation. First, a negative and linear relationship exists between the particulate impacts of yellow-dust storms and visibility. In other words, the better the visibility is, the fewer impacts will result from particulate pollution. Second, I assume that a positive and linear relationship exists between the wind impacts of yellow-dust storms and wind velocity. That is to say, the higher the wind velocity is, the larger the impacts due to severe winds. Third, I assume that other occurrences of dust storms did not incur other types of impacts other than those on April 6, 2000. I need this assumption to limit my impact evaluation to the sectors with quantitative calculation results, including construction, transportation, trade and catering services, and households. Fourth, I assume that observed impacts of yellow-dust storms result from either severe winds or particulate pollution, with the impacts on the first three

[24] All dollar values are in US dollars ($). 1US $ = 8.3 RMB in 2000 value.

sectors mainly resulting from severe winds, and the impacts on households mainly resulting from particulate pollution. On the basis of these assumptions, I estimate the impacts by different weights of wind speed and visibility.

Heavily relying on these four assumptions, I develop two indices of visibility and wind velocity, by dividing the values of visibility and wind velocity of each occurrence by that of April 6. Thus, I extend Table 4-1 into Table 5-2.

Next, I estimate the impacts of the other nine occurrences one by one, and I provide one example of the detailed calculations for the occurrence on March 3, 2000, in Appendix D. Having calculated the other occurrences analogously to the one on March 3, I present my summation of immediate impacts in Table 5-3.

The results in Table 5-3 show that the immediate impacts of production disruption and reduction on these sectors all exceed millions of RMB. Trade and catering services are estimated to suffer the greatest immediate impacts, with a decrease in sales of 296 million RMB. Construction and transportation lost 227 million and 27 million RMB, respectively. In sum, 4,225 workdays may have been lost due to emergency hospital visits after yellow-dust storms, which leads to an economic production loss of 460 thousand RMB. Thus, the total loss for the four sectors is 550,334 thousand RMB.

5.1.2 Delayed Impacts

Independent of the immediate impacts discussed above, I evaluate the delayed impacts of yellow-dust storms for three sectors: (1) agriculture, (2) manufacturing, and (3) households.

Table 5-2 Comparison of Meteorological Conditions During Yellow-Dust Events in Beijing in 2000

Data	Visibility (Kilometer)	Visibility Index (April 6 = 1)	Wind Speed (m/s)	Wind Speed Index (April 6 = 1)
March 3	4	2	6	0.6
March 18	8	4	10	1
March 23	10	5	13	1.3
March 27	10	5	12	1.2
April 4	8	4	9	0.9
April 6	2	1	10	1
April 7	8	4	11	1.1
April 9	8	4	11	1.1
April 25	7	3.5	5	0.5
April 29	10	5	10	1

Source: Monitoring data are from Beijing Meteorological Bureau. Quoted from G. Z. Wu and S. Y. Fan, 2000. "Inner Mongolia Is the Main Sand Source of Sand Storm in Beijing Region." *Inner Mongolia Environmental Protection*, Vol. 12, No. 4, p. 5. Indices and calculations are developed by the author.

Table 5-3 Estimation of Immediate Impacts of Ten Occurrences of Yellow-Dust Storms on Beijing in 2000

Date	Impacts on Construction	Impacts on Transportation	Impacts on Trade and Catering Services	Impacts on Households
	(Thousand RMB)			
March 3	14,052	1,664	18,297	68
March 18	23,420	2,773	30,495	34
March 23	30,446	3,605	39,644	27
March 27	28,104	3,328	36,594	27
April 4	21,078	2,496	27,446	34
April 6	23,420	2,773	30,495	136
April 7	25,762	3,050	33,545	34
April 9	25,762	3,050	33,545	34
April 25	11,710	1,387	15,248	39
April 29	23,420	2,773	30,495	27
Total	**227,174** ($ 27,370 thousand)	**26,898** ($3,241 thousand)	**295,802** ($35,639 thousand)	**460** ($55 thousand)

Source: Estimated by the author.

I assume that yellow-dust storms mainly affect agriculture by a high concentration of particulate matter. Because there are no numerical studies on yellow-dust storm influences on agriculture, I adopt an estimation of 10% yield-decrease due to particulates (Chapter 4). I multiply the estimated coefficient by the total output of the agriculture sector in Beijing in 2000 to derive the economic impact on agriculture to be 788,412 thousand RMB ($94,989 thousand). The details of my calculation are shown in Appendix E-1.

For economic impacts on the Manufacturing sector, I assume that they resulted from a 1% decrease in product yield of sophisticated-equipment manufacturing, which involves Electric-equipment Manufacturing, Electronic and Communication Manufacturing, and Equipment and Meter Manufacturing (Chapter 4). Because I do not have sectoral socioeconomic data for 2000, I assume that the production activities of manufacturing sectors changed so little between 1999 and 2000 that I can regard them as the same in those two years. Then, I summed the value added of these three sectors in the 1999 input-output table, and multiplied the sum of the output value by 1% to derive the yield loss of manufacturing. My estimation shows a loss of 855,268 thousand RMB ($ 103,044 thousand) in the Manufacturing sector in 2000 (Appendix E-2).

To evaluate the economic impacts on the Household sector, I resort to dose-response functions for numerical relationships between the environmental indicators and economic implications. To determine the changes of PM_{10} exclusively caused by dust storms, I first estimate the average PM_{10} during all occurrences of dust storms in Beijing in 2000. Then, I compare that estimation with the control point, treating the difference as the effects caused by those ten occurrences of dust storms. Next, I estimate the total workday losses by inputting the increase in PM_{10} value into the dose-response functions, as shown in Table 3-3. I select a lower estimation of workday losses, a 0.2% increase per $\mu g/m^3$ of PM_{10} (discussed in Chapter 4). Finally, I multiply the number of workday losses by the average per capita GDP produced in one day in Beijing in 2000, and I estimate that yellow-dust storms resulted in 10,893 lost workdays and corresponding economic loss of 1,185 thousand RMB ($143 thousand) in Beijing in 2000 (Appendix E-3).

I summarize the impacts I estimated and show my calculation results in Table 5-4. I present the details of my calculations in Appendix E.

5.1.3 Discussion of Total Direct Impacts

After quantifying both the immediate impacts of all occurrences of yellow-dust storms and the delayed impacts, I sum them on a sectoral basis to derive the total direct impacts in 2000. I present my calculation results of total direct impacts along with immediate impacts and delayed impacts I have evaluated in previous steps in Table 5-5.

From the sum row at the bottom of Table 5-9, we can see that the delayed impacts (1,644,865 thousand RMB) of dust storms are more costly than the immediate impacts (550,334 thousand RMB), even though they were not instantly evident as immediate impacts. Altogether, dust storms in Beijing in 2000 may have resulted in total direct impacts of 2,195,119 thousand RMB.

From the perspective of the breadth of the impacts, the direct impacts of yellow-dust storms have reached all types of sectors, from primary industry (Agriculture), to secondary industry (Manufacturing and Construction), and tertiary industry (Services). Among the six sectors (the Agriculture, Manufacturing, Construction, Transportation, Trade and Catering Services, and Households) I have examined here, the Manufacturing sector appears to have lost the most among all the affected sectors, showing both the largest absolute value (855,268 thousand

Table 5-4 Delayed Impacts of Yellow-Dust Storms in Beijing in 2000

Affected Sectors	**Estimated Impacts**	Calculation Results		**Notes**
		(Thousand RMB)	**(Thousand dollars)**	
Agriculture	High concentrations of particulates depressed optimal yields of about 70% of the crops grown in Beijing by 5%.	788,412	94,989	1. Calculation details are shown in Appendix E-1. 2. Assume that one occurrence of yellow-dust storm resulted in a yield decrease of 5% in Beijing. 3. Assume that the yield of crops shows a positive relationship with gross-output value. 4. Forestry, Animal Husbandry, and Fisheries are included.
Manufacturing	Particulates may have caused 1% decrease in product yield of sophisticated-equipment manufacturing.	855,268	103,044	1. Calculation details are shown in Appendix E-2. 2. Sectors including Electric-equipment Manufacturing, Electronic and Communication Manufacturing, and Equipment and Meter Manufacturing are considered.
Household	There was a 0.2% increase in workday losses per $\mu g/m^3$ of PM_{10}.	1,185	143	1. Calculation details are shown in Appendix E-3. 2. Only employed workers were calculated.
Total		1,644,865	198,177	

Source: Calculated by the author.

Note: The numbers in the column of "Estimated Impacts" are estimated by the author based on the literature review.

Table 5-5 Summary of Direct Impacts of Yellow-Dust Storms in Beijing in 2000

Affected Sectors	Immediate Impacts	Delayed Impacts	Total Direct Impacts	Percentage of the Total Direct Impacts
	Thousand RMB			
Agriculture	N.A.	788,412	788,412	35.9
Manufacturing	N.A.	855,268	855,268	39.0
Construction	227,174	N.A.	227,174	10.4
Transportation	26,898	N.A.	26,898	1.2
Trade and Catering Services	295,802	N.A.	295,802	13.5
Households	460	1,185	1,645	0.0
Total	550,334 ($ 66,305 thousand)	1,644,865 ($ 198,177 thousand)	2,195,119 ($ 264,472 thousand)	100.0

Source: Calculated by the author, with details of calculations in Appendices C, D, and E.
N.A.: not applicable.

RMB), and the largest value (38.98% of the total). Economic losses of the Agriculture sector of 788,412 thousand RMB are similar to those in the Manufacturing sector. These most prominent losses are both delayed impacts gradually generated throughout the year. In a one-day period, the Construction, the Transportation, and the Trade and Catering Services sectors all lost millions of RMB, which seems reasonable, given the apparent impacts during dust storms.

In my analysis, the economic losses of the Household sector resulted from workday losses of employed workers, yet I have limited the workday losses merely to those caused by hospital visits as derived from dose-response functions. I could not include other workday/work-hour losses also caused by dust storms, such as traffic delays and inconvenient commuting, because people's reactions to yellow-dust storms are still unknown. Thus, my estimation of both immediate impacts (460 thousand RMB) and delayed impacts (1,185 thousand RMB) tends to be an underestimation, which may explain why the Household sector shows much less impact than other affected sectors.

In sum, having obtained these numerical results of direct economic impacts on an individual-sector basis, I am able to continue to use them in the input-output analysis, to examine the inter-sectoral interactions.

5.2 Input-Output Analysis for Total Economic Impacts

Because all sectors in the regional economy need to purchase inputs from as well as sell their products to other industries, it is inevitable that other sectors not directly affected by yellow-dust storms may also be influenced through inter-industry material and service flows. Such interactions among sectors tend to magnify the impacts, generating indirect effects. I trace such effects with input-output techniques, because these are currently most feasible in this context and helpful for examining the impacts on a sectoral basis (see Chapter 3).

5.2.1 Research Assumptions

1. Given the static and open properties of the available 1999 Beijing input-output table, I use the following three assumptions of a static and open input-output model: "(a) constant returns to scale, (b) homogeneous products with no joint production, and (c) constant direct-input coefficient (note: defined in section 4.1.1.)" (Polenske and Fournier, 1993, p. 209).

2. I regarded economic losses after the occurrence of a dust storm as permanent. In other words, I do not cover any increases in sales, production, consumption, and investment resulting from disaster remediation and mitigation.

3. I treat household income is either spent as household consumption or saved. In other words, household income equals the sum of consumption and savings. In the context of the statistics in China, the savings refer to the difference in the amount of savings compared to the previous year.

5.2.2 Modifications of the Original 1999 Beijing Input-Output Table

I made two modifications to the available 1999 Beijing input-output table: (1) sector aggregation, and (2) household-sector adjustment.

Sector Aggregation. First, I aggregated the 49 sectors in the original table into 15, for two reasons. One is that industries in some broad categories of sectors have similar consumption and production relationships and appear to be affected by dust storms in similar ways. The other reason is that it is impossible to determine the differences, presumably small, in impacts among industries, due to limited data and information. I assume that such an aggregation does not influence the accuracy and correctness of my calculation results and that it may increase the simplicity of my calculation and analysis. I present the list of 15 aggregated sectors in Table 5-10 and a detailed explanation of my treatment in Appendix B.

Table 5-6 Fifteen-Sector Aggregation

No.	15-Sector Aggregation
1	Agriculture, Forestry, Animal Husbandry, and Fishery
2	Mining
3	Manufacturing
4	Electricity, Gas, Water Production and Supply
5	Construction
6	Transportation, Storage, Post and Telecommunications
7	Wholesale, Retail Trade and Catering Services
8	Finance and Insurance
9	Real Estate Trade
10	Social Services
11	Health Care, Sports, and Social Welfare
12	Education, Culture, Art, Radio, Film and Television
13	Scientific Research and Polytechnical Services
14	Geological Prospecting and Water Conservancy
15	Government Agencies, Party Agencies, Social Organizations, and Others

Source: Aggregated by the author, with details in Appendix B.

