How the Guangzhou Government Can Curtail Air Pollution from Road Traffic in a Least Costly Manner

by

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DISCLAIMER

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Summary

This thesis attempts to explore relationship between the growth in motor vehicle fleet and air pollution, particularly PM_{10} pollutant, in urban Guangzhou. It reviews the current status of ambient air quality, the harmful effects of PM_{10} emission on human health and measures of curtailing this problem in the urban Guangzhou.

The thesis is divided into four parts.

Part I looks at the main air pollution problems in the urban Guangzhou and gives a monetary valuation of the PM_{10} pollutant. I start off in chapter 1 by giving an overview of the robust economic growth in Guangzhou and the factors contributing to its growth. However, the environment suffers from this growth. Chapter 2 addresses the main air pollution problems in the urban Guangzhou. Ambient PM_{10} concentration is extremely high and significantly above WHO guideline and Chinese National Ambient Air Quality standard (CNAAQ standard). The main reasons for this are the growing motor vehicle fleet, bad city planning, lack of market-oriented prices for fuel oil, low proportion of urban land to road infrastructure, low investment in public transportation, etc. Chapter 3 gives a monetary valuation of the effects that PM_{10} pollutant has on human health. Dose-response function of PM_{10} applied to data on Guangzhou reveals that 3300 premature deaths (estimated) could be avoided each year if Guangzhou met the Class II of CNAAQ Standard for PM_{10} and the Guangzhou Government could save 10 percent of its GDP in 1994. What a heavy toll!

Part II provides a theoretical framework to curtail air pollution problems based on the theory of cost-effectiveness (chapter 4).

Part III gives an overview of possible measures that could be used to curtail air pollution based on experience worldwide (chapter 5). I will also give an application of the theory through a practical evaluation of five selected measures (chapter 6). The main results I have obtained are that the bus lane measure is the most cost-effective measure, toll roads and fuel taxation are the next best cost-effective measures, while the metro measure is the most expensive one.

Part IV attempts to give the Guangzhou Government a recommendation on those measures which should be carried out with first priority based on their cost-effectiveness (under certain simplified assumptions).

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Part I

1 Guangzhou Survey

The purpose of this chapter is to give readers a broad outline of Guangzhou and its success in transitioning to a market-oriented economy with socialistic characteristics. I will particularly look at three main factors contributing to this success and their negative effects as well.

1.1 A Brief Introduction to Guangdong Province and its Capital City Guangzhou

1.1.1 Geographic Location

Guangdong, one of the southernmost provinces of China, constitutes the region through which South China's trade is primarily channeled. The province covers an area of 179,766 km^2, of which more than three-fourths is mountainous or hilly. The only large areas of flatland are the Pearl River Delta[1] and the region around the port city of Shantou in the east. The South China Sea creates a coastline of 4,300 km, the longest of any Chinese province, providing coastal shipping links with the other provinces as well as international trade.

Guangzhou, situated in the south-central part of Guangdong Province and in the northern part of the Pearl River Delta, is the capital city of Guangdong Province. With Hong Kong and Macao in its vicinity, Guangzhou is a prosperous trading center as well as an important gateway between China and the rest of the world. It is also a lovely city with a green scenery and tropical flowers blooming all year round (Figure A.1 in Appendix 1 shows the location of Guangzhou).

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1 The Pearl River and the Pearl River Delta

The Pearl River is 2214 meters long and has a drainage area of 453,690 square kilometers. It converges three major rivers: West, North and East Rivers. The Pearl River is the name given to the lower course of the West beyond the confluence.

The Pearl River Delta region has an area of 18,682 square kilometers and a total population of 13,6 million, of which 7 million are urban residents.

The region is often regarded as the dragon's head of Guangdong's economy.

Source: China Statistical Yearbook (1996)

Guangzhou is a historic city with civilization that is more than 2,800 years old. There are a lot of interesting legends concerning its past. One of the beautiful stories which gives the city the name "Goat City" says that five gods riding on five goats brought the first grain to the city.

1.1.2 Climate

Guangzhou is located in the southern sub-tropical zone with a marine monsoon climate. This climate is warm, sunny and rainy, with little fluctuation of temperature. The annual rainfall is between 1689.3 mm and 1876.5 mm, and the rainfall from rainy season - April to September - accounts for about 85 percent of the annual rainfall. The average year-round temperature is 22°. August is the hottest month, with an average temperature of 28°. January is the coldest month, with an average temperature of 13°. The dry monsoon alternating with wet monsoon is a prominent feature of the Guangzhou monsoon (Guangzhou Statistical Yearbook, 1995).

1.1.3 Total Area and Population

Guangzhou covers an area of 7434.4 km^2, which is about 4.2 percent of the land territory of Guangdong Province and 17.87 percent of the Pearl River Delta. It has jurisdiction over eight districts and four counties. The eight districts, which are Yuexiu, Dongshan, Haizhu, Liwan, Tianhe, Beiyun, Huangpu, and Fangcun, comprise the urban area and claim 1443.6 km^2, or about 19 percent of the city's total area. The four rural county-level cities, Huadu, Conghua, Zengchen and Panyu, occupy the remaining 81 percent (Guangzhou Statistical Yearbook, 1995).

The total population of Guangzhou was 6,370,241 in 1994, of which there were 3,803,148 people in the urban area, and 2,567,093 people in the four counties (Guangzhou Statistical Yearbook, 1995).

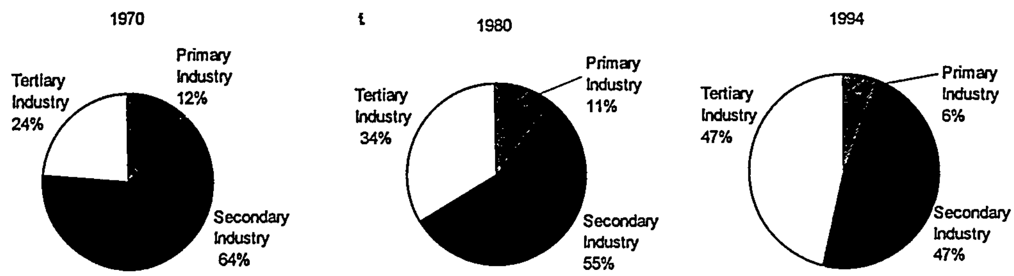
1.2 Economic Development Since Chinese Economic Reform in 1978

Deng Xiaoping's initiation of reform and open policy, especially the special policies towards Guangdong Province, offered an unprecedented opportunity for Guangzhou to develop its economy. In 1984, Guangzhou was designated one of the fourteen *coastal open cities.* Its status as an open city ensured preferential treatments in foreign trade and investment. In order to attract more foreign investment, the *Guangzhou economic and technological development zone* was also established in 1984. Bestowed with more favorable policy treatments, Guangzhou's economic growth began to flourish in the following areas:

1. Guangzhou's GDP grew at an annual average rate of 12.2% in the period of 1979-1990, while it continued to grow at an annual average rate of 20% during 1991-1994. Its overall economic strength in China jumped from being in sixth place in 1980 to third place in 1994, just after Shanghai and Beijing.

2. Guangzhou has succeeded in readjusting its industrial structure. Putting emphasis on secondary industry has been the main direction for its industrial development for a long period of time. However, the tertiary industry has boomed these years. Its contribution to Guangzhou's GDP rose from 34.3% in 1980 to 47% in 1994 (see Figure 1.1).

Figure 1.1 The change of components of Guangzhou's GDP in term of value added



Source: Guangzhou Statistical Yearbook (1995)

3. In recent years, Guangzhou has gradually increased investments in communication, transportation and telecommunication networks. Guangzhou's highways radiate in all directions. The arterial highways, including Guang-Shan, Guang-Zhan, Guang-Shao, Guang-Shen and Guang-Zhu, link many provincial counties and other provinces such as Guangxi, Hunan, Fujian, Jiangxi as well (see Figure A.2 in Appendix 1). A 15-kilometer-long highway encircling the city has opened to traffic. A network of transportation routes, comprising buses of different capacities and special line buses, has been established. The construction of metro Line One (East-West line) began at the end of 1993, and it was opened to traffic in October, 1997.

