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Evaluation of Yellow-Dust Storms and Countermeasure Policies in North China Using Regional Input-Output Models

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Abstract:

The frequent yellow-dust storms in China in recent years have widely disrupted economic activities, destroyed farm land, and created a great hazard to human health. Meanwhile, there are various programs with vast investment from different levels of governments In China to prevent, and mitigate the impact of yellow-dust storms. However, little is known about the casual factors, socioeconomic impact of yellow-dust storms, and the effectiveness of those investments. This paper designs an evaluation framework by incorporating four major elements: yellow-dust storm occurrences, economic activities, environmental resources, and policy initiatives. Geographic Information System (GIS) techniques are used to process spatial environmental data to quantify the causal relationship between yellow-dust storm occurrences, and environmental resources and climatic factors. The trans-boundary impact is also controlled by creating a set of models with different buffer zones around observation locations. Input-output techniques are applied to evaluate the immediate, delayed, direct, and indirect impact of yellow-dust storms on economic activities. Both demand-driven and supply-driven impacts are calculated for Beijing, China based on data collected in 2003. Then, a framework to evaluate policy initiatives is constructed. A particular investment project, the Beijing-Tianjin Sand Source Treatment Engineering program, is chosen to do a cost-benefit analysis based on the above results. The result indicates a big success at the starting year of this project, but ever since the benefit-cost ratio has been declining. This research illustrates a holistic approach to deal with new emerging global environmental issues like yellow-dust storms, and the associated challenges and opportunities that input-output techniques face in the process.

Keywords: Yellow-Dust Storms, Forestry, China, Input-Output Model

INTRODUCTION

Yellow-dust storm (YDS) is the generic term for a serious environmental phenomenon in Northeast Asia, which involves strong winds that blow a large quantity of the dust and fine sand particles away from the ground and carry them over a long distance with severe social and environmental impacts along its way. Although YDS as a natural phenomenon has a history of more than thousands of years, statistics indicate an increased frequency, expanded geographic coverage, and accelerated damage intensity over the past 50 years (GEF 2002). According to statistics available in China, the average occurrence of YDS was 5 times a year in 1950s, 8 times in 1960s, 14 times in 1970s, and 23 times in 1990s. This region experienced 32 YDS events in 2001, and the most severe YDS for decades in early 2002 (?).

Local atmospheric conditions, topography, stocks of water resources, and global climate influence the formation of YDS. Meanwhile, human activities have recently significantly intensified the occurrences of YDS. Over-grazing on grassland and depleting forest for lumber production destroy vegetation covers and expose surface soil to strong wind. Over-consumption of water decreases the ground water level and makes the surface soil loose and dry. Global warming effect increases temperature, and defrost soil early in the spring. When precipitation is low, temperature is high, and strong winds blow, YDS probably will occur in sandy areas, transport a long distance, and generate trans-boundary environmental problems. The occurrence of YDS reflects typical sustainability issues that face developing countries, such as over-exploration of natural resources, environmental pollution, unbalanced rural-urban development, and environmental justice.

Large scale YDS has significant environment effects that cause enormous economic losses, and present serious public health concerns over a wide geographic area. The total suspended particulates may be tens or hundreds times higher than the normal standards, which can hinder sophisticated manufacturing, block transportation, damage agricultural products, and delay construction, trade, and catering services (Ai 2003, ?). For example, a YDS occurred in 1993 in Gansu Province, China directly affected area of 1.1 million square kilometers, caused 85 deaths and 246 injuries, destroyed 4,412 houses, killed 120,000 livestock, and damaged 373,000 hectares of crops land. The direct economic cost of the YDS alone was estimated to be more than 550 million RMB, or about $66 million at current exchange rate. Another YDS in April 2000 in Beijing shut down nearly 60 million square meters construction sites, caused 129 flight delays, and increased road accidents of 20-30% over normal conditions (Ai 2003). A high concentration of particulates also poses hazards to human 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-mouth disease (Kar and Takeuchi 2002, Zhu and Zhou 2002).

In recent years, governments in this region have acknowledged the damage of YDS, and begun to put huge investment to reduce the frequency of YDS occurrences, and to mitigate its negative social and environmental impact. For example, the total investment related to YDS for the next ten years in China alone is estimated to be about $ 35 billion (People's Daily, 12/21/01). Most investment will go to reforestation, grassland regulation, tillage management, water conservation, and soil preservation.

Despite the increasing severity of YDS and the huge amount of investment from governments, policy makers and academic analysts still know little about this topic. Specifically, three questions are critical to improve our understanding of YDS, and to evaluate the effectiveness of public investment in this area, but have been rarely addressed:

1. What factors cause the occurrences of YDS and, more important, to what extent?
2. How much damage YDS can cause, directly and indirectly, immediately and delayed?
3. How to evaluate YDS-mitigating policies, economically, environmentally, and socially?

The objective of this paper is to propose a research framework to answer the three questions. The next session describes the framework. The 3rd session answers the first question using the six provinces in Northwestern China as a case. The 4th session answers the second question using 2000 Beijing as a case. The 5th session answers the third question using the Beijing-Tianjin Sand Source Treatment Engineering Plan as a case. The last session will draw conclusions and propose future research topics.