Household-Sector Adjustment. The second modification I made to the 1999 Beijing input-output model is to transform the open model into a partially closed one. To do this, I add one row and one column to the intermediate sectors, based on the open input-output model, to make the household sector one of the "endogenous" sectors in the model (Table 5-11).

Specifically, I move the Household Consumption column from the Final Demand sector and set up a 16th column in the endogenous part of the table. Then I establish a 16th row for Labor Compensation below the last (the 15th) row of Intermediate Inputs in the input-output table. Because the information in the row of Labor Compensation in the 1999 Beijing input-output table is missing, I fill in the row by adjusting Beijing statistical data of household wages and salaries. I need to make these adjustments, rather than to input the data of household wages and salaries directly, because economists assume that households may receive labor compensation from other sources in addition to wages and salaries. Furthermore, I assume that the sum of household consumption and savings is numerically equal to labor compensation. Then, I follow four calculation steps.

Table 5-7 Transformation of an Open Input-Output model into a Partially Closed One

		Intermediate Demands **Sector 1 … Sector n**	**Household Consumption** **Sector n+1**	**Final Demand**	**Total Output**
Intermediate Input	**Sector 1** . . . **Sector n**	X_{ij}	H_j	Y_{ij}	X_j
Labor Compensation Sector n+1		h_j			
Other Primary Inputs		V_j			
Total Inputs		X_j			

Source: The author.

First, I locate the statistical information necessary for the wage adjustment, including (1) the household consumption, (2) the savings of residents in Beijing in 1999, and (3) 1999 Beijing statistical data of household wages and salaries by sector in Beijing.

Second, I calculate the sum of household consumption spent on every sector (denoted by TC) and add TC to household savings (HS) and denote the sum as TCHS. I also calculate the sum of wages and salaries from all sectors (TW).

Third, I compare the difference between TCHS and TW. I split the difference into each sector according to their weights, which I calculate by dividing each sector's wages by TW.

Fourth, I add the split difference to the value of household wages and salaries (Row 2 in Table G-1). The values of adjusted wages and salaries are equal to the Labor Compensation, which I enter in the1999 Beijing input-output table.

I present the data for my calculation in Appendix H. With my calculation result, I can fill in the missing information of the row of Labor Compensation in the 1999 Beijing input-output table. The value of household savings is at the intersection of the Household Consumption column and the Labor Compensation row. I now have complete information for a 16x16 matrix of intermediate transactions, which provides me adequate information for input-output analysis.

After aggregating 49 sectors into 15 and incorporating households as a sector in the input-output table, I have a table consisting of 16 sectors ready for my regional economic impact analysis of dust storms, using a partially closed input-output model. I show my modified transaction table for Beijing in 1999 in Appendix I, on the basis of which I will examine how those direct impacts on the six affected sectors spread to the whole regional economy through inter-sector interactions. I quantify the total economic impacts on Beijing's regional economy by both backward and forward linkages, as I show, respectively, as follows.

5.2.3 Calculations of Total Impacts Caused by Backward Linkages

Because of production disruption during and after dust storms, the six sectors (Agriculture, Manufacturing, Construction, Transportation, Trade and Catering Services, and Household) have shown a decrease in their sectoral output (Table 5-6). Consequently, these six sectors would demand fewer inputs from other sectors that supply them with their outputs. Thus, in addition to the direct economic impacts of production disruption I elaborated above, dust storms would have inevitably affected other sectors in Beijing through decreases in demand for supplies, or backward linkages. Analysts measure these changes in a regional economy in lieu of changes in final demand (Equation 3.2). However, in the case of yellow-dust storms, although I cannot obtain adequate information on changes in final demand in each sector, I regard the direct impacts on each sector (Table 5-5) as an acceptable substitute. In other words, I derive the total economic impacts by multiplying the Leontief inverse of the direct requirement matrix, $(I-A^*)^{-1}$, by direct economic impacts (as a substitute for the changes in final demand) on each sector. I show my calculations in the following steps:

a. Calculation of the direct-coefficient matrix A* of the 16-sector Beijing 1999 transaction table (Table J-1);
b. Calculation of the Leontief inverse of matrix A* (Table J-2)
c. Calculation of the product of $(I-A^*)^{-1}$ and direct economic impacts on each sector, which summarizes the total economic impacts caused by backward linkages (Table 5-8).

In Table 5-8, we can see how the direct impacts of the six sectors spread to all the sectors in Beijing's regional economy. In absolute value, the Manufacturing, Agriculture, Trade and

Catering Services, Household, and Construction sectors are the top five sectors that experienced the greatest total impacts. It is no surprise that these sectors are also those affected most by direct impacts. In order, they consist of 41.7, 23.5, 11.1, 7.1, and 5.7 percent of the total economic impacts. The percentage values of other sectors are all minor.

In addition, I also show my numbers as a percentage of the economic impacts on each sector and that sector's output. I believe that such a comparative measure is more meaningful. For example, we can tell that a one million RMB loss to a sector with a 10 million RMB output is dramatically greater than the same amount of loss to a sector with a one billion RMB output. The case of the Mining sector (No. 2) is just such an example. Although the absolute value of the total impacts on the Mining sectors (61.9 million RMB) is not among the top ones, it amounts to 2.2 percent of its sectoral output, being the second largest percentage rate among all sectors. Thus, it would be incorrect to exclude the Mining sector from the list of most seriously affected sectors. Apart from the Agriculture sector (with a loss of 5.2% of its total output), the other sectors are almost evenly affected through backward linkages, showing much less evident losses (0.1-0.4 of their sectoral output).

My calculations show that the total economic impacts caused by backward linkages are 4,032.3 million RMB ($ 485.8 million), which includes the direct impacts (see Table 5-5), the indirect impacts on other sectors due to decreases in demand during and after production disruption, and the induced impacts, as shown on the Household sector. The absolute value of the economic impacts is equivalent to 1.6 percent of Beijing's gross domestic product (GDP) in 2000.

Table 5-8 Total Impacts of Yellow-Dust Storms Caused by Backward Linkages on Beijing in 2000

No.	Sectors	Total Economic Impacts Caused by Backward Linkages		Percentage of Impacts/Total	Sectoral Output	Percentage of Impacts/Sectoral Output
		Million RMB	Million $	(%)	Million RMB	(%)
1	Farming, Forestry, Animal Husbandry, and Fishery	946.8	114.1	23.5	18,208.9	5.2
2	Mining	61.9	7.5	1.5	2,844.3	2.2
3	Manufacturing	1,681.7	202.6	41.7	246,847.4	0.7
4	Electricity, Gas, Water Production and Supply	34.4	4.1	0.9	11,224.9	0.3
5	Construction	230.7	27.8	5.7	66,445.0	0.3
6	Transportation, Storage, Post and Telecommunication	114.5	13.8	2.8	27,306.6	0.4
7	Wholesale, Retail Trade and Catering Services	445.8	53.7	11.1	25,153.5	1.8
8	Finance and Insurance	86.3	10.4	2.1	62,022.3	0.1
9	Real Estate Trade	7.3	0.9	0.2	6,032.3	0.1
10	Social Services	62.2	7.5	1.5	34,408.7	0.2
11	Health Care, Sports, and Social Welfare	1.2	0.1	0.0	6,677.6	0.0
12	Education, Culture, Art, Radio, Film and Television	9.7	1.2	0.2	16,491.5	0.1
13	Scientific Research and Polytechnical Services	38.4	4.6	1.0	24,682.2	0.2
14	Geological Prospecting and Water Conservancy	0.6	0.1	0.0	636.7	0.1
15	Government Agencies, Party Agencies, Social Organizations, and Others	24.6	3.0	0.6	12,690.3	0.2
16	Household	286.1	34.5	7.1	137,118.4	0.2
	Total	4,032.3	485.8	100.0	698,790.5	1.6*

Source: Calculated by the author. Detailed calculations are shown in Appendix J.

Note: 1. US $/ RMB = 8.3, in 2000 value. 2. The number with "*" is the percentage of total economic impacts/gross domestic product in Beijing in 2000.

5.2.4 Calculations of Total Impacts Caused by Forward Linkages

In addition to the backward inter-sector interactions, I examine the economic impacts of forward linkages that are generated by a lack of supply from the six sectors directly affected by dust storms. Because of the production disruption of the six sectors (Agriculture, Manufacturing, Construction, Transportation, Trade and Catering Services, and Household), they could provide fewer inputs for other sectors that need their inputs. I trace these impacts caused by the forward linkages using different equations and, accordingly, different matrices in the input-output model than for backward linkages. As I demonstrate in Equation (3.4), I evaluate the total economic impacts on a regional economy by changes in value added of each sector, which is how I measured the direct economic impacts. My calculations of total economic impacts caused by forward linkages involve the following steps:

a. Calculation of matrix F^* of the 16-sector Beijing 1999 transaction table (Table J-3);
b. Transposition of the F^* matrix to derive $(F^*)^T$;
c. Calculation of the Leontief inverse of matrix $(F^*)^T$ to derive $(I-(F^*)^T)^{-1}$ (Table J-4);
d. Calculation of the product of $(I- (F^*)^T)^{-1}$ and direct economic impacts on each sector (Table 5-9).

My calculation results (Table 5-9) show that the total economic impacts caused by forward linkages are 13,992.7 million RMB ($ 1,685.9 million), which is equal to 2.0 percent of Beijing's GDP in 2000. Compared to the total economic impacts caused by backward linkages, both the absolute value and the percentage value are higher. That is to say, Beijing's regional economy is affected more seriously through forward linkages than backward linkages.

In absolute value, the Manufacturing and the Household are the top two sectors being affected by dust storms, showing 5,317.8 million RMB and 2424.2 million RMB (38.0 and 17.3 percent of the total economic impacts, respectively). When examined sector individually, the Agriculture sector (No.1) still shows the most serious economic impacts, 6.2 percent of its sector's output. The Trade and Catering Services sector (No.7) shows the second largest economic impacts caused by forward linkages, while the Mining sector (No. 2) does not show impacts ranking as high as with the impacts caused by backward linkages.

When comparing the economic impacts on each sector caused by backward and forward linkages, I find that the Agriculture sector consistently shows the most serious impacts, which far exceed those of other sectors. Other sectors are affected through inter-sector interaction quite differently: some show larger losses through backward linkages, and some show the opposite. To study the underlying reasons for the difference in allocation of the direct impacts among sectors, I conduct further linkage analyses below.

5.2.5 Linkage Analysis

Using the method I introduce in Appendix A, I calculate both backward and forward linkages of 16 sectors in the Beijing 1999 input-output table and show them in Table 5-10.

With only one exception, the forward linkages of each sector are higher than their backward linkages; the average of the forward linkages is 5.451, about3.5 times the average of the backward linkage (1.565). This shows that the dust storms affected the regional economy more heavily through forward linkages than through backward linkages.

On a sectoral basis, the forward linkage of the Mining sector is unusually large (almost six times the average of the forward linkage). I assume that the Mining sector sells many more products to other sectors than it purchases from other sectors. Fortunately, dust storms usually do not result in severe losses in the Mining sector; otherwise, it could affect the regional economy greatly with moderate changes in its output. The other sectors with high forward linkages, the Agriculture, Manufacturing, Transportation, Trade and Catering Services, and Household sectors, were all directly affected by dust storms. Thus, the total economic impacts on Beijing's regional economy were significantly larger than those of the direct economic impacts.

When examining the backward linkages, I found that the two sectors with the largest backward linkages were the Manufacturing sector (2.136) and the Construction sector (2.022). They are also the only two sectors with backward linkages above 2.000, 1.4 and 1.3 times the average backward linkage, respectively. That is to say, decreases in demand in the Manufacturing and the Construction sectors, compared to all the other sectors, may result in the largest losses to Beijing's regional economy. Correspondingly, increases in the investment in these sectors may have the largest potential power to augment the regional economy by requiring large quantities of goods and services from other sectors.

For this reason, many disasters, such as earthquakes and tornados, may have both positive and negative impacts on a regional economy in the long run. On the one hand, they diminish the regional output by damaging the infrastructure and disrupting socioeconomic activities; on the other hand, they trigger a new round of regional activities in the economy through the building of more houses and public facilities, which consequently induces more output and creates more employment opportunities in the Manufacturing and Construction sectors, through backward linkages. However, because yellow-dust storms do not involve large-scale remediation and mitigation activities afterwards and would not boom a new round of investment activities on the Manufacturing or the Construction sectors, I argue that the economic impacts on a regional economy may be permanent, and may not easily recover to its normal level.