4. Urban households' living standards have steadily improved

- *Income Level*

  Along with the rapid economic development, urban residents' income has experienced a whopping increase. According to the sample surveys in 1994, the average annual income available for living[2] per Guangzhou resident was RMB[3]7046 ($817). The real increase from 1993 was 17.82% after inflation. Although both the absolute value and the relative increase rate of income were at the top of the ten largest Chinese cities, they were still much lower than those of so called "Four Asian Tigers" [4].

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2 This figure refers to the actual income of the surveyed households available for daily life, excluding financial support and gifts to others, and allowances received for help in compiling the survey (China Statistical Yearbook, 1996).

3 RMB is an abbreviation of Chinese currency "Ren Min Bi". An exchange rate of US$1 = RMB8.62 is used in the whole thesis.

4 The Four Asian Tigers are Hong Kong, Taiwan, Singapore and South Korea,

- *Consumption Structure*

  The consumption structure has also experienced great changes since the 1980s. The percentage of consumption expenditures on food of the total consumption expenditures has gradually decreased, while the percentages of consumption expenditures on housing, transport, travel, education, and medical care have increased. The percentage of consumption expenditures on housing will, according to the Guangzhou Blueprint, increase from 2.71% in 1993 to 8% by 2000, and further up to 11.5% and 13% by 2005 and 2010, respectively. The percentage of consumption expenditures on medical care will increase from 2.17% in 1993 to 5% by 2000, and further up to 6% and 7% by 2005 and 2010, respectively.

- *Ownership of Main Durable Consumer Goods*

  According to the sample surveys during 1990-1993, the traditional "four big things" (si da jian): wrist watch, bicycle, sewing machine and electric fan, are being replaced by the new "four big things" which are washing machine, refrigerator, color TV, and video recorder. Among the markets of the new "four big things", the first three are already used extensively in the urban areas, and are now gradually being replaced by hi-fi systems, air conditioners, motor cycles, telephone sets, etc. For example, the year-end ownership of telephone sets, air conditioners, color TVs, refrigerators and washing machines per 100 households were 50, 34.7, 109.7, 97.3, and 98.7 respectively, which were increases of 44.09%, 82.63%, 10.47%, 4.96% and 1.44% from 1993, respectively (see Table 1.1).

Table 1.1 *Guangzhou urban households' ownership of main durable consumer goods*

Items unit: sets per 100 households	1993	1994	2000	2005	2010
Color TV	99.3	109.7	100	105	110
Refrigerator	92.7	97.3	98	98.5	99
Washing Machine	97.3	98.7	99	99.5	99.8
Hi-Fi system	27	37.3	38	45	55
Air Conditioner	19	34.7	60	75	84
Telephone	34.7	50	90	95	98
Motorcycle	9.7	7.3	18	23	26
Car	NA		2	10	30

Source: The Guangzhou Planning Committee (1996) and Guangzhou Statistic Yearbook (1995)

What factors contribute to these social and economic developments? Do they have any negative effects on society and environment? There are particularly three important factors - foreign investment, urbanization and motorization - that I will focus upon in the rest of this chapter.

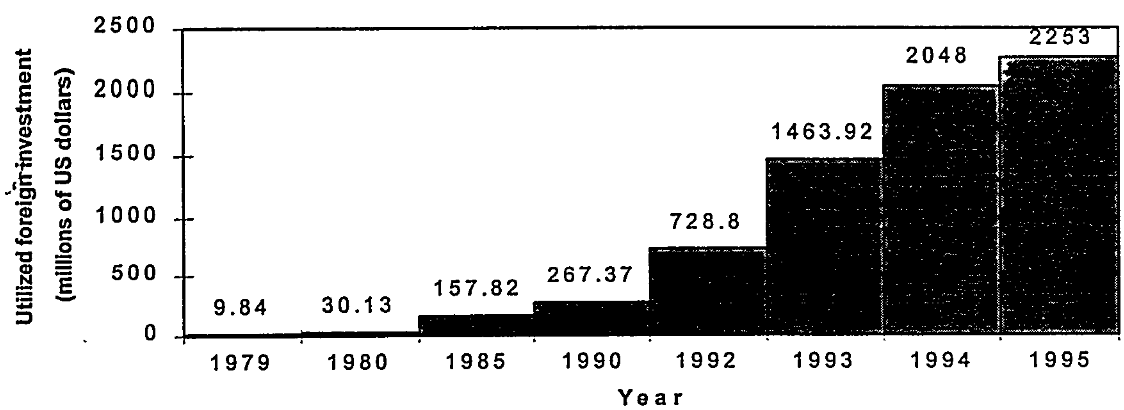
1.3 Three Factors Contributing to the Economic Development and Their Negative Effects

1.3.1 Foreign Investment as An Engine of Economic Growth

Foreign investment in Guangzhou has increased dramatically in the past years (see Figure 1.2). By the end of 1995, the total utilized foreign investment recorded $2253 million which also took a relatively great share of China's total. This source of money usually accounts for more than one-third of Guangzhou's economic development funds.

In 1994, the total output value of industrial enterprises with foreign capital was RMB44.2 billion ($5.13 billion), accounting for 35.7% of the Guangzhou's gross output value of industry.

Figure 1.2 Utilized foreign investment in Guangzhou



Source: Guangzhou Statistical Yearbook (1995), Yusuf and Wu (1997)

There are several reasons why foreign investors prefer to invest in Guangzhou /Guangdong Province.

- Guangzhou/Guangdong Province has benefited not only from its special geographic location, but also from the language and cultural similarities with its nearest outside neighbor, Hong Kong[5]. This specific advantage may greatly reduce communication problems. Hong Kong has been China's largest investor since the late 1980s. The share of Hong Kong's investment accounted for more than 40% of total foreign investment in China in 1995. In addition, there is also a fact that Guangdong is the original home for almost two-thirds of all overseas Chinese. Traditionally, the original home is most likely to be the first place where the overseas Chinese investors prefer to invest. This particular custom has also led to an enormous investment from the overseas Chinese investors.

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5 There are many different dialects in China that may cause great difficulties to communicate between Chinese. In Hong Kong and Guangdong Province people speak Cantonese which is almost like an another language for most of the Chinese.

- Guangdong province has greatly benefited from China's liberal economic policies by being allowed to adopt some "special policies and flexible measures":

  - The province was given more freedom in managing foreign trade. Many Guangdong branches of national trading companies were allowed to become independent. For export goods manufactured in Guangdong, Guangdong could basically make its own decisions, including determining prices. The increased foreign currency income (including funds from processing assembly, compensation trade, and joint manufacturing enterprises) that sales abroad generated would largely remain in Guangdong.

  - Guangdong was given new fiscal independence. Beginning in 1980, instead of sending a certain percentage of taxes collected to the central government, Guangdong would pass on, in addition to customs fees and fees collected directly by Beijing, a fixed sum (baogan), which would remain constant for five years.

  - The province was given increased financial independence. Banks in Guangdong were given more leeway to make their own investment decisions. When the province planned to use foreign currency, it would notify the central government, rather than ask for permission, and the banks would make payments accordingly. The province was permitted to set up an independent provincial investment company that could deal directly with overseas business and financial institutions.

  - The province was given greater flexibility in determining wages. It could raise salaries above the national guidelines and decide how to adjust wages, including the proportion of salary to be paid out in bonuses.

  - The province was given increased leeway to set prices in certain categories and to allow the market to determine certain other prices.