RESEARCH FRAMEWORK

There are four elements in the analytical framework: environmental resources, YDS, economic activities, and policy initiatives. Their definition and inter-relationship are described below:

Environmental Resources: In this framework, environmental resources refer to vegetation, water, and sand resources, which can either deter or stimulate YDS. Vegetation resources include forestry, grassland, and cultivated farmland, which are believed to be the deterring factors of YDS. Water resource take either the deterring form of precipitation or the stimulating form of consumption of ground water. Sand sources as the origin of YDS include deserts, desertification areas, dry lakes and river beds, and wind erosion land. The three sources not only affect the occurrence of YDS, but also interact with each other. Vegetation especially forest coverage in an area affects the volume of local precipitation and the capacity to store water on ground. They also help preserve soil and resist wind erosion.

Yellow-Dust Storms: A YDS is defined as a kind of catastrophic weather that strong wind curls up plentiful sand dust and makes air feculent and horizontal visibility below 1 km (Wang and Ren 2003). It is characterized by severe winds, high concentration of particulates, and dry and cold air. The average wind velocity during a YDS 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]. The average mass concentration of aerosols during a YDS can far exceed the normal level. For example, a dust storm in spring of 2001 in Beijing was 6000 mg m^{-3}, i.e., 30 times more than that on non-dust storm days (Zhuang et al. 2001). A 4-day long dust storm in China during 14-17 April, 1998 caused about 38.3 g per square meters of dust fell in

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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

Beijing in 15 hours (Sun et al. 2000). YDS is usually associated with high pressure cold air masses moving southward from Siberia. The dry and cold air causes dramatic changes in temperature, which can have severe impacts on crops and livestock.

Economic Activities: Economic activities refer to both production represented by value added (wages, profits, rents, and subsidies) and consumption represented by final demand (personal and public consumption, investment, and net foreign trade) for each industrial sector. The impact of YDS on economic activities can be direct (physical damage, death, injury), indirect (multiplier effects in other sectors), immediate (strong wind, concentration of particulates, and cold air), and accumulative (soil erosion, pollution). The impact can be captured by an input-output model, which portrays the input and output for each industrial sector, and the interaction among them.

Policy Initiatives: These initiatives include forestation, anti-desertification, water conservation, and watershed management, tillage regulation and soil preservation, return-farmland-to-forest, return-grazing-land-to-grassland etc. Intrigued by intensified YDS in recent years, these initiatives take a comprehensive approach to reduce economic damage, improve environmental quality, and more important, promote socio-economic development in frequent-YDS areas, which are usually poor, rural with hash living environment. For example, many initiatives involve improvement of irrigation infrastructure in water-scarce areas, agriculture restructure from low-productive plantation to economic forestry, change of energy consumption from lumbering to coal or coke, and in come cases, land use planning to relocate farmer from infertile areas. This paper focuses on the economic effect of these initiatives. Social and environmental impact is left for future research.

The four elements are closely related to each other in a dynamic process. Environmental resources determine the occurrences and frequency of YDS. Desertification expands YDS areas, and intensifies its magnitude, while vegetation slows up wind, shortens the YDS transport path, and helps deposit dust particulates. Local climate factors like precipitation, temperature, and wind speed are associated with environmental resources, and in turn reinforce or mitigate YDS impact. These relationships can be captured through panel data analysis. The total economic damage (direct, indirect, immediate, and delayed) of YDS can be calculated using Input-Output techniques, and the average cost for a YDS day can be inferred based on its magnitude. Policy initiatives target environmental resources by increasing vegetation coverage and decrease sand sources, thus reduce the frequency and magnitude of YDS, and subsequently economic damage. Because of the scale of the investment, these initiatives are believed to have a significant impact on local economic activities. For example, most investment (75 %) goes to forest industry (China Forestry Yearbook, 2002), which definitely will affect the other industrial sectors. Therefore, the economic impact of policy initiatives comes from two channels: YDS reduction and investment, which can be estimated through regression forecasting and input-output models. By comparing the economic impact (benefit) with the total investment (cost), we can evaluate these policy initiatives cost-effectively. Figure 1 shows the interaction between the four elements and required analysis methods.

