Economy and Environment Program
for Southeast Asia
22 Cross Street
#02-55 South Bridge Court
Singapore 048421
Tel: (65) 6438 7877
Fax: (65) 6438 4844
E-mail: eepsea@idrc.org.sg
Web site: www.eepsea.org

RESEARCH REPORT

No. 2010-RR2

# Environmental Cost Analysis of the Relocation of Pollution-intensive Industries Case Study: Transfer of Ceramics Industry from Foshan to Qingyuan, Guangdong Province

**Liu Li and Li Bin**
**College of Environmental Science and Engrg**
**South China University of Technology**
**Guangzhou 510006, P. R. China**
**Tel: 86-20-39380505**

In recent years, Chinese policy makers have tried to balance development in different regions of the country by relocating industrial production from prosperous zones to less developed areas. However, this type of industrial relocation is usually accompanied by the transfer of pollution problems. To shed more light on the costs and benefits of this important policy tool, a new EEPSEA study looks at the relocation of ceramics production from one region of Guangdong Province to another.

The study finds that the transfer of some ceramics production from populous Foshan to less densely populated Qingyuan would be an effective way of reducing the overall negative effect of the industry's air pollution. However, the study underlines the importance of using effective pollution-abatement technology. It recommends that such technology should be implemented in Foshan and in any new ceramics factories in Qingyuan. It finds that the value of the health benefits produced by installing this technology will greatly exceed the cost of putting the technology in place.

Published by the Economy and Environment Program for Southeast Asia (EEPSEA)
22 Cross St, #02-55 South Bridge Court, Singapore 048421(www.eepsea.org)
Tel: +65-6438 7877, fax: +65-6438 4844, email: eepsea@idrc.org.sg

EEPSEA Research Reports are the outputs of research projects supported by the Economy and Environment Program for Southeast Asia. All have been peer reviewed and edited. In some cases, longer versions may be obtained from the author(s). The key findings of most *EEPSEA Research Reports* are condensed into *EEPSEA Policy Briefs*, available upon request. The Economy and Environment Program for Southeast Asia also publishes *EEPSEA Special Papers*, commissioned works with an emphasis on research methodology.

ISBN: **978-981-08-6552-8**

# Environmental Cost Analysis of the Relocation of Pollution-intensive Industries Case Study: Transfer of Ceramics Industry from Foshan to Qingyuan, Guangdong Province

Liu Li and Li Bin

March 2010

Comments should be sent to: Ms LIU Li, College of Environmental Science and Engineering, South China University of Technology, Guangzhou 510006, P. R. China
Tel: 86-20-39380505
Email: liuli@scut.edu.cn

---

The Economy and Environment Program for Southeast Asia (EEPSEA) was established in May 1993 to support research and training in environmental and resource economics. Its objective is to enhance local capacity to undertake the economic analysis of environmental problems and policies. It uses a networking approach, involving courses, meetings, technical support, access to literature and opportunities for comparative research. Member countries are Thailand, Malaysia, Indonesia, the Philippines, Vietnam, Cambodia, Lao PDR, China, and Papua New Guinea.

EEPSEA is supported by the International Development Research Centre (IDRC), the Swedish International Development Cooperation Agency (Sida), and the Canadian International Development Agency (CIDA).

EEPSEA publications are also available online at http://www.eepsea.org

# ACKNOWLEDGEMENTS

I would like to thank EEPSEA for providing me with generous research funding for this study. In addition, I am especially indebted to Dr. Hermi Francisco and Ms. Catherine Ndiaye for their kind support throughout the study. I would like to express my deepest gratitude to Dr. Benoit Laplante for his valuable guidance and helpful suggestions.

I wholeheartedly thank my primary advisor, Professor Shiqiu Zhang, for her continuous encouragement and valuable advice. In addition, I wish to extend my sincere thanks to Weibin Pan and Yuhong Guo for their help in data collection. I would also like to thank Ya Li, Xiangyu Zheng, Minxia Yan, Buyun Tan, Xiang Peng, and Meiling Kang for their assistance during the field survey.

TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# ENVIRONMENTAL COST ANALYSIS OF THE RELOCATION OF POLLUTION-INTENSIVE INDUSTRIES CASE STUDY: CERAMIC INDUSTRY TRANSFER FROM FOSHAN TO QINGYUAN, GUANGDONG PROVINCE

**Liu Li and Li Bin**

## EXECUTIVE SUMMARY

Industry relocation has occurred more and more frequently in recent years, both regionally and globally. In Guangdong Province, China, industry relocation is a key way to balance the regional development gap. The relocation of manufacturing is usually accompanied by the transfer of accompanying pollution. This research looks at the environmental costs/benefits of the relocation of the ceramic industry, a pollution-intensive industry, from Foshan City to Qingyuan City in Guangdong Province. The study focuses on the health costs/benefits of the change in air quality due to the relocation of ceramic production. The cost of illness, the human capital approach and years lost due to disability were used to evaluate the health costs/benefits. Pollution abatement technology was also considered in order to discover the least costly way to control air pollution in Foshan. Using scenario analysis, it was found that the transfer of the ceramic industry from Foshan to Qingyuan would be an effective way of reducing the negative effect of the industry's air pollution due to the great difference in population density between these locations. The suggested technology should be adopted to reduce the health cost of pollution from the ceramic industry.

## 1.0 INTRODUCTION

### 1.1 Related Research

Due to economic globalization, industry migration has occurred more and more frequently in the past 30 years, both regionally and globally. In developing countries or regions, industry migration can help to raise incomes, promote the construction of infrastructure, and facilitate technology transfer. In developed countries or regions, the migration of industry can help to upgrade and reconfigure industrial structures. It has been noticed that pollution is transfered along with industry migration. Environmental degradation has been getting more and more serious in developing countries, particuarly since the 1990s.

During the 1990s environmental standards were tightened in developed countries, while the environmental status of developing countries became worse due to industrialization. Some early research found that environmental regulation had some effect on trade and Foreign Direct Investment (FDI) (Tobey 1990, 1993; Grossman and

Krueger, 1993; Low and Yeats, 1992; Mani and Wheeler, 1997). Other studies came to the conclusion that environmental regulation does substantially affect trade and investment flow as tighter environmental policies increase production costs and limit pollution-intensive industry investment. Factory location will also be affected by environmental regulation, especially for pollution-intensive industries (Levinson, 1996; Smarzynska and Wei, 2001; Eskeland and Harrison, 2002; Keller and Levinson, 2002). There is empirical evidence that higher labor costs and tighter environmental regulation in developed countries and areas lead to the emigration of labor-intensive and dirty industries (Copeland and Taylor, 2003).

Some research has been done on the relocation of domestic industry. Matthew E. Kahn (2004) found that domestic pollution havens may grow when there are substantial differences in the intensity of labor and environmental regulations.

In China, remarkable economic growth has been accompanied by serious environmental pollution problems in the last three decades. Two thirds of Chinese cities still fail to meet the air quality standard established by the National Environment Protection Agency[1] (NEPA), which means that a large population of urban residents are exposed to polluted air. However, domestic industry transfer has become more and more popular in China because great differences exist both at inter-provincial level and inner-provincial level. For example, Guangdong is one of the leading provinces in China for economic growth but at the same time, some regions in Guangdong are very poor. Mostly, there are no significant differences in environmental regulation between regions within a province but the enforcement of environmental regulation is inconsistent in different regions. From the beginning of this century, the Guangdong provincial government has carried out industry migration policies in order to balance regional development. Underdeveloped areas tried to attract labor and pollution-intensive industries, such as the ceramic industry, paper-making, cement and plastics, from the Pearl River Delta Region in order to grow their economy. It seems that industry relocation is good all round – but this solution is not so simple when social and environmental problems are considered, especially for relatively underdeveloped regions.

## 1.2 Purpose of the Study

The study pays attention to domestic pollution havens in the case of industry migration. In China, central and local government put forward industry policies that can effectively influence industrial development. As has been noted, domestic industry migration has been actively encouraged because it is regarded as a way of balancing regional economic development.

The research will look into the case of the relocation of the ceramics industry from Foshan City to Qingyuan City in Guangdong Province. It will try to evaluate the

---

[1] National Environment Protection Agency has been changed into Ministry of Environmental Protection since March, 2008.

environmental effects of industry relocation, focusing on the effect on human health of particulate air pollution caused by the movement of the ceramics industry from Foshan City to the nearby city of Qingyuan, under the same environmetal regime.

The study will check the rationality of the ceramics industry relocation in two ways. Firstly, it will compare the health benefits in Foshan with the health costs in Qingyuan. Secondly, it will compare the health costs of air pollution in Qingyuan with the technical cost of using cleaner technology, assuming that Foshan reduces its air pollution by transferring its ceramics industry to Qingyuan or by adopting cleaner technology.

The research tries to answer the following specific questions.

What is the health benefit of the reduction in dust emissions in Foshan City?

How should this health benefit be monetarized?

What is the health cost of the increase in dust emissions in Qingyuan City?

How should this be monetarized?

What is the technical cost of adopting dust-catching technology to reduce dust emissions?

What is the best way to reduce the dust pollution caused by the ceramics industry in Foshan City?

What are the policy implications of the above findings?

## 1.3 Structure of the Report

In this report, section 2 will describe the relevant policies and the status quo regarding industry relocation at provincial and prefectural levels. Section 3 explains air pollution control technology for ceramic production. The suggested pollution control technology is also specified in this section. Section 4 puts forward the calculation step by step and scenario analysis is introduced in this section. In section 5, the health effects of particulate air pollution produced by the relocation of the ceramics industry are estimated. The technical cost of cleaner technology is considered in cost-benefit analysis for various scenarios. Section 6 features a sensitivity analysis to see what would happen to the cost and/or benefit if the affected area was 1,000 km$^2$ and 2,000 km$^2$. A field survey including a household questionnaire and interview is introduced in section 7. A discussion of the results and the conclusion can be found in section 8.

# 2.0 DESCRIPTION OF THE POLICIES AND STATUS OF THE RELOCATION OF THE CERAMICS INDUSTRY

## 2.1 Economic Status Quo

Guangdong Province has experienced rapid economic growth in last three decades but an imbalance exists in the regional economy of the province. Guangdong Province has experienced 30 years of rapid growth since Chinese Reform and Openness. Its Gross Domestic Product (GDP) increased to over 3 trillion yuan in 2007 from over 2 trillion yuan in 2005, which is now one-eighth of national GDP and is more than that of Singapore, Hongkong and Taiwan individually. From the viewpoint of economic development, a great gap exists between different regions in Guangdong. According to its natural geography and social and economical status, Guangdong is divided into four regions, which consist of the Pearl River Delta (PRD), the East, the West, and the Mountainous region located in the north. A great gap exists between the PRD region and the other three regions. Both the East and West of Guangdong Province economically lag far behind PRD, as does the Mountainous region. To fill the gap in economic development between the PRD region and the non-PRD regions in the province, the Guangdong provincial government has made great efforts to encourage industry relocation between these regions.

The study sites, Foshan and Qingyuan, belong to the PRD region and the Mountainous region in the north respectively. Their economic status differs greatly.

Foshan City covers a total area of 3,848 km². In 2007, the population in Foshan was 5.9 million, ranking sixth out of the 21 cities of Guangdong. The GDP of Foshan in 2007 was 358.8 billion yuan, ranking third in the province. Guangdong's major industries include the manufacture of electronics, textiles, plastics and leather, ceramics, household electrical appliances, building materials, silk, chemical fibers and garments.

Qingyuan has a population of 3.6 million. It is surrounded by mountainous areas and covers an area of 19,160 km². In 2007, the GDP of Qingyuan was about 59.7 billion yuan, ranking thirteenth out of the 21 cities of Guangdong. Qingyuan is northeast of Foshan. It is about 130 km from Chancheng District, Foshan, to Yuantan Town, Qingyuan. The GDP per capita of Qingyuan in 2007 was only about a quarter of Foshan's.

Table 1. Difference in Development between Foshan and Qingyuan in 2007

| Items | Foshan City | Qingyuan City |
|---|---|---|
| Areas (km²) | 3,848 | 19,160 |
| Population (million) | 5.92 | 3.65 |
| GDP (billion yuan) | 358.8 | 59.7 |
| GDP per capita (thousand yuan) | 60.9 | 16.4 |
| Industry added value (billion yuan) | 203.6 | 27.6 |

Source: Guangdong Statistical Yearbook, 2008.

## 2.2 Industry Relocation Policies

The provincial government has taken various measures to reduce the gap between different regions. Industry relocation, or shift, is a key policy; it aims to increase investment in less developed areas by encouraging manufacturing in the PRD to move to less developed regions in the province.

The Decision about Speeding up the Development of Mountainous Regions by Guangdong Provincial Committee of Communist Party and Guangdong Provincial Government (Decision 2002) was issued in 2002. Decision 2002 outlined the planning and organization of industry relocation. In 2005, Guangdong provincial government issued Opinion on Guangdong Mountainous Regions and Both East and West Wings Acting together with Pearl River Delta to Promote Industry Shift in 2005 (Opinion 2005). Opinion 2005 stated that the provincial government was willing to promote the development of industry relocation parks which would follow the principles of market-oriented benefit sharing, and also sustainable development. The principle of sustainable development means that the planning and building of industry relocation parks should work in tandem with with the planning of industry development, town construction and environmental protection. A Catalogue of Production to Be Shift to Mountainous Regions from Pearl River Delta Region was also put forward by the Economy and Trade Committee (ETC) of Guangdong Province. The catalogue included seven groups and 75 kinds of products. The provincial government exerted itself to push the relocation of the manufacturing of the products listed in this catalogue within the province (that is, from the PRD region to the Mountainous regions).

Industry relocation has had obvious positive effects on the economic development of relatively underdeveloped regions in Guangdong Province. By the end of 2007, 23 authorized industry relocation (or ‘shift’) parks had been established. In 2006, the industrial added value of five cities in the Mountainous regions increased by 33.1% – this was 14.8% higher than the overall provincial level. Qingyuan City, together with Heyuan City, had the highest increase rate of GDP in 2006. Industry relocation was the main driving force for economic development in the Mountainous regions.

The provincial authorities are paying more and more attention to the environmental issues related to industry relocation. The provincial government issued *Some Opinions on Environmental Protection during Industiral Shift Motivated by Pearl River Delta Region and Other Regions in the Province* in March 2006 (Opinion 2006). The Environmental Protection Bureau (EPB) of Guangdong Province emphasized that environmental damage should be minimised during industrial relocation. Opinion 2006 was issued four years after Decision 2002, implying that environmental problems had arisen from industry relocation and that the EPB had noticed the phenomenon and was subsequently trying to deal with these issues.

## 2.3 Ceramics Industry Relocation in Guangdong Province

There were two large manufacturing bases for ceramic products in Guangdong Province before the industry was relocated. One was Foshan City and the other was Chaozhou City[2]. As some Foshan ceramics factories have expanded and relocated production, there are now large-scale ceramic industry parks in Qingyuan, Zhaoqing, Heyuan and Meizhou. This is consistent with *Development Planning about Building Materials Industries in Guangdong Province* of 2005–2010.

The ceramics industry is a mainstay of local industry, with nearly 400 ceramic-producing enterprises in Foshan, generating an industrial output value of 40 billion yuan, or 7% of the total value of municipal industrial output. About 80% of ceramics enterprises are located in Chancheng District and Nanhai District[3]. Air pollution is the main environmental problem caused by Foshan ceramics firms. In Foshan City, waste gas emission from the ceramics industry accounts for 50% of total emission and its industrial dust (particulate matter pollutant) forms 99% of the total emission of the whole city. The ceramics industry is also the second-largest industry for producing sulfur dioxide emission, accounting for more than 25% of the total emission of the city (Zhong Zhizhen, 2006).

Foshan municipal government plans to move out some ceramics plants in order to upgrade its industy structure and improve its environmental status. It wants to achieve higher economic efficiency by pushing the ceramics industry to upgrade its technology and reduce pollution without reducing local ceramics production. To facilitate the development of the ceramics industry, Foshan municipal government decided to foster a group of ceramic plants which have both high economic efficiency and good environmental performance, to strengthen and improve a group of plants which have the potential to grow to be a good firms in terms, both economically and environmentally, and to phase out or relocate a group of plants with serious environmental problems[4].

An official from Foshan EPB stated that they will stagger the renovation of 115 ceramic factories in Chancheng District in phases and by classified groups. In Chancheng District, 90 small and middle-sized factories with high pollution and of little economic

[2] Chaozhou is the largest production base which is different from Foshan in terms of product and energy. Its products are predominantly art ceramics, household porcelain and sanitary porcelain products. The ceramic plants in Chaozhou City use liquefied petroleum gas as fuel, which has low pollution levels, high energy efficiency and can also guarantee the quality of the ceramic products. For example, Xingye Ceramic Corporation’s main product is household porcelain and its daily consumption of liquefied petroleum gas is 7.5 tonnes, while its annual product value is more than 80 million yuan. Its products are exported to Europe and Australia but not to low-end markets such as the Middle East.