Table 5-9 Total Impacts of Yellow-Dust Storms Caused by Forward Linkages on Beijing in 2000

No.	Sectors	Total Economic Impacts Caused by Forward Linkages		Percentage of Impacts/Total	Sectoral Output	Percentage of Impacts/Sectoral Output
		Million RMB	Million $	(%)	Million RMB	(%)
1	Farming, Forestry, Animal Husbandry, and Fishery	1,136.7	136.9	8.1	18,208.9	6.2
2	Mining	29.4	3.5	0.2	2,844.3	1.0
3	Manufacturing	5,317.8	640.7	38.0	246,847.4	2.2
4	Electricity, Gas, Water Production and Supply	96.3	11.6	0.7	11,224.9	0.9
5	Construction	1,404.9	169.3	10.0	66,445.0	2.1
6	Transportation, Storage, Post and Telecommunication	407.5	49.1	2.9	27,306.6	1.5
7	Wholesale, Retail Trade and Catering Services	711.6	85.7	5.1	25,153.5	2.8
8	Finance and Insurance	695.9	83.8	5.0	62,022.3	1.1
9	Real Estate Trade	112.0	13.5	0.8	6,032.3	1.9
10	Social Services	616.1	74.2	4.4	34,408.7	1.8
11	Health Care, Sports, and Social Welfare	156.2	18.8	1.1	6,677.6	2.3
12	Education, Culture, Art, Radio, Film and Television	311.7	37.5	2.2	16,491.5	1.9
13	Scientific Research and Polytechnical Services	278.9	33.6	2.0	24,682.2	1.1
14	Geological Prospecting and Water Conservancy	11.4	1.4	0.1	636.7	1.8
15	Government Agencies, Party Agencies, Social Organizations, and Others	282.0	34.0	2.0	12,690.3	2.2
16	Household	2,424.3	292.1	17.3	137,118.4	1.8
	Total	13,992.7	1,685.9	100.0	698,790.5	2.0*

Source: Calculated by the author. Detailed calculations are shown in Appendix J.

Note: 1. US $/ RMB = 8.3, in 2000 value. 2. The number with "*" is the percentage of total economic impacts/gross domestic product in Beijing in 2000.

Table 5-10 Backward and Forward Linkages of 16 Sectors in Beijing

Sectors	Total Backward Linkages	Total Forward Linkages
Farming, Forestry, Animal Husbandry, and Fishery	1.565	7.135
Mining	1.528	31.082
Manufacturing	2.136	5.907
Electricity, Gas, Water Production and Supply	1.447	7.006
Construction	2.022	1.196
Transportation, Storage, Post and Telecommunication	1.738	6.130
Wholesale, Retail Trade and Catering Services	1.568	9.698
Finance and Insurance	1.774	4.694
Real Estate Trade	1.792	4.995
Social Services	1.682	5.123
Health Care, Sports, and Social Welfare	1.737	2.416
Education, Culture, Art, Radio, Film and Television	1.558	3.880
Scientific Research and Polytechnical Services	1.433	3.337
Geological Prospecting and Water Conservancy	1.610	3.148
Government Agencies, Party Agencies, Social Organizations, and Others	1.653	2.579
Household	1.225	6.336
Weighted Average	1.565 [a]	5.451 [b]

Source: Calculated by the author based on the modified 1999 Beijing input-output table.

Notes:

a. The weights of backward linkages are calculated by dividing each sector's output by total output.

b. The weights of forward linkages are calculated by dividing each sector's input by total input.

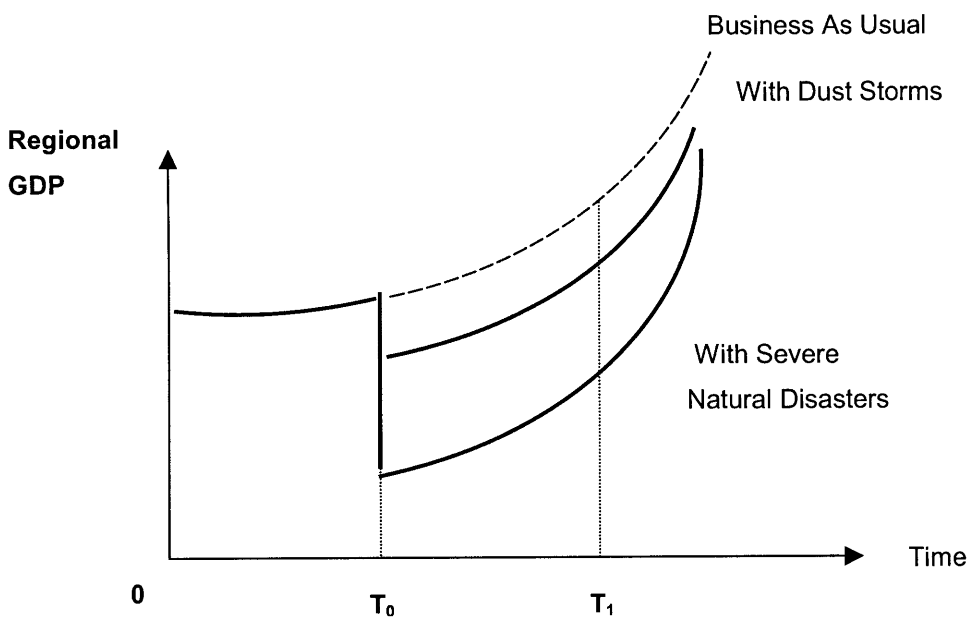

Figure 5-1 Comparison of Economic Impacts of Dust Storms and Other Severe Disasters on Regional Economy

Source: The author.

I compare the tendencies of the economic impacts of yellow-dust storms and other severe natural disasters on the regional economy in Figure 5-1. I use dotted lines to show the economic growth that a region would have had without disasters as a baseline, and I compare the different paths of regional economic changes after a yellow-dust storm and other severe natural disasters. The vertical axis is an indicator for regional GDP, and the horizontal axis shows the time period ranging from some point before the disaster to a few years afterwards. We can see that both yellow-dust storms and other disasters would lead to abrupt reductions in regional-economic activities, although the dust storms may not lead to as many losses as other disasters. Because yellow-dust storms in Beijing did not result in much damage of infrastructure, during the mitigation period they would not lead to large-scale construction to stimulate the regional economy, either. Thus, the stimulation effect through demand-driven relationships, or backward linkages after dust storms, may be very minor, and the losses resulting from a dust storm can be permanent, without much tendency to recover. In contrast, a region affected by a more severe disaster can initiate a new round of construction and mitigation activities, and may potentially show a larger GDP than it would have had after a less severe disaster, like a yellow-dust storm. Thus, the most effective and critical means to reduce the negative impacts of yellow-dust storms would be by focusing on prevention, in order to mitigate their impacts before they happen.

5.3 Sensitivity Analysis

Acknowledging that my quantitative analyses involve a considerable number of estimates, I conduct a sensitivity analysis in order to determine a range of the total economic impacts. I make different assumptions and assign lower and upper values for each input variable for which I have specified, with the values based on my own judgment in my previous calculations (I term these values "current.") I exclude those input variables with explicit statistics, such as the area of disrupted construction sites and the number of air flights rescheduled because of the April 6, 2000, dust storm in Beijing.

To evaluate the immediate impacts of the April 6, 2000, dust storm in Beijing, I summarize my different estimates of variables in Table 5-11. For the percentage of road accident increase, I make my assumptions based on the information reported in the 2000 Beijing Statistical Yearbook that "road accidents increased 20-30% over normal conditions" (Duan and Zhang, 2001, p. 364). So I specify an increase of 30% as the upper estimate, and an increase of 10% as the lower estimate, because I suspect that some factors other than dust storms, such as peak commuting hours, may also result in road accident increases. For the other two variables, losses in trade and catering services and losses in labor workdays, I can only estimate the value based on the duration of dust storms, which is usually a few hours. Because people may make up their working hours or resume shopping and dining after dust storms, I assume that a lower value than duration of dust storms is possible. For some socioeconomic activities with strict time requirements, such as goods delivery, the losses can be permanent. Therefore, I also list higher estimates of such losses in Table 5-11. With a range of estimates for the dust storm on April 6, 2000, I can continue with estimates of total immediate impacts for all the occurrences of dust storms in Beijing that year. I show my calculation results in Appendix K.

Table 5-11 Range of Estimates for Immediate Impacts of April 6, 2000 Dust Storm on Beijing

Input Variables	Lower	Current	Upper	Evidence/Reasons
Road Accident Increase	10%	20%	30%	Road accidents increased 20-30% over normal conditions (Duan and Zhang, 2001, p. 364).
Trade and Catering Services Losses	¼ business hours in a day	½ business hours in a day	¾ business hours in a day	Estimated by the author.
Household Workday Losses	¼ business hours in a day	½ business hours in a day	¾ business hours in a day	Estimated by the author.

Source: The author.

For the delayed impacts of the April 6, 2000 dust storm in Beijing, I summarize my estimates of different variables in Table 5-12. As I have discussed in Chapter 4, in the long term, some positive effects of dust storms would occur, which might cancel some of the negative impacts. Thus, when integrating the considerations for both positive and negative impacts, my estimates of delayed impacts tend to be lower than those just negative impacts. I show my estimates and corresponding reasons in Table 5-12.

With these different estimates, I derive the range of immediate impacts and delayed impacts as I show in Table 5-13. The total immediate impacts of ten dust storms in 2000 on Beijing would range from 401,813 thousand RMB to 698,855 thousand RMB ($ 48,411 thousand to $ 84,199 thousand); the upper estimate is 1.7 times the lower estimate. The delayed impacts would range from 822,433 thousand RMB to 2,467,298 thousand RMB ($ 99,088 thousand to 297,264 thousand); the upper estimate is 3.0 times the lower estimate. Apparently, the delayed impacts are more serious than immediate impacts: the lowest estimate of delayed impacts is still higher than the upper estimate of immediate impacts. Moreover, the range of delayed impacts is much larger than that of the immediate impacts. That is to say, the uncertainties for delayed impacts of dust storms are more significant than for immediate impacts.

Using the results in Table 5-13, I summarize the immediate impacts and delayed impacts sector by sector and input the lower and upper estimates (see Table K-4) into the Beijing input-output model. I show the results of backward linkages in Table 5-14, and the results of forward linkages in Table 5-15.

My sensitivity analyses show that the total economic impacts caused by backward linkages range from 1.0 to 2.3 percent of Beijing's GDP in 2000, which produces a difference of 1.3 percent. The range of the total economic impacts caused by forward linkages is much larger: the difference is 5.5 percent of Beijing's GDP in 2000 (the upper estimate is 8.4, while the lower is 2.9). That is to say, changes of input variables would produce a much larger range of effects through forward linkages than backward linkages. In other words, my results for total impacts caused by backward linkages may involve less bias than those for forward linkages.

Table 5-12 Range for Estimates of Delayed Impacts of Dust Storms on Beijing in 2000

Input Variables	Lower	Current	Upper	Evidence/Reasons
Agriculture Yield Decrease	5%	10%	15%	1. Chameides et al. (1999) conclude that high concentrations of particulates are currently depressing optimal yields of about 70% of the crops grown in China by 5–30%. 2. Other effects caused by dust storms may also influence crop yield, such as wind erosion (negative effects) and acid-erosion amelioration (positive effects; see Chapter 4). These may all cancel some of the negative impacts caused by particulates. Thus I did not use the upper range of 30% in my study.
Manufacturing Production Loss	0.5%	1%	1.5%	1. Peng (2000) briefly mentioned that less than 5% of the defects of products are caused by human and environmental effects. 2. Decreases in O_3, NO_x, and SO_2 after dust storms may have some positive impact by relieving the corrosion rate of manufacturing equipment (see Chapter 4). Thus, I assume the corrosion impacts of particulates during dust storms only resulted in a very low percentage of defected products, ranging from 0.5% to 1.5%.
Household Workday Losses	0.1	0.2	0.3	1. According to the dose-response functions suggested by ECON Center for Economic Analysis (2000), the percentage of annual increase rate of workday losses corresponding to per $\mu g/m^3$ increase of particulates is 0.2-0.6 days for each affected person. 2. The positive effects of decreases in O_3 and SO_2 cancel some of the negative effects of an increase in PM_{10} after a dust storm. Thus, I did not choose the upper range (0.6) in the dose-response functions.

Source: The author.