- Many local governments have made efforts to simplify the application procedures of establishing a new enterprise financed either by all foreign funds or by joint ventures. Whereas the Ministry of Foreign Economic Relation and Trade takes three months to process an application, the local governments in Guangdong often take less than one month, or even a week.

1.3.2 The Process of Urbanization

With initial success of rural reform, urban reform was called for and started in 1984. Since then Chinese cities have experienced tremendous changes. In 1984, there were only 320 cities in China with a combined urban population exceeding 200 million. By 1995, there were 640 cities with a combined urban population of 351 million. Yet, it accounted for only 29% of the total population of China (China Statistical Yearbook, 1996). One important reason for the low level of urbanization is the strict urban resident registration system and family planning policy[6]. The urbanization in Guangzhou and the Pearl River Delta region is among the highest regions in China.

Migration and Floating Population

There have been great changes in the urban employment system since the reform. Enterprises are now relatively free to hire contracted workers and there is a great demand for labor in urban industry, retail, and service sectors. Meanwhile, surplus labor forces from the rural areas are more mobile than ever before, and many of them migrate into urban areas for urban jobs (Table 1.2). Therefore, during the last decade, the floating population (see Appendix 2) in large- and medium-size cities in China has been escalating to more than 80 million in 1994. They live and work in cities, and some even bring their families with them.

Table 1.2 The migration of rural labors in Guangzhou

	1988	1990	1991	1992	1993	1994
Percentage of migrated labor force to total labor force (%)	7.6	3.7	4.5	5.0	9.2	10.1

Source: Stares and LIu (1996)

The floating population in Guangzhou increased from 306,000 in 1980 to 1.68 million in 1994. Most of them live in the old urban core[7], causing the population density there to be very high. According to a census of 1989, the average population density in the urban Guangzhou was 2455 people per km^2, while, it was 16,400 people per km^2 in the built-up areas and 39,100 person in the old urban core.

Increases in Urban Land Use

In correspondence with the fast urbanization process in Guangzhou, the newly built-up areas have expanded by leaps and bounds over the past decade. From 1980 to 1994 the urban built-up areas increased from 135.96 km^2 to 216 km^2, that is an increase of 3.4 percent per year. The constructed area in the urban

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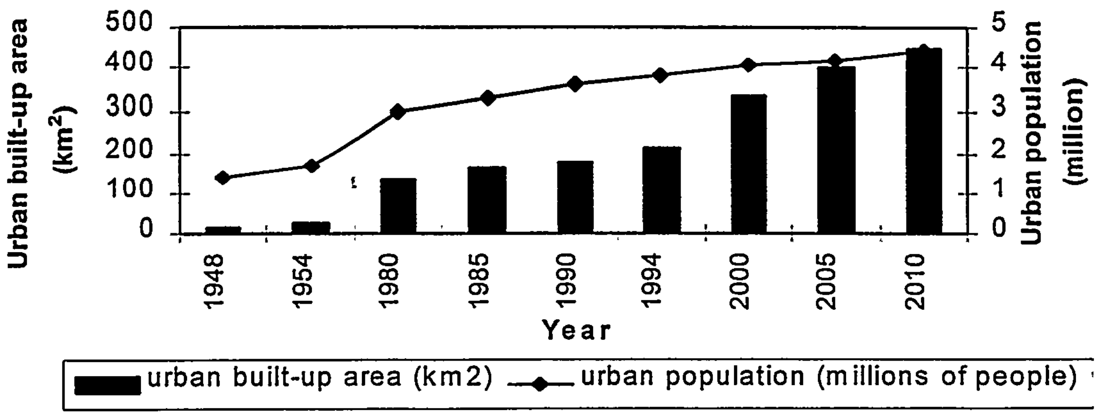
6 In 1948, China enacted the household registration system (*hukou*), designating households as rural or urban. This system was iron-clad, and converting from a rural to an urban hokou was nearly impossible. Members of urban households could live in cities and towns, received state-subsidized grain suppliers, and could work in government enterprises and had social advantages in form of medical care, housing, etc. These rights were denied to peasants with rural hukous. In 1980 policymakers introduced the household responsibility system, which allowed households to determine how to allocate labor between farm and off-farm activities. Although rural residents could leave the land, they still could not legally reside in cities. Without urban registration, migrants are essentially second-class citizens, and their stay in the city is subject to the whim of the authorities. They are often regards as "blind flow" by the official media (source: The World Bank, 1997).

The family planning policy refers to "one child per family" policy which was introduced in 1970s.

7 The old urban core covers a total area of 54.4 km^2, including Yuexiu District, Dongshan District, Liwan District and a part of Haizhu district (see Figure A.3 in Appendix 1).

Guangzhou will reach 335,3 km² by 2000 and 446,10 km² by 2010 (see Figure 1.3).

Figure 1.3 Built-up area and total population in the urban Guangzhou



Source: Offered by Yi Ge at Guangzhou Research Institute of Environmental Protection

Impacts on the Environment

The environment has suffered from the fast urbanization process.

- The land use for construction in Guangzhou has become less orderly these years. A great deal of cultivable land, forest land, and even natural reservations and scenic spots have been exploited for construction use, resulting in severe soil erosion.

  - During the period of 1980 to 1994, the cultivable land per Guangzhou resident decreased from 55 m^2 to 32 m^2, i.e. a 3.8% decrease per year (see Table 1.3). Among the four counties, Panyu was the most severe one. The cultivated land area per rural resident decreased from 98 m^2 in 1990 to 65 m^2 in 1994, i.e. a 9.8% decrease per year, while it was 230 m^2 in 1949!

Table 1.3 Urbanization and cultivable land reduction in Guangzhou

Year	1949	1980	1990	1993	1994
Total population (million)	2.47	5.01	5.94	6.24	6.37
Urbanization level (%)	47.6	50.1	57.4	60.2	60.7
Area of cultivable land (1,000 hectare)	210.9	182.7	164.6	138	134
Cultivable land per person in Guangzhou (m^2/person)	128	55	42	33	32

Source: The Guangzhou Planning Committee (1996)

The projected urbanization level in Guangzhou is to reach 73% - 78%, which is only comparable with that of western Europe and North America in 1980s.

- Accelerating urbanization provides the opportunity and potential for development. At the same time, it puts great pressure on the existing public transportation and infrastructure facilities, which are far from sufficient to meet the demand. This will likely deteriorate traffic congestion and air quality.

1.3.3 The Process of Motorization

Driven by a fast pace of economic growth, China's motorization has seen significant changes during recent years. The national motor vehicle fleet grew from 3 million in 1985 to more than 10 million by the end of 1994. Despite this impressive growth, China's per capita motor vehicle ownership remains among the lowest in the world at 8 vehicles per 1,000 people. Private motor vehicle ownership is quite low - less than 2 vehicles per 1,000 people - but has been growing by almost 50 percent a year (The World Bank, 1997).

The growth of motorization in some of the more developed Chinese cities during the last several years is even more impressive. Table 1.4 shows that Beijing and Guangzhou have seen more rapid growth in motor vehicle ownership than the country as a whole.