[3] Foshan City has five districts including Chancheng, Nanhai, Shunde, Sanshui and Gaoming. Nanzhuang Town, known as the ‘No. 1 Town of Building Ceramic Production in China’, is located in Chancheng District.

[4] For example, 16 ceramic plants in Nanzhuang Town, Chancheng District, needed to be phased out or shifted and were closed before the end of 2007. In fact, the phasing-out of ceramic plants with heavy pollution and low economic returns is also driven by the increasing cost of fuel, raw materials and labour. For example, more than 10 ceramic plants stopped production in 2005.

benefit would be closed down or moved out by the end of 2008, leaving about 25 ceramics factories.

Qingyuan City is relatively underdeveloped and has made efforts to attract investment in order to accelerate economic growth. With the introduction of manufacturing industries, its environmental status is getting worse. In recent years, Qingyuan has experienced rapid development, mostly due to industry transfer. In 2002 its industrial output was 7.8 billion yuan and it ranked No. 18 out of the 21 cities in Guangdong Province but by 2006 its industrial output had increased to 61.6 billion yuan and it ranked No.12 out of 21 cities. According to the *Bulletin on Qingyuan Environmental Status in 2004*, Qingyuan's daily average concentration of sulfur dioxide was 0.028 mg/m$^3$, an increase of 27.3% since 2003. In addition, its daily average concentration of total suspended particles was 0.146 mg/m$^3$, an increase of 10.6% since 2003. Qingyan's total emission was about 50 billion m$^3$, an increase by 28% since 2003. *Bulletin on Qingyuan Environmental Status in 2005* showed that emission of industrial waste air and wastewater were 71 billion m$^3$ and 37 million tonnes respectively, an increase of 43% and 23%. These data demonstrated that environmental quality has deteriorated since 2003. The correlation between industry development and environmental pollution has been demonstrated in this case.

The Ceramic Industry Park is located in Yuantan Town in Qingcheng District, Qingyuan City. According to *Plan for Qingyuan Ceramic Industry Park*, the ceramic industry park is to be developed in three stages and will cover 1,000 hectares. When it is fully developed the park will be able to support 150 ceramic production lines and offer more than 30,000 jobs. At present, the first and second development stages have been completed. Ceramic factories have been built along the new Qingfo first-class road, a belt of more than 10 km for the production of ceramics. Fourteen large-sized factories have been built and more than 72 production lines have been put into operation. In 2006, the industry output of the ceramic industry park was 3.4 billion,yuan while the ceramic plants offered more than 10,000 jobs. The ceramic industry has become the main industry of Yuantan Town.

Although environmental protection had been urged from the start of the park's construction, ceramic production in this industry park has had obvious environmental impacts. Local residents suffer from the odious smell and heavy dust pollution from the ceramics factories. Some villagers have complained that plants and crops have been damaged by the pollution created by the production of ceramics. The environmental problem they complained about the most was industrial dust pollution. Researchers found that in the downtown of Qingcheng District local residents seldom complained about pollution from the ceramic industry. Quite a lot of downtown residents said that the relocation of the ceramic industry had had little environmental effect because the downtown of Qingcheng District was over 5 km from the industry park, but they also confirmed that Yuantan Town was heavily polluted by the ceramic industry.

A field survey was carried out in both Foshan and Qingyuan and is explained in section 7.

## 3.0 AIR POLLUTION CONTROL TECHNOLOGY FOR THE CERAMICS INDUSTRY

### 3.1 Technological Processes of Ceramic Production

The technological processes of building and sanitary ceramic production usually includes disintegrating raw material, body preparation, glaze preparation, molding, firing, final inspection, inspection and packaging. For example, the technological process involved in making dry-pressed ceramic tiles is shown in figure 1 (Chen Shiming et al. 2005).

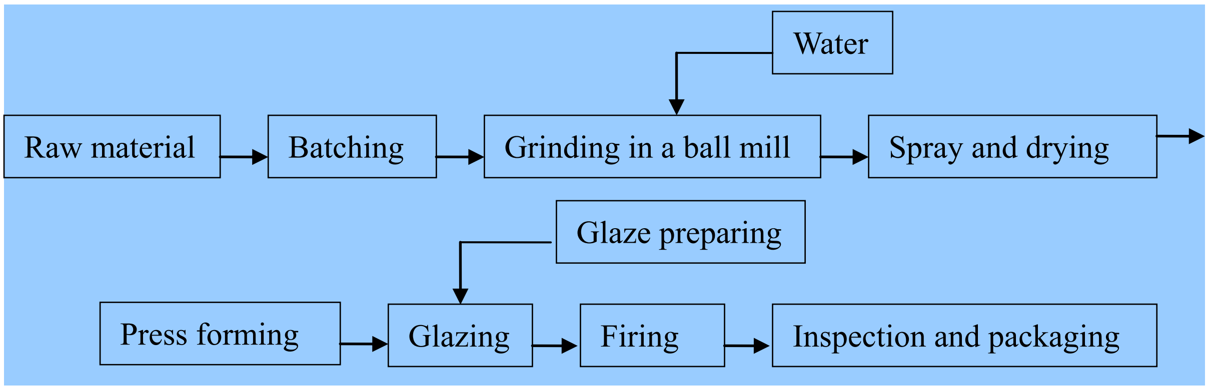



Figure 1. Processes Involved in Making Dry-pressed Ceramic Tiles

Many stages of ceramic technology (including the transportation of raw materials and coal, crushing the raw material, batching, forming, drying and firing) discharge dust. Most of the stages (e.g. transportation, crushing the raw material, batching and so on) discharge particulate matter near the ground. This type of dust emission usually happens in the workshop and affects air quality within a small scope so its impact on regional air quality won't be considered in this study.

This study focuses on the two technology stages that are the most important sources of particulate matter pollution. They are the roller kiln (the firing equipment) and the spray tower. These two stages account for the majority of dust emission in Chancheng District (Jia Yan et al. 2006) and it is known from monitoring data that dust emission from the spray tower are usually much higher than those from the roller kiln (see Table 2).

Table 2. Dust Emission Monitoring Data from Four Ceramic Plants in 2004

| Name of plant | Roller kiln | | Spray tower | |
|---|---|---|---|---|
| | Exhaust air volume ($m^3/h$) | Concentration of dust ($mg/m^3$) | Exhaust air volume ($m^3/h$) | Concentration of dust ($mg/m^3$) |
| Qianghui Ceramic Co. | 11483 | 15.4 | 86117 | 708.0 |
| Donglong Ceramic Plant | 14769 | 336.7 | 29051 | 243.9 |
| Yulong Ceramic Plant | 6201 | 30.5 | 8546 | 96.0 |
| Xinglong Ceramic Plant | 5984 | 148.8 | 16782 | 111.8 |

Source: Yang Ke et al. (2004).

### 3.2 Particulate Matter Pollution Control Technology

Industrial dust discharged by the ceramic industry comes from fuel burning (including oil and coal water slurry), ceramics raw materials, and the particles attached to the clay base and the materials it releases (such as lead, cadmium and their oxides). Usually, the buring of gas fuel does not give off particle pollutants.

#### 3.2.1 Cleaner Fuel

At present, building and sanitary ceramic production in Foshan uses mostly heavy oil, coal water slurry and diesel oil as its fuel. Heavy oil or coal water slurry is usually used during spray pelletization and drying, while diesel oil or industrial diesel oil is used during the firing process.

According to *Environmental Protection Planning of Chancheng District, Foshan City (2006-2020)*, no coal fuel (including coal water slurry, coal pieces, water gas and so on) is allowed to be used in the district. Ceramic plants are to be encouraged to use natural gas and liquefied petroleum gas (LPG). *Environmental Protection Planning* wanted all ceramic kilns to use natural gas and LPG for fuel after 2008 in order to reduce emissions of dust (particles) and sulfur dioxide. But the goal set forth in *Environmental Protection Planning* has still not been achieved. Only some of the ceramic plants in

Chancheng District use natural gas and/or LPG at the moment[5]. This means that quite a lot of ceramic plants still use oil and coal for fuel.

The annual fuel cost of a Model 4000 spray tower varies according to the fuel used. The New Zhongyuan Ceramics Limited Company has given the data below (table 3).

[5] Some of the ceramic plants have not changed their fuel source to natural gas/LPG because they are worried about a stable supply of natural gas. They suggest that local government should keep enough natural gas in reserve in order to ensure security of supply.

Even if the price of coal rose to more than 400 yuan per ton and the price of heavy oil dropped to about 3,000 yuan per ton by the end of 2008/beginning of 2009, the annual fuel cost using coal water slurry was lower than that of using heavy oil and natural gas.

Table 3. Costs of Different Types of Fuel

| Fuel type | Coal water slurry | Heavy oil | Natural gas | Water gas |
|---|---|---|---|---|
| Price of fuel | 369 yuan /tonnes | 3,400 yuan/tonnes | 1.8 yuan /m$^3$ | 0.28 yuan/m$^3$ |
| Calorific value | 14,025 KJ/KG | 39,710 KJ/KG | 35,112 KJ/m$^3$ | 5,852 KJ/m$^3$ |
| Annual cost (10,000 yuan) | 269 | 875 | 524 | 489 |

Particle pollutants from ceramic kilns come from the burning process. If gas is used as the fuel then this stage of the ceramics process will not emit dust particles. Ceramic plants emit more soot dust when they are fueled by coal water slurry than when using heavy oil and diesel oil. Table 4 shows emissions when burning different fuels.

As mentioned previously, building and sanitary ceramic plants usually use diesel oil or industrial diesel oil. Ceramic production in Foshan consumed 549,000 tonnes of fuel oil in 2007. Supposing all the fuel oil is diesel oil used in kilns, the soot dust emission would be 142.8 tonnes, which would account for only a very small proportion, less than 5%, of the total emission in Chancheng District, Foshan City. T The total emission of particle matter in Chancheng District was 3,249.52 tonnes in 2007 according to statistical data from the local environmental protection department. This study will give more emphasis to the spray-drying tower stage.

Table 4. Emission Factors for Burning Different Fuels without End-point Treatment

| Fuel type | Exhaust gas | Dust emission |
|---|---|---|
| Coal water slurry* | 9,186.57 m$^3$(N) per ton of raw material** | 134 kg per ton of raw material |
| Heavy oil | 15,366.93 m$^3$(N) per ton of raw material | 3.28 kg per ton of raw material |
| Diesel oil | 26,018.03 m$^3$(N) per ton of raw material | 0.26 kg per ton of raw material |
| Natural gas | 136,259.17 m$^3$(N) per 10,000 m$^3$ of raw material | 0 |
| LPG | 375,170.58 m$^3$(N) per 10,000 m$^3$ of raw material | 0 |

Source: Handbook of Pollutant Production and Emission Coefficient of Industrial Pollution Source for the 1st National General Survey of Pollution Sources (tenth volume).

Note: (1)* The emission factor of soot dust to coal water slurry being burned is 134 kg per ton of raw material when the ash content of the fuel is about 15%. (2)** The raw material of coal water slurry is coal.

### 3.2.2 Dust-catching Technology

At present, dust-catching equipment is mainly used to reduce the dust emissions from ceramic production. Common dust-catchers include wet dust separators, cyclone dust collectors, bag-house dust filters and static precipitators. Granite film dust remover is a kind of wet dust separator. Its separation efficiency can be above 90% and it can also desulphurize exhaust gas. The soot dust concentration of the treated exhaust gas can be lower than 200mg/$m^3$. The cyclone dust collector can be used for exhaust gas with a high dust concentration and its separation efficiency is 60-70%. The cyclone dust collector is cheap and is able to achieve high efficiency when working together with other types of dust-catchers. Bag-house dust filters can reach a separation efficiency of 95-99%. The dust concentration of exhaust gas is lower than 50mg/$m^3$ after being treated with a bag-house dust filter. A static precipitator is good at catching small particles and its separation efficiency can be 99%. (Preparation Group of Pollutant Discharge Standard for Ceramic Industry, 2008.) The operating principles of different types of dust-catchers are as follows:

**Cyclone Dust Collector**

The flue gas filled with dust is drawn into a room between the vent-pipe and the crust of the dust collector where it is turned into a downward outer vortex. The suspended particles move to the wall of the dust collector thanks to the centrifugal force and reach of the outer vortex. In the end, the particles reach the bottom of the dust collector and are discharged through dust emission holes. Purified gas forms an upward internal vortex which is then emitted via a vent-pipe.

**Gas Scrubbing Tower**

Let flue gas go through a water surface with medium. Air will then detour and continue going upward. At the same time, dust and particles will hit the medium and be kept. Then the dust and particles will be discharged with the wastewater.

**Multi-stage Spray Dust Removal System**

The gas discharged from a cyclone dust collector is led into multi-stage spray dust removal system and then is purified by a multi-stage water spray and purifying water curtain. Each spray room has spray nozzles – the greater the number of spray nozzles, the better the effect. The dust goes into a wasterwater treatment station along with the spray water. There are usually between four and five stages of spraying.

The spray-drying tower is the stage that discharges most of the dust in building and sanitary ceramic plants. The following will look into dust-catching technology for spray-drying towers. Yang Ke et al. (2004) suggested that combined dust separating technology should be used to achieve favorable results. For example, a cyclone dust collector could firstly be used to separate the fine ceramic powder from the flue gas. Then the second step is to separate the dust using a gas scrubbing tower or a multi-stage spray dust removal system. The gas scrubbing tower is an effective technology. After flue gas has been treated by gas scrubbing tower, its dust concentration will not exceed 150 $mg/m^3$. For a Model 3200 spray-drying tower, gas scrubbing equipment will cost 350,000, yuan while 400,000 yuan for a Model 4000 spray-drying tower. A multi-stage spray dust removal system is cheaper than a gas scrubbing tower and its dust removal efficiency is 80% with between four and five stages of spraying.

For a spray-drying tower, a bag-house dust filter is old dust-catching technology. The technology suggested by *Description of Preparing Pollutant Discharge Standard for Ceramic Industry* is a combination of a plenum pulse bag filter and an alkaline-solution-spray desulfuration dust-catching system. This technological process is shown in figure 2. With this suggested technology separation efficiency will be as high as 99% and the dust concentration in the exhaust gas will be not more than 100 $mg/m^3$. According to "*Requirements for Inspection and Acceptance of Ceramic Plants' Environmental Comprehensive Improvement in Chancheng District, Foshan City*", the dust concentration of exhaust gas from spray-drying towers should not be higher than 100$mg/m^3$.

The equipment needs to have a simple structure, stable operation and be easy to maintain. According to *Description of Preparing Pollutant Discharge Standard for Ceramic Industry*, the construction investment needed to establish pollution control is 281,000 yuan for a Model 3200 spray-drying tower. Its operating cost is 17.4 yuan per hour, including the power cost, the cost of the agent and bags.

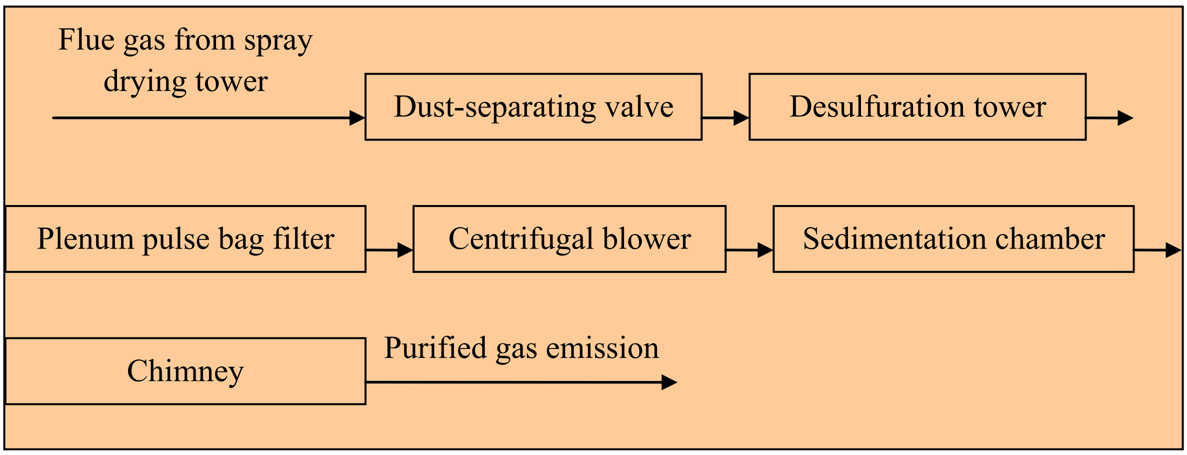



Figure 2. Exhaust Gas Treatment for a Spray-drying Tower (suggested by Pollutant Emission Standard for the Ceramic Industry)

Comparing the available feasible technology, the technology suggested by *Description of Preparing Pollutant Discharge Standard for Ceramic Industry* is better due to its higher dust removal efficiency and lower cost. This study examines the technical cost of pollution control with the data of the suggested technology.