Table 5-13 Results of Immediate and Delayed Impacts of Dust Storms on Beijing in 2000

Sectors	**Immediate Impacts** (Thousand RMB)			**Delayed Impacts** (Thousand RMB)		
	Lower	Current	Upper	Lower	Current	Upper
Agriculture				394,206	788,412	1,182,618
Manufacturing				427,634	3. 855,268	1,282,902
Construction [a]	227,174	227,174	227,174			
Transportation [b]	26,508	26,898	27,288			
Trade and Catering Services	147,901	295,802	443,703			
Households	230	460	690	593	1,185	1,778
Total	401,813 ($48,411 thousand)	550,334 ($66,305 thousand)	698,855 ($84,199 thousand)	822,433 ($99,088 thousand)	1,644,865 ($198,177t housand)	2,467,298 ($297,265 thousand)

Source: The author.

Note:

a. For the Construction sector, because explicit statistics are available, I did not make any estimates. So I regard the economic impacts on the Construction sector as accurate, without variance.

b. Here the Transportation sector includes both road and air transportation. I adjusted the economic impacts for road accidents, but did not change the variables for air transportation.

5.4 Summary of Calculations

In this chapter, I conducted a quantitative analysis of dust storms in Beijing in 2000 applying the methodology introduced in Chapter 4. My results show that the impacts of yellow-dust storms have affected all types of sectors, from primary industry (Agriculture), to secondary industry (Manufacturing and Construction), and tertiary industry (Services). Delayed impacts of yellow-dust storms are more significant than direct impacts on Beijing in 2000. From my results of total direct impacts on six sectors, I note that the delayed impacts (1,644.8 million RMB, or $ 198.2 million) of dust storms are more costly than the immediate impacts (550.3 million RMB, or $ 66.3 million), even though they were not as instantly evident as those of the immediate impacts.

From a regional perspective, I have examined the inter-sectoral interactions using input-output techniques. I quantitatively evaluated the total impacts of yellow-dust storms in Beijing in 2000 generated by both backward linkages and forward linkages. I measured the total economic impacts caused by backward linkages by using the traditional Leontief inverse matrix, and I traced the impacts caused by forward linkages by changes in value added.

In total, my calculations show that the total economic impacts caused by backward linkages are 4,032.3 million RMB ($ 485.8 million), which is equivalent to 1.6 percent of Beijing's gross domestic product (GDP) in 2000. The total economic impacts caused by forward linkages are 13,992.7 million RMB ($ 1,685.9 million), which is equal to 2.0 percent of Beijing's GDP in 2000.

Compared to the total economic impacts caused by backward linkages, both the absolute value and the percentage value of the impacts caused by forward linkages are higher. That is to say, Beijing's regional economy is affected more seriously through forward linkages than backward linkages. The Agriculture sector appears to be affected most severely by both backward and forward linkages.

Because backward linkages and forward linkages among sectors are substantially intertwined, the total economic impacts on Beijing's regional economy are not the sum of economic impacts caused by backward and forward linkages. Rather, the total economic impacts should be somewhere between the 13,992.7 million RMB, or $ 1,685.9 million (the higher value of economic impacts caused by backward linkages and forward linkages) and 18,025.0 million RMB, or $ 2,171.7 million (the sum of impacts caused by both linkages), or between 5 and 7 percent of Beijing's GDP in 2000.

Table 5-14 Total Economic Impacts Caused by Backward Linkages

No.	Sectors	Total Economic Impacts (Million RMB)			Total Economic Impacts (Million $)			Percentage of Impacts/Sectoral Output (%)		
		Lower	Current	Upper	Lower	Current	Upper	Lower	Current	Upper
1	Farming, Forestry, Animal Husbandry, and Fishery	475.2	946.8	1,418.4	57.3	114.1	170.9	2.6	5.2	7.8
2	Mining	34.4	61.9	89.4	4.1	7.5	10.8	1.2	2.2	3.1
3	Manufacturing	905.3	1,681.7	2,458.1	109.1	202.6	296.2	0.4	0.7	1.0
4	Electricity, Gas, Water Production and Supply	18.6	34.4	50.2	2.2	4.1	6.0	0.2	0.3	0.4
5	Construction	229.2	230.7	232.2	27.6	27.8	28.0	0.3	0.3	0.3
6	Transportation, Storage, Post and Telecommunication	77.3	114.5	151.6	9.3	13.8	18.3	0.3	0.4	0.6
7	Wholesale, Retail Trade and Catering Services	231.9	445.8	659.8	27.9	53.7	79.5	0.9	1.8	2.6
8	Finance and Insurance	48.1	86.3	124.5	5.8	10.4	15.0	0.1	0.1	0.2
9	Real Estate Trade	4.0	7.3	10.6	0.5	0.9	1.3	0.1	0.1	0.2
10	Social Services	36.8	62.2	87.7	4.4	7.5	10.6	0.1	0.2	0.3
11	Health Care, Sports, and Social Welfare	0.7	1.2	1.7	0.1	0.1	0.2	0.0	0.0	0.0
12	Education, Culture, Art, Radio, Film and Television	5.5	9.7	13.9	0.7	1.2	1.7	0.0	0.1	0.1
13	Scientific Research and Polytechnical Services	22.2	38.4	54.7	2.7	4.6	6.6	0.1	0.2	0.2
14	Geological Prospecting and Water Conservancy	0.3	0.6	0.8	0.0	0.1	0.1	0.0	0.1	0.1
15	Government Agencies, Party Agencies, Social Organizations, and Others	13.7	24.6	35.6	1.7	3.0	4.3	0.1	0.2	0.3
16	Household	165.3	286.1	406.9	19.9	34.5	49.0	0.1	0.2	0.3
	Total	2,268.5	4,032.3	5,796.1	273.3	485.8	698.3	1.0*	1.6*	2.3*

Source: The author. Calculation details in Appendix K.

Note: 1. US $/ RMB = 8.3, in 2000 value. 2. The number with "*" is the percentage of total economic impacts/gross domestic product in Beijing in 2000.

Table 5-15 Total Economic Impacts Caused by Forward Linkages

No.	Sectors	Total Economic Impacts (Million RMB)			Total Economic Impacts (Million $)			Percentage of Impacts/Sectoral Output (%)		
		Lower	Current	Upper	Lower	Current	Upper	Lower	Current	Upper
1	Farming, Forestry, Animal Husbandry, and Fishery	569.5	1,136.7	1,703.8	68.6	136.9	205.3	3.1	6.2	9.4
2	Mining	15.0	29.4	43.9	1.8	3.5	5.3	0.5	1.0	1.5
3	Manufacturing	2,689.6	5,317.8	7,945.9	324.1	640.7	957.3	1.1	2.2	3.2
4	Electricity, Gas, Water Production and Supply	49.1	96.3	143.6	5.9	11.6	17.3	0.4	0.9	1.3
5	Construction	825.0	1,404.9	1,984.8	99.4	169.3	239.1	1.2	2.1	3.0
6	Transportation, Storage, Post and Telecommunication	220.7	407.5	594.2	26.6	49.1	71.6	0.8	1.5	2.2
7	Wholesale, Retail Trade and Catering Services	359.2	711.6	1,064.0	43.3	85.7	128.2	1.4	2.8	4.2
8	Finance and Insurance	355.5	695.9	1,036.4	42.8	83.8	124.9	0.6	1.1	1.7
9	Real Estate Trade	57.1	112.0	166.9	6.9	13.5	20.1	0.9	1.9	2.8
10	Social Services	315.9	616.1	916.4	38.1	74.2	110.4	0.9	1.8	2.7
11	Health Care, Sports, and Social Welfare	79.2	156.2	233.2	9.5	18.8	28.1	1.2	2.3	3.5
12	Education, Culture, Art, Radio, Film and Television	158.8	311.7	464.5	19.1	37.5	56.0	1.0	1.9	2.8
13	Scientific Research and Polytechnical Services	141.8	278.9	416.0	17.1	33.6	50.1	0.6	1.1	1.7
14	Geological Prospecting and Water Conservancy	5.8	11.4	17.0	0.7	1.4	2.1	0.9	1.8	2.7
15	Government Agencies, Party Agencies, Social Organizations, and Others	143.8	282.0	420.2	17.3	34.0	50.6	1.1	2.2	3.3
16	Household	1,226.3	2,424.3	3,622.4	147.7	292.1	436.4	0.9	1.8	2.6
	Total	7,212.3	13,992.7	20,773.2	868.9	1,685.9	2,502.8	2.9*	5.7*	8.4*

Source: The author. Calculation details in Appendix K.

Note: 1. US / RMB = 8.3, in 2000 value. 2. The number with "*" is the percentage of total economic impacts/gross domestic product in Beijing in 2000.

In my sensitivity analysis, I noted that the range of delayed impacts is much larger than that of the immediate impacts, and the range of the total economic impacts caused by forward linkages is much larger than that of backward linkages. Using the method above, the total economic impacts caused by dust storms on Beijing in 2000 would range between 2.9 to 10.7 percent of Beijing's GDP in 2000.

Chapter 6
CONCLUSIONS AND FURTHER DISCUSSION

Having summarized my calculations and analyses in previous chapters, I conclude my study with research findings, from which I develop several policy implications. Then I discuss some research limitations of my study and propose critical further research areas.

6.1 Summary of Research Findings

For a first quantitative analysis of yellow-dust storms both in China and in other developed countries, I have compiled the disparate information relevant to yellow-dust storms and identified the gaps of data requirements and availability. Based on previous studies of impact-categorization methods and evaluation techniques, I endeavored to connect the environmental system with socioeconomic activities and to measure all types of impacts in economic terms to the greatest extent possible. I set up a research framework for economic-impact analysis of yellow-dust storms, and I evaluated the impacts, applying multidisciplinary methodologies. By performing a case study of Beijing in 2000, I examined manifold impacts of yellow-dust storms from a regional-economic perspective and quantified the impacts despite very limited socioeconomic information.

Through data compilation, I noted that systematic socioeconomic studies of yellow-dust storms were missing. In contrast to the heated discussion of scientific aspects of yellow-dust storms, apparently there is a lack of studies on the connection of the environmental system and the socioeconomic system. Such a research gap results from both inadequate socioeconomic statistics and non-uniform impact-evaluation methodologies. Thus, creation of an applicable research framework may be more valuable than detailed calculations at this stage. Once possessing a sound research framework, analysts can subsequently, with additional data, improve both the research methodology and data inputs, thereby enhancing the accuracy of the numerical results.

Using my proposed research framework and multidisciplinary methodologies, I conducted a quantitative analysis of the case, studying the economic impacts on Beijing in 2000. I concluded that negative impacts of yellow-dust storms are absolutely larger than immediate impacts. I proved that the impacts of yellow-dust storms have affected all sectors, from primary industry (Agriculture), to secondary industry (Manufacturing and Construction), and tertiary industries (Services). Delayed impacts of yellow-dust storms were more significant than direct impacts on Beijing in 2000. The Construction, Transportation, and Trade and Catering Services sectors were mainly affected immediately after dust storms, while the Agriculture and Manufacturing sectors showed fewer effects than other sectors until some time after the dust storms.

From a regional perspective, I examined the inter-sectoral interactions using input-output techniques. I quantitatively evaluated the total impacts of yellow-dust storms in Beijing in 2000 generated by both backward linkage and forward linkages. When comparing the economic impacts on each sector caused by backward and forward linkages, I found that the Agriculture sector consistently shows the most serious impacts, which far exceed those of other sectors. For other sectors, they are affected through the inter-sector interaction differently; some show larger losses through backward linkages, and some the reverse. In total, my calculations show that the total economic impacts caused by backward linkages are 4,032.3 million RMB ($ 485.8 million), which is equivalent to 1.6 percent of Beijing's gross domestic product (GDP) in 2000. The total economic impacts caused by forward linkages are 13,992.7 million RMB ($ 1,685.9 million), which is equal to 2.0 percent of Beijing's GDP in 2000. Both the absolute value and the percentage value of the impacts caused by forward linkages are higher than those caused by backward linkages. It appears that Beijing's regional economy is affected more seriously through forward linkages than backward linkages. Also from my linkage analysis, I infer that yellow-dust storms would not show as strong stimulating effects on the regional economy afterwards as other severe disasters, because yellow-dust storms in Beijing are not so severe as to cause large-scale damage to infrastructure and facilities. Consequently, dust storms would not create an economic boom in the construction and manufacturing activities during the remediation period, as do disasters like earthquakes or floods. In this regard, prevention of dust storms plays a more critical role than remediation.