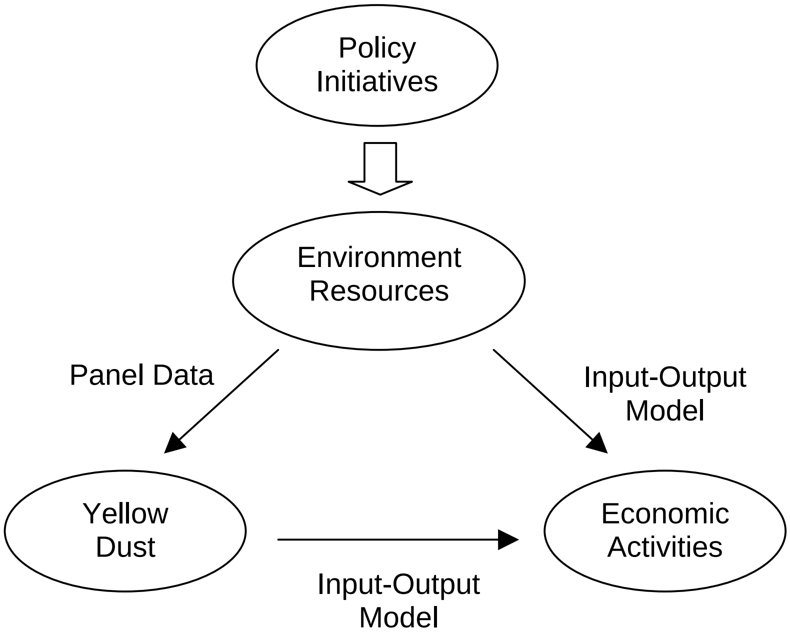


Figure 1 Framework of Analysis

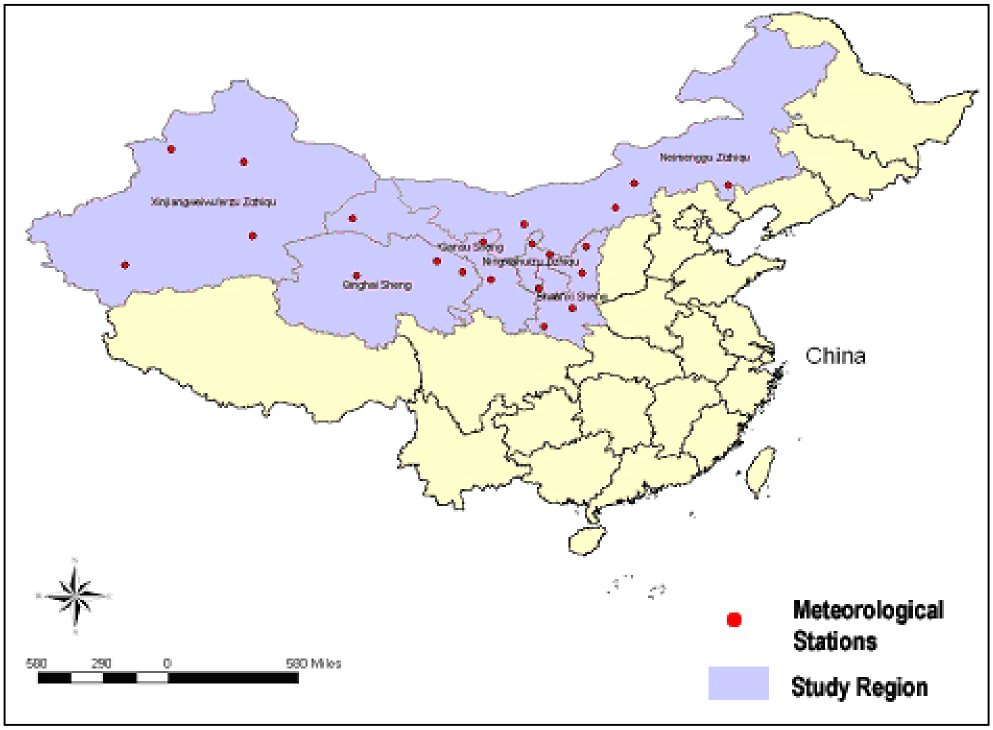
GENERATION OF YELLOW-DUST STORMS

There have been a few studies on the generation of YDS focusing on wind, sand, vegetation, water, and temperature. Zhou (2001) studied the windy days and the occurrence of yellow-dust storms in Beijing in April for about 40 years, and found a strong correlation. Another study by Chen (2003) in Xinjiang Province showed a similar result with wind speed a prominent factor to influence the occurrence of dust storms. The stability, roughness, and possible erosion of surface soil can determine how easy dust can form in the case of strong surface wind. Accordingly, vegetation covers can stabilize and maintain the soil, and help resist wind erosion, thus reduce the chance of dust formulation. Gu Wei (2002) showed negative correlation between the vegetations and the days of the dust storm qualitatively by using the observation information of the days in 66 weather stations in the middle-west of Inner Mongolia. Abundant rain and snow can hold back sand blow. If the snow thaws, the water will supply moisture of soil, improve the soil status and then restrain from the occurring of the sandstorm. Zeng (2003) found that snowfall in December 2002 and January 2002 in the middle-south and south area in Inner Mongolia, northeast, and north in China resisted the dust storm occurrence. Guo also found that a distinct increase of the rainfall would decrease the frequency of the dust storms. They further suggest the volume of groundwater and upper water also affect the frequency of dust storms (Guo et. al. 2003). Only one study on temperature is identified, which pointed a negative relationship between dust storm frequency and temperature (Zhang 1982).

The previous research provided valuable information on the causality of YDS, but offered little help to quantify the relationship, which is critical for cost-benefit analyses of policy initiatives. The biggest challenge of quantification is the trans-boundary nature of YDS. For example, place A can be attacked by YDS originated far away even A has no sand source, with plenty of precipitation, and well forested. In order to quantify the casual relationship between environmental resources and YDS, trans-boundary issue must be considered and controlled in the analysis. This is done through panel data regression with the assistance of spatial analysis function in Geographic Information Systems (GIS) software.