# 4.0 METHODOLOGY

This research examines the environmental costs of the relocation of the ceramic industry from Foshan City to Qingyuan City in Guangdong Province. The analysis focuses strictly on the environmental costs and benefits of the ceramics industry relocation without considering other issues such as unemployment, the cost of moving facilities etc. To estimate the environmental costs and benefits, the study focuses on the health impacts of air particulate pollution from the ceramic industry. Various scenarios wre used to look for possible solutions for pollution from ceramic production in Foshan City.

Moreover, a field survey has been conducted to look into the social, economic and health impacts on local residents of the relocation of the ceramic industry. The field survey includes a household questionnaire and interviews. For details see section 7.

## 4.1 Geographic Scope and Population to be Considered

### Foshan City

Most of the ceramic firms in Chancheng, Foshan, are located in Nanzhuang Town, Chancheng District. The area of Nanzhuang Town is 75.75 $km^2$ while Chancheng District covers 154.02 $km^2$.

The long-term dominant wind direction in Foshan is northeast/north from September to March and south/southeast from April to August. Nanzhuang Town is located in the south of Chancheng District. Data from Xiqiaoshan monitoring station, which is located in the Nanhai District of Foshan City and to the southeast of Nanzhuang Town, shows an annual average concentration of $PM_{10}$ of about 0.06mg/$m^3$ in the last five years while the $PM_{10}$ of Chancheng increased from 0.071 mg/$m^3$ to 0.115 mg/$m^3$ in the same period. This implies a weak association between the air quality in Nanhai District and ceramic production in Chancheng District. During the summer and autumn the dominant wind direction is south and southeast, which means that air pollution from ceramic production mainly affects the east and northeast part of Chancheng District. Our questionnaire survey showed that the residents who live 5 km away from the ceramic plants seldom feel the environmental impacts.

The population area affected by the environmental impact of ceramic production was confined to Chancheng District in Foshan City.


Figure 3. Geographic Scope of the Study, Foshan City

**Qingyuan City**

In Qingyuan, Yuantan Town belongs to Qingcheng District. Yuantan Town covers 228.37 km$^2$ and Qingcheng District covers 927 km$^2$. The ceramic industry park spreads along Qingfo Highway and is located in the middle of Yuantan Town (see figure 4). The long-term dominant wind direction is northeast in winter and south in summer. Yuantan Town belongs to the Mountainous area. Here we will study the environmental impacts on Yuantan Town and the population of Yuantan Town, Qingyuan City. As the pollution can affect the areas beyond Qingyuan City, our study will under-estimate the damage from air pollution.

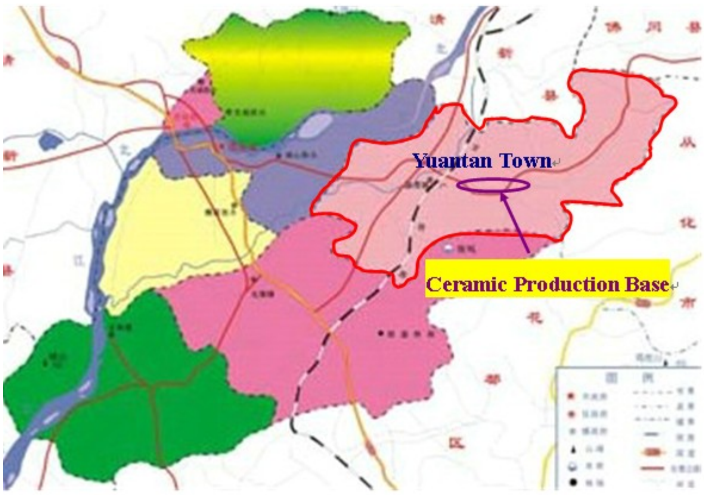



Figure 4. Geographic Scope of the Study, Qingyuan City

## 4.2 Estimation of PM Concentration

Ceramic production brings about environmental pollution, which mainly includes air pollution, water pollution and solid waste pollution. Here we will focus on the health impacts of air pollution.

This study considers the health impacts of PM though the most significant air pollutants from ceramic production, sulfur dioxide and airborne particulate matter. There are three reasons for this. Firstly, statistical data shows that about 99% of particulate matter comes from the ceramic industry in Foshan. Secondly, the monitoring results from the Pearl River Delta Regional Air Quality Monitoring Network, 2006-2008, show that the concentrations of respirable suspended particulates in Chancheng District, Foshan City, exceed 0.10 $mg/m^3$, Class 2 of NAAQS (i.e. National Ambient Air Quality Standards). The third reason comes from the World Health Organization's conclusion (2005) about the considerable uncertainty of the association between $SO_2$ and health.

In Chancheng District, the majority of industrial dust is discharged from ceramic production. Data of industrial dust emissions and the concentration of PM10 from 2004 to 2007 were obtained from the district's environmental protection department (see Table 5).

Table 5. Industrial Dust Emissions and Concentration of $PM_{10}$ in Chancheng District, 2004-2007

| Year | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|
| Industrial dust emissions (tonnes) | 1,791.98 | 1,934.47 | 2,329.71 | 3,249.52 |
| $PM_{10}$ ($mg/m^3$) | 0.071 | 0.093 | 0.115 | 0.146 |

In Yuantan Town, ceramic production is also the biggest source of local industrial dust emissions. According to the *Research Report of Qingyuan Environmental Protection Planning* (2007-2020), ceramic production accounts for more than 99.5% of local industrial dust emission. Therefore, the same method has been used to show the relationship between industrial dust emission and the concentration of $PM_{10}$ in Yuantan Town. Table 6 shows data from the environmental protection department of Qingcheng District.

Table 6. Industrial Dust Emissions and Concentration of $PM_{10}$ in Yuantan Town, 2004-2006

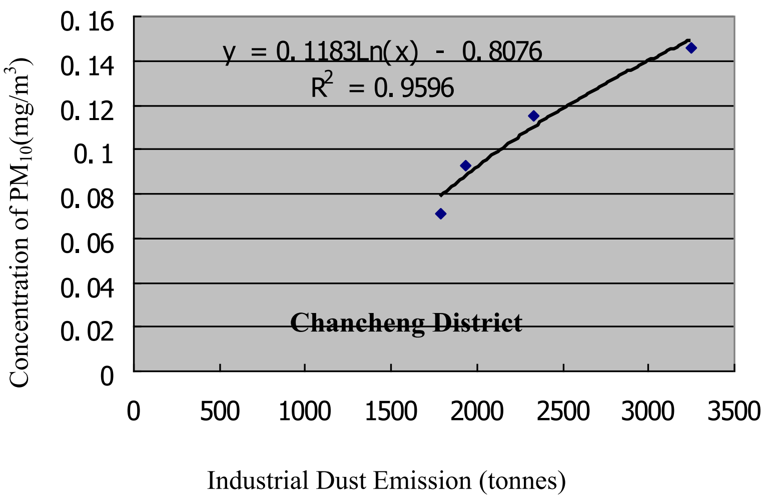
| Year | 2004 | 2005 | 2006 |
|---|---|---|---|
| Industrial dust emission (tonnes) | 105.75 | 308.68 | 597.42 |
| $PM_{10}$ ($mg/m^3$) | 0.088 | 0.100 | 0.110 |

Using the data for industrial dust emissions and the concentration of $PM_{10}$ in ambient air in Chancheng District (Foshan City) and Yuantan Town (Qingyuan City), the relationship between these two variables can be explained in the following formula (also see Figure 5).

Chancheng District: $y = 0.1183Ln(x) - 0.8076$ (Equation 1)

Yuantan Town: $y = 0.0119x^{0.3412}$ (Equation 2)

Where y is the concentration of $PM_{10}$ and x is the volume of particulate matter emissions. The formula is used to estimate the concentration of $PM_{10}$ in Chancheng District and Yuantan Town in different scenarios.



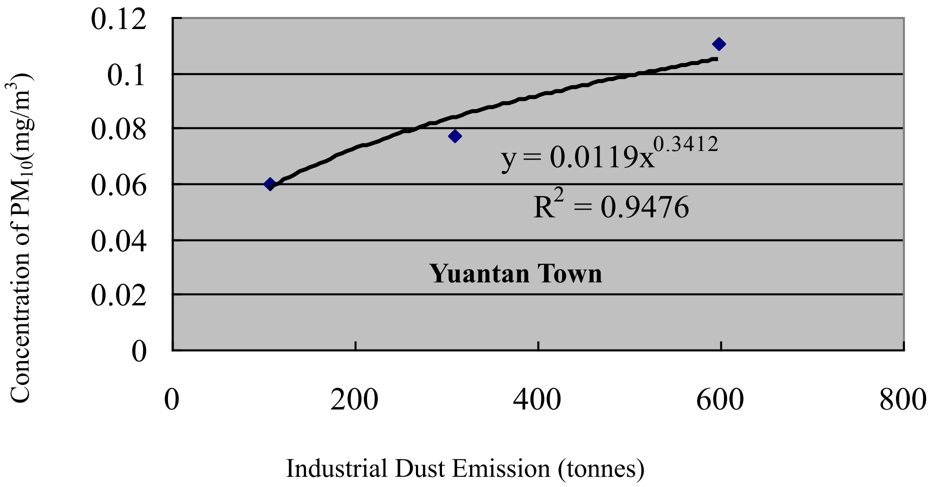




Figure 5. Simulation of the Relationship between Industrial Dust Emissions and the Concentration of $PM_{10}$ in Chancheng District and in Yuantan Town.

## 4.3 Valuation of the Health Effects

### 4.3.1 Exposure-response Relationship

Researchers have demonstrated the link between the effects on human health and concentrations of air pollutants. Pope et al. (1995) said that a link between respiratory disease and particulate air pollution and/or sulfur oxide pollution had been well established by the 1970s.

Airborne particulate matter (PM) has broad adverse health effects, predominantly for the respiratory and cardiovascular systems. There is little evidence to suggest a threshold of PM concentration below which no adverse health effects could be anticipated. This means that even in a relatively clean area (i.e. where the concentration of PM is below the national standard or the WHO (2005) suggested standard), long-term and short-term exposure to PM will still have adverse effects on human health.

Sulfur dioxide is another significant pollutant and many studies focus on the negative health impacts associated with it, including increased cases of sickness, damage to pulmonary function, and death. Though there was evidences of Beijing, Chongqing and Montreal showing an association between respiratory illnesses and sulfur dioxide (Dong et al., 1995; Venners et al., 2003; Goldberg, 2006), WHO (2005) pointed out that:

> *"There is still considerable uncertainty as to whether $SO_2$ is the pollutant responsible for the observed adverse effects or whether it is a surrogate for ultrafine particles or some other correlated substance."*

Considering the uncertainty of the association between $SO_2$ and health, this study only evaluates the diverse health effects of particulate air pollution.

There are three indexes representing particulate pollution, which include total suspended particles (TSP), respirable paticles (i.e. $PM_{10}$, particles with an aerodynamic diameter of less than 10μm) and fine particles ($PM_{2.5}$, particles with an aerodynamic diameter of less than 2.5μm). The early relevant literature studied the health effects of total suspended particles (TSP) and respirable paticles. Since the 1990s, especially after the important study of six U.S. cities by Dockery et al. (1995), researchers have placed more emphasis on fine particles because fine particles are thought to pose a particularly great risk to health. In China, the majority of the literature is about the health effects of TSP and $PM_{10}$. In Shanghai, Dai et al. (2004) observed the relationship between respirable and fine particle pollution and daily mortality. The possible reason that there have been so few studies about $PM_{2.5}$ could be that the routine Chinese air quality monitoring system generates data about concentrations of TSP and $PM_{10}$, but not $PM_{2.5}$. But, as WHO suggested,

> *"A $PM_{2.5}/PM_{10}$ ratio of 0.5 is typical of developing country urban areas and is at the bottom of the range found in developed country urban areas (0.5–0.8)."*

So the result of epidemiological observations about $PM_{2.5}$ can be adopted in this case.

Health impacts include increased respiratory symptoms, decreased lung function, increased hospitalizations and other healthcare visits for respiratory and cardiovascular disease, increased respiratory morbidity, increased mortality from cardiopulmonary disease and also restricted activity days (RAD).

The majority of the studies that have investigated the relationship between particulate matter and health effects (including morbidity and mortality) have assumed linear function for exposure-response relation. Samoli et al. (2005) confirmed the association between ambient particles and mortality in the cities being studied that can be adequately estimated using the linear model, though some researchers have tried using a non-linear concentration-response model to estimate the relationship between PM and mortality. This study will use the linear function for the concentration-response (C-R) relationship.

Tables 7 and 8 show studies of the C-R relationship between PM and health endpoints in China and other countries. Table 9 shows the adopted C-R function in this study. For example, each $1\mu g/m^3$ increase in $PM_{10}$ concentration leads to respiratory mortality increasing by 0.0408%, as shown in line 3 in Table 9. Chronic obstructive pulmonary disease will increase by 0.2% as TSP concentration increases by $1\mu g/m^3$.

Table 7. Concentration-response Functions for PM Derived from Domestic Epidemilogical Studies

| Reference | Study area | Summary of findings |
|---|---|---|
| CHANG Guiqiu et al. (2003) | Beijing | Each 100μg/m$^3$ increase in $PM_{10}$ led to respiratory disease deaths, cardiovascular and cerebrovascular (CVD and CHD) deaths, coronary disease deaths and chronic obstructive pulmonary disease (COPD) deaths increasing by 4.08%, 4.98%, 3.77%, 4.95% respectively. |
| JING Libin et al. (2000) | Benxi | The relative risks of chronic obstructive pulmonary disease (COPD) and acute respiratory diseases increased by 20% and 30% respectively with a 100μg/m$^3$ increase in TSP. |
| JING Libin et al. (1999) | Benxi | With a 100μg/m$^3$ increase in TSP, the relative risks of total mortality, COPD mortality, CHD mortality and CVD mortality are 1.08, 1.24, 1.24 and 1.08 respectively. |
| LIN Gang et al. (2007) | Fushun | A 50μg/m$^3$ increase in a four-day lag of TSP is associated with an excess respiratory disease mortality increase of 2.195% (95% CI=0.00195-0.04245). |
| DAI Haixia et al. (2004) | Shanghai | A 10μg/m$^3$ increase in $PM_{10}$ and $PM_{2.5}$ were associated with 0.53% (95% *CI*: 0.22%-0.85%), 0.85% (0.32%-1.39%) increase in total daily mortality respectively. |
| KAN Haidong et al. 003) | Shanghai | An increase of relative risk of non-accident mortality on each 10μg/m$^3$ over a 48-hour moving average of $PM_{10}$, $SO_2$ and $NO_2$ corresponds to 1.003 (95% *CI*: 1. 00121. 005), 1. 016 (95% *CI*: 1. 01121. 021), and 1. 020 (95% *CI*: 1. 01221. 027) respectively. |
| JIA Jian et al. (2004) | Shanghai | Relative non-accidental mortality associated with each 10μg/m$^3$ increment of $PM_{10}$, $SO_2$ and $NO_2$ over a 48-hour moving average were 1.007 (95% *CI*: 1.003-1.011), 1.011 (95% *CI*: 1.001-1.021), 1.010 (95% *CI*: 1.000-1.020) respectively. |
| KAN Haidong et al. (2007) | Shanghai | A 10μg/m$^3$ increase in the two-day moving average (lag01) concentration of $PM_{2.5}$ corresponded to 0.36% (95% CI 0.11%, 0.61%), 0.41% (95% CI 0.01%, 0.82%) and 0.95% (95% CI 0.16%, 1.73%) increase of total, cardiovascular and respiratory mortality. |
| XU Zhaoyi et al. (1996) | Shenyang | The risks of all causes, COPD and CVD mortality were estimated to increase by 2%, 3% and 2% with a 100μg/m$^3$ increase in TSP, and by 2%, 7% and 2% with a 100μg/m$^3$ in $SO_2$. |

| Reference | Study area | Summary of findings |
|---|---|---|
| WANG Huiwen et al. (2003) | Shenyang | Each 50μg/$m^3$ increment of TSP was associated with an OR of 1.0122% (95% *CI*: 1.0036-1-0209) of cardiovascular disease mortality in the general population. |
| ZHANG Xiaoping et al. (2007) | Taiyuan | For each 100μg/$m^3$ increase in the average $PM_{10}$ concentration, the corresponding OR of the effect on the total deaths of cerebrocardiovascular diseases was 1.126, and cardiac diseases 1.305. |
| QIAN Zhengmin et al. (2007) | Wuhan | Every 10 μg/$m^3$ increase in $PM_{10}$ daily concentration at lag 0 day was significantly associated with an increase of mortality in non-accidental (0.36%; 95% CI 0.19–0.53%), cardiovascular (0.51%; 95% CI 0.28–0.75%), stroke (0.44%; 95% CI 0.16–0.72%), cardiac (0.49%; 95% CI 0.08–0.89%), respiratory (0.71%; 95% CI 0.20–1.23%), and cardiopulmonary (0.46%; 95% CI 0.23–0.69%). |