I conclude my calculations with a sensitivity analysis, which shows that the range of delayed impacts is much larger than that of the immediate impacts, and the range of the total economic impacts caused by forward linkages is much larger than that of backward linkages. Numerically, the total economic impacts caused by backward linkages range from 1.0 to 2.3 percent of Beijing's GDP in 2000. The range of the total economic impacts caused by forward linkages is from 2.9 to 8.4 percent of Beijing's GDP in 2000.

6.2 Additional Findings on Water Resource Management

An issue independent from the traditional input-output model is the economic impacts of water-resource pressure. Yellow-dust storms have placed great pressure on water resources, both for more demand for clean water and more discharge of wastewater after the storms. One quantifiable example is car washing. It is estimated that cleaning a car requires 200~300 liters of water (Sun, 2001). In 2000, there were, altogether, 1,364,718 motor vehicles in Beijing. Assuming that 80% of the cars were either operated or parked outdoors during a given dust storm, we can postulate that around 1 million vehicles needed cleaning after each storm. Assuming that 80% of the owners of these vehicles had the vehicles cleaned by water, then one occurrence of a dust storm would have consumed 160 to 240 thousand tons of water. When compared with the daily production capacity of water supply in Beijing of 3,670 thousand tons (BMSB, 2001, p. 467), car cleaning for one occurrence of dust storms can consume around 5% of the daily total.

Because Beijing has been one of the top cities facing a water crisis in the recent century (see Chapter 4), the impacts of yellow-dust storms on water resources are particularly crucial to Beijing. With rivers drying up after excessive intake for human activities, Beijing has had to rely upon neighboring regions for water, which consequently exacerbates the burden on other regions' resources. This may also contribute to the causes of regional desertification, and, consequently, more severe yellow-dust storms in the northern part of China. These impacts, along with the already heavy burden on resources due to intensive socioeconomic activities, not only bring environmental problems but also a potential economic burden to the city, and they may, in turn, restrict the rapid growth of the local economy.

In Figure 6-1, I illustrate the interactive relationship between yellow-dust storms, water resources, and human socioeconomic activities. First, water shortages, especially in the spring, have been one of the leading causes of yellow-dust storms. If arid or semi-arid areas did not exist, there would be no sources of yellow-dust storms. Yellow-dust storms, in turn, have exerted an even greater pressure on water resources, both increasing water demand and wastewater pollution after each dust storm. Thus, the arrow between Yellow-Dust Storms and Water Resources goes in both directions. Second, socioeconomic activities have generated a rapidly increasing demand for water resources from the environmental system and have caused severe water-scarcity problems, while water scarcity has been a significant constraint for regional economic development. Again, I show the relationship between Socioeconomic Activities and Water Resources by the two-way arrow. Third, socioeconomic activities, which extensively involve excessive exploitation of natural resources, have exacerbated yellow-dust storms in the recent years, which, in turn, have affected socioeconomic activities in many ways, unfortunately, more often than not, in negative ways. Thus, I show the relationship between Socioeconomic Activities and Yellow-Dust Storms also as a two-way arrow. I emphasize Humans as a major stakeholder in my figure, because humans have played an active role in connecting economic and environmental systems and essentially caused the vicious cycle among socioeconomic activities, yellow-dust storms, and water resources. Thus, human has interaction relationships with all these issues as I show by the two-way arrows as well. Only when humans take preventive measures as a priority, can the vicious cycle between humans, economic, and environmental systems be alleviated.

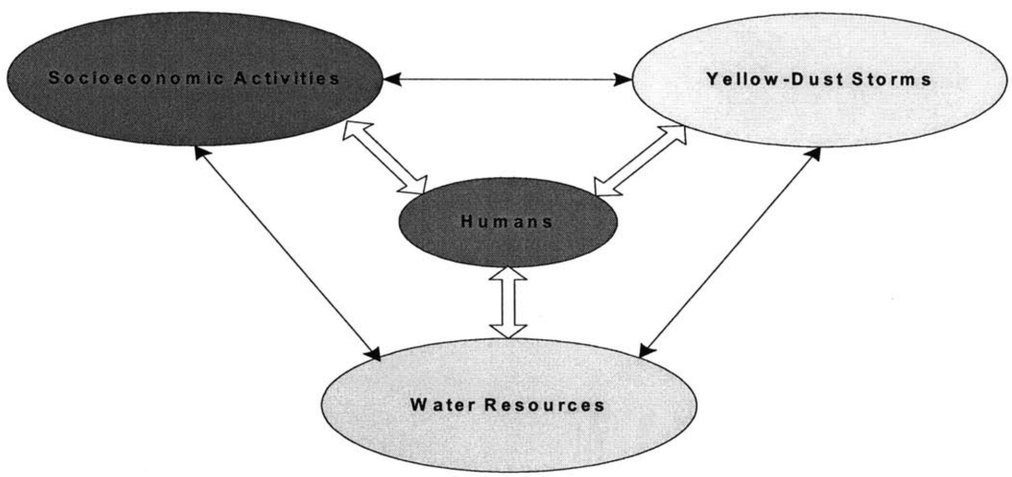

Figure 6-1 Interactions Among Human, Economic, and Environmental Systems
Source: The author.

6.3 Policy Recommendations

Based on my impact analysis and research findings regarding the yellow-dust storms in China, I have formulated four main policy recommendations.

First, the government should facilitate data-compilation concerning yellow-dust storms for a better understanding and subsequently more effective control of yellow-dust storms than at present. In particular, two sets of information are necessary: one is a regional input-output account; the other is a socioeconomic-information database of yellow-dust storms compiled both for each region and for the occurrence period. Only when both of the information sets are complete, can analysts conduct numerical analyses more accurately than at present. Thus, government officials should consider including yellow-dust storms in the annual disaster statistics and strengthening the data-collection and compilation efforts for regional and multiregional analysis.

Second, policy analysts should regard "prevention" as the priority of dust-storm control. On the basis of both quantitative and qualitative analyses, I conclude that the most cost-effective way is for policy makers and planners to give prevention of yellow-dust storms the priority, because mitigation of yellow-dust storms afterwards would not stimulate the regional economy as much as other severe disasters, and appropriate prevention measures (such as reasonable water-resource planning) may benefit both the regional economy and the environment.

Third, dust-storm prevention/control measures should not be limited to planting trees, as is the current situation in China. Although the yellow-dust storm problem has gained much attention from both local governments and the central government in China, currently most of the yellow-dust-control projects are limited to reforestation and desertification control. However, necessary prevention measures should also extend to sectors other than agriculture and forestry. As is shown by the present economic-impact analysis, the economic impacts on Agriculture, Construction, and Manufacturing as well as other sectors, can be very costly. The Chinese government should encourage research on prevention measures, such as how to improve the means and the properties of sealing to protect crops and sophisticated equipment from dust, and how to depress the elevated dust from open construction sites. Such prevention measures might help avoid potentially high costs.

Last, but not least, water-resource planning should be integrated into dust-storm control, because it is closely related to the impacts of yellow-dust storms on a regional economy. Although a vicious cycle seems to have formed among the human, economic, and environmental systems, analysts have not paid adequate attention to the integration of a resources account into regional-economics studies. Thus, people tend to underestimate the value of water resources, which may lead to further extravagant use of this limited resource and consequently more intensified dust storms.

6.4 Research Limitations

In terms of a regional study, input-output techniques have proven to be helpful in quantifying the socioeconomic impacts accurately and systematically. However, due to data limitations and underdeveloped methodology, my study may have incorporated some biases. I discuss limitations and possible biases of my analysis and further explore those impacts that may produce potential impacts on Beijing but are omitted in the input-output analysis.

One limitation is that I derive my results from the regional-output changes in input-output models, which do not separate sectors' regional output losses and benefits. The challenge lies in determining how to handle that fact that what constitutes a loss for some sectors is an opportunity for others. For instance, cleanup and maintenance after dust storms brings costs to manufacturers and households, while it may increase the available work opportunities in the service industry, such as car-cleaning and sanitation sectors. Regional economists usually regard this as a benefit to the industry's productivity and therefore as an increase in regional output and employment. However, the essential output should be the net value of real output minus stock, disaster, and pollution. Thus, my economic-impact analysis does not provide information at a sector or individual level, and I have actually conducted the impact analysis from human's perspective, producing a numerical result in economic terms.

Second, my one-year period and single-region study may have produced an underestimation of the impacts of yellow-dust storms. Within the single-region constraint, I could not capture the net impacts with interregional flows, such as economic immigrants, cross-region investment, and employment changes. This appears to be an important factor for impact analyses, given that the yellow-dust storm is a transboundary environmental problem. In addition, with the one-year constraint, I did not include cumulative environmental impacts that result from interactions between acid matter in the atmosphere and particulate matters carried by yellow-dust storms. Neither did I evaluate people's behavior and changes in preferences, such as those related to travel, investment, and insurance. Other intangible impacts, such as mental stress, anxiety, and even frustration during and after dust storms, inevitably influence labor productivity, and, in turn, influence economic output. However, I could not locate any scientific evidence to quantify such impacts.

6.5 Further Research Areas

Finally, I suggest the following additional studies. First, analysts should take full advantage of input-output techniques to make accurate socioeconomic impact analyses, for yellow-dust storms as well as other natural disasters. To do this, they need to develop a simple and uniform disaster-assessment framework worldwide. Such a framework will supplement traditional input-output analysis, but demand fewer data, so that every region can afford to compile the data. Then, analysts can track, evaluate, compare, and manage disasters more easily. I recognize that the effects of disasters vary greatly with regard to location, topography conditions, season, and time, as well as other factors. However, analysts may want to conduct a quick review of the comprehensive impacts before processing detailed data for input-output analysis.

Second, multiregional and time-series economic-impact studies should be developed. Because the yellow-dust storm is a transboundary environmental problem, analysts can capture the total impacts of yellow-dust storms only at an international level, rather than by regarding any one of the affected regions as a closed system. In the case of Beijing, my single-region analysis focuses only on the local impacts, but leaves aside the impacts that Beijing may have brought to other regions, such as carrying pollutants and infectious diseases to other regions, and the impacts of investment, tourism, and economic immigrants among regions during and after dust storms.

6.6 Conclusion

Through both quantitative and qualitative analyses of dust storms in China, I have identified a current research gap, proposed a conceptual framework, and applied it in practice. To conclude, I want to stress that my pioneering study must still be considered preliminary because of the limitations of available information. The goal of this study is not to provide precise figures for policy makers' investment decisions. Rather, it is a starting point for an integrated economic-impact analysis across disciplines and provides a reference for other analysts to verify and improve. With additional data and information, analysts will become able to evaluate the impacts of dust storms, as well as other disasters, more accurately than at present.

APPENDICES

Appendix A: Basics of Input-Output Models

The basic input-output table is generally constructed for a specific geographic region (Table A-1). In each column of an input-output table, or for each intermediate purchaser (sector j), the amount that it purchases directly from a particular seller (sector i) per dollar's worth of output is called the technical coefficient, or direct-input coefficient, commonly denoted by:

$$a_{ij} = X_{ij}/X_j \qquad \text{(A-1)}$$

Assuming the technology remains unchanged in the short term, analysts regard the technical coefficients as fixed. The total output of Sector i (X_i) is used exclusively for two purposes: (1) intermediate products (X_{ij}), as the input for other sectors as well as itself, and (2) final demand (Y_{ij}), as the consumption and accumulation. Thus, the output relationship (in the horizontal direction) can be denoted as:

$$\sum_{J=1}^{n} aij\ Xj + Yi = Xi \qquad (i=1, 2, \ldots, n) \qquad \text{(A-2)}$$

Or it can be put simply in the way as:

$$AX + Y = X \qquad \text{(A-3)}$$

Table A-1 Basic Format of Input-Output Model

		Intermediate Demands	Final Demand	Total Output
		Sector 1 … Sector n		
Intermediate Input	Sector 1 . . . Sector n	X_{ij}	Y_{ij}	X_j
Other Primary Input		V_j		
Total Input		X_j		

After transformation of the matrix, I derive the Leontief input-output relationship as below:

$$X = (I-A)^{-1} Y \quad \text{(A-4)}$$

Where:

A: the matrix of direct-input coefficients (a_{ij})
$(I-A)^{-1}$: the Leontief inverse indicating input-output relations among sectors;
X: a matrix of total output of every sector;
Y: a matrix representing the final demands for all the sectors.

Analysts use linkage analysis, including both backward and forward, to trace the changes in the regional economy. The backward linkage examines the demand-driven effects, namely, how one unit's output change in sector j influences the amount of output change in the other sectors that supply raw and intermediate materials. For sector j, the direct backward linkage is defined as the column sum of the intermediate technical coefficients, or $\sum a_{ij}$ ($i = 1, 2 \ldots n$). From the Leontief inverse of the A matrix, analysts may derive the total backward linkages (TBL) for each sector, as the row of the column sums of the $(I-A)^{-1}$. The larger the TBL, the more sector j depends on other sectors in the economy, and the more that economy might be expected to be stimulated by increases in output of sector j.