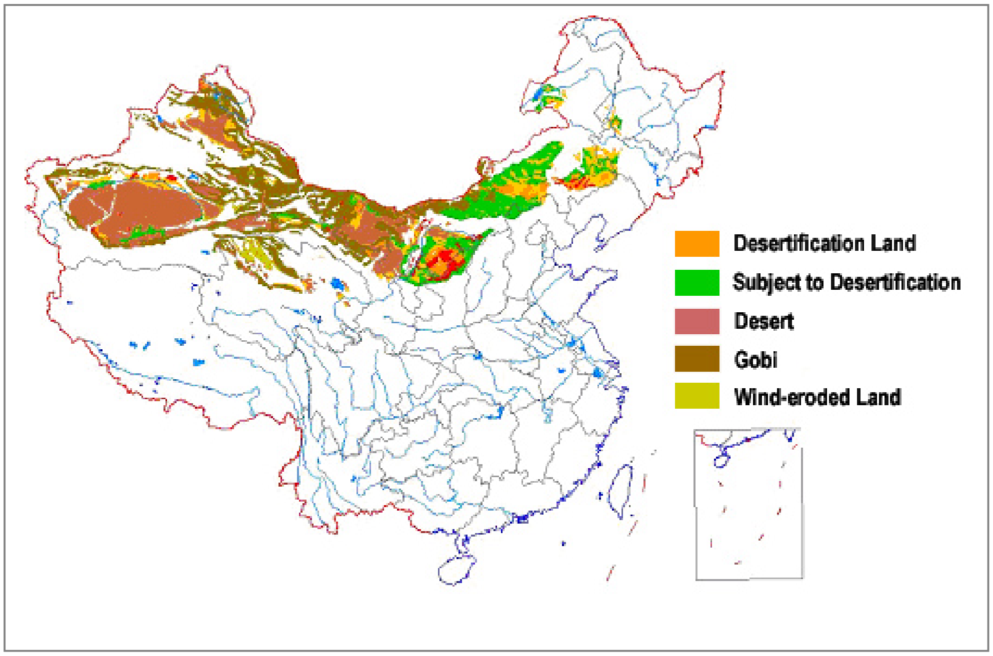
Observation of YDS is at a point, say a meteorological station, while environmental resources are calculated for an area. Therefore, a natural way to link the two is to create a buffer zone for each YDS observation point, and examine how environmental resources in the buffer zone affect the occurrences of YDS. Obviously, the buffer size matters. For example, environmental conditions within a 10 meter buffer of point A may have nothing to do with the frequency of YDS in A. On the other hand, if the buffer is too big, say 20,000 km (half distance of equator), for sure it could not explain YDS in point A. Therefore, with the buffer zone increasing from zero to infinite, there should be a peak point where environmental resources in that zone best explain the occurrences of YDS at the center. This buffer zone is the most efficient generation area for YDS because marginal contribution of environmental resources to YDS begins decreasing outside that buffer. It is also the peak impact distance of average YDS because marginal impact of YDS on the buffer center begins decreasing if the YDS come from outside of that buffer. In other words, the trans-boundary effect reaches peak at that buffer boundary.

The case study region is the six provinces in northwestern China, where YDS frequently occur. They cover a total area of four million square kilometers (1.6 million square miles) with a population of 110 million. There are two major data sources: the meteorological station data and the environmental resource maps. They include 30 year (1971 to 2000) observations on weather and YDS from 21 stations in the region, and sand, forest, agriculture, and grassland maps in China (Figure 2, 3). Therefore, it is a typical panel data analysis. The dependent variable is number of YDS days per year at each station, and the independent variables include annual rainfall, average temperature, and average wind speed at each station location, and vegetation and sand sources in a buffer zone of each station. The buffer is created, and its area if calculated in ArcView 3.X by writing Avenue scripts. Seven buffers distances were used: 50KM, 100KM, 150KM, 200KM, 300KM, 400KM, and 500KM.



Source: the Authors

Figure 2 Six Provinces and 21 Meteorological Stations in Northwest China



Source: China Data Center, Univ. Michigan

Figure 3 Desertification Land in China

Two types of models are developed. The first model adopts a simple cross-section analysis for the 21 stations over the seven buffer zones to identify the "peak" buffer. The dependent variable is the average YDS days at each station, and the independent variables are on the average value of the environmental and weather characteristics[2]. Table 1 shows the estimation results of the seven models. About half of YDS events in the 21 stations can be explained by the five environmental and weather variables. The R Square peaks at the 100 KM buffer model, which suggests that the trans-boundary effect of YDS maximizes between 100 km and 150 km (Table 1).

Buffer	**50 KM**	**100 KM**	**150 KM**	**200 KM**	**300 KM**	**400 KM**	**500 KM**
Constant	9.86 (1.1)	8.67 (1.1)	13.89 (1.3)	9.84 (1.1)	8.45 (0.9)	7.12 (0.7)	7.64 (0.7)
Rainfall (mm)	-0.0014 (-1.4)	-0.0009 (-0.9)	-0.0013 (-1.2)	-0.0012 (-1.1)	-0.0014 (-1.2)	-0.0014 (-1.1)	-0.0014 (-1.1)
Temperature	-0.011 (-0.2)	0.0067 (0.1)	-0.010 (-0.2)	0.006 (0.09)	0.024 (0.4)	0.031 (0.5)	0.03 (0.6)
Wind Speed (0.1m/s)	0.041 (0.2)	0.150 (0.7)	0.0037 (0.015)	0.213 (0.9)	0.273 (1.2)	0.271 (1.2)	0.277 (1.3)
Sand Area (per 100 KM^2)	0.051 (1.1)	0.011 (0.9)	0.0032 (0.5)	0.00026 (0.07)	-0.0004 (-0.2)	0.00002 (0.02)	0.00012 (0.1)
Vegetation (per 100 KM^2)	-0.034 (-0.5)	**-0.034** **(-2.2)**	-0.011 (-0.9)	-0.008 (-1.4)	-0.0037 (-1.3)	-0.0021 (-1.2)	-0.0015 (-1.2)
R Square	0.47034	0.58596	0.45264	0.47889	0.46704	0.45324	0.45569

Source: the Authors

Table 1 Estimation Results of Cross-section Regressions (No. of Obs = 21)

The second model implements panel data analysis to quantify the environmental and weather impact on YDS generation within the identified "peak" buffer zone. The dependent variable is the annual observation of YDS days at each station from 1971 to 2000. No lagged dependent variable is included because Hausman test does not indicate a strong correlation between the lagged dependent variable and the error term. Estimated Generalized Least Squares (EGLS) and random effects method in panel data are used for model estimation.