Table 8. Concentration-response Functions for PM Derived from Epidemilogical Studies in Other Countries

| Reference | Study area | Summary of findings |
|---|---|---|
| Samet et al. (2000) | 20 U.S. cities | The estimated increase in the relative rate of death from all causes and from cardiovascular and respiratory causes were 0.51% (95% posterior interval, 0.07% to 0.93%) and 0.68% (95% posterior interval, 0.20% to 1.16%) for each 10μg/m$^3$ increase in the $PM_{10}$. |
| Dockery et al. (1993) | Six U.S. cities | The adjusted mortality-rate ratio for the most polluted of the cities, compared with the least polluted was 1.26 (95% confidence interval, 1.08 to 1.47). |
| Pope et al. (1995) | 151 U.S. metropolitan areas | All causes of mortality and cardiopulmonary disease mortality increased by 4.0% and 8.0% respectively for each 10μg/m$^3$ increase in the $PM_{2.5}$ (fine particulate). |
| Pope et al. (2002) | All 50 states of U.S.A. | Each 10μg/m$^3$ elevation in fine particulate air pollution was associated with approximately a 4%, 6% and 8% increased risk of all causes, cardiopulmonary, and lung cancer mortality, respectively. |
| Schwartz et al. (1992) | Philadelphia, Pennsylvania | Total mortality was estimated to increase by 7% (95% CI, 4 to 10%) with each 100μg/m$^3$ increase in TSP. Cause-specific mortality was also associated with a 100-μg/m$^3$ increase in TSP: chronic obstructive pulmonary disease, +19% (95% CI, 0 to 42%), pneumonia, +11% (95% CI, -3 to +27%), and cardiovascular disease, +10% (95% CI, 6 to 14%). |
| Samoli et al. (2005) | 22 European cities | Estimated increase of about 0.5% for total mortality and 0.7% for cardiovascular and respiratory mortality, with a 10μg/m$^3$ increment in $PM_{10}$. |
| Laden et al. (2000) | Six U.S. cities | A 10 μg/m$^3$ increase in $PM_{2.5}$ from mobile sources accounted for a 3.4% increase in daily mortality [95% confidence interval (CI), 1.7-5.2%], and the equivalent increase in fine particles from coal combustion sources accounted for a 1.1% increase [CI, 0.3-2.0%]. $PM_{2.5}$ crustal particles were not associated with daily mortality. |
| Verhoeff et al. (1996) | Amsterdam, Netherlands | The relative risk for a 100μg/m$^3$ increase in black smoke on the same day was 1.19 [95% confidence interval (CI) = 1.02-1.38], and for a 100μg/m$^3$ increase in $PM_{10}$ was 1.06 (95% CI = 0.99-1.14). |

Table 9. Exposure-response Coefficients of $PM_{10}$/TSP (per 1μg/$m^3$) Adopted in this Study

| Health endpoints | Pollutant | Coefficient | References |
|---|---|---|---|
| Mortality | | | |
| Respiratory mortality | $PM_{10}$ | 0.0408% | CHANG Guiqiu et al. (2003) |
| Cardiovascular disease mortality | $PM_{10}$ | 0.068% | Samet (2000) |
| Morbidity | | | |
| Outpatient visits | | | |
| Internal medicine | TSP | 0.022% | KAN Haidong et al. (2002) |
| Pediatrics | TSP | 0.025% | KAN Haidong et al. (2002) |
| Hospital admission | | | |
| Respiratory diseases | $PM_{10}$ | 0.12% | Aunan et al. (2004) |
| Cardiovascular diseases | $PM_{10}$ | 0.07% | Aunan et al. (2004) |
| Chronic obstructive pulmonary disease (COPD) | TSP | 0.2% | JING Libin et al. (2000) |

### 4.3.2 Estimating and Monetizing Health Effects

To estimate health effects, some assumptions were put forward. (1) It is assumed that there would be no threshold of PM concentration below which there are no adverse health effects (WHO, 2005). (2) The relationship between PM and effects on health is assumed to be linear. The association between PM and health endpoints are to be estimated with a linear model (Samoli, 2005). (3) It is supposed that the average medical costs in Foshan and Qingyuan are the same.

The effects on health of a change in air quality due to the relocation of the ceramic industry can be estimated with the following equation.

$$E = E_0 \times [1 + \beta \times (C - C_0)] \qquad \text{(Equation 3)}$$

Where $C$ and $C_0$ are the PM concentration in the scenario without industry relocation and the existing concentration of PM (i.e. PM10 or TSP) respectively, $\beta$ is the exposure-response coefficient, $E$ and $E_0$ are the corresponding health status (i.e. morbidity or mortality) of $C$ and $C_0$. Effects on health ($\Delta E$) could be estimated by

$$\Delta E = E - E_0 = E_0 \times \beta \times (C - C_0) \qquad \text{(Equation 4)}$$

The health effects of a change in air quality due to the relocation of the ceramic industry include three component parts.

(1) *Mortality*

Here we estimated the change in premature mortality due to respiratory diseases and cardiovascular diseases because most relevant epidemiologic studies about PM and mortality focus on mortality due to these causes (Dockery, 1993; Pope 1995; Qian and Kan, 2005). Its benefit/cost was valued using the human capital approach. The health benefit represents the increase in human capital from a reduction in premature death. The mortality benefit/cost ($HE_a$) will be estimated using the following equation:

$$HE_a = \Delta I \times HC_a = \Delta I \times YLL \times GDP \qquad \text{(Equation 5)}$$

Where $\Delta I$ is the health effect estimated by equation (2), $HC_a$ is human capital per case of premature death, $YLL$ is years of lost life and GDP is local GDP per capita in Chancheng District (Foshan) and Yuantan Town (Qingyuan) in 2007. The average number of years of life lost due to premature death for repiratory and cardiovascular diseases is 18 (Han et al., 2006)[6]. So here $YLL$ is designated as 18.

(2) *Outpatient and Hospital Admission*

Both outpatient and hospital admission are considered here. The health endpoints of outpatient and hospital admission included outpatient visits linked to internal medicine and pediatrics, and hospital admission for respiratory diseases and cardiovascular diseases.

The cost of illness ($HE_b$) includes the illness costs of outpatient visits ($HE_{b1}$) and hospital admission ($HE_{b2}$). The illness cost of outpatient visits is the same as its medical cost, which can be estimated with:

$$HE_{b1} = \Delta I \times mc_1 \qquad \text{(Equation 6)}$$

Where $\Delta I$ is the health effect estimated by equation (2), $mc_1$ is the medical cost per outpatient case and was 108.2 yuan in Guangdong Province in 2006[7].

---

[6] The average number of years of lost life (YLL) is calculated by the following formula:

$$YLL = \sum(\text{age specific expected lifespan} \times \text{age specific death toll}) / \sum \text{age specific death toll}$$

Han et al. (2006) used the data of the fifth national census in 2000 to get the average number of years of life lost to premature death from different diseases.

[7] The data comes from *Health Statistical Information of Guangdong Province (Simplified Edition)* compiled by The Department of Health, Guangdong Province. It is the medical cost per outpatient case in Guangdong Province.

The illness costs of hospital admission include the medical costs ($MC_2$) and also the economic cost of absence from work ($HC_b$). That is,

$$HE_{b2} = MC_2 + HC_b \qquad \text{(Equation 7)}$$

$$MC_2 = \Delta \times mc_2 \qquad \text{(Equation 8)}$$

$$HC_b = \Delta \times DAY \times GDP / 365 \qquad \text{(Equation 9)}$$

Where $\Delta$ is the effect on health estimated by equation 4, $mc_2$ is the medical cost per case of hospital admission, DAY is average hospital stay days, GDP is local GDP per capita in 2007. Here respiratory diseases and cardiovascular diseases are considered and the medical costs per case of hospital admission are 3,006 yuan and 6,627 yuan for respiratory diseases and cardiovascular diseases respectively. DAYs are 7.9 days and 12 days for respiratory diseases and cardiovascular diseases, respectively[8].

(3) *Years Lost due to Disability (YLD)*

Relevant studies show that chronic obstructive pulmonary disease (COPD) patients suffer long-term pain and are sometimes unable to work. The illness cost of COPD would be underestimated by the medical cost. Here YLD was applied in estimating the illness cost of COPD. YLD is one of the two component parts of Disability Adjusted Life Year (DALY) while DALY is "a summary measure of population health that combines in a single indicator years of life lost from premature death and years of life lived with disabilities." (Colin et al., 2003) The DALY consists of the years lost due to disability (YLD) and the years of lost life (YLL), i.e. the years lost due to premature mortality.

YLD is the disability component of DALY. The basic formula for calculating YLD is:

$$YLD = \Delta \times DW \times L \qquad \text{(Equation 10)}$$

Where:

$\Delta$ = number of incident cases

$DW$ = disability weight (in the range 0-1)

$L$ = average years of the case until remission or death

Then the economic lost of YLD ($HE_c$) due to COPD can be calculated with formula (9). In this case, $DW$ is 0.4 and $L$ is 23 (YU et al., 2007).

---

[8] Here the data of $mc_2$ and DAY come from the *Chinese Health Statistial Yearbook 2006*. The yearbook showed the average disease-specific hospital stay days and the medical cost according ICD-10 (*International Statistical Classification of Diseases and Related Health Problems, 10th Revision*).

$$HE_c = YLD \times GDP = \Delta \times OW \times \times GDP \quad \text{(Equation 11)}$$

## 4.4 Scenario Design

Here the base scenario is set out and four comparative scenarios are subsequently put forward. The environmental benefit/cost for both places was measured in different scenarios.

### 4.4.1 Base Scenario

To estimate the cost or benefit of pollution control, there should be a base of environmental quality, population and technology. A base scenario is compared with the possible scenarios to identify the effects of different pollution control measures.

The base scenario consists of three aspects including air $PM_{10}$ concentration, affected population and control technology.

(1) *Chancheng District (Foshan)*

In 2007, ceramic output was larger than before in Chancheng District. The ceramic output included about 490 million $m^2$ of tiles, 2.2 million pieces of sanitary ceramics and 32.1 million pieces of household porcelain. But at the same time, the district's $PM_{10}$ concentration was 0.146 mg/$m^3$, higher then before and dust emission increased to 3,250 tonnes, which is 40% more than 2006. There were 115 ceramic plants and 188 spray-drying towers in 2007 in Chancheng District.

Foshan municipal government put forward an industry policy for regulating and improving the ceramic industry in 2007. According to the policy, Chancheng District would phase out or relocate 90 heavily polluting ceramic plants between 2007 and 2009. After these changes, the scale of the ceramic industry would be 60% of what it was in 2007, and the number of spray-drying towers would decrease by 55%.

The 25 ceramic plants that would be retained would be those with advanced technology and good economic and environmental performance. All the retained plants should meet the environmental standards required by local government. That is, the dust/particle concentration of exhaust gas from their spray-drying towers should be lower than 100mg/$m^3$.

Ceramic production capacity in Chancheng District can be divided into two parts. (i) The first is production capacity that meets the required emissions standard, which we will call the 'clean' part of the production capacity. The clean part of the production capacity comprises those 25 ceramic plants that would be retained after the implementation of local policy for regulating and improving the ceramics industry. (ii) The second part comprises the production capacity to be phased out or relocated between 2007 and 2009, which we will call the 'unsettled' part of the production capacity. This part of the production capacity accounted for 40% of the total ceramic output in 2007 in Chancheng

District. To control particle pollution in Chancheng District, the pollution from the second part needs to be reduced.

In the base scenario, the $PM_{10}$ concentration would be 0.146 mg/$m^3$ in Chancheng District. The affected population would be 972,000. Eighty-eight spray-drying towers out of a total of 188 towers would be equipped with dust-catching equipment and the dust concentration of their exhaust gas would meet the emission standard of 100 mg/$m^3$.

(2) *Yuantan Town (Qingyuan)*

Yuantan Town began to build its ceramic industry park in 2002. The ceramic plants were first put into operation in 2004. Therefore, the conditions in Yuantan in 2002 have been taken as the base scenario. In the base scenario, there was no ceramic production in Yuantan so dust emission from ceramic production is zero. Concentration of $PM_{10}$ in Yuantan Town was 36μg/$m^3$ and its affected population was 94,000. The scenario assumes that there was no ceramic production in Yuantan Town.

### 4.4.2 Comparative Scenarios

The study assessed several possible solutions (i.e. comparative scenarios) to reduce particle pollutant emissions in Chancheng District. The cost and benefit of the different solutions was analysed to find out the most cost effective solution.

Here are the four scenarios:

The first scenario assumes that all the spray-drying towers would be treated so that their exhaust gas dust/particle concentration is not higher than the local environmental standards of 100mg/$m^3$. All ceramic production capacity would be held in Chancheng District. In Chancheng District, about 85 spray-drying towers meet the emission standard. The other 103 spray towers exceed the required concentration standard. Their exhaust gas dust/particle concentration is about 180 mg/$m^3$. The technology suggested in *Description of Preparing Pollutant Discharge Standard for Ceramic Industry*, mentioned in section 3.2, is a well-developed technology and is economically feasible – it can help the unsettled production capacity to meet local emission standards.

The second and the third scenarios assume that the production capacity of those ceramic plants which exceeded the required pollution emission standards (that is, the unsettled part of the production capacity) would be relocated to Yuantan Town, Qingyuan City.

The second scenario assumes that the unsettled part of the production capacity is relocated without dust-catching technology. This means the emission concentration of the relocated enterprises would be about 180 mg/$m^3$.

The third scenario assumes that the unsettled part of the production capacity is relocated and that the suggested dust-catching technology is applied to the relocated plants, which means that these plants would meet discharge standards.

The fourth scenario assumes that all the spray-drying towers are treated. The dust emission would be concentrated in Yuantan Town as much as possible, under the condition that the $PM_{10}$ in the town's air meets national standards. The rest of the capacity would be located in Chancheng District. This will be fully explained in section 5.1.

The costs and benefits of all four scenarios are listed in Table 10.

Table 10.Costs and Benefits of Different Scenarios

| Scenario | Costs | Benefits |
|---|---|---|
| Scenario 1 | Cost of adopting dust-catching technology for the unsettled part of ceramic production capacity in Chancheng | Health benefit of better air quality because of pollution abatement in Chancheng |
| Scenario 2 | Health cost of worse air quality because of additional pollution in Yuantan | Health benefit of better air quality because of pollution abatement in Chancheng |
| Scenario 3 | Health cost of worse air quality because of additional pollution in Yuantan<br>Cost of adopting dust-catching technology for the unsettled part of ceramic production capacity in Yuantan | Health benefit of better air quality because of pollution abatement in Chancheng |
| Scenario 4 | Health cost of worse air quality because of additional pollution in Yuantan<br>Cost of adopting dust-catching technology for the unsettled part of ceramic production capacity in both places | Health benefit of better air quality because of pollution abatement in Chancheng |

## 5.0 HEALTH IMPACTS OF AIR POLLUTION FROM THE CERAMIC INDUSTRY

### 5.1 Data

(1) *Volume of dust/particle emissions*

To estimate the volume of dust emissions, the study assumes that:

The production capacity can be substituted with the number of spray towers because of the close relationship between them.

All the spray-drying towers are Model 3200.

The annual dust emission from a Model 3200 spray-drying tower can be estimated with the following data.

The average emission rate of waste gas is 16,000 $m^3$ per hour.

A spray-drying tower will be in operation 24 hours a day and 300 days a year.

The dust concentration of the waste gas is 100 $mg/m^3$ if a spray tower uses dust-catching technology and is 180 $mg/m^3$ without dust-catching technology.

Here we assume that the clean part of the production capacity discharges waste gas from a spray-drying tower with an average dust concentration of 100 $mg/m^3$. The unsettled part of the exhaust gas has a dust concentration of 180 $mg/m^3$. If the unsettled part adopts the suggested pollution control technology, its dust emission concentration would then be 100 $mg/m^3$. Then, the annual dust emission of the spray-drying tower would be 11.5 tonnes with dust-catching technology, and 20.7 tonnes without dust-catching technology.

The total volume of dust/particle emissions in Chancheng District or Yuantan Town depends on the numbers of spray-drying towers with or without emission control.

As mentioned in section 4.4.1, 45% of the 188 spray-drying towers used dust-catching technology (that is, the clean part of the production capacity). This means that 85 spray-drying towers meet the related emission standard. The dust concentration of the waste gas of these towers is assumed to be 100 $mg/m^3$. The annual dust emission of each tower would be 11.5 tonnes. All of these towers would be kept in Chancheng District.