Table 1.4 Growth of motor vehicle ownership, Selected Cities

City	Motor Vehicles (1,000) (excluding. Motorcycles)			Population (millions)		Motor Vehicles per 1,000 People	
	1990	1993	Annual % Change	1990	1993	1990	1993
Beijing, urban area	258	402	16	6.99	8.41	37.0	47.8
Shanghai, urban area[1]	172	230	10	7.83	9.48	21.9	24.3
Guangzhou, urban area	94	152	17	3.58	3.7	26.2	41.0
China	5,836	8,776	15	1,134	1,185	5.1	7.4

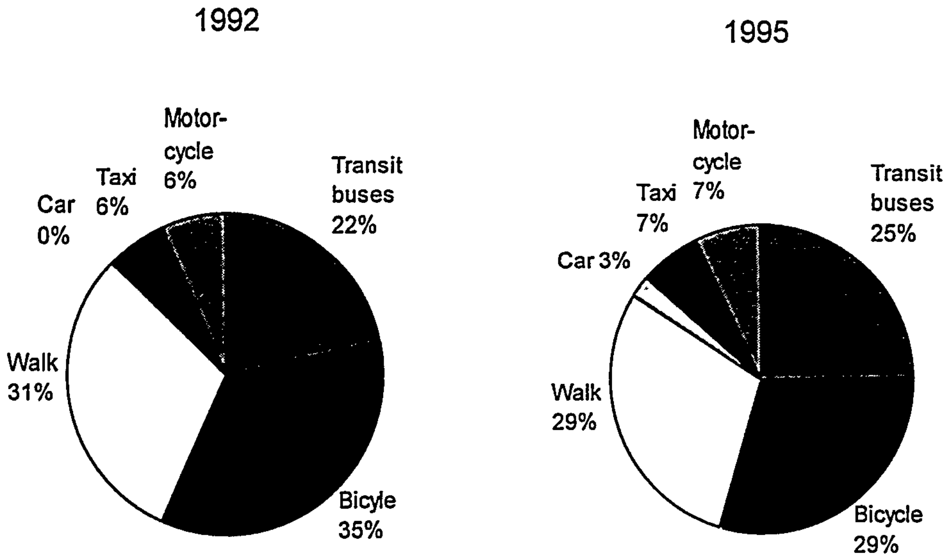
Note 1: The figure is a bit low maybe because the physical conditions for motor vehicle use are unfavorable for such a big city with a high population density.

Source: Stares and Liu (1996)

Guangzhou's motorization rate is low for its level of income relative to other East Asian economies. Two factors make Guangzhou different. Higher residential densities and more integrated land uses result in shorter work journeys, making walking and cycling possible. And until recently policies discouraged individual vehicle ownership (see next section). All these suggest a huge potential for continuing rapid motorization in the years to come.

Cycling and walking are still the dominant transportation modes for Guangzhou residents (see Figure 1.4). Though motorcycle use and car use have increased dramatically, it has been at the expense of walking and cycling, and possibly of public transportation also. This trend will continue to keep the pace with increasing incomes and motorization.

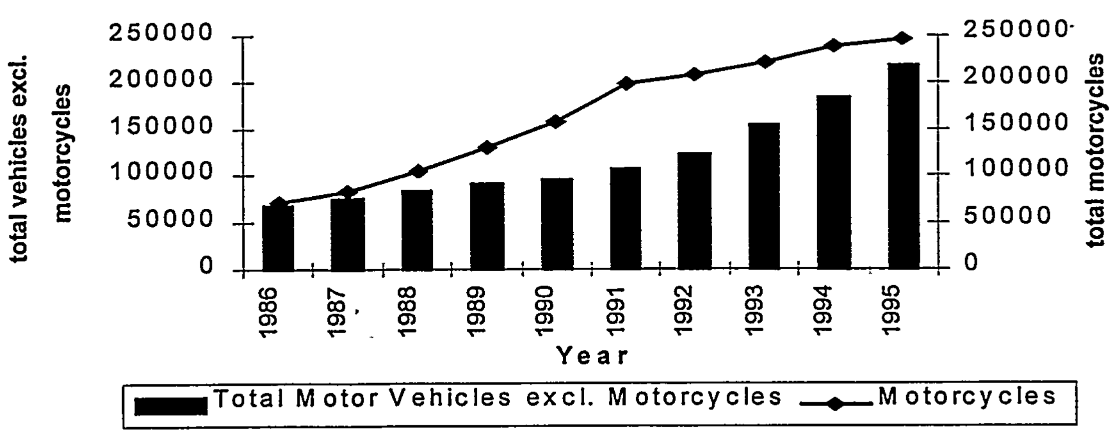
Figure 1.4 Transportation modes in the urban Guangzhou



Source:Offered by Yi Ge at Guangzhou Research Institute of Environmental Protection

An important aspect of the growing motorization in the urban Guangzhou is the dramatic growth of motorcycle ownership (see Figure 1.5). Guangzhou experienced an average annual growth rate of 18 percent in the number of motorcycles during 1986-1991, a much higher rate than for other vehicles (passenger vehicles and goods vehicles). In response to this growth, the Guangzhou Government capped the growth rate in 1992 by imposing an annual quota on new motorcycle licenses of 12,000 units per year. However, the motorcycle fleet still grew at an average rate of 4.5 percent a year during 1991-1995. By 1994, motorcycle ownership per 1,000 people reached 63 units in the urban Guangzhou.

Figure 1.5 Growth of motorcycle ownership and a comparison with the other vehicles in the urban Guangzhou



Source. Offered by Yi Ge at Guangzhou Research Institute of Environmental Protection

Development of Chinese Auto Industry and the Future Car Ownership

In 1994, the central government of China promulgated an auto industry development policy that aims at promoting the motor vehicle industry to lead the development of the national industry sector. The central focus of the policy is on the formation of a domestic market, particularly a market for private cars, to ensure economies of scale for the domestic industry. The policy aims to encourage private car ownership, and calls for the elimination of government controls on vehicle purchases, for car prices to be determined by the market, and for taxes on cars to be reduced (Stares and Liu, 1996).

Based on this national policy, Guangzhou has also made its own policy which aims at developing its auto industry into a pillar industry. During the Eighth Five-Year Plan (1991-1995), Guangzhou accumulatively produced 480,000 motorcycles and 125,500 vehicles, of which 70,000 passenger cars, and finished the gross output value in an order of RMB24.8 billion ($2.88 billion). During the Ninth Five-Year Plan (1996-2000), Guangzhou plans to invest about RMB16.28 billion ($1.89 billion) to increase the production capacity of motor vehicles and motorcycles to 250,000-260,000 units and 1 million units, respectively. The gross output value is projected to increase to RMB40.2 billion, or a six-fold increase from 1995 (The Guangzhou Planning Committee, 1996).

Taking into account the increasing income levels, the changing consumption structure and the ambitious auto industry development policy, the demand for motor vehicle is likely to increase sharply in the near future, particularly for passenger cars. A group of researchers from the World Bank have studied the future car ownership in China based on future forecasts of three main factors: affordability, need for car use, and infrastructure for car use. The results are summarized in Table 1.5.

Table 1.5 The car ownership in major Chinese cities by 2010 (cars per 1,000 people)

Density and public transit assumptions	Beijing	Shanghai	Guangzhou
Current ownership rate	24	15	21
Basic projected rate	96	105	116
Actual residential density			
Better public transit	77	84	92
Worse public transit	106	116	127
Reduced residential density			
Better public transit	92	100	110
Worse public transit	116	127	140

Source: The World Bank (1997)

The car ownership rates in some urban areas are expected to grow by four to seven times over the next fifteen years and could double again in the following ten years. The actual growth rates will depend on how residential densities change as existing cities grow and new cities are built and on the success of policies for improving mass transport. Cities with lower population densities and poor public transit may have 20 percent more cars than the projected average. But cities that organize themselves well, with higher densities and good public transit, would have 20 percent fewer cars than average.

Careful readers might have noted that the figures given in Table 1.1, Table 1.4 and Table 1.5 are not quite consistent, partly due to the different sources. Other reasons are: (i) Table 1.1 provides a car ownership per *100 households*, while the other two provide the car ownership *per 1,000 people.* Unfortunately, I don't know how many people there are in each household. (ii) Table 1.4 gives the car ownership *per 1,000 urban residents* in the major cities, while Table 1.5 gives the car ownership per *1,000 people* in the major cities, I'm not sure which people the latter refers to? Does it mean both of the urban and the rural residents or just the urban residents? However, all of these tables do give us a clear picture of the future car ownership in the urban Guangzhou and other major Chinese cities as well.