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[2] The estimator is unbiased and consistent, but not efficient because of information loss by averaging the variables, which can be corrected in the panel data analysis.

Variable	**Coefficient**	**Std. Error**	**t-Statistic**
Constant	8.508	0.9572	8.9
Rainfall (mm)	-0.0005	6.33E-05	-7.2
Temperature	-0.0198	0.0041	-4.8
Wind Speed (0.1m/s)	0.1609	0.0142	11.4
Sand Area (per 100 KM^2)	0.0052	0.0006	4.2
Vegetation Area (per 100 KM^2)	-0.035	0.0024	-8.0
R Square **=** 0.6470, Buffer = 100 KM			

Source: the Authors

Table 2 Estimation Results of Panel Data (unbalanced observations: 623)

All coefficients are significant at 95 percent level with expected signs except temperature. More rainfall and vegetation coverage tends to reduce YDS occurrences, while stronger wind and increased sand area in the buffer zone are likely to induce more YDS events. Higher temperature is associated with fewer YDS occurrence, which is contradicted with our expectation probably due to the different definition of temperature. This paper uses the annual average temperature rather than the average temperature in spring. A higher annual average temperature may indicate a warmer local climate, which is usually associated with more vegetation cover and precipitation.

The model also shows YDS occurrence is more sensitive to vegetation cover than to sand area, and more sensitive to wind speed than that to rainfall. A 10 % increase of vegetation cover in the 100 KM buffer zone (about 3000 square KM) will reduce 1 YDS day annually, while a 10 % increase of sand area in the buffer zone only increases about 0.2 YDS day annually. A 10 % increase of rainfall (about 286 mm per year) will decrease annual YDS by only 0.14 day, while a mere 1 m/s increase of annual wind speed will increase YDS by 1.6 days annually. These findings imply that forestation, which increases vegetation cover while reduces wind speed, might be the best way to reduce YDS occurrences. However, the effectiveness of forestation may vary from place to place. For example, for an area with only several annual YDS days, one day reduction means a big progress, but this area might be already well covered by forest, and leave little space for further improvement.

SOCIOECONOMIC IMPACT OF YELLOW-DUST STORMS

Research on YDS in the past decade has focused on the phenomena itself, such as the causation, source areas, transport trajectories, particulate properties etc. In contrast, socioeconomic-impact evaluation of YDS, either quantitatively or qualitatively, is apparently missing. There are two major reasons why socioeconomic-impact evaluation is a challenge. First, unlike the damages caused by earthquakes and floods, the physical damage caused by YDS is not usually evident. YDS usually occurs in a short period of time, but they happen frequently during any given period of time. Accordingly, there lack reliable techniques to assess the multiple socioeconomic impacts of YDS. Most analysts determine only the direct costs, based on the direct damages caused by the storm, which we are showing are only a small portion of the total cost. Second, despite of the significant monetary or physical losses to a regional economy, YDS is not listed as a disaster by Chinese government, thus no data have been included in major data sources such as official reports, database, government documents, yearbooks etc. However, such studies are urgently needed, because socioeconomic information on YDS will call for attention and action to fight against this environmental disaster, help officials to identify the most vulnerable groups and correspondingly enhance preparedness. They will also provide planners with a basis for appropriate investment in disaster mitigation and control.

Based on the data collected from field surveys, interviews, online publication, and newspapers, we conducted a case study in Beijing to measure the impacts of YDS on Beijing’s economy in 2000. Beijing is selected because scholars have accumulated more information in this capital city than in any other region in China. As a metropolis with a dense population and fast-growing socioeconomic activities, it is probably more economically vulnerable to YDS than other less-developed regions and is likely to be affected in more ways. Because scientific research related to YDS in 2000 are particularly plentiful, this year is selected as the time period of this case study.

Furthermore, because of the frequent occurrence of YDS, it might be difficult to distinguish successive occurrences, especially for their long-term effects. Consequently, we evaluate the total impacts of all occurrences of YDS in 2000, instead of any single one. In addition, we had accessed only to a static 1999 input-output table for Beijing, we ignore those delayed impacts only apparent after one year.

The input-output technique is commonly used for economic-impact analyses because it incorporates detailed information on a sectoral basis, thus showing more accurate results in evaluating both tangible and intangible economic impacts on a regional level. We believe that such a sectoral perspective, compared with other available economic-impact evaluation techniques, may best clarify and systemize the manifold impacts of YDS exhaustively and accurately. The 1999 input-output table for Beijing is a single-region open table including 49 sectors, treating the household sector and other components of final demand as exogenous. We made two important modifications. First, the 49 sectors are aggregated into 15, as it is impossible to determine the differences, presumably small, in impacts among 49 sectors, due to limited data and information. Because industries in some broad categories of sectors have similar consumption and production relationships and appear affected by YDS in similar ways, such an aggregation (see Table 3) does not compromise our calculation results, but it does simplifies our analysis. Second, the 15 sector input-output table is transformed from an open model into a partially closed one, treating households as endogenous to the regional economy. This approach is important because households are affected by dust storms in many ways, involving property loss, health impacts and corresponding increases in expenses, and so on. In addition, the household sector plays an important role as the supplier of labor; thus, it can induce reasonable ripple effects in a regional economy.