The other 103 towers (that is, the unsettled part of the production capacity) do not use dust-catching technology. The average dust concentration of their waste gas is 180 $mg/m^3$ and the annual dust emission of each tower would be 20.7 tonnes. The total dust emission of the unsettled part that do not use dust-catching technology, is 2,132.1 tonnes. If using dust-catching technology, the total dust emission of the unsettled part would be 1,184.5 tonnes because the average emission would be 11.5 tonnes in each case. This means that dust emission would decrease by 947.6 tonnes if dust-catching technology was used in the unsettled part of the production capacity. For different ways of dealing with the unsettled production capacity, see the different scenarios.

If all the production capacity was in Chancheng District and the unsettled part of the production capacity was treated with the suggested technology (that is, scenario 1), then dust emissions from the unsettled part would decrease by 947.6 tonnes while the emissions from the clean part would be unchanged. Dust emissions in Chancheng would decrease by 947.6 tonnes, making 2,301.9 tonnes in total, while that of Yuantan would remain the same as in the base scenario.

If the unsettled part of the production capacity was relocated to Yuantan Town, without the adoption of pollution control technology, while the clean part was kept in Chancheng as before (scenario 2), the dust emissions from the unsettled part without the dust-catching technology would be relocated to Yuantan Town. The 1,117.4 tonnes of dust emissions from the clean part would be kept in Chancheng District.

If the unsettled part of the production capacity was shifted to Yuantan Town and if it adopted the pollution control technology, while the clean part was kept in Chancheng as before (scenario 3), the dust emissions of the unsettled part with the dust-catching technology would be relocated to Yuantan Town. Then the dust emissions from ceramics production would be 1,184.5 tonnes in Yuantan and 1,117.4 tonnes in Chancheng.

The results of $PM_{10}$ concentration estimates using equations 1 and 2 show that the ambient $PM_{10}$ concentration of Yuantan Town would exceed the relevant standards[9] in scenarios 2 and 3. Considering that the relevant standards should be observed, scenario 4 should be considered. In this scenario, the unsettled part of the production capacity would use dust-catching technology, which means that the total dust emissions in both places would be 2,301.9 tonnes and the ambient $PM_{10}$ concentration of Yuantan would be 100μg/m$^3$, as is required by National Ambient Air Quality Standards. Therefore, only 506 tonnes of dust emissions would be shifted to Yuantan. In Chancheng District, the dust emission would be 1,795.9 tonnes.

Data for dust emissions in both places in the mentioned four scenarios are listed in Table 11.

Table 11. Volume of Dust Emissions in Different Scenarios

| Scenario | Chancheng District (Foshan), tonnes | Yuantan Town (Qingyuan), tonnes |
|---|---|---|
| Base scenario | 3,249.5* | 0 |
| Scenario 1 | 2,301.9 | 0 |
| Scenario 2 | 1,117.4 | 2,132.1 |
| Scenario 3 | 1,117.4 | 1,184.5 |
| Scenario 4 | 1,795.9 | 506 |

Note: This data comes from the local environmental protection department.

(2) *PM Concentration*

The environmental status bulletin of Foshan showed that the annual concentration of $PM_{10}$ in Chancheng District (Foshan) was 146μg/m$^3$ in 2007. For Yuantan, the concentration of TSP was about 60μg/m$^3$ before the ceramic plants were introduced. With the ratio of $PM_{10}$/TSP being 0.6, the $PM_{10}$ concentration was 36μg/m$^3$ in Yuantan Town before the relocation of the ceramic industry. The $PM_{10}$ concentrations in other scenarios have been estimated by the models mentioned in section 4.2 (see Table 10). Wei and Chapman (2001) observed that the ratios of PM10/TSP were 29%~61% in four Chinese cities and the ratio for Guangzhou was 61%. Medina (2004) suggested that the ratio of $PM_{10}$/TSP should be 0.55~0.70. This study sets the ratio at 0.6.

[9] See section 5.1 (2) PM concentration.

As can be seen in Table 12, the concentration of $PM_{10}$ in Chancheng District or Yuantan Town would exceed 100μg/m$^3$, or Class 2 of the National Ambient Air Quality Standards (GB 3095-1996-revised version) [NAAQS], which is applicable to residential, mixed commercial or residential, cultural and village areas, in scenarios 1 to 3.

Table 12.Annual Average Concentration of $PM_{10}$ in Chancheng and Yuantan

| Scenario | Chancheng District (Foshan), μg/m$^3$ | Yuantan Town (Qingyuan), μg/m$^3$ |
|---|---|---|
| Base scenario | 146 | 36 |
| Scenario 1 | 108 | 36 |
| Scenario 2 | 65 | 163 |
| Scenario 3 | 65 | 133 |
| Scenario 4 | 79 | 100 |

In scenario 4 the national standards would be met for both places. Scenario 4 supposes that all the spray-drying towers are treated, which means that the particle concentration of the exhaust gas from all the spray-drying towers would be about 100 μg/m$^3$.

Considering the health benefit per 1μg/m$^3$ increase in Chancheng District is much larger than the health cost per 1μg/m$^3$ decrease in Yuantan Town because of the large difference in population density between the two places, it would be best to reallocate the dust emissions as much as possible to Yuantan Town as its air quality would meet Class 2 of NAAQS. With equation 2, the $PM_{10}$ concentration of Yuantan Town would be 100μg/m$^3$ if the dust emissions increase by 506 tonnes in Yuantan. Thus, the dust emissions in Chancheng would be 1,795.9 tonnes and the $PM_{10}$ concentration in Chancheng would be 79 μg/m$^3$. In scenario 4, the $PM_{10}$ concentration in both Chancheng and Yuantan would meet national standards.

(3) *Population*

Here the affected population is defined as the population that will be affected by the change in air quality (i.e. $PM_{10}$ concentration) in the different scenarios. It is assumed that there is no change in population between the different scenarios.

In Chancheng District (Foshan) the resident population of 2007 (i.e. the base scenario) is the affected population. According to the local statistics book, the resident population was 972,000 in 2007, though the population of registered permanent residents was only 596,000. This means that more than a third of the residents of Foshan are a floating population.

In Yuantan Town (Qingyuan) the population was 94,000 in 2007. The population of Yuantan in 2007 is defined as the affected population because the current population faces the environmental quality change resulting from the relocation of the ceramic industry.

(4) *Mortality and Morbidity Data*

The health endpoints due to changes in ambient $PM_{10}$ concentration include both mortality and morbidity. Morbidity factors include chronic obstructive pulmonary disease (COPD), outpatient visits (including internal medicine and pediatrics) and hospital admissions (including respiratory and cardiovascular diseases).

The health data was collected from the *Chinese Health Statistical Yearbook*, provincial and municipal health departments and local hospitals and clinics. When necessary data was not available from provincial and local health departments, researchers resorted to national data. For example, the *Chinese Health Statistical Yearbook* provides data on medical costs for hospital admissions. Researchers went to local clinics and hospitals with this data and consulted doctors in relevant departments in order to make sure that the data was suitable for the study areas.

The evidence of environmental costs/benefits for the effects on health of the relocation of the ceramics industry was found during data collection. For example, the total number of visits to Yuantan Health Center increased by over 30% during the period that ceramic production was gradually increased since 2003.

(5) *Cost of Emission Control Technology*

In Chancheng District, about one half of the spray-drying towers are Model 3200. Here we assume that the technology suggested by the Pollutant Emission Standard for Ceramic Industry is used to control the dust emissions of the unsettled part of the production capacity. The cost of dust pollution control for each spray-drying tower is as follows.

Fixed cost: The construction investment is 281,000 yuan. The service life of the equipment is about 10 to 12 years. The annual cost of the fixed investment is about 25,600 yuan.

Operating cost: The operating cost is 17.4 yuan per hour. The annual operating cost is about 125,300 yuan.

So the annual total cost for each spray-drying tower will be 150,900 yuan.

## 5.2 Important Parameters

The important parameters are summarized in the following table. These parameters are important variables that will have substantial influence on the results of the study.

Table 13.Important Parameters

| Place | Chancheng District (Foshan)[1] | Yuantan Town (Qingyuan)[2] |
|---|---|---|
| GDP per capita (Yuan) | 70,390 | 27,106 |
| Population (persons) | 972,000 | 94,000 |

Data source: 1. The Statistical Bulletins of the Economic and Social Developments in Chancheng District, Foshan City, 2007; 2. Yuantan Town Government.

## 5.3 Results

### 5.3.1 Valuation of health impacts

(1) *Health Benefit in Chancheng District*

In Chancheng District, the air quality would be improved in all of the scenarios. This means that there would be health benefits because of a reduction in dust emissions from local ceramic production. Compared with the base scenario, the health benefits for Chancheng in the different scenarios are listed in Tables 14 and 15. As the tables show, the health benefits of scenarios 2 and 3 are the same because of the same change in $PM_{10}$ concentration for the unsettled part of the production capacity being relocated to Yuantan Town (Qingyuan) in the both scenarios.

Table 14.Reduced Cases of Illness in Chancheng District (Foshan City)

| Endpoint | Scenario 1 | Scenarios 2 & 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 17 | 35 | 29 |
| CVD and CHD mortality | 34 | 73 | 61 |
| COPD | 1,004 | 2,152 | 1,785 |
| **Outpatient visits** | | | |
| Internal medicine | 15,934 | 34,143 | 28,326 |
| Pediatrics | 6,613 | 14,172 | 11,757 |
| **Hospital admissions** | | | |
| Respiratory diseases | 407 | 867 | 717 |
| Cardiovascular diseases | 213 | 453 | 375 |

Table 15.Health Benefits for Chancheng District, Different Scenarios (Million Yuan)

| Endpoint | Scenario 1 | | Scenarios 2 & 3 | | Scenario 4 | |
|---|---|---|---|---|---|---|
| **Mortality** | | | | | | |
| Respiratory mortality | 20.99 | | 44.74 | | 37.01 | |
| CVD and CHD mortality | 43.58 | | 92.90 | | 76.84 | |
| COPD | 650.35 | | 1,393.61 | | 1,156.18 | |
| **Outpatient visits** | | | | | | |
| Internal medicine | 1.72 | | 3.69 | | 3.06 | |
| Pediatrics | 0.72 | | 1.53 | | 1.27 | |
| **Hospital admissions** | | | | | | |
| Respiratory diseases | 1.84 | | 3.93 | | 3.25 | |
| Medical costs | | 1.22 | | 2.61 | | 2.16 |
| Absence from work | | 0.62 | | 1.32 | | 1.09 |
| Cardiovascular diseases | 1.90 | | 4.05 | | 3.35 | |
| Medical costs | | 1.41 | | 3.00 | | 2.48 |
| Absence from work | | 0.49 | | 1.05 | | 0.87 |
| Total | 721.11 | | 1,544.46 | | 1,280.97 | |

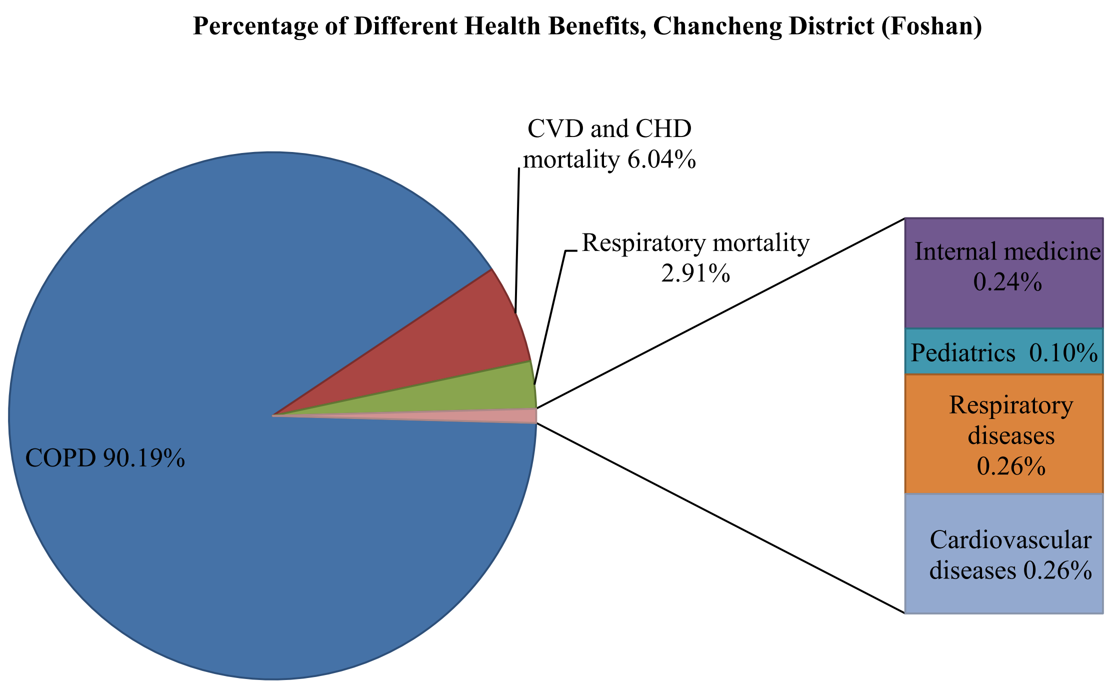



Figure 6. Percentage of Different Health Benefits, Chancheng District (Foshan)

(2) *Health Costs in Yuantan Town*

In scenario 1, the unsettled part of the production capacity controls its dust emissions on the spot without relocating to Yuantan Town. Therefore no health costs will occur in Yuantan.

As the unsettled part of the production capacity would be relocated to Yuantan in scenarios 2, 3 and 4, there would be health costs for Yuantan. These are listed in Tables 16 and 17.

Table 16.Increased Cases of Illness in Yuantan Town (Qingyuan City)

| Endpoint | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 4 | 3 | 2 |
| CVD and CHD mortality | 17 | 13 | 8 |
| COPD | 291 | 222 | 147 |
| **Outpatient visits** | | | |
| Internal medicine | 5,185 | 3,962 | 2,617 |
| Pediatrics | 2,152 | 1,645 | 1,086 |
| **Hospital admissions** | | | |
| Respiratory diseases | 132 | 100 | 66 |
| Cardiovascular diseases | 69 | 53 | 35 |

Table 17.Health Costs for Yuantan Town, Different Scenarios (Million Yuan)

| Endpoint | Scenario 2 | | Scenario 3 | | Scenario 4 | |
|---|---|---|---|---|---|---|
| **Mortality** | | | | | | |
| Respiratory mortality | 1.86 | | 1.42 | | 0.94 | |
| CVD and CHD mortality | 8.10 | | 6.19 | | 4.08 | |
| COPD | 72.56 | | 55.44 | | 36.62 | |
| **Outpatient visits** | | | | | | |
| Internal medicine | 0.56 | | 0.43 | | 0.28 | |
| Pediatrics | 0.23 | | 0.18 | | 0.12 | |
| **Hospital admissions** | | | | | | |
| Respiratory diseases | 0.47 | | 0.36 | | 0.24 | |
| Medical costs | | 0.40 | | 0.30 | | 0.20 |
| Absence from work | | 0.07 | | 0.06 | | 0.04 |
| Cardiovascular diseases | 0.52 | | 0.39 | | 0.26 | |
| Medical costs | | 0.46 | | 0.35 | | 0.23 |
| Absence from work | | 0.06 | | 0.04 | | 0.03 |
| Total | 84.30 | | 64.41 | | 42.54 | |

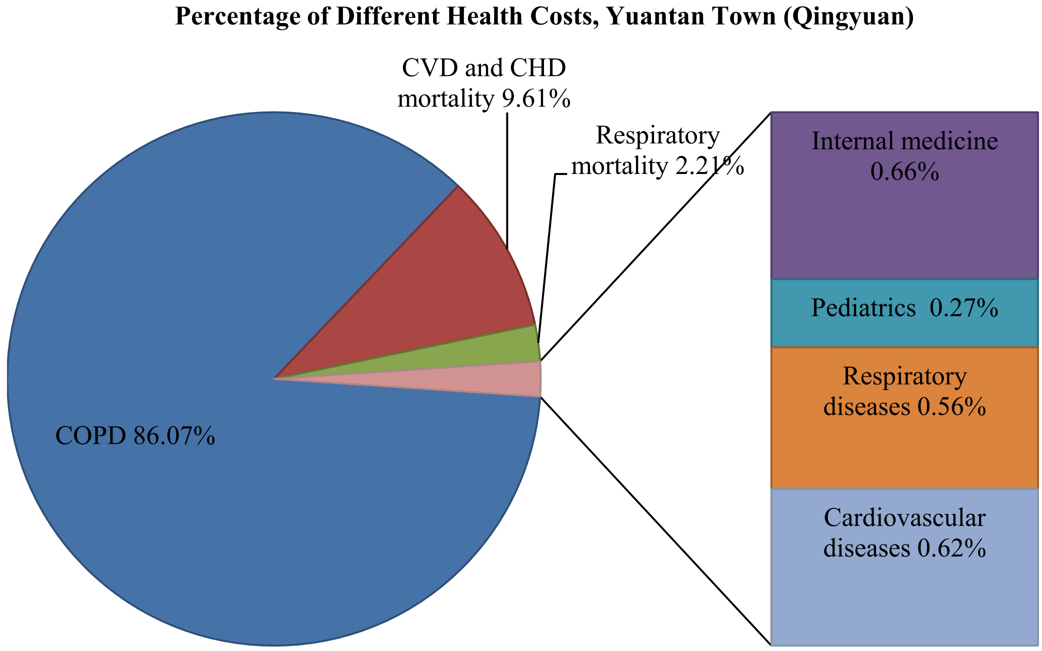



Figure 7. Percentage of Different Health Costs, Yuantan Town (Qingyuan)

### 5.3.2 Costs and Benefits of Different Scenarios

Table 18 shows the costs and benefits of the four different scenarios. It shows that the net benefit of scenario 3 is the biggest while that of scenario 1 is the smallest. The net benefits of other scenarios are bigger than that of scenario 1 by far, which means the relocation of ceramics production to Yuantan Town (Qingyuan) is a good choice.