Impacts on Urban Infrastructure and Environment

The increases in motorization and urbanization will create important challenges for both infrastructure and environment in the urban Guangzhou.

Distinct improvement in city traffic infrastructure facilities.

- Road Construction
  - Guangzhou will invest about RMB35 billion ($4 billion) in road and bridge projects, including the metro by 2000. An expressway around the city and four new expressways in the downtown area will be constructed.
- Public Transportation
  - By 1995, the public transportation network consisted of 63 inner city lines, 128 special lines, 107 city-county lines, 30 passenger shipping lines, and 20 mini-bus lines.
- Transport Capacity
  - By 1995, Guangzhou had 2,214 buses, 1,068 mini-buses, 12,000 taxies, and 68 passenger vessels. In 1993, the total passenger volume recorded 1,030 million passengers.

Impacts on the environment

- Although the number of vehicles in Guangzhou is less than one-tenth of that in Los Angeles and Tokyo, vehicle emissions are about the same for all three cities (the World Bank, 1997). This is one of the main causes of the adverse impacts on human health and the environment. It imposes also large cost burdens on the society. These will be discussed in detail in chapter 3.
- Another great problem - traffic congestion - rises with the freedom and flexibility of transport afforded by motorization.

- Traffic congestion causes journeys to take more time to complete and motor vehicles to operate at a much lower speed. Average speed for motor vehicles on the urban Guangzhou's center area is around 16.3 kilometers an hour. At this low speed, fuel consumption is twice than on more freely flowing urban highways. Meanwhile, traffic congestion also substantially increases emissions per trip (see Table 1.6).
- Traffic congestion affects all road users, particularly bus services. It results in poorer service and rising bus fares, which in turn encourages the passengers to find some other ways to make their journeys, adding further to congestion.

Table 1.6 Different driving modes generate different emissions, United States, 1984

Driving mode	Hydrocarbons (ppm)	Carbon monoxide (ppm)	Nitrogen oxides (ppm)	PM_{10} (g/km)[1]
Idling	1.34	16.19	0.11	
Cruising				
15 km/h				1.4
20km/h				1.1
24 km/h	5.11	67.36	0.75	1
48 km/h	2.99	30.02	2.00	0.4
72 km/h	2.90	27.79	4.21	0.2

Note 1: Figures on this column are for buses and quoted from Silborn, Solheim et al., (1996), the other figures are for motor vehicles and quoted from The World Bank (1997)

Summing up, if rapid urbanization and motorization are not carefully managed, their positive effects on social and economic development will be overshadowed by the negative effects, producing environmental problems that would rival those of Bangkok and Mexico City.

2 The Environmental Impacts of Road Traffic

2.1 A General Description of the Environmental Impacts of Road Traffic

Motor vehicle engines emit many types of pollutants such as nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), sulfur dioxide (SO_2), ground-level ozone (O_3) and lead. They cause a great deal of environmental problems which have consequences on human health, surroundings, outdoor life, natural environment, cultural environment, landscape and so on (see Table 2.1).

Table 2.1 Environmental impacts of traffic and their consequences

Environmental Impacts	Consequences for
Noise	Health, surroundings, outdoor life
Vibration	Health, surroundings, cultural environment
Air pollution	Health, surroundings, natural and cultural environment, global climate
Soil and water pollution	Health, surroundings, natural environment, soil and water resources
Energy consumption	Global resource management
Land use	Natural environment, outdoor life, city and land-scape, natural and cultural environment, agri-culture
Landscape and city space	Surroundings, outdoor life, natural environment
Natural environment and outdoor recreation	Surroundings, outdoor life, natural environment
Cultural environment and heritage	Surroundings, cultural environment

Source: Silborn, Solheim et al., (1996)

I will focus only on the environmental impacts of road traffic on air pollution in my thesis.

2.2 Local, Regional, Global Environmental Problems

Exhaust emissions from motor vehicles may result in a variety of adverse environmental effects on local, regional and even global scales.

- **Local environmental problem.** Air pollution has a significant negative effect on human health, productivity, crop yields, and corrosion. These negative effects mainly arise from hydrocarbons, particulate matter, nitrogen oxide, carbon monoxide and ozone.
- **Regional environmental problem.** Forest damage and acidification are well-known problems caused by nitrogen oxide, sulfur dioxide, hydrocarbons and ozone.
- **Global environmental problem.** The most important global environmental problem is the greenhouse effect, caused by carbon dioxide and ground-level ozone, which is connected with the dinitrogen oxide pollutant to a certain extent.

I will focus only on the local environmental problems caused by road traffic in my thesis.

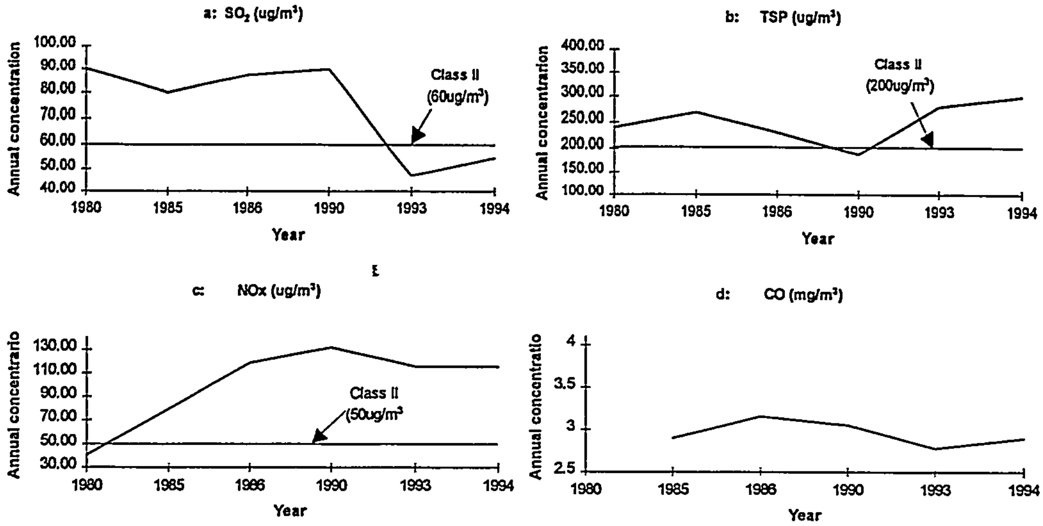
2.3 Air Pollution in the Urban Guangzhou and its Causes

2.3.1 Current Status of Air Quality in the Urban Guangzhou

According to the annual monitoring data of four main air pollutants (see Figure 2.1), the overall air quality in the urban Guangzhou neither deteriorated significantly nor improved significantly along with the rapid economic growth.

- Ambient NO_x and TSP concentrations significantly exceeded their respective Class II of Chinese National Ambient Air Quality standards (CNAAQ Standard) (see Table 2.2) during the period of 1980 to 1994 (see Figure 2.1 b, c).
- The ambient SO_2 concentration has begun to rise since 1993 after a few years successive fall (see Figure 2.1 a).
- Figure 2.1 d can not tell us whether the ambient CO concentration was under control or not during the period of 1980 to 1994 because Table 2.2 dose not provide the annual standard for CO concentration.