In contrast, an analyst uses the forward linkage to examine how one unit's change of sector j's output influences output in other sectors that purchase the products of sector j. To derive the forward linkages, analysts need to set up a new matrix, commonly called the F matrix. Each element of the F matrix is defined as $f_{ij} = X_{ij}/X_i$. And the direct forward linkage (TFL) is defined as the row sums of the F matrix. By deriving the Leontief inverse of F matrix, analysts may derive the total forward linkages (TFL) for each sector, as the column of the row sums of the $(I-F)^{-1}$. The larger a sector's TFL, the more its output is utilized as an input to production in the local economy and, correspondingly, the heavier impacts it will bring to the economy if it is affected, for example, by dust storms.

In terms of the treatment of components of final demand, there are two main input-output models: (1) an open input-output model, and (2) a partially closed input-output model. An open input-output model treats all components of final demand--namely, investment, consumption, capital formation, import, and export--as exogenous. For a partially closed input-output table, one or more components of final demand are treated endogenously. In terms of the Leontief inverse, these two models imply a different relationship of flows between sectors. In an open input-output model, the Leontief inverse does not capture induced effects. Examples may include spending in the economy or expenditures by employees on food, services, and other household expenses. Analysts use A* to denote the technical coefficients of a partially closed table, in order to differentiate them from the A matrix in an open model. Accordingly, analysts use $(I-A^*)^{-1}$ of a partially closed model to measure all impacts of the economy, including the direct, indirect, and induced effects (Chen, 1992, p. 31; Davis, 1990, p. 59).

Appendix B: Aggregation of Sectors in the 1999 Beijing Input-Output Table

No	15-sector Aggregation	Abbreviation	Corresponding 49-Sector Aggregation
1	Farming, Forestry, Animal Husbandry, and Fishery	Agriculture	1. Agriculture, 2. Forestry, 3. Fishery, 47.Services for Farming, Forestry, Animal Husbandry and Fishery
2	Mining	Mining	4. Coal-selection, 5. Gasoline and Natural Gas Extraction, 6. Metal Mineral Quarrying, 7. Non-metal Ore Extraction
3	Manufacturing	Manufacturing	8. Food Production and Cigarette, 9. Textile, 10. Clothing, Leather, Fur and Other Fiber Production, 11. Wood Process and Furniture Manufacturing, 12. Papermaking and Education-equipment Making, 13. Petroleum and Coke-making, 14.Chemistry, 15. Non-metal Mineral Products Manufacturing, 16. Metal-smelting and Manufacturing, 17. Metal-products Manufacturing, 18. Machinery, 19. Transportation-utility Manufacturing, 20. Electric-equipment Manufacturing, 21. Electronic and Communication Manufacturing, 22. Equipment and Meter Manufacturing, 23. Machinery Repairing, 24. Other Manufacturing, 25. Waste Materials
4	Electricity, Gas, Water Production and Supply	Electricity	26. Electric Power Supply, 27. Steam and Hot Water Supply, 28. Gas Supply, 29. Water Supply
5	Construction	Construction	30. Construction
6	Transportation, Storage, Post and Telecommunication	Transporta-tion	31, Water Transportation, 32.Other Transportation and Warehouse, 33. Post and Telecommunication, 36. Water Passenger-transportation, 37.Other Passenger-transportation
7	Wholesale, Retail Trade and Catering Services	Trade	34.Commerical, 35.Catering Trade
8	Finance and Insurance	Finance	38. Finance and Insurance
9	Real Estate Trade	Real Estate	39. Real Estate Trade
10	Social Services	Social	40. Public Utilities, 41. Residential Services, 42.Other Social Services
11	Health Care, Sports, and Social Welfare	Health	43. Health Care, Sports and Social Welfare
12	Education, Culture, Art, Radio, Film and Television	Education	44. Education, Culture, Arts, Radio, Film and Television
13	Scientific Research and Polytechnical Services	Science	45. Scientific Research, 46. Polytechnic Services
14	Geological Prospecting and Water Conservancy	Geology	48. Geological Prospecting and Water Conservancy
15	Government Agencies, Party Agencies, Social Organizations, and Others	Government	49. Administrative Agencies and Others

Source: The 1999 Beijing input-output table was provided by Professor Xikang Chen at the Institute of System Science at Chinese Academy of Sciences in Beijing, in March 2002.

Appendix C: Calculations of Immediate Impacts of 04/06/2000 Dust Storm on Beijing

Regarding immediate economic impacts of yellow-dust storms, I have covered the impacts on construction, transportation, trade and catering services, and on human health in order.

C-1 Impact on Construction Sector

The construction sector's activities are usually disrupted when yellow-dust storms occur with strong winds. I assume that the total value added of the construction sector has a positive linear relationship with the construction area. I multiply the average daily value added of the construction sector, by the percentage of affected construction area, and then by the length of time of the disruption, to derive the economic impact on construction sector.

1. Total construction area: 69,959 thousand square meter (source: Beijing Statistical *Information Net, http://www.bjstats.gov.cn/was40/detail?record=135&channelid=37838&presearchword=*), or approximately 70 million square meter.
2. Nearly 60 million square meters of construction sites shut down construction activities, and several shelters and granaries were damaged (Zheng S.H., S.R.,Wang, and Y.M. Wang, 2000).
3. Percentage of construction area affected: 60/70 = 86%.
4. Value added of construction sector in Beijing in 2000 was 19.88 billion RMB (source: BMSB, Beijing Economic and Social Development Report 2000).
5. Daily construction output: 19.88 billion/365 =54,466 thousand RMB.
6. Decrease of output due to one half day (0.5) of disruption of 86% construction activities: 54,466 X 0.5 X 86% = 23,420 thousand RMB.

C-2 Impact on Transportation Sector

There are two main types of economic impacts on the transportation sector caused by yellow-dust storms: one is related to air-flight changes, the other is related to increased air accidents. My application of parameters and calculation process for these two types of impacts are as follows.

C-2-1 Losses Related to Air-Flight Changes

To calculate losses related to air-flight changes, I borrow the loss estimation of air-flight changes in the United States in 1992, and adjust the loss from the US dollars to China RMB by the exchange rate and the consumer price index.

1. In the United States, the cost of a diverted flight can be as high as $150,000 and a cancellation close to $40,000 (Irrgang and McKinney, 1992).
2. A comparison of the 1992 value added for the transportation sector in China and in the United States:

Table C-1 Value Added of Transportation Sector in China and In the United States in 1992

Country	**Value Added of Air-Transportation Services in 1992**	**Source**
China	1. Passenger Air-Transportation: 4,164,840 thousand RMB 2. Goods Air-Transportation: 2,040,560 thousand RMB 3. Total: 6,205,400 thousand RMB	Department of National Economic Accounting, State Statistical Bureau of P. R. China, Input-output Table of China 1992. Beijing: China Statistical Press, pp. 201-203.
United States	42.2 billion US dollars	U.S. Department of Transportation, Bureau of Transportation Statistics, April 1998.

3. US dollars and RMB exchange rate in 1992: 1 USD = 5.5 RMB (s*ource:* *http://www.x-rates.com/cgi-bin/hlookup.cgi*).
4. Value added of Transportation sector of 1992 China in US dollars:
   6,205,400 thousand RMB / 5.5 = 1,128,255 thousand US dollars = 1.1billion US dollars
5. US/China ratio of value added in Air Transportation sector: 42.2 / 1.1 = 38.4
6. In terms of US dollars, the cost of one diverted flight in 1992 China can be as high as 3906 (= 150,000/ 38.4) and one cancellation close to 1,042 (= 40,000/ 38.4).

7. In terms of RMB, the cost of one diverted flight in 1992 China can be as high as 21,483 (= 3906 X5.5), and one cancellation can be close to 5731 (= 1042 X 5.5).
8. Total cost in 1992 value: 21,483 X (9 + 52) + 5,731 X 48 = 1,585,551 RMB
9. National Household Consumption Index from 1992 to 2000 in China:
10. 1978 =100, 1992 = 270.3, 2000 = 459.4, 2000/1992 = 1.7
    (S*ource: Beijing Statistical Yearbook, 1993 and 2000*).
11. Total losses of Air-Flight Changes in 2000 value:
    1,585,551 X 1.7 = 2,695,437 RMB = 2,695 thousand RMB.

C-2-2 Losses Related to Road Accidents

To calculate losses related to road accidents, I multiply the average losses in road accidents by the increased number of accidents caused by dust storms.

1. The Number of Annual Road Accidents in Beijing 2000: 33,057
2. Total Economic Loss in the road accidents: 142,726,934 RMB
3. Average Economic Loss per accident: 142,726,934 /33,057 = 4,18 RMB
4. Average Daily Road-Accident Occurrences: 33,057/365 = 90
5. Traffic flow apparently decreased, and road accidents increased 20-30% over normal conditions (Duan and Zhang, 2001, p.364).
6. Estimated Number of 20% Increases in road-accident occurrence due to dust storms: 90X0.2 = 18
7. Estimated Economic Loss in road accidents due to dust storms: 18 X 4318 = 77,724 RMB = 78 thousand RMB

C-2-3 Total Loss of Air Flights Changes and Road Accidents

2,695,437 + 77,724 = 2,773,161 RMB = 2,773 thousand RMB

C-3 Impact on Trade and Catering Services

I assume that trade and catering services are seriously affected by dust storms: all outdoor businesses have to close, and people do not go shopping or dine out when dust storms occur. Because a dust storm lasts only a few hours, and usually occurs in the morning, I assume that only one-half day of sales is affected.

1. Value added of Trade and Catering Services sector in Beijing in 2000 was 22.26 billion RMB (source: BMSB, Beijing Economic and Social Development Report 2000).
2. Average daily value added: 22.26 billion/365 = 60.99 million RMB
3. Half-day economic loss: 30.495 million RMB = 30,495 thousand RMB

C-4 Impacts on Human Health

I assume that acute health impacts of yellow-dust storms only include emergency visits due to eye-infection diseases spread by dust particles, and only impacts on employed workers lead to economic losses. By identifying the dose-response of concentration of particles and an increase in particulate matter concentration on April 6, 2000, I estimate the persons that may have been affected, and the number of workday losses.

1. Dose-response relationship (Chapter 4) shows that: there would be an increase of incidences emergency visits of 0.011% of all population in one year, when there is one microgram' increase of PM10 per cubic meters.
2. The total number of employed workers in Beijing in 2000: 6,192,927 persons. (*Source: Beijing Statistical Yearbook, 2001, p. 82*).
3. I take the annual average value of PM_{10} as the control value, and derive the increase in concentration of inhalable particles resulted from yellow-dust storms by subtracting annual average from the daily value of PM_{10}. Then I reached 1,338 μg/m3 (see p. 44).
4. Estimated number of emergency visits for one day:
   0.011% X 6,192,927 X 1,338 / 365 = 2,497
5. I assume that each outpatient loses half workday (0.5) due to hospital visits. The total workday losses in Beijing due to the dust storm are: 2497 X 0.5 = 1,248 (days)
6. The total number of employed workers in Beijing in 2000: 6,192,927 persons. (*Source: Beijing Statistical Yearbook,* 2001, p. 82).
7. In 2000, Beijing's gross domestic product (GDP) was 246 billion RMB. Then the average per capita GDP per day is: 246 billion/ (365 X 6,192,927) = 108.8 RMB
8. Total GDP lost due to labor's workday losses:
   108.8 X 1,248 = 135,782 RMB =136 thousand RMB

Appendix D: Estimation of Immediate Impacts of 10 Dust Storms on Beijing in 2000

Because there are no available socioeconomic data except those for April 6, 2000, I will estimate the impacts of other occurrences by comparing the intensity of the other nine yellow-dust storms with the one on April 6, 2000. I estimate impacts by different weights of wind speed and visibility.

Take the occurrence on March 3, 2000 for example. On March 3, 2000, the visibility index is 2, and the wind speed index is 0.6. With my assumptions of impacts' positive relationship with wind speed and negative relationship with visibility as discussed above, I conclude that the occurrences on March 3, 2000 experienced lighter impacts than that of April 6, 2000.

Particularly, because the visibility index is 2, there were one-half (1/2) of workday losses compared to that of April 6; because the wind speed index is 0.6, the impacts on construction, transportation, trade, and catering services are 60% of those of April 6. In real figures, workday losses were 624 (= 1,248 X (1/2)) days; impacts on construction sector were 14,052 (= 0.6 X 23,420) thousand RMB; impacts on transportation sector were: 1,664 (= 0.6 X 2,773) thousand RMB; impacts on trade and cater services: 18,297 (= 0.6 X 30,495) thousand RMB.