The net benefit of scenario 3 (that is, to relocate to Yuantan Town the unsettled part of the production capacity, with dust-catching technology) is a little bigger than that of scenario 2 (that is, to relocate to Yuantan Town the unsettled part of the production capacity, without dust-catching technology).

Table 18.Costs and Benefits, Different Scenarios (Million Yuan)

| Costs/benefits | | Health Benefit/Cost | Tech. cost | Net benefit |
|---|---|---|---|---|
| Scenario 1 | Chancheng | 721.11 | -15.54 | 705.57 |
| | Yuantan | n/a | n/a | |
| Scenario 2 | Chancheng | 1,544.46 | n/a | 1,460.16 |
| | Yuantan | -84.3 | n/a | |
| Scenario 3 | Chancheng | 1,544.46 | n/a | 1,464.51 |
| | Yuantan | -64.41 | -15.54 | |
| Scenario 4 | Chancheng | 1,280.97 | -8.9 | 1,222.89 |
| | Yuantan | -42.54 | -6.64 | |

In scenario 4, only 506 tonnes of dust emissions would be shifted to Yuantan. In Chancheng District, the dust emissions would be 1,795.9 tonnes. It should be noticed that the ambient $PM_{10}$ concentration of both places meets national standards in this case, though its net benefit is lower than that of scenarios 2 and 3 by about 20%.

## 6.0 SENSITIVITY ANALYSIS

Suppose the areas affected by dust pollution from ceramics production in Chancheng and Yuantan were larger than anything defined in all four scenarios. At the same time, we assumed that the change in concentration of $PM_{10}$ in the air would be the same in all four scenarios.

### 6.1 Case 1: The Affected Area is 2,000 km$^2$

Here we suppose that the affected area in each place is about 2,000 km$^2$. Apart from Chancheng District, the population density of Foshan City is about 2,300 people per km$^2$. The GDP per capita in Foshan City in 2007 was 60,917 yuan. The area affected by Yuantan's ceramic production would include a part of Guangzhou City and a part of Qingyuan City. Excluding Yuantan Town, the population density of the area affected by Yuantan's ceramic production is about 440 people per km$^2$. The GDP per capita of the area was 30,850 yuan in 2007.

The total population affected by ceramic production in Chancheng is 5,217,800, and in Yuantan is 873,500.

Table 19. Population of an Affected Area of 2,000 km$^2$

| Place | Area (km$^2$) | Population (thousands) | Population density (people per km$^2$) |
|---|---|---|---|
| Chancheng District | 154.02 | 972 | 6,311 |
| Around Chancheng | 1,845.98 | 4,245.8 | 2,300 |
| Total | 2,000 | 5,217.8 | 2,609 |
| Yuantan Town | 228.37 | 94 | 412 |
| Around Yuantan | 1,771.63 | 779.5 | 440 |
| Total | 2,000 | 873.5 | 437 |

(1) *Health Benefits of Pollution Control in Chancheng District*

The air quality in Chancheng District and adjacent areas would be improved in all four scenarios. That is, there would be health benefits thanks to the reduction in pollution from Chancheng's ceramic industry. The health benefits of different scenarios are shown in Tables 20 and 21.

Table 20. Reduction in Illness in Chancheng District and Adjacent Areas

| Endpoint | Scenario 1 | Scenarios 2 & 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 89 | 190 | 157 |
| CVD and CHD mortality | 185 | 394 | 326 |
| COPD | 5,391 | 11,552 | 9,584 |
| **Outpatient visits** | | | |
| Internal medicine | 85,533 | 183,285 | 152,058 |
| Pediatrics | 35,502 | 76,076 | 63,115 |
| **Hospital admissions** | | | |
| Respiratory diseases | 2,184 | 4,656 | 3,851 |
| Cardiovascular diseases | 1,142 | 2,434 | 2,014 |

Table 21.Health Benefits to Chancheng District and Adjacent Areas of Different Scenarios (Million Yuan)

| Endpoint | Scenario 1 | Scenarios 2 & 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 97.51 | 207.85 | 171.93 |
| CVD and CHD mortality | 202.47 | 431.57 | 356.98 |
| COPD | 3,021.33 | 6,474.28 | 5,371.25 |
| **Outpatient visits** | | | |
| Internal medicine | 9.25 | 19.83 | 16.45 |
| Pediatrics | 3.84 | 8.23 | 6.83 |
| **Hospital admissions** | | | |
| Respiratory diseases | 9.45 | 20.13 | 16.65 |
| Medical costs | 6.57 | 13.99 | 11.57 |
| Absence from work | 2.88 | 6.14 | 5.08 |
| Cardiovascular diseases | 9.86 | 21.01 | 17.38 |
| Medical costs | 7.57 | 16.13 | 13.35 |
| Absence from work | 2.29 | 4.88 | 4.03 |
| Total | 3,353.71 | 7,182.91 | 5,957.47 |

(2) *Health Costs of an Increase in Pollution in Yuantan Town*

As some ceramic production capacity would be shifted to Yuantan Town, the air quality of Yuantan Town and adjacent areas would worsen as ceramic plants were introduced. Therefore, there would be health costs. The health costs of different scenarios would vary. The health cost of scenario 1 would be zero because there would be no shift in ceramic production to Yuantan.

Table 22. Increased Cases of Illness in Yuantan Town and Adjacent Areas

| Endpoint | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 35 | 27 | 18 |
| CVD and CHD mortality | 154 | 118 | 78 |
| COPD | 2,699 | 2,062 | 1,365 |
| **Outpatient visits** | | | |
| Internal medicine | 48,108 | 36,744 | 24,319 |
| Pediatrics | 19,968 | 15,251 | 10,094 |
| **Hospital admissions** | | | |
| Respiratory diseases | 1,222 | 933 | 616 |
| Cardiovascular diseases | 639 | 488 | 322 |

Table 23.Health Costs in Yuantan Town and Adjacent Areas of Different Scenarios (Million Yuan)

| Endpoint | Scenario 2 | | Scenario 3 | | Scenario 4 | |
|---|---|---|---|---|---|---|
| **Mortality** | | | | | | |
| Respiratory mortality | 19.67 | | 15.03 | | 9.91 | |
| CVD and CHD mortality | 85.65 | | 65.42 | | 43.16 | |
| COPD | 766.15 | | 585.17 | | 387.30 | |
| **Outpatient visits** | | | | | | |
| Internal medicine | 5.21 | | 3.98 | | 2.63 | |
| Pediatrics | 2.16 | | 1.65 | | 1.09 | |
| **Hospital admissions** | | | | | | |
| Respiratory diseases | 4.49 | | 3.43 | | 2.26 | |
| Medical costs | | 3.67 | | 2.81 | | 1.85 |
| Absence from work | | 0.82 | | 0.62 | | 0.41 |
| Cardiovascular diseases | 4.88 | | 3.73 | | 2.46 | |
| Medical costs | | 4.23 | | 3.23 | | 2.13 |
| Absence from work | | 0.65 | | 0.50 | | 0.33 |
| Total | 888.21 | | 678.40 | | 448.82 | |

Table 24. Costs and Benefits of Different Scenarios (Million Yuan)

| Costs/benefits | | Health benefit | Health cost | Tech. cost | Net benefit |
|---|---|---|---|---|---|
| Scenario 1 | Chancheng | 3,353.71 | n/a | -15.54 | 3,338.17 |
| | Yuantan | n/a | n/a | n/a | |
| Scenario 2 | Chancheng | 7,182.91 | n/a | n/a | 6,294.70 |
| | Yuantan | n/a | - 888.21 | n/a | |
| Scenario 3 | Chancheng | 7,182.91 | n/a | n/a | 6,488.97 |
| | Yuantan | n/a | - 678.40 | -15.54 | |
| Scenario 4 | Chancheng | 5,957.47 | n/a | -8.9 | 5,493.11 |
| | Yuantan | n/a | - 448.82 | -6.64 | |

(1) *Costs and Benefits of Different Scenarios*

In all the scenarios, the costs of technical pollution control remain unchanged. Using the health costs and benefits for the two locations, the net benefit of different scenarios can be calculated.

### 6.2 Case 2: The Affected Area is 1,000 km$^2$

Here the affected area in each location is about 1,000 km$^2$. The affected populations are shown in the table below.

Table 25.Population of the Affected Area of 1,000 km$^2$

| Place | area (km$^2$) | Population (thousand) | Population density (people per km$^2$) |
|---|---|---|---|
| Chancheng District | 154.02 | 972 | 6,311 |
| Around Chancheng | 845.98 | 1,945.8 | 2,300 |
| Total | 1,000 | 2,917.8 | 2,609 |
| Yuantan Town | 228.37 | 94 | 412 |
| Around Yuantan | 771.63 | 339.5 | 440 |
| Total | 1,000 | 433.5 | 437 |

The health benefits of reducing pollution are shown in Tables 26 and 27.

Table 26. Reduced cases of Illness in Chancheng District and Adjacent Areas

| Endpoint | Scenario 1 | Scenarios 2 & 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 50 | 106 | 88 |
| CVD and CHD mortality | 103 | 220 | 182 |
| COPD | 3,015 | 6,460 | 5,359 |
| **Outpatient visits** | | | |
| Internal medicine | 47,830 | 102,493 | 85,031 |
| Pediatrics | 19,853 | 42542 | 35,294 |
| **Hospital admissions** | | | |
| Respiratory diseases | 1,221 | 2,604 | 2,154 |
| Cardiovascular diseases | 639 | 1,361 | 1,126 |

Table 27. Health Benefits to Chancheng District and Adjacent Areas of Different Scenarios (Million Yuan)

| Endpoint | Scenario 1 | Scenarios 2 & 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 54.53 | 116.23 | 96.14 |
| CVD and CHD mortality | 113.22 | 241.34 | 199.62 |
| COPD | 1,689.53 | 3,620.42 | 3,003.61 |
| **Outpatient visits** | | | |
| Internal medicine | 5.18 | 11.09 | 9.20 |
| Pediatrics | 2.15 | 4.60 | 3.82 |
| **Hospital Admissions** | | | |
| Respiratory diseases | 5.28 | 11.26 | 9.31 |
| Medical costs | 3.67 | 7.83 | 6.47 |
| Absence from work | 1.61 | 3.43 | 2.84 |
| Cardiovascular diseases | 5.51 | 11.75 | 9.72 |
| Medical costs | 4.23 | 9.02 | 7.46 |
| Absence from work | 1.28 | 2.73 | 2.26 |
| Total | 1,875.40 | 4,016.69 | 3,331.43 |

The health costs of increased pollution from ceramic production are shown in tables 28 and 29.

Table 28. Increased Cases of Illness in Yuantan Town and Adjacent Areas

| Endpoint | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|
| **Mortality** | | | |
| Respiratory mortality | 18 | 13 | 9 |
| CVD and CHD mortality | 77 | 58 | 39 |
| COPD | 1,340 | 1,023 | 677 |
| **Outpatient visits** | | | |
| Internal medicine | 23,875 | 18,235 | 12,069 |
| Pediatrics | 9,910 | 7,569 | 5,010 |
| **Hospital admissions** | | | |
| Respiratory diseases | 606 | 463 | 306 |
| Cardiovascular diseases | 317 | 242 | 160 |

Table 29. Health Costs to Yuantan Town and Adjacent Areas of Different Scenarios (Million Yuan)

| Endpoint | Scenario 2 | | Scenario 3 | | Scenario 4 | |
|---|---|---|---|---|---|---|
| **Mortality** | | | | | | |
| Respiratory mortality | 9.76 | | 7.46 | | 4.92 | |
| CVD and CHD mortality | 42.51 | | 32.47 | | 21.42 | |
| COPD | 380.22 | | 290.41 | | 192.21 | |
| **Outpatient visits** | | | | | | |
| Internal medicine | 2.58 | | 1.97 | | 1.31 | |
| Pediatrics | 1.07 | | 0.82 | | 0.54 | |
| **Hospital admissions** | | | | | | |
| Respiratory diseases | 2.23 | | 1.70 | | 1.12 | |
| Medical costs | | 1.82 | | 1.39 | | 0.92 |
| Absence from work | | 0.41 | | 0.31 | | 0.20 |
| Cardiovascular diseases | 2.42 | | 1.85 | | 1.22 | |
| Medical costs | | 2.10 | | 1.61 | | 1.06 |
| Absence from work | | 0.32 | | 0.24 | | 0.16 |
| Total | 440.80 | | 336.67 | | 222.74 | |

The costs of technical pollution control remain unchanged. Using the health costs and benefits for the two locations, the net benefit of different scenarios can be calculated.

Table 30. Costs and Benefits of Different Scenarios (Million Yuan)

| Costs/benefits | | Health benefit | Tech. cost | Net benefit |
|---|---|---|---|---|
| Scenario 1 | Chancheng | 1,875.40 | -15.54 | 1,859.86 |
| | Yuantan | n/a | n/a | |
| Scenario 2 | Chancheng | 4,016.69 | n/a | 3,575.89 |
| | Yuantan | - 440.80 | n/a | |
| Scenario 3 | Chancheng | 4,016.69 | n/a | 3,664.48 |
| | Yuantan | - 336.67 | -15.54 | |
| Scenario 4 | Chancheng | 3,331.43 | -8.9 | 3,093.15 |
| | Yuantan | - 222.74 | -6.64 | |

## 7.0 FIELD SURVEY

To better understand the economic, social and health impacts on residents of the relocated ceramic industry, researchers carried out a field survey that included a household questionnaire and interviews. The field survey was created in order to obtain quantitive and qualitative information about the residents' attitudes and the health and economic impacts on them of the industry relocation. A household questionnaire was used in this survey. Interviewing local residents also helped us to learn the history and development of the situation.

### 7.1 Questionnaire Survey

(1) Preparing the Household Survey

The preparation of the household questionnaire survey included questionnaire design and a pre-test. Because the social and economic status of Foshan and Qingyuan is different, researchers designed two versions of the questionnaire, one for Foshan and one for Qingyuan. The two versions of the questionnaire are almost the same except that there are some different options in the sets of answers for the questions about expenses and income.

Each of the questionnaires consists of three sections. Section 1 consists of six questions regarding personal information about respondents and their families. The second section includes questions about household expenses and income and residents' attitudes towards the relocation of the ceramic industry. Section 3 looks into the residents' knowledge of the health impacts of environmental pollution and the residents' health status.

(2) Methodology

The places to be investigated were deliberately selected. The first place is the core and its circumjacent areas of ceramic production, i.e. Nanzhuang Town in Foshan and the Ceramic Industry Shift Park in Qingyuan. The second place is the core area for living and business in the center of the city, which includes the downtown of Chancheng District, Foshan and the central district of Yuantan Town in Qingyuan. The third place is the downtown area, which is further from the core area of ceramic production than the second disctrict. The third area includes the downtown of Nanhai District which surrounds Chencheng District, Foshan and the central business district of Qingcheng District, Qingyuan. See Figure 8.

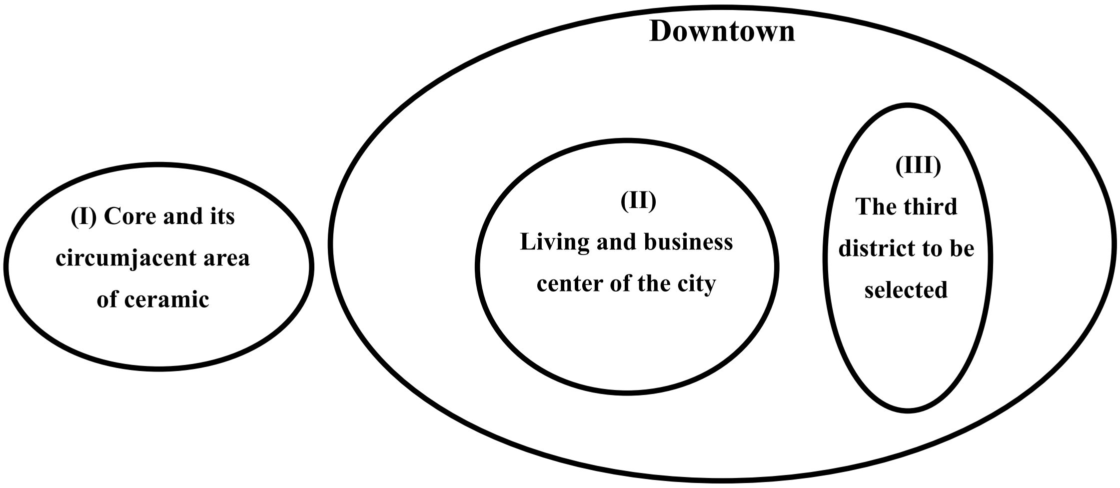



Figure 8. Questionnaire Survey Areas

The household questionnaire survey was carried out in two ways.