Figure 2.1 Change of air quality in the urban Guangzhou during 1980 - 1994



Source: The Guangzhou Planning Committee (1996)

Table 2.2 The Chinese National Ambient Air Quality Standards and WHO guidelines

Pollutant ($\mu g/m^3$)	Averaging time	China Class I	China Class II	China Class III	WHO Guidelines
SO_2	Annual	20	60	100	40 - 60
	Daily	50	150	250	
TSP	Annual	80	200	300	60 - 90
	Daily	120	300	500	150 - 230[a]
PM_{10}	Annual	40	100	150	
	Daily	50	150	250	70
CO	Daily	4 mg/m^3	4 mg/m^3	6 mg/m^3	10 mg/m^3[b]
	Annual	40	40	80	
NO_2	Daily	80	80	120	150
	1 hour	120	120	240	400
	Annual	50	50	100	
No_x	Daily	100	100	150	
	1 hour	150	150	300	
Ozone	8 hours				100 - 120
Lead	Annual	0.7			0.5 - 1.0

Note: Class I are tourist, historic, and conservation areas. Class II are residential urban and rural areas. Class III are industrial areas and heavy traffic areas.

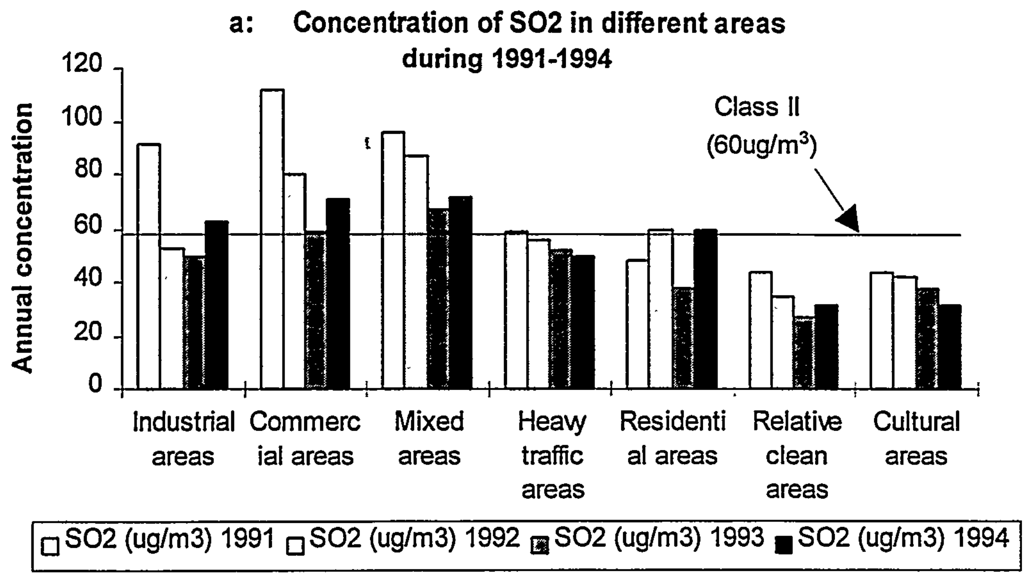
a: Guideline values for combined exposure to sulfur dioxide and TSP.

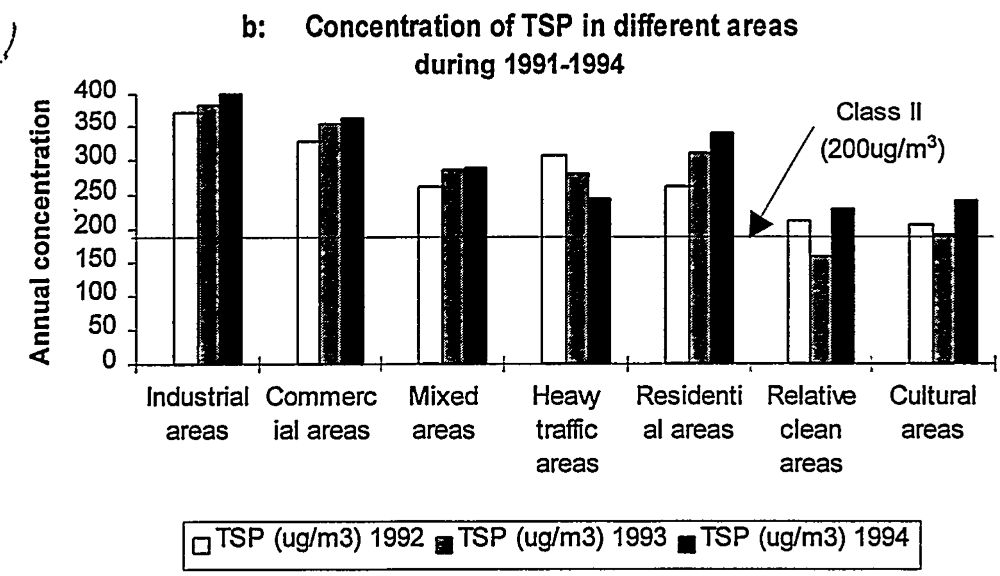
b: 8 hours.

Source: The World Bank (1997) and GB3095 (1996) offered by Yi Ge at the Guangzhou Research Institute of Environmental Protection

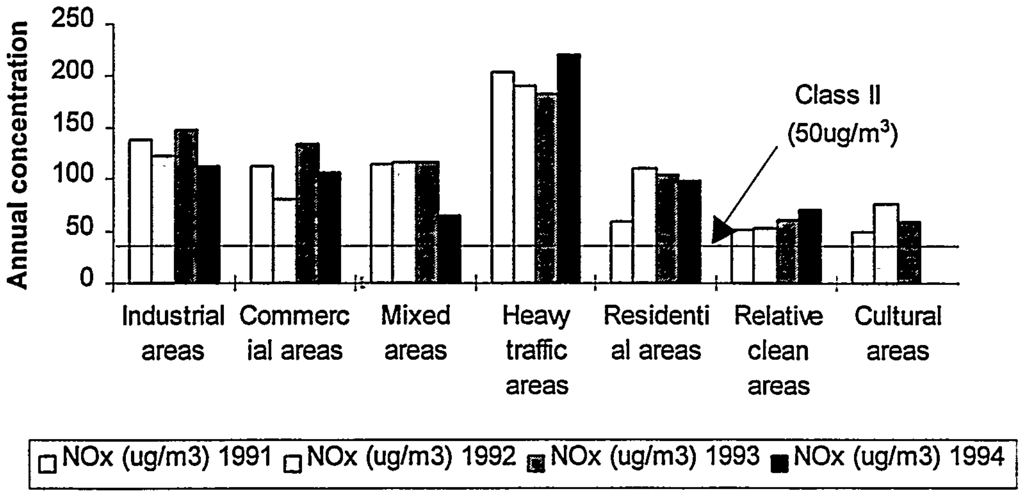
Figure 2.2 to Figure 2.4 show the current status of air quality in the urban Guangzhou.

Figure 2.2 Average annual concentration of different air pollutants in the urban Guangzhou divided by city functions