Appendix E: Calculations of Delayed Impacts of Dust Storms on Beijing in 2000

E-1 Impact on Agriculture

I assume that yellow-dust storms mainly affect agriculture by a high concentration of particulate matter. Because there are no numerical studies on yellow-dust storm influences on agriculture, I adopt an estimation of yield-decrease due to particulates. I multiply the estimated coefficient by the total output of the agriculture sector in Beijing to derive the economic impact on agriculture. The required parameters and calculation process are as follows.

1. Chameides et al. (1999) conclude that high concentrations of particulates are currently depressing optimal yields of about 70% of the crops grown in China by 5–30%.
2. I assume that the occurrences of the yellow-dust storm in 2000 resulted in a 10% decrease of the yield in crops in Beijing, and that the yield of crops has a positive linear relationship with gross output value.
3. Beijing 2000 gross output value of agriculture was 11,263,033,000 RMB (*Beijing Yearbook, 2000*).
4. Decrease in output for agriculture, forestry, animal husbandry, and fisheries:
   10% X 70%X 11,263,033,000 = 788,412,310 RMB = 788,412 thousand RMB.

E-2 Impacts on Manufacturing

I assume that particulates do not result in significant increases in product defects, and accordingly lead to 1% decrease in product yield of sophisticated-equipment manufacturing, which involves Electric-equipment Manufacturing, Electronic and Communication Manufacturing, and Equipment and Meter Manufacturing. Because I do not have sectoral socioeconomic data for 2000, I assume that the production activities of manufacturing sectors changed so little between 1999 and 2000 that I can regard it is the same in both years. Then, I assumed the value added of these three sectors in the 1999 input-output table, and multiplied the output value by 1% to derive the yield loss of manufacturing.

1. Total value added of sophisticated-equipment manufacturing sectors in 1999 Beijing is 8,552,684 thousand RMB, including:
   (1) Electric-equipment Manufacturing (sector 20): 1,603,218 thousand RMB
   (2) Electronic and Communication Manufacturing (sector 21): 6,301,196 thousand RMB
   (3) Equipment and Meter Manufacturing (sector 22): 648,270 thousand RMB
2. Total losses due to 1% decrease in product yield:
   8,552,684 X 1% = 855,268 thousand RMB.

E-3 Impacts on Human Health

I start with an estimation of the average PM_{10} during all occurrences of dust storms in Beijing in 2000. Then, I compare it with the control point, treating the difference as the effects by those ten occurrences of dust storm. Next, I estimate the total workday losses by inputting the increase in PM_{10} value into the dose-response functions, as shown in Table 5-2. Finally, I multiply the number of workday losses by average per capita GDP produced one day in Beijing in 2000.

I assume that the values of PM_{10} during dust storms have a positive correlation with the distance of visibility. Analogous to my calculation in Appendix C, I estimated the value of PM_{10} on each occurrence of dust storms and calculate the average as shown below.

Table E-1 Estimation of PM_{10} for Ten Occurrences of Yellow-Dust Storms in Beijing in 2000

Date of Occurrences	PM10 (μg/m3)
March 3	750
March 18	375
March 23	300
March 27	300
April 4	375
April 6	1500
April 7	312
April 9	312
April 25	357
April 29	250
Total	483

Source: Calculated by the author.

1. Differences of the average PM_{10} value (483) during dust storms in Beijing and the control location (162): 321$\mu g/m^3$.
2. Based on the discussion in Section 5.1.2.4, I assume that there has been a 0.2% increase in workday losses corresponding to per $\mu g/m^3$ of PM_{10}.
3. The total number of employed workers in Beijing in 2000: 6,192,927 persons. (*Source: Beijing Statistical Yearbook,* 2001, p. 82).
4. Based on dose-response relationship, estimated workday losses for the whole year: 0.2% X 6,192,927 X 321/ 365 = 10,893.
5. In 2000, Beijing's gross domestic product (GDP) was 246 billion RMB. Then the average per capita GDP per day is: 246 billion/ (365 X 6,192,927) = 108.8 RMB
6. Total GDP lost due to labor's workday losses:
   108.8 X 10,893 = 1,185,479 RMB =1,185 thousand RMB

Appendix F: Meteorological Categorization and Description of Strong Winds

Table F-1 Meteorological Categorization and Description of Strong Winds

Wind Speed [25] (m/s)	Grade of Wind Intensity	Indicative Evidences on Land	Possible Impacts
10.8 – 13.8	6	Trees shake; Electricity pipelines whistle; Umbrellas are difficult to hold in air.	Mainly damage crops; usually do not cause any damages to buildings and infrastructure.
13.9 – 17.1	7	Difficult to walk against winds.	
17.2 – 20.7	8	Small branches of trees can be broken; Extremely hard to walk against winds.	
20.8 – 24.4	9	Chimneys and other prominent parts of houses rock; Minor damage to buildings and other facilities.	May damage both crops and forests; and destroy buildings and infrastructure to different extent.
24.5 – 28.4	10	Trees are knocked down or pulled off by roots; buildings and other facilities show considerable damages; Seldom happens on land.	
28.5 – 32.6	11	Buildings and other facilities show severe damages. Rarely happens on land.	

Source: Online information posted by Committee for Disaster Reduction of Jiangxi Province, China, at http://www.weather.org.cn/JX_ZHJZ/kepu/13dafeng.asp. This is an abbreviated list, edited by the author.

[25] It is the equivalent wind speed gauged at the level of ten meters above the ground.

Appendix G: Input-Variables for Input-Output Analysis

I input my calculation results of direct impacts of yellow-dust storms as input-variables for input-output analysis, and derive the total impacts. To match the unit in 1999 Beijing input-output table of ten thousand RMB, I have changed the unit of my calculation result in Table 5-7 to the following format.

Table G-1 Input-Variables for Input-Output Analysis

No. in Aggregated Input-Output Table	Sectors	Input-Variables for Input-Output Analysis
1	Farming, Forestry, Animal Husbandry, and Fishery	78,841
2	Mining	0
3	Manufacturing	85,268
4	Electricity, Gas, Water Production and Supply	0
5	Construction	22,717
6	Transportation, Storage, Post and Telecommunications	2,690
7	Wholesale, Retail Trade and Catering Services	29,580
8	Finance and Insurance	0
9	Real Estate Trade	0
10	Social Services	0
11	Health Care, Sports, and Social Welfare	0
12	Education, Culture, Art, Radio, Film and Television	0
13	Scientific Research and Polytechnical Services	0
14	Geological Prospecting and Water Conservancy	0
15	Government Agencies, Party Agencies, Social Organizations, and Others	0
16	Household	165

Source: Calculated and compiled by the author.
Unit: Ten thousand RMB.

Appendix H: Labor Compensation Calculation

Because the information in the row of Labor Compensation in the 1999 Beijing input-output table is missing, I fill in the row by adjusting the Beijing statistical data of household wages and salaries. I make adjustments by comparing the difference from statistical wages and salaries and household income, which is the sum of household consumption and savings. Furthermore, I split the difference for each sector and add it to each sector's wages and salaries. I follow the four calculation steps illustrated in Chapter 5 and present the data for my calculation in Table H-1.

Table H-1 Calculation Process of Labor Compensation in the 1999 Beijing Input-Output Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
I	606300	54681	3552635	392602	0	173059	1099572	992849	56775	227744	102752	289242	0	0	5610	7553820
II	32558	30739	1E+06	75629	639996	308533	648227	184006	178713	848926	240504	639970	451952	20751	571909	6246634
III	0.0052	0.0049	0.22	0.0121	0.1025	0.0494	0.1038	0.0295	0.0286	0.1359	0.0385	0.1025	0.0724	0.0033	0.0916	1
IV	19452	18365	821059	45186	382380	184340	387297	109938	106776	507209	143695	382364	270029	12398	341699	3732604
V	52012	49106	2195373	120820	1022419	492893	1035567	293956	285501	1356191	384215	1022377	722011	33150	913646	9979238

Source: Calculated by the author, based on the statistics in the Beijing Statistical Yearbook 2000.

Note: 1. Unit: Ten Thousand RMB. 2. A list of sector names (denoted by 1-15) is presented in Appendix B.

Row I: Household Consumption. Source: the column of Household Consumption in 1999 Beijing input-output table

Row II: Wages and Salaries. Source: Beijing Statistical Yearbook 1999-2000.

Row III: Weights of Wages of Each Sector, calculated by dividing each sector's wages by the total of the row.

Row IV: Split Value to Add to Wages and Salaries, calculated by multiplying the weights by difference between TCHS and TW (Chapter 5).

Row V: Adjusted Wages and Salaries, or Labor Compensation, calculated by adding the split value to each sector's wages and salaries.

Appendix I: 1999 Beijing 16-Sector Partially Closed Transaction Table

	No	PURCHASING SECTORS															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Agri-culture	Mining	Manu-facturing	Electri-city	Cons-truction	Trans-portatio	Trade	Finance	Real Estate	Social Service	Health	Edu-cation	Science	Geology	Govern ment	House-hold
PRODUCING SECTORS	1	353986	117	716311	1	1	2	56500	0	1026	2160	1781	18	181	0	0	606300
	2	5287	33975	1080239	55860	109415	2051	3833	0	7858	16762	1519	3277	4176	497	2414	54681
	3	251010	35987	12148182	155358	3292473	738218	407477	884620	69584	641060	275109	145956	282027	7618	179382	3552635
	4	28450	9719	310965	19896	30016	30605	54047	69026	19256	76373	6620	13483	29924	1034	16467	392602
	5	499	156	11261	2970	912	8271	10932	26142	7321	158999	4609	2333	6232	191	13052	0
	6	28211	7267	1024196	46094	317658	250390	116781	206826	22472	137573	14618	168125	65751	1755	141235	173059
	7	144046	7980	1559237	50731	438019	126045	71377	196203	21369	110898	60464	25108	34132	1676	47707	1099572
	8	11057	9780	967392	41873	65662	274566	127618	1072862	209039	76091	1462	54301	21311	6923	174943	992849
	9	0	450	22261	39	1174	4319	38800	283043	5872	21202	1370	804	3178	26	6590	56775
	10	3875	16590	550466	9938	288664	70926	153570	812010	34456	405819	4597	39388	68971	4154	54541	227744
	11	157	99	3373	218	1653	4448	1550	1096	577	20085	11586	6769	12690	25	6610	102752
	12	1695	870	36549	4070	18634	17337	28708	157890	1730	25191	3129	215775	120284	1907	36795	289242
	13	3865	1470	493742	42787	151747	15425	87515	14478	5494	48472	311	81172	196047	3508	11478	0
	14	340	3848	0	0	0	0	0	0	0	1889	0	0	0	1607	0	0
	15	59201	28	2842	92	98653	28820	0	24665	3050	192056	10472	1979	15214	1851	11003	5610
	16	52012	49106	2195373	120820	1022419	492893	1035567	293956	285501	1356191	384215	1022377	722011	33150	913646	3732604

Source: Calculated by the author, based on modified 1999 Beijing input-output table.

Unit: Ten thousand RMB.