Firstly, investigators went to public places to ask local residents to fill in the questionnaire. Public places such as libraries, parks, small restaurants, banks, telecom business offices, and streets were chosen for the survey. It was found that most of the respondents were living near the survey places and that respondents had different occupations.

Secondly, questionnaires were distributed to students in local schools and the students' parents were asked to answer the questionnaire. Questionnaires were distributed to Foshan No.1 Middle School in Chancheng District (Foshan City), Qingcheng Middle School in Qingcheng District (Qingyuan City) and Dalong Elementary School in Yuantan Town, Qingcheng District (Qingyuan City). Foshan No.1 Middle School is a boarding senior middle school. Students' families are from all over the city while quite some of them are from Chancheng District, Foshan. Qingcheng Middle School is not a boarding school and nearly all of its students are from Qingcheng District[10]. Dalong Elementary School is the school nearest to the ceramic industry park and all of its pupils are from Yuantan Town.

(3) Description of the primary survey results

We received 261 finished questionnaires from Qingyuan and 307 from Foshan. The social and economic conditions in these two cities are very different.

Education Level

The overall education level of the sample is higher in Foshan than in Qingyuan. The percentage of respondents with senior high school and higher education is about 85% in Foshan while it is less than 60% in Qingyuan (see Table 31 and Figure 9).

Table 31.Educational Status in Foshan and Qingyuan

| Education level | Foshan | | Qingyuan | |
|---|---|---|---|---|
| | Number of persons | Percentage to total respondents | Number of persons | Percentage to total respondents |
| Elementary school | 13 | 4.2 | 19 | 7.3 |
| Junior high school | 31 | 10.1 | 90 | 34.5 |
| Senior high school | 114 | 37.1 | 73 | 28.0 |
| Higher education | 146 | 47.6 | 77 | 29.5 |
| N/a | 3 | 1.0 | 2 | 0.8 |
| Total | 307 | 100 | 261 | 100 |

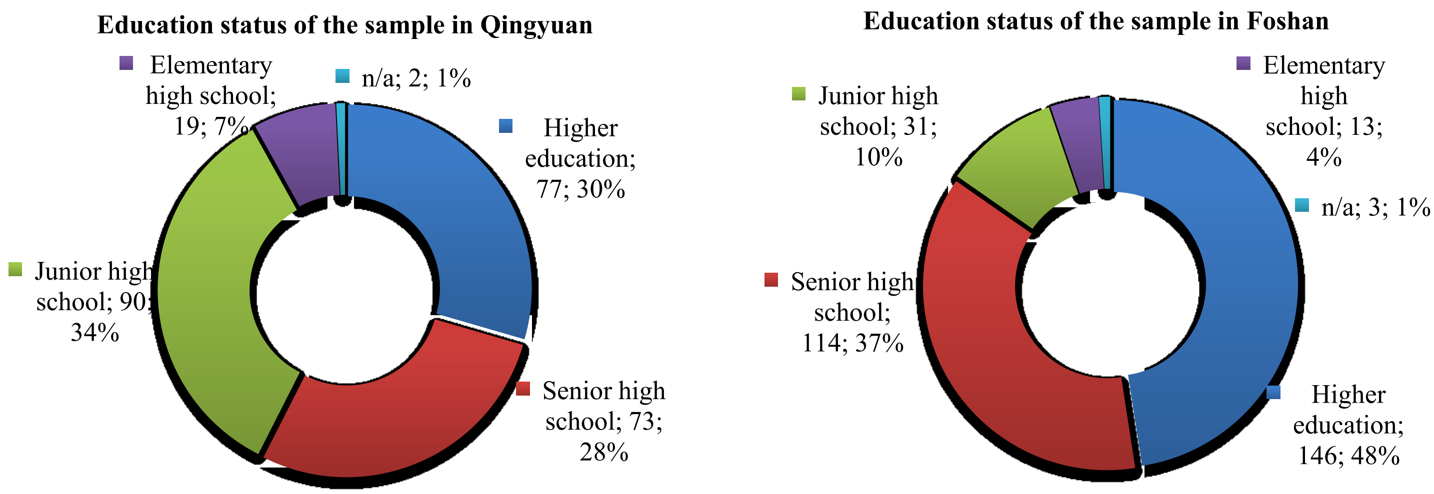



Figure 9. Educational Status of the Samples in Foshan and Qingyuan

[10] Yuantan Town belongs to Qingcheng District and is located in the east of the district.

Household Size

The size of the household of respondents in Foshan was smaller than that of Qingyuan. The average household size in Qingyuan was five people while it was three people in Foshan. The percentage of households with more than four people was 30% in Foshan and more than 85% in Qingyuan. See table 32 and figure 10.

Table 32.Size of Households in Foshan and Qingyuan

| Household size | Foshan | | Qingyuan | |
|---|---|---|---|---|
| | Number of households | Percentage to total households | Number of households | Percentage to total households |
| 1 | 76 | 24.8 | 25 | 9.6 |
| 2 | 21 | 6.8 | 2 | 0.8 |
| 3 | 118 | 38.4 | 9 | 3.4 |
| 4 | 49 | 16.0 | 67 | 25.7 |
| 5 | 25 | 8.1 | 61 | 23.4 |
| ≥6 | 18 | 5.9 | 97 | 37.2 |
| Total | 307 | 100 | 261 | 100 |

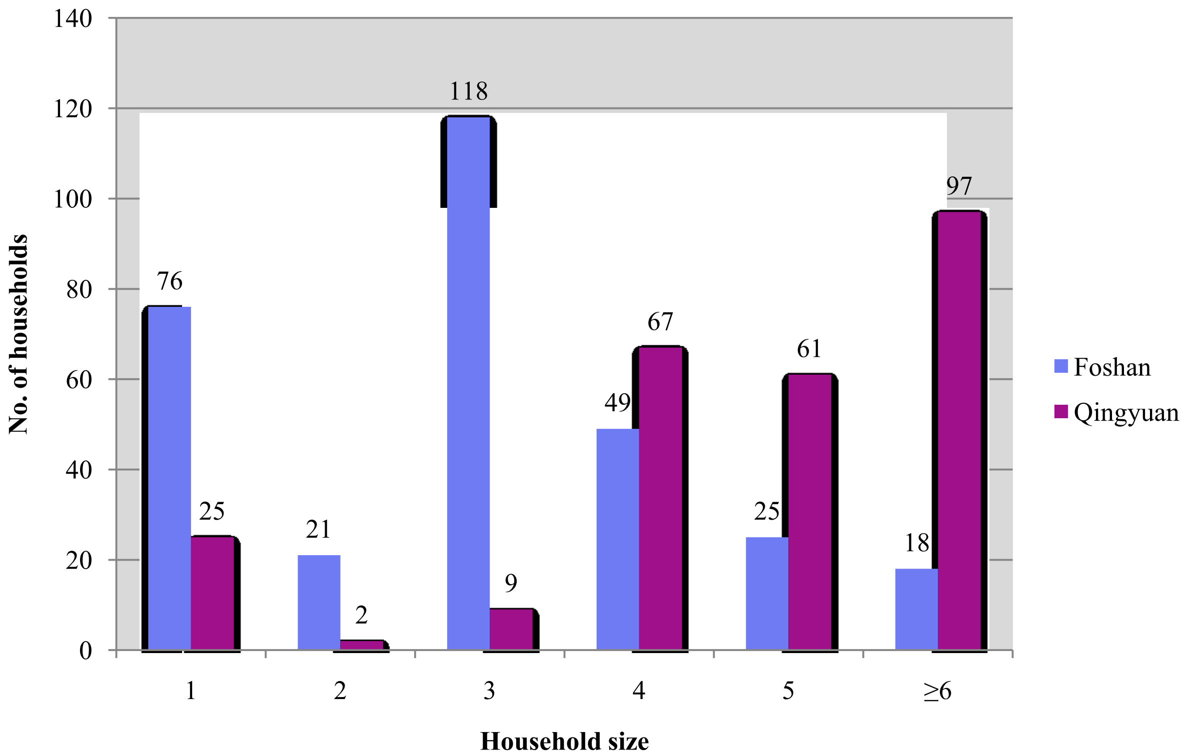



Figure 10. Size of Households in Foshan and Qingyuan

Household Income

As mentioned before, the economic status of Foshan and Qingyuan is very different. Data regarding the annual income per capita of households in the two cities supports this difference. The percentages of households with an annual income per capita of less than 6,000 yuan were 4.23% and 39.46% in Foshan and Qingyuan respectively. The percentage of households with an annual income per capita of more than 20,000 yuan is more than 50% in Foshan, which is far more than that in Qingyuan (13.03%). See Tables 33 and 34.

Table 33. Annual Income per Capita of Households in Foshan

| Annual income per capita (Yuan) | Number of households | Percentage to total number of households | Cummulative percentage |
|---|---|---|---|
| 6,000 | 13 | 4.23 | 4.23 |
| 6,001-12,000 | 35 | 11.40 | 15.64 |
| 12,000-24,000 | 84 | 27.36 | 43.00 |
| 24,001-48,000 | 90 | 29.32 | 72.31 |
| 48,001-96,000 | 48 | 15.64 | 87.95 |
| 96,001-180,000 | 6 | 1.95 | 89.90 |
| 180,001-240,000 | 3 | 0.98 | 90.88 |
| >240,000 | 6 | 1.95 | 92.83 |
| n/a | 22 | 7.17 | 100 |

Table 34. Annual Income per Capita of Households in Qingyuan

| Annual income per capita (Yuan) | Number of households | Percentage to total number of households | Cummulative percentage |
|---|---|---|---|
| <1,000 | 22 | 8.43 | 8.43 |
| 1,001-3,000 | 53 | 20.31 | 28.74 |
| 3,001-6,000 | 28 | 10.73 | 39.46 |
| 6,001-8,000 | 12 | 4.60 | 44.06 |
| 8,001-10,000 | 18 | 6.90 | 50.96 |
| 10,001-15,000 | 45 | 17.24 | 68.20 |
| 15,001-20,000 | 36 | 13.79 | 81.99 |
| >20,000 | 34 | 13.03 | 95.02 |
| n/a | 13 | 4.98 | 100 |

Attitude to the Relocation of the Ceramic Industry

The percentage of households with someone working in the ceramics industry was 34% in Foshan and 16% in Qingyuan.

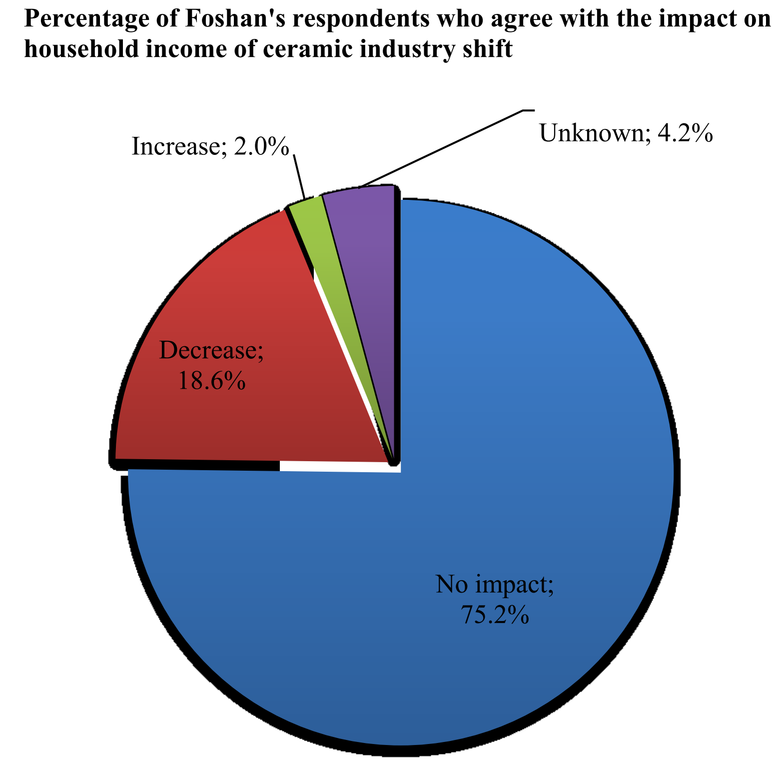
No more than 30% of respondents thought that the relocation of ceramic production would adversely affect local economic development. Only about 10% of respondents in Qingyuan thought that the impact on the local economy of the introduction of ceramic production was positive, while more than 40% thought that it was negative.

Table 35.Respondents' Attitudes Towards the Impact on Local Economic Development of the Relocation of the Ceramics Industry

| Attitudes about the economic effects of the industry relocation | Foshan | | Qingyuan | |
|---|---|---|---|---|
| | Number of respondents | Percentage of total respondents | Number of respondents | Percentage of total respondents |
| Great positive impact | 30 | 9.8 | 10 | 3.8 |
| Positive impact | 136 | 44.3 | 17 | 6.5 |
| No impact | 45 | 14.7 | 122 | 46.7 |
| Negative impact | 75 | 24.4 | 79 | 30.3 |
| Great negative impact | 9 | 2.9 | 27 | 10.3 |
| Unkown | 12 | 3.9 | 6 | 2.3 |
| Total | 307 | 100 | 261 | 100 |

As far as household income was concerned, the majority of respondents in both cities thought that the relocation of the ceramics industry had had no impact on their household income. See figure 11.

As to the overall influence on respondents personally, over 40% of Foshan's respondents thought that the influence of the relocation of the ceramics industry was favorable while only 23% of Qingyuan's respondents thought that the influence of the ceramic industry's relocation was favorable (see Table 36).



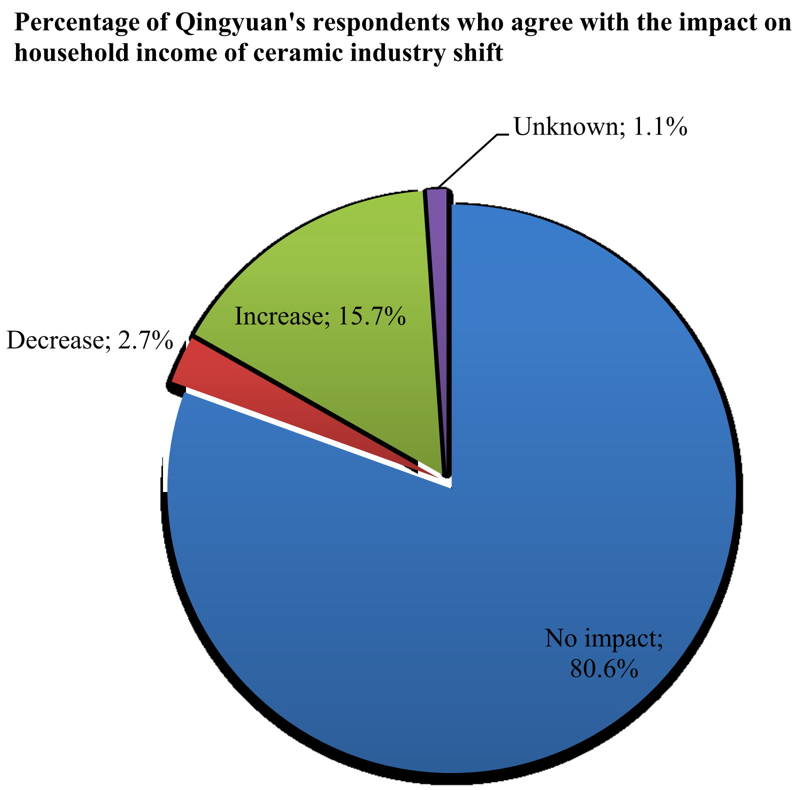




Figure 11. Perceived Impact of Relocation on Household Income

Table 36.Attitudes to the Overall Influence on Respondents Personally of the Relocation of the Ceramics Industry

| Attitudes to the overall influence on respondents personally | Foshan | | Qingyuan | |
|---|---|---|---|---|
| | Number of respondents | Percentage of total respondents | Number of respondents | Percentage of total respondents |
| Favorable | 125 | 40.7 | 60 | 23.0 |
| No impact | 114 | 37.1 | 98 | 37.5 |
| Unfavorable | 55 | 17.9 | 90 | 34.5 |
| Unknown | 13 | 4.2 | 13 | 5.0 |
| Total | 307 | 100 | 261 | 100 |

## 7.2 Interviewing Local Residents

Researchers met some local residents and talked to them about what they thought about the relocation of the ceramic industry. The residents being interviewed included villagers living in the ceramic production areas and workers in ceramic factories, citizens living in the downtown areas of Foshan and Qingyan, and immigrant workers who had left their home towns to look in the cities for job opportunities.