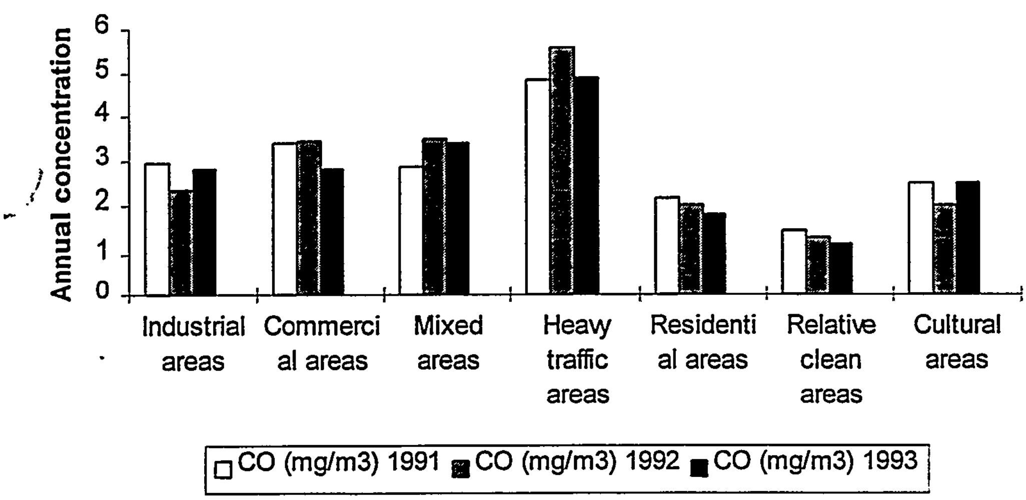




c: **Concentration of NOx in different areas during 1991-1994**



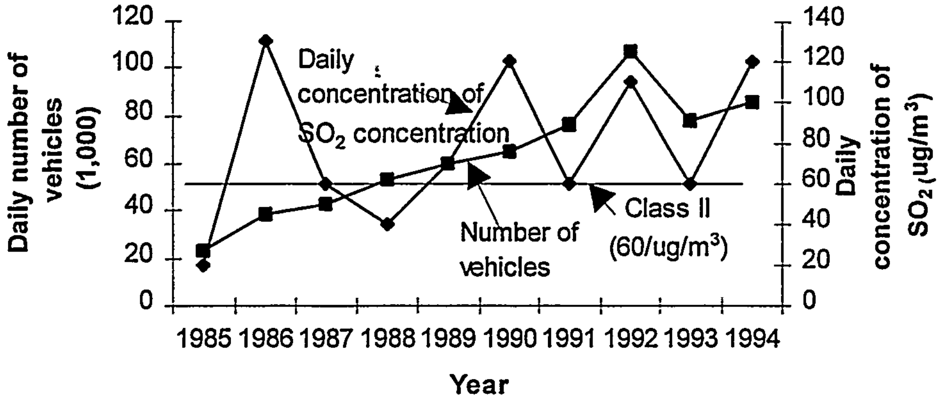
d: **Concentration of CO in different areas during 1991-1994**



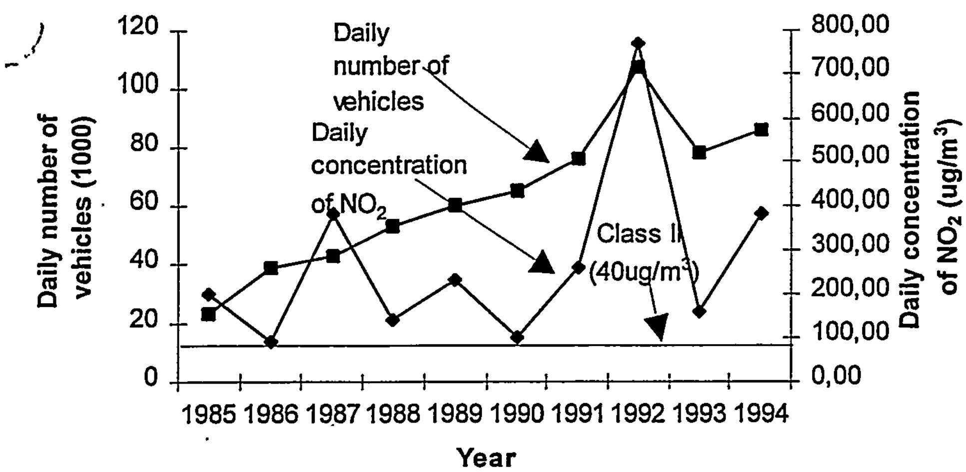
Source: Offered by Ge Yi at Guangzhou Research Institute of Environmental Protection

Figure 2.3 Monitoring data of SO_2 and NO_2 on a main road and a cross road in Guangzhou

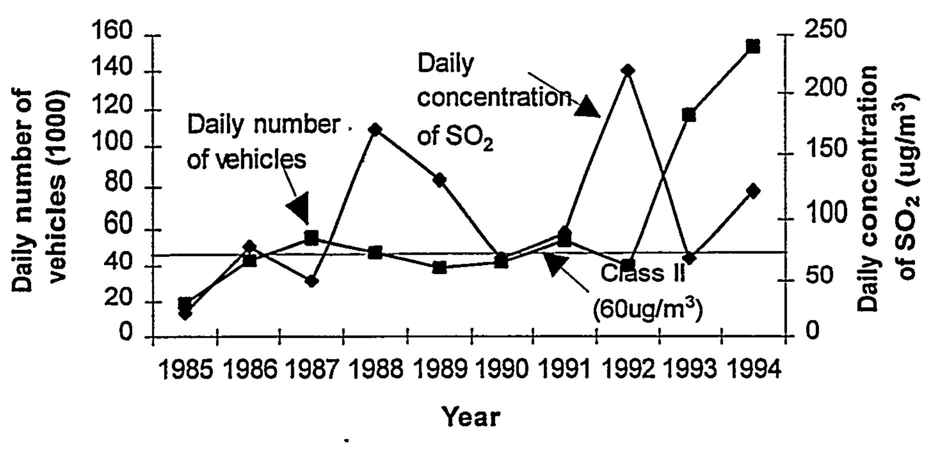
a: The daily concentration of SO_2 and the number of vehicles on the cross of North Renmin Road and Dongfeng Road



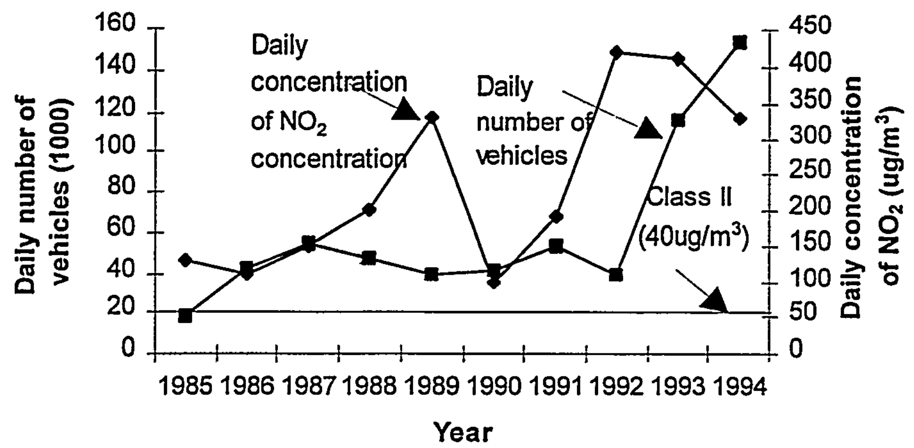
b: The daily concentration of NO_2 and the number of vehicles on the cross of Renmin Road and Dongfeng Road



c: The daily concentration of SO_2 and the number of vehicles in the City Hall area