The analysis starts with a single YDS event on April 6, 2000. Damages from six industrial sectors (agriculture, manufacturing, construction, transportation, trade and catering services, and households) are collected or inferred through market-value approach or does-response analysis. All those records largely show immediately visible impacts that occur on the day of YDS; we call them “immediate impacts.” There are other types of impacts that are revealed or even strengthened only after a certain period after the YDS; we define them as “delayed impacts.” By this categorization, immediate and delayed impacts together add up to the direct impacts of that YDS event. To infer the direct impacts of other YDS events in 2000 in Beijing, an index is created based on the two characteristics of YDS: wind speed and visibility (Table 3). For example, if the index of a YDS event is twice of that of the April 6 YDS, the direct impact is estimated to be doubled. In this way, the total direct cost of all YDS events in 2000 in Beijing is estimated to be 2,195.1 million RMB, or $ 264.5 Million. Next multiplying the Leontief inverse of the direct requirement matrix, $(I-A^*)^{-1}$, by direct economic impacts (as a substitute for changes in final demand), we get the total economic impact (direct and indirect) on each sector.

Data	**Visibility (Kilometer)**	**Wind Speed (m/s)**	**Intensity Index (Wind Speed/Visibility)**
March 3	4	6	1.5
March 18	8	10	1.25
March 23	10	13	1.3
March 27	10	12	1.2
April 4	8	9	1.125
April 6	2	10	5
April 7	8	11	1.375
April 9	8	11	1.375
April 25	7	5	0.714
April 29	10	10	1
Average	7.5	9.7	1.3

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 authors.

Table 3 Comparison of the Intensity of Ten YDS Events in Beijing in 2000

The results show that delayed impacts of YDS were more significant than direct impacts on Beijing in 2000. Only one-quarter of direct cost are caused by immediate impacts, while three-quarters are caused by delayed impacts. The Construction, Transportation, and Trade and Catering Services sectors were mainly affected immediately after YDS, while the Agriculture and Manufacturing sectors showed fewer effects than other sectors until some time after YDS. The results also indicate that direct cost may take a small portion of the total cost, which means traditional evaluation method based on direct cost may significantly under-estimate YDS damages. The multiplier effect is large in Manufacturing and Transportation sectors, while low in Agriculture, Construction, and Trade and Catering Service sectors.

Table 4 Immediate, Delayed, Direct, and Indirect Impacts of YDS in Beijing in 2000

Affected Sectors	**Immediate Impacts**	**Delayed Impacts**	**Total Direct Impacts**	**Total Impacts (Direct + Indirect)**	**Multiplier Effect (Total/Direct)**
	Million RMB				
Agriculture	N.A.	788.4	788.4	946.8 ~ 1,136.7	1.2 ~ 1.4
Manufacturing	N.A.	855.3	855.3	1,681.7 ~ 5,317.8	1.97 ~ 6.21
Construction	227.2	N.A.	227.2	230.7 ~ 1,404.9	1.02 ~ 6.19
Transportation	26.9	N.A.	26.9	114.5 ~407.5	4.26 ~ 15.1
Trade and Catering Services	295.8	N.A.	295.8	445.8 ~ 711.6	1.5 ~ 2.4
Households	0.46	1.185	1.645	286.1 ~ 2424.3	?
Total	550.3 ($ 66.3)	1,644,865 ($ 198.2)	2,195.2 ($ 264.4)	4,032.3 ~ 13,992.7 ($485.8 ~ $1,685.9)	1.84 ~ 6.37

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

In absolute value, the Manufacturing, Agriculture, Trade and Catering Services, Household, and Construction sectors are the sectors that experienced the greatest total impacts in Beijing (see Table 5) comprising 90% of the total in the region as a whole. As a proportion of a sector's total output, however, the agriculture sector is the most severely affected (with a loss of 5.2% of its total output). Although our estimation of the impacts on the mining sector (61.9 million RMB) is not among the top ones, it is equivalent of 2.2% of its sectoral output--the second largest percentage rate among all sectors. The other sectors, almost evenly affected, show much less evident losses through demand-driven effects (0.1–0.4% of their sectoral output). Overall, our calculations show that the total economic impacts caused by demand-driven effects are 4,032.3 million RMB ($485.8 million, 1.6% of Beijing's GDP in 2000), which includes direct impacts, indirect impacts on other sectors due to decreases in demand during and after production disruption, and induced impacts, as shown in the household sector.

We further evaluate the total economic impacts on a regional economy by changes in value added of each sector. Our calculations (see Table 5) show that the total economic impacts caused by supply effects are 13,992.7 million RMB ($1,685.9 million), which is equal to 2.0% of Beijing's GDP in 2000. Compared to the impacts caused by demand-driven effects, Beijing's regional economy is affected more seriously through supply effects, in both absolute and percentage terms.

As shown in Table 3, an average intensity YDS event in 2000 in Beijing has a visibility of 7.5 KM, and a wind speed of 9.7 m/s. Based on the index, the ten YDS events in 2000 in Beijing are estimated to be equivalent to 13 average YDS days. Therefore, one YDS day on average causes 309 million RMB, or $ 37.4 million (demand-driven) to 1,072 million RMB, or $129.6 million (supply-driven) in 2000 in Beijing. Based on this information, we can infer how much damage could be prevented by investing in the forestry, water, and agriculture to reduce the frequency of YDS occurrences through various policy initiatives at either national or local level. This is the focus of the next session.