The interview questions included the following.

(1) What do they think of local ceramic industry development? Is it good or bad for local economic development and local residents?

(2) How does ceramic industry development affect their economic status? Does the entry of the ceramic industry supply more employment opportunities and increase the residents' income? Or does the emigration of ceramic production reduce employment opportunities and decrease the residents' income?

(3) How do they know about the pollution of the ceramic industry?

The findings from the interviews are summarized below:

(1) The ceramic production areas are located in the suburbs of these two cities. The residents living downtown seldom feel the environment pollution caused by ceramic production. This is the same for both Foshan and Qingyuan cities. At the same time, most of the residents living in the core and adjacent areas of ceramic production complain a lot about the pollution and industrial dust. This means that the area where inhabitants can obviously feel the health impacts of ceramic pollution is rather small. This is one of the evidences that supported the confine of the geographical scope in the study.

(2) As for the impact on household income of the relocation of the ceramic industry, most local residents said that the relocation of ceramic production would not really affect their household income. Even the workers in ceramic plants thought this. For example, in Qingyuan not all of the residents thought that the relocation of the ceramic plants would promote local economic development and increase their income. They said that Qingyuan would have other opportunities to develop its economy and to increase their earnings

even if the ceramic industry was not introduced to Qingyuan. But in Foshan, some residents in and surrounding the core ceramic production area said that unemployment obviously increased because the ceramic industry was relocated, which resulted in some social problems such as an increase in crime. This means that the impact of the relocation of the ceramic industry on individual income varies with occupation, living place, education background and so on.

(3) Most of the workers in the ceramic plants that settled in Foshan and Qingyuan came from other areas of the country. In Qingyuan, the ceramic plants rarely hired the original inhabitants unless the inhabitants' land had been occupied for ceramic production. Therefore, most of the workers in the ceramics plants did not care where the plants were located. The situation was quite similar in Foshan. Most of the ceramics workers left their home towns to work in Foshan, so the majority of the labor force was floating.

# 8.0 DISCUSSION AND CONCLUSION

## 8.1 Discussion

(1) *Comparison of the Health Costs and Health Benefits*

There is a linear relationship between health benefit/cost and a change in $PM_{10}$ concentration. The health benefit for every 1μg/m$^3$ decrease of $PM_{10}$ concentration in Chancheng District is 19.10 million yuan, while the health cost to Yuantan Town for every 1μg/m$^3$ increase of $PM_{10}$ concentration is 660,000 yuan. The great gap between these figures stems from two factors. The difference in GDP per capita between the two cities is the first factor. The GDP per capita in Chancheng was 2.6 times of that of Yuantan. The second factor is the difference of the affected populations. The population of Chancheng District, Foshan, was more than 10 times of that of Yuantan Town, Qingyuan. The population density of Chancheng is 6,311 people per km$^2$ while it is 412 people per km$^2$ in Yuantan.

In all the scenarios, the health cost to Yuantan Town (Qingyuan) was not more than 6% of the health benefit to Chancheng District (Foshan) as the shift in ceramic production took place. Though the ratio is about 10% in the sensitivity ananlysis, the health cost of Yuantan is still less than the health benefit of Chancheng by far because of the great difference in the affected population and GDP per capita in these two places.

In China, the population density of relatively developed areas is commonly greater than that of underdeveloped areas. This study indicates that the relocation of heavily-polluting industries to areas with less population density would reduce the health impacts from air pollution. Water pollution issues are not the same because the dispersion and transformation of water pollution is different to air pollution.

(2) *Composition of health benefits/costs*

It is noticed that the proportion of medical costs of outpatient and hospital admissions was very small for both Qingyuan and Foshan. As shown in Figures 6 and 7, the percentage of medical costs of outpatient and hospital admissions was no more than 2% of the total health benefit/cost. The majority of the health benefit/cost was attributed to years of lost life due to premature death and years lost due to disability caused by chronic disease (i.e. COPD).

The medical cost of outpatient and hospital admission was possibly underestimated because some patients do not visit hospital for various reasons such as poverty, inconvenience, self medication and so on. According to The Third National Health Service Survey Research, the percentage of two-week non-visit-hospital patients was 48.9% in 2003. This would not substantially change the results.

(3) *Comparison of the Scenarios*

Four scenarios were put forward to study the costs and benefits of controlling dust pollution in Chancheng District, Foshan City. Only scenario 1 featured no relocation of ceramic production capacity, meaning that all ceramic production capacity was kept in Chancheng in this scenario.

Total ceramic production capacity was divided into two parts. One was the clean part of the production capacity that met the relevant standards for dust emissions; the other part was the unsettled part that did not meet the relevant standards for dust emissions.

All the other three scenarios involved the relocation of ceramic production capacity. In scenario 2, the unsettled part of the production capacity would be relocated in Yuantan Town but would not use dust-catching technology. In scenario 3, the unsettled part of the production capacity would be relocated in Yuantan and would use the suggested dust-catching technology. In scenario 4 all of the unsettled part of the production capacity would use the suggested dust-catching technology but only some of the unsettled part would be shifted to Yuantan in order to maintain the $PM_{10}$ concentration in ambient air in Yuantan at the relevant national air quality standard ($100 \mu g/m^3$).

The results show that the net benefit of scenario 1, without the relocation of ceramic production capacity, is much less than that of the other three scenarios that do involve relocation, with scenario 1 having only 48%-58% of the net benefits of the latter scenarios. These results imply that keeping all ceramic production capacity in Chancheng District is not a good choice if dust pollution is to be controlled in the district.

Out of all four scenarios, the net benefit of scenario 3 was always larger than the others. This suggests that the best choice would be to shift all the unsettled part of ceramic production capacity to Yuantan along with dust-catching technology. But the ambient $PM_{10}$ concentration in the air in Yuantan would exceed the national standard in scenarios 2 and 3. That is, regardless of the use of dust-catching technology, the relocation of all the unsettled part of the production capacity would push Yuantan's air quality beyond the national standard.

It should be noted that air ambient $PM_{10}$ concentration in both places would only conform to national standards (100μg/$m^3$) in scenario 4, and the net benefit of scenario 4 is about 84% of that of scenario 3.

(4) *About Pollution Control Technology*

Comparing the scenarios that do or do not use the suggested dust-catching equipment, it was found that the net benefit of scenarios with dust-catching equipment is always larger than those without dust-catching equipment. In scenario 1, where there was no relocation of ceramics production, the net benefit of adopting dust-catching technology would be as large as 705.57 million yuan. In scenarios 2 and 3, the unsettled part of ceramic production capacity would be shifted to Yuantan. The net benefit of scenario 3, which uses the suggested technology, would be larger than that of scenario 2, which does not use the technology, by 4.35 million yuan.

It can be concluded that it is worthwhile to adopt the suggested pollution control technology in any case.

(5) *Exposure-response Relation*

In choosing the exposure-response relation to be used in the study, priority was given to the relevant results of the research that was conducted in China because of the socio-economic similarity between their study areas and our study areas. In fact, the results of the domestic research were consistent with that of research in other countries and areas.

## 8.2 Conclusion

The relocation of production capacity is common during economic development. Industry relocation happens between different countries and also within countries. It is also common in China for pollution to spread along with relocated industries.

This research investigates the relocation of the ceramic industry in Guangdong Province, P.R.C. In this case, Chancheng District (Foshan City), a rather developed area, planned to control air pollution from the ceramic industry by adopting dust-catching technology for ceramic production and/or relocating some ceramic production capacity to Yuantan Town (Qingyuan City), a relatively less developed area. Yuantan Town is a place with a low population density and its air quality was very good before the ceramic industry arrived. The relocation of ceramic production to Yuantan along with strict controls on emissions would be the proper and most effective use of environmental capacity.

Four scenarios were put forward for pollution control in Chancheng District. After anyalysis of the scenarios, it was found that Chancheng could not meet national air quality standards if it retained all of its ceramics capacity, even though dust-catching technology would be adopted by all the ceramic manufacturers. It was therefore necessary to relocate some ceramic production capacity out of Chancheng District, but the relocation of the ceramic production should not make the air quality in the industry's new location exceed national standards. Scenario 4 (that is, all the unsettled part of ceramic production capacity uses dust-catching technology and only some of the unsettled part would be shifted to Yuantan) advanced the solution of maximizing the net benefit on condition that the air quality would meet national standards in both of the two places.

Scenario analysis shows that whether ceramic production capacity is relocated or not, ceramic manufacturers should take the suggested technical measures to reduce dust emissions. The cost of using the suggested dust-catching technology would be lower by far than the health benefit of dust emission reduction by adopting the suggested dust-catching technology.

## REFERENCES


Apheis, M.S. 2004. Public Health Impact of $PM_{10}$ in 19 European cities, JECH, 2004, 58: 831-836.

Brunnermeier, S.B. and Levinson, A. 2004. Examining the Evidence on Environmental Regulations and Industry Location. The Journal of Environment & Development, Vol. 13, No. 1, 6-41.

Chen Shiming, Yin Yiqiang, et al. 2005. The Potential and Ways of Cleaner Ceramics Production in Foshan, Journal of Foshan Science and Technology Institute (Natural Science Edition), Vol 23 (1): 45-48.

Cole, M.A. 2004. Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages, Ecological Economics, 48 (2004): 71– 81.

Copeland, B.R. and Taylor, M.S. 2003. Trade and the Environment: Theory and Evidence, Princeton University Press.

Copeland B. R. and Scott Taylor, M. 1994. North–South Trade and the Environment, Quarterly Journal of Economics, 109 (1994): 755-87.

Dai Haixia, SONG Weimin et al., Study on relationship between ambient $PM_{10}$, $PM_{2.5}$ pollution and daily mortality in a district in Shanghai, JOURNAL OF HYGIENE RESEARCH, Vol. 33 No. 3: 293-297.

Dockery D.W.; Pope C.A.; and Xiping Xu et al. 1993. An Association between Air Pollution and Mortality in Six U.S. Cities, N England J Med, 1993, Vol 329:1753-1759.

Dong Jingwu; Xu Xiping; Chen Yude; and Dockery, D.W. et al. 1995. Research on the relationship between air pollution and daily mortality in Beijing urban residents in 1990-1991, Journal of Hygiene Research, Vol.24 No. 4 :212-214.

Goldberg, M.S.; Burnett, R.T.; Yale, J-F.; Valois, M-F.; and Brook, J.R. 2006. Associations between ambient air pollution and daily mortality among persons with diabetes and cardiovascular disease, Environmental Research 100 (2006) 255–267.

Han Mingxia; GUO Xiaomin; and Zhang Yanshen. 2006. The human capital loss of air pollution in cities, China. China Environmental Science, 2006, 26(4)：509-512.

He Jie. 2006. Pollution haven hypothesis and environmental impacts of foreign direct investment: The case of industrial emission of sulfur dioxide ($SO_2$) in Chinese provinces, Ecological Economics, 2006, 60:228-245.

Huang Wen-shan; Hu Heng-sheng; and Liu Hang et al. Study of the Relationship Between Air Pollution and Respiratory Diseases in Nanning, J Environ Health, Vol.21(6): 384-386.

Jia Yan; Yin Hua; and Chang Rui, et al. 2006. The cleaner production of building ceramic industry, Ceramics, 2006, No.7: 49-51.

Kan Haidong; London, S.J.; and Guohai Chen, et al. 2007. Differentiating the effects of fine and coarse particles on daily mortality in Shanghai, China, Environment International 33 (2007): 376–384.

Kahn, M.E. 2004. Domestic pollution havens: evidence from cancer deaths in border counties, Journal of Urban Economics 56 (2004): 51–69.

Laden, F.; Neas, L. M.; and Dockery, D.W. et al. 2000. Association of Fine Particulate Matter from Different Sources with Daily Mortality in Six U.S. Cities, Environmental Health Perspectives, Vol108: 941–947 (2000).

Li Wenyong; Liang Xiao Yang; and Li Min, et al. Hazard of Ceramic Dust on Workers Health, Occupation and Health, Vol. 22 No.21: 1777-1779.

Lin Gang; Du Ying-jie; Kenji, T.; and Wang Xiaoke. Quantitative Analysis of the Relationship between Total Suspended Particles (TSP) and Respiratory Diseases Mortality of Urban Residents in Fushun, China, Asian Journal of Ecotoxicology. Vol. 2(3): 280-283.

Mani, M. and David Wheeler, D. 1997. In Search of Pollution Havens? Dirty Industry in the World Economy 1960-1995, World Bank, Washington, D.C.

Mathers, C.D.; Bernard, C.; and Iburg, K.M. et al. 2003. Global Burden of Disease in 2002: data sources, methods and results, WHO: Global Programme on Evidence for Health Policy Discussion Paper No. 54, Dec 2003.

Pope, C.A. III; 3rd C.A; Burnett R. T.; and Thun, M.J. et al. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution, JAMA, Vol. 287, No.9: 1132-1141.

Pope, C.A. III ; Thun, M.J.; Namboodiri, M.M.; and Dockery, D.W. et al. 1995. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults, Am. J. Respir. Crit. Care Med., Vol 151, No.3: 669-674.

Pope, C.A. III; Bates, D.V.; and Raizenne, M.E. 1995. Health Effects of Particulate Air Pollution: Time for Reassessment? Environmental Health Perspectives Volume 103, Number 5, May 1995.

Preparation Group of Pollutant Discharge Standard for Ceramic Industry. 2008. Description of preparing Pollutant Discharge Standard for Ceramic Industry (for comment), http://www.zhb.gov.cn/info/gw/bgth/200801/t20080129_117766.htm

Qian Xiaolin and Kan Haidong. 2005. Epidemiologic Research Progress on Effects on Cardiovascular System of Particulate Matter, Chinese J Epidemiol, 2005, Vol. 26, No. 12: 999-1001.

Qian Zhengmin; He Qingci; and Lin Hung-mo et al. 2007. Association of daily cause-specific mortality with ambient particle air pollution in Wuhan, China, Environmental Research 105 (2007): 380–389.

Samet, J.M.; Dominici, F.; and Curriero F.C. et al. 2000. Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987–1994, N Eng J Med, 2000, Vol.343: 1742-1749.

Samoli, E.; Analitis, A.; Touloumi, G.; and Schwartz, J. et al. 2005. Estimating the Exposure-Response Relationships between Particulate Matter and Mortality within the APHEA Multicity Project, Environmental Health Perspectives Volume 113.

Shah, J.J.; Nagpal, T.; and Brandon, C.J. 1997. Urban air quality management strategy in Asia: guidebook, [R], Washington D.C.: World Bank, 1997.

Smarzynska, B.K. and Wei Shangjin. 2001. Pollution Havens and Foreign Direct Investment: Dirty Secret or Popular Myth? September 2001. Policy Research Working Paper Series 2673, World Bank.

Tobey, J. A. 1990. The Effects of Domestic Environmental Policies on Patterns of World Trade: An Empirical Test, Kyklos, 43: 191 - 209.

Van Der Veeren, R.J.H.M. et al. 2001. Benefits of a Reallocation of Nitrate Emission Reductions in the Rhine River Basin, Environmental and Resource Economics 18: 19-41, 2001.

Venners S. A.; Binyan Wang; and Zhonggui Peng, et al. 2003. Particulate Matter, Sulfur Dioxide, and Daily Mortality in Chongquing, China, Environmental Health Perspectives, Vol. 111, No. 4 (Apr., 2003), pp. 562-567.

Verhoff, A.P.; Hoek, G.; and Schwartz, J. et al. 1996. Air Pollution and Daily Mortality in Amsterdam, Epidemiology, Vol. 7, No. 3 (May, 1996), pp. 225-230.

Wei Fusheng and Chapman, R.S. 2001. Research on Respiratory Health Effects of Air Pollution [M], Beijing, Chinese Environmental Science Press, 2001, 81-1-5.

World Health Organization. 2005. WHO Air quality guidelines for particulate matter, ozone, nitrogen, dioxide and sulfur dioxide.

Yang Ke; Yang Yun; and Cheng Xiaoqin. 2004. Dust emission control of building ceramic production in Chancheng District, Foshan City, Ceramic Studies Journal, 2004, No.4: 22-25.

Yu Fang; Guo Xiaomin; and Zhang Yanshen et al. 2007. Economic cost estimation of the health effects due to air pollution of China in 2004, Journal of Enivron Health, Dec 2007, Vol.24, No 12: 999-1003.

Zhang Zhihui. 2005. Research progress in pollution haven hypothesis, Xuehai. (2): 187-191.

Zhong Zhizhen. 2006. Discussion on the environmental problems of ceramic industry in Chancheng District, Foshan City, Environment, 2006 (S1): 45-46.