Appendix J: Calculation Process for Linkage Analysis Using Input-Output Models

Table J-1 Direct Input Coefficient Matrix (A* Matrix)

(Direct Input per Unit of Output)

	PURCHASING SECTORS															
No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PRODUCING SECTORS	Agri-culture	Mining	Manu-facturing	Electri-city	Cons-truction	Trans-portation	Trade	Finance	Real Estate	Social Service	Health	Edu-cation	Science	Geology	Govern ment	House-hold
1	0.124	0.000	0.021	0.000	0.000	0.000	0.010	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.007
2	0.002	0.063	0.031	0.027	0.010	0.000	0.001	0.000	0.006	0.002	0.001	0.001	0.001	0.003	0.001	0.001
3	0.088	0.067	0.349	0.076	0.313	0.151	0.069	0.096	0.051	0.084	0.161	0.032	0.051	0.047	0.049	0.043
4	0.010	0.018	0.009	0.010	0.003	0.006	0.009	0.008	0.014	0.010	0.004	0.003	0.005	0.006	0.005	0.005
5	0.000	0.000	0.000	0.001	0.000	0.002	0.002	0.003	0.005	0.021	0.003	0.001	0.001	0.001	0.004	0.000
6	0.010	0.014	0.029	0.022	0.030	0.051	0.020	0.022	0.016	0.018	0.009	0.037	0.012	0.011	0.039	0.002
7	0.051	0.015	0.045	0.025	0.042	0.026	0.012	0.021	0.016	0.015	0.035	0.006	0.006	0.010	0.013	0.013
8	0.004	0.018	0.028	0.020	0.006	0.056	0.022	0.116	0.153	0.010	0.001	0.012	0.004	0.043	0.048	0.012
9	0.000	0.001	0.001	0.000	0.000	0.001	0.007	0.031	0.004	0.003	0.001	0.000	0.001	0.000	0.002	0.001
10	0.001	0.031	0.016	0.005	0.027	0.015	0.026	0.088	0.025	0.053	0.003	0.009	0.013	0.026	0.015	0.003
11	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.007	0.002	0.002	0.000	0.002	0.001
12	0.001	0.002	0.001	0.002	0.002	0.004	0.005	0.017	0.001	0.003	0.002	0.047	0.022	0.012	0.010	0.004
13	0.001	0.003	0.014	0.021	0.014	0.003	0.015	0.002	0.004	0.006	0.000	0.018	0.036	0.022	0.003	0.000
14	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000
15	0.021	0.000	0.000	0.000	0.009	0.006	0.000	0.003	0.002	0.025	0.006	0.000	0.003	0.012	0.003	0.000
16	0.018	0.091	0.063	0.059	0.097	0.101	0.174	0.032	0.209	0.177	0.225	0.223	0.131	0.206	0.249	0.045

Source: Calculated by the author, based on modified 1999 Beijing input-output table.

Table J-2 Leontief Inverse Matrix: $(I-A^*)^{-1}$ Matrix

(Direct and Indirect Input per Unit of Final Demand)

PRODUCING SECTORS	PURCHASING SECTORS															
No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Agri-culture	Mining	Manu-facturing	Electri-city	Cons-truction	Trans-portatio	Trade	Finance	Real Estate	Social Service	Health	Edu-cation	Science	Geolog y	Govern ment	House-hold
1	1.147	0.005	0.040	0.005	0.015	0.009	0.016	0.006	0.007	0.007	0.011	0.005	0.004	0.005	0.006	0.011
2	0.009	1.073	0.054	0.035	0.030	0.011	0.006	0.008	0.012	0.010	0.011	0.004	0.005	0.008	0.006	0.004
3	0.181	0.143	1.598	0.149	0.534	0.287	0.148	0.216	0.150	0.186	0.290	0.092	0.108	0.119	0.130	0.081
4	0.015	0.023	0.019	1.013	0.011	0.012	0.013	0.014	0.020	0.015	0.009	0.006	0.008	0.011	0.009	0.007
5	0.001	0.002	0.002	0.002	1.002	0.003	0.003	0.006	0.007	0.023	0.003	0.001	0.002	0.002	0.005	0.000
6	0.021	0.023	0.056	0.032	0.054	1.068	0.029	0.040	0.030	0.031	0.022	0.046	0.019	0.021	0.049	0.006
7	0.070	0.027	0.081	0.036	0.074	0.047	1.026	0.041	0.033	0.031	0.055	0.016	0.016	0.023	0.027	0.020
8	0.017	0.033	0.061	0.034	0.034	0.083	0.037	1.152	0.187	0.027	0.018	0.025	0.013	0.061	0.068	0.019
9	0.001	0.002	0.004	0.002	0.002	0.004	0.008	0.036	1.011	0.004	0.002	0.001	0.001	0.003	0.005	0.002
10	0.010	0.042	0.038	0.014	0.046	0.032	0.036	0.114	0.050	1.065	0.013	0.016	0.019	0.038	0.027	0.007
11	0.000	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.003	1.007	0.002	0.003	0.001	0.002	0.001
12	0.002	0.004	0.005	0.004	0.005	0.007	0.008	0.022	0.007	0.006	0.004	1.052	0.025	0.016	0.014	0.005
13	0.006	0.007	0.026	0.025	0.025	0.009	0.019	0.008	0.008	0.011	0.006	0.021	1.040	0.026	0.007	0.002
14	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.010	0.000	0.000
15	0.024	0.002	0.003	0.001	0.011	0.008	0.002	0.007	0.005	0.028	0.007	0.001	0.004	0.013	1.004	0.001
16	0.061	0.135	0.149	0.095	0.178	0.158	0.217	0.104	0.263	0.236	0.278	0.268	0.167	0.255	0.296	1.062

Source: Calculated by the author, based on modified 1999 Beijing input-output table.

Table J-3 Forward Linkages Matrix (F* matrix)

(Direct Sales per Unit of Output)

PRODUCING SECTORS	PURCHASING SECTORS															
No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Agri-culture	Mining	Manu-facturing	Electri-city	Cons-truction	Trans-portation	Trade	Finance	Real Estate	Social Service	Health	Edu-cation	Science	Geology	Gover nment	House-hold
1	0.194	0.019	0.010	0.025	0.000	0.010	0.057	0.002	0.000	0.001	0.000	0.001	0.002	0.005	0.047	0.004
2	0.000	0.120	0.002	0.009	0.000	0.003	0.003	0.002	0.001	0.005	0.000	0.001	0.001	0.060	0.000	0.004
3	0.393	3.798	0.492	0.277	0.002	0.375	0.620	0.156	0.037	0.160	0.005	0.022	0.200	0.000	0.002	0.160
4	0.000	0.196	0.006	0.018	0.000	0.017	0.020	0.007	0.000	0.003	0.000	0.003	0.017	0.000	0.000	0.009
5	0.000	0.385	0.133	0.027	0.000	0.116	0.174	0.011	0.002	0.084	0.003	0.011	0.062	0.000	0.078	0.075
6	0.000	0.007	0.030	0.027	0.001	0.092	0.050	0.044	0.007	0.021	0.007	0.011	0.006	0.000	0.023	0.036
7	0.031	0.014	0.017	0.048	0.002	0.043	0.028	0.021	0.064	0.045	0.002	0.017	0.036	0.000	0.000	0.076
8	0.000	0.000	0.036	0.062	0.004	0.076	0.078	0.173	0.469	0.236	0.002	0.096	0.006	0.000	0.019	0.021
9	0.001	0.028	0.003	0.017	0.001	0.008	0.009	0.034	0.010	0.010	0.001	0.001	0.002	0.000	0.002	0.021
10	0.001	0.059	0.026	0.068	0.024	0.050	0.044	0.012	0.035	0.118	0.030	0.015	0.020	0.030	0.151	0.099
11	0.001	0.005	0.011	0.006	0.001	0.005	0.024	0.000	0.002	0.001	0.017	0.002	0.000	0.000	0.008	0.028
12	0.000	0.012	0.006	0.012	0.000	0.062	0.010	0.009	0.001	0.011	0.010	0.131	0.033	0.000	0.002	0.075
13	0.000	0.015	0.011	0.027	0.001	0.024	0.014	0.003	0.005	0.020	0.019	0.073	0.079	0.000	0.012	0.053
14	0.000	0.002	0.000	0.001	0.000	0.001	0.001	0.001	0.000	0.001	0.000	0.001	0.001	0.025	0.002	0.002
15	0.000	0.009	0.007	0.015	0.002	0.052	0.019	0.028	0.011	0.016	0.010	0.022	0.005	0.000	0.009	0.067
16	0.333	0.192	0.144	0.350	0.000	0.063	0.437	0.160	0.094	0.066	0.154	0.175	0.000	0.000	0.004	0.272

Source: Calculated by the author, based on modified 1999 Beijing input-output table.

Table J-4 Leontief Inverse of Forward Linkages Matrix $(I-(F^*)^T)^{-1}$

(Direct and Indirect Sales per Unit of Value Added)

	No	PURCHASING SECTORS															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Agri-culture	Mining	Manu-facturing	Electri-city	Cons-truction	Trans-portation	Trade	Finance	Real Estate	Social Service	Health	Edu-cation	Science	Geology	Gover nment	House-hold
PRODUCING SECTORS	1	1.307	0.354	0.065	0.098	0.002	0.071	0.164	0.043	0.043	0.045	0.015	0.031	0.028	0.031	0.072	0.066
	2	0.014	1.202	0.013	0.024	0.001	0.014	0.024	0.011	0.010	0.015	0.004	0.007	0.006	0.075	0.004	0.017
	3	2.252	13.921	2.972	2.038	0.054	1.886	3.162	1.197	1.121	1.329	0.368	0.754	0.904	0.916	0.413	1.631
	4	0.044	0.434	0.041	1.064	0.002	0.054	0.083	0.034	0.030	0.034	0.011	0.024	0.035	0.028	0.010	0.049
	5	0.522	3.165	0.559	0.537	1.016	0.551	0.910	0.311	0.303	0.415	0.115	0.229	0.262	0.212	0.195	0.513
	6	0.174	0.862	0.171	0.204	0.007	1.243	0.302	0.158	0.135	0.144	0.048	0.093	0.070	0.059	0.065	0.189
	7	0.231	0.852	0.161	0.245	0.008	0.192	1.301	0.138	0.189	0.168	0.053	0.112	0.102	0.059	0.048	0.247
	8	0.319	1.586	0.306	0.423	0.022	0.383	0.566	1.426	0.783	0.532	0.088	0.281	0.135	0.116	0.142	0.354
	9	0.056	0.271	0.046	0.077	0.003	0.054	0.090	0.074	1.062	0.055	0.016	0.031	0.021	0.019	0.017	0.072
	10	0.303	1.411	0.257	0.377	0.035	0.294	0.475	0.196	0.223	1.317	0.112	0.161	0.124	0.129	0.234	0.380
	11	0.076	0.341	0.067	0.078	0.003	0.060	0.126	0.042	0.044	0.044	1.035	0.034	0.025	0.023	0.022	0.090
	12	0.164	0.662	0.124	0.177	0.005	0.190	0.238	0.107	0.101	0.109	0.057	1.230	0.089	0.045	0.036	0.227
	13	0.142	0.622	0.116	0.170	0.005	0.135	0.211	0.086	0.089	0.106	0.059	0.155	1.134	0.043	0.044	0.184
	14	0.006	0.026	0.005	0.007	0.000	0.005	0.009	0.005	0.004	0.005	0.002	0.004	0.004	1.028	0.003	0.008
	15	0.144	0.599	0.113	0.161	0.006	0.162	0.222	0.119	0.111	0.109	0.049	0.096	0.050	0.041	1.041	0.194
	16	1.383	4.775	0.893	1.328	0.028	0.836	1.818	0.749	0.748	0.697	0.386	0.637	0.348	0.325	0.230	2.116

Source: Calculated by the author, based on modified 1999 Beijing input-output table.

Appendix K: Calculations for Sensitivity Analysis

Table K-1 Calculation Results of Immediate Impacts on April 6, 2000

Sector	Lower	Current	Upper
Road Transportation	39	78	117
Trade and Catering Services	15,247	30,495	45,742
Household	68	136	204

Unit: Thousand RMB.

Table K-2 Calculation Results of Immediate Impacts for All the Occurrences in 2000

Variable	Lower	Current	Upper
Road Transportation	390	780	1,170
Transportation (Road and Air)	26,508	26,898	27,288
Trade and Catering Services	147,901	295,802	443,703
Household	230	460	690

Unit: Thousand RMB.

Table K-3 Calculation Results for Delayed Impacts in 2000

Variable	Lower	Current	Upper
Agriculture	394,206	4. 788,412	1,182,618
Manufacturing	427,634	5. 855,268	1,282,902
Household	593	6. 1,185	1,778

Unit: Thousand RMB.

Table K-4 Input Variables into Input-Output Models of Three Alternative Estimations

No.	Sectors	Input-Variables for Input-Output Analysis (Ten thousand RMB)		
		Lower	Current	Upper
1	Farming, Forestry, Animal Husbandry, and Fishery	39,421	78,841	118,262
2	Mining	0	0	0
3	Manufacturing	42,763	85,527	128,290
4	Electricity, Gas, Water Production and Supply	0	0	0
5	Construction	22,717	22,717	22,717
6	Transportation, Storage, Post and Telecommunications	2,651	2,690	2,729
7	Wholesale, Retail Trade and Catering Services	14,790	29,580	44,370
8	Finance and Insurance	0	0	0
9	Real Estate Trade	0	0	0
10	Social Services	0	0	0
11	Health Care, Sports, and Social Welfare	0	0	0
12	Education, Culture, Art, Radio, Film and Television	0	0	0
13	Scientific Research and Polytechnical Services	0	0	0
14	Geological Prospecting and Water Conservancy	0	0	0
15	Government Agencies, Party Agencies, Social Organizations, and Others	0	0	0
16	Household	82	165	247

Source: The author.

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