Table 5 Total Impacts of Yellow-Dust Storms on Each Sector of Beijing in 2000

No.	Sector	Sectoral output in 1999	Impacts caused by demand-driven effects			Impacts caused by supply effects		
			Total impacts	Impacts/ total	Impacts/ sectoral output	Total impacts	Impacts/ total	Impacts/ sectoral output
	Unit	Million	Million RMB	%	%	Million	%	%
1	Agriculture	18,208.9	946.8	23.5	5.2	1,136.7	8.1	6.2
2	Mining	2,844.3	61.9	1.5	2.2	29.4	0.2	1.0
3	Manufacturin	246,847.4	1,681.7	41.7	0.7	5,317.8	38.0	2.2
4	ElecGasWat	11,224.9	34.4	0.9	0.3	96.3	0.7	0.9
5	Construction	66,445.0	230.7	5.7	0.3	1,404.9	10.0	2.1
6	TransStorage	27,306.6	114.5	2.8	0.4	407.5	2.9	1.5
7	Trade	25,153.5	445.8	11.1	1.8	711.6	5.1	2.8
8	Finance	62,022.3	86.3	2.1	0.1	695.9	5.0	1.1
9	RealEstate	6,032.3	7.3	0.2	0.1	112.0	0.8	1.9
10	Social	34,408.7	62.2	1.5	0.2	616.1	4.4	1.8
11	HealthSports	6,677.6	1.2	0.0	0.0	156.2	1.1	2.3
12	EduCulture	16,491.5	9.7	0.2	0.1	311.7	2.2	1.9
13	Science	24,682.2	38.4	1.0	0.2	278.9	2.0	1.1
14	Geology	636.7	0.6	0.0	0.1	11.4	0.1	1.8
15	GovOthers	12,690.3	24.6	0.6	0.2	282.0	2.0	2.2
16	Household	137,118.4	286.1	7.1	0.2	2,424.3	17.3	1.8
	Total	698,790.5 ($84,191.6 million)	4,032.3 ($485.8 million)	100.0	1.6*	13,992.7 ($1,685.9 million)	100.0	2.0*

Notes 1. US $/ RMB = 8.3, in 2000 value.

2. Numbers with “*” are percentage of total economic impacts/gross domestic product (GDP) in Beijing in 2000.

YDS POLICY INITIATIVES AND COST BENEFIT ANALYSIS

Despite of the huge investment, policy initiatives to deal with YDS in China are still in an early conceptual stage, which are narrow in objective, incapable of facilitating public participation, and unable to cope well with the broad socioeconomic and environmental impacts of YDS. In this session, we will review the three fields that YDS policy should address, and go to details in one particular field. We further discuss the three major issues and associated three concerns in that field. Lastly, we pick up a case project, evaluate its environmental and social benefit, and then apply a cost-benefit analysis to the project in terms of saved YDS cost.

The findings from previous sessions suggest that governments should intervene at least in three fields related to YDS: damage mitigation, industry regulation, and event prevention. Damage mitigation aims to compensate for the costs brought by YDS. YDS should be included in the official disaster mitigation mechanism designed for other severe disasters like floods and earthquakes, so government aids can be easily accessible to the affected people in YDS areas. The Aids should be “compatible” with the characteristics of YDS damages. For example, in rural YDS areas wells are often buried and wheat seeds are blown out from the surface soil, while in cities tremendous water is needed to clean streets, buildings, and vehicles. Industry regulation is designed to increase industrial sectors’ capacity to against YDS attacks especially in YDS frequent-occurred areas, such as improved seal standards for industrial buildings in manufacturing, safer guideline of transportation in YDS weather, and more protective design of irrigation infrastructure or greenhouse in agriculture. Right now, these two types of policies have got much attention from governments. The third field, YDS prevention, is the focus on this research, which aims to reduce the frequency and intensity of YDS occurrences.

The focal issue of YDS prevention is vegetating in decertification areas that YDS originate, which involve three interacted issues: vegetating itself, water and soil preservation, and agriculture restructuring. Vegetating includes various programs ranging from forestation, grassland building, grazing-prohibition, and return-agriculture-to-forest. Water and soil preservation programs include watershed management, efficient irrigation, drinking water source protection, infrastructure improvement etc. Vegetating can not be sustained under the condition of water scarcity and soil erosion, while itself in turn also facilitates water and soil preservation. Many policy initiatives in China also involve agriculture restructuring and poverty elimination. In some YDS frequent-occurred areas, the deteriorated environment can not support many human settlements: the land production is low, and the living environment is poor. Tillage or grazing can easily damage the local ecosystem. In this case, governments encourage local farmers to shift from the traditional planting to more diversified, higher value added sectors such as fruit, vegetable, fodder, and husbandry. In areas where environment is extremely inclement, emigration policy might be implemented. Therefore, YDS prevention actually has three major concerns: environment betterment, social development, and economic damage reduction. The last one is the target of assessment. We choose the Beijing-Tianjin Sand Source Treatment Engineering project, the biggest YDS prevention project in China, as a case.

The Beijing-Tianjin Sand Source Treatment Engineering (BTSSTE) project in China, designed specifically to protect Beijing and Tianjin from YDS attacks, launched in March 2003, due to the intensified YDS occurrences in recent years. The project covers 458,000 square KM and 19.6 million people in five provinces. Major components of the project include return-farmland-to-forest 26,000 square KM, reforestation 49,440 square KM, grassland building 17,680 square KM, 66,059 water resources, watershed management 23,445 square KM, and180,000 emigrants. The project will last till 2010 with a total investment of $ 6.7 billion.

The project has yielded tremendous environmental and social benefit in the past four years. In a sample survey of 19 from the total 75 counties in the project area, decertification area reduced 4,369, 2,654, and 828 square KM each year comparing to 2000, a reduction of 16%, 27%, and 5% respectively. The total YDS affected population reduced from 2.96 million in 2000 to 2.78 million in 2003, a reduction of

5.9%. Forestation area increased 18%, and the forestry coverage rate increased from 19.3% to 20.9% (SFA 2003). Meteorological observation also shows particulate intensity in Beijing decreased 28%, and the overall dust deposit in Beijing reduced 13.2% in 2002, comparing to 2001 (CCTV News, 9/12/2003). Traditional agriculture has been upgraded steadily. Growth of forestry and animal husbandry out-performed traditional farming by 25 and 8 percentage points from 2000 to 2003. Grazing livestock decrease 29% in three years due to emigration and grazing-prohibition (SFA 2003). A total of 1.45 million people under poverty line have been cleaned from the list. Net per capital income of farmers in the project area increased from 1,456 RMB to 1,739 RMB, an annual increase of 6.1% in three years, higher than the 2.1% average of the non-metro area in this project (China Environment Daily, 8/24/2004).

Based on the increased forestation area each year, we can calculate the number of days of YDS is reduced, and the cost saved. By comparing the cost saved (benefit) with the project investment (cost), we know the cost-effectiveness of this project on YDS prevention. Table 6 lists the forestation area, YDS days reduced, cost saved, project investment, and the benefit/cost ratio of this project from 2000 to 2004.

The results suggest the project was very cost-effective in the first year. The benefit/cost ratio ranged from 1.34 to 4.64 indicating a great success of the project. However, the ratio has been decreasing since 2000. Although the cost is still within the range of benefits, it almost exceeds the up-bound benefit in 2003. This trend is confirmed by an increasing cost function of forestation (million RMB per square KM) as shown in Table 6. This is consistent with intuition that with more trees planted, the marginal benefit of tree planting is decreasing while its marginal cost is increasing because easy-for-planting areas are filled first.

Beijing-Tianjin YDS Project	**Benefit**			**Cost**	**Trend**	
	Forestation Area (SQ KM)	**YDS Reduction (Days)**	**YDS Cost Saved (Million RMB)**	**Fixed Investment (Million RMB)**	**Benefit/Cost**	**Unit Cost of Forestation （M RMB/SQ KM)**
2003	8,244	2.75	850 ~ 2,948	2,588	0.33 ~ 1.14	0.314
2002	6,764	2.25	696 ~ 2,411	1,232	0.56 ~ 1.96	0.182
2001	3,393	1.13	349 ~ 1,211	450	0.78 ~ 2.69	0.133
2000	1,562	0.52	161 ~ 557	120	1.34 ~ 4.64	0.077
Total	11,962	6.65	2,056 ~ 7,127	4,340	0.47 ~ 1.64	0.303

Source: China Forestry Statistical Yearbook 2002

Table 6 Cost-Benefit Analysis of the Beijing-Tianjin YDS Project from 2000 to 2003

CONCLUSION

By targeting the generation, socioeconomic impact, and project evaluation of YDS, this research aims to improve our understanding and accordingly management of YDS occurrences in China. It describes the dynamic interaction among environmental resources, YDS occurrences, economic activities, and policy initiatives, and establishes a framework to quantify their relationships. Nevertheless, this is an over-simplified representation of a complex network, which may involve thousands of variables with spatial and temporal variations.

The research quantifies relationships between rainfall, temperature, wind speed, vegetation cover, and sand source areas and the annual YDS days. For example, a 10 % increase of vegetation cover in the 100 KM buffer zone (about 3000 square KM) will reduce 1 YDS day at the buffer center annually. The research also tackles the trans-boundary issue of YDS, and identifies the distance (100 ~ 150 KM) of “peaked” trans-boundary effects. It also indicates the usefulness of spatial analysis function developed in GIS software to process, store spatial data, and to capture spatial relationships as illustrated in this case.

The research also demonstrates the power of Input-output techniques in evaluating the socioeconomic impacts of natural disasters by capturing both the immediate and delayed impacts, and both direct and indirect effects. If combined with Environmental Accounting (EA) or Social Account Matrix (SAM) techniques, more accurate evaluation can be done by capturing the contribution of environmental resources and social improvement of YDS projects to economic activities.

Lastly, the research suggests three fields that governments should take an active role in defying YDS. It chooses a specific YDS prevention project, the Beijing-Tianjin Sand Source Treatment Engineering (BTSSTE) project, and examines its environmental, social, and economic benefits. The cost-benefit analysis indicates a big success in the starting year of this project, but ever since the benefit-cost ratio has been declining.

New emerging global environmental issues like YDS require new ways of thinking and solutions. By adopting a holistic approach, this paper offers a “pilot” attempt to address these issues while anticipating more relevant studies will come in the future.

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