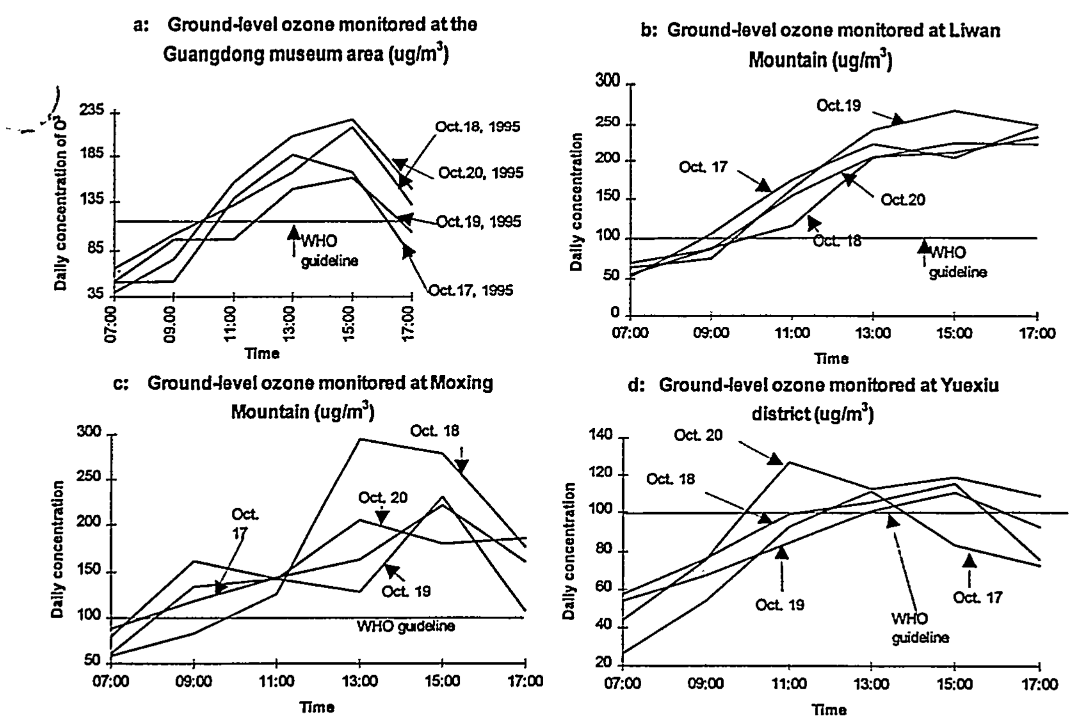


d: **The daily concentration of NO_2 and the number of vehicles in the City Hall area**



Source: The Guangzhou Planning Committee (1996)

Figure 2.4 Monitoring data of ground-level ozone in Guangzhou in 1995



Source: Guangzhou Planning Committee (1996)

2.3.2 The Main Air Pollution Problems

SO_2 emission

- The average ambient SO_2 concentration in the urban area decreased 39 percent during 1980-1994 due to (i) a switch to liquefied petroleum gas and pipe gas to the urban households, (ii) moving the heavy polluted enterprises out of the city center, and (iii) carrying out more stringent pollution control policies. But it has shown increasing levels since 1993, therefore the ambient SO_2 concentration is likely to exceed its Class II of CNAAQ standard in the years to come if the Guangzhou Government dose business as usual (see Figure 2.1 a).

- The most polluted areas were mixed areas (a mixture of industrial, commercial, and residential activities), commercial areas, industrial areas and heavy traffic areas (see Figure 2.2a). This is a result of bad city planning in the urban Guangzhou (I will come back to this point at the end of this Chapter).
- The concentration appeared to be quite high in some heavy traffic areas, such as on the cross of North Renmin Road and Dongfeng Road, and Guangzhou City Hall area during the last decade (see Figure 2.3a, c). However, the figures do not show a strong relationship between the concentration of SO_2 and the increasing vehicle fleet. Actually, Figure 2.2 a shows that the concentration decreased in the heavy traffic areas during 1991-1994 (maybe it has increased since 1995, but I don't have the available data).

NO_x emission

- The average ambient NO_x concentration in the urban area more than tripled during 1980-1994, and significantly exceeded its Class II of CNAAQ standard almost every year during 1980-1994 (see Figure 2.1 c).
- The most polluted areas were heavy traffic areas, industrial, mixed and commercial areas. Figure 2.2 c also shows an increasing trend in the relative clean areas.
- On the cross of North Renmin Road and Dongfeng Road, the average daily concentration of NO_2 even reached a high level as 770 $\mu g/m^3$ in 1992 because of a sharp increase in the vehicle fleet through the road (if the data is correct). Average daily concentration as high as 300 $\mu g/m^3$ could also be found regularly on the other main roads in different years, which indicated that its 1-hour standard of 120 $\mu g/m^3$ was frequently and significantly exceeded (see Figure 2.3 b, d).
- Figure 2.3 b, and d also show that the NO_2 emission is more traffic-related than the SO_2 emission.
- At present, motor vehicles account for 79% of NO_x emissions in the urban Guangzhou.

CO emission

- The annual ambient CO concentration in the urban area was kept stable at a level of 3 mg/m^3 during 1980-1994. However, I can't say whether it exceeded its Class II of CNNAQ standard or not due to lack of an annual standard for CO concentration (see Figure 2.1 d).
- The highest concentration was still found in the heavy traffic areas (see Figure 2.2 d)

- At present, motor vehicles are responsible for 89% of CO emissions in the urban Guangzhou.

TSP emission

- For the ambient TSP concentration in the urban area, it significantly exceeded its Class II of CNAAQ standard almost every year during 1980-1994 (see Figure 2.1 b).
- The high concentration could be found everywhere in the city (see Figure 2.2 b).
- The high ambient TSP concentration causes ambient air smoggy, and increases the number of foggy days. As a result, the total annual sunshine hours have been reduced 30% since 1964 (The Guangzhou Planning Committee, 1996).

Ground-level ozone emission

In addition to high ambient NOx concentrations, the ambient ground-level ozone concentration was high too.

- During the Seventh Five-Year Plan (1986-1990), some weak photochemical pollution in some areas was observed. The situation has even deteriorated since then.
- According to 10-day monitoring data measured at 10 monitoring stations in October, 1995, the daily concentration of photochemical oxidant - ground-level ozone - exceeded its Class II or even Class III of CNAAQ standard regularly for several days (see Figure 2.4). This showed that the photo-chemical pollution already took place in the urban Guangzhou, and the potential risk for severe photochemical pollution is quite high. Figure 2.4 also shows that the concentration appeared to be related to traffic. It reached the highest level at 15 o'clock, and then decreased.

Figure 2.2 also shows that the air quality in the relatively clean areas such as Lihu park and the residential areas has not improved noticeably in recent years. This implies that air pollution has had a tendency to expand from the old urban core to the newly built-up and the rural areas.

2.3.3 Main Causes of Air Pollution in the Urban Guangzhou

- Growing motor vehicle fleet and urbanization
  - As mentioned in Chapter 1, the total motor vehicle fleet has seen a whopping increase these years. This will clearly worsen air quality in the urban Guangzhou.
  - Moreover, the average driving speed of motor vehicles in the urban Guangzhou is quite low because of the crowded streets and the mixed use of road by motor vehicles, bicycles and pedestrians. Without separation, this exacerbates the situation.(see Table 1.6).

- The urbanization has consequences on both motorization and environment as discussed in chapter 1.

- Air quality standards and the vehicle emissions
  - The current vehicle fleet is highly polluting, in part because of outdated vehicle designs and inadequate emissions for new vehicles. For example, truck engines are based on designs that are more than twenty years old, and most car engine designs are at least ten years old. Current emission standards for gasoline-fueled engines are based on 1978 European and 1981 U.S. standards. Not all of the vehicles require catalytic converters to meet current standards. Emission standards for diesel-fueled engines are also weak, converting only tailpipe smoke and not particulates and nitrogen oxides. Chinese standards for cars allow forty times more carbon monoxide, six times as many hydrocarbons, and eight times as many nitrogen oxides than U.S. standards. Motorcycle standards are even more lax than those for cars, and standards for two-stroke engines are similar to those for trucks (the World Bank, 1997).
  - But even these standards are weakly enforced. Emissions from in-use vehicles are ten to fifty times those of vehicles in the U.S. and Japan. Relative to U.S. automobiles, domestically manufactured Chinese cars emit thirty to forty times as much carbon monoxide, forty to sixty times as many hydrocarbons, and eight to fifteen times as many nitrogen oxides (The World Bank, 1997).

- Fuels and fuel pricing
  - Although about half of the gasoline produced in China is unleaded, most of this is low grade (82 RON) or high grade for export. The domestic supply of 90 RON and higher-grade unleaded gasoline accounts for only about 20 percent of the gasoline consumption, and much of it is contaminated by leaded fuel at storage terminals[8].
  - The quality of the diesel fuel is poor - with low stability and a high aromatic content - resulting in high vehicle emission of particulates and smoke.

- The pump prices of the gasoline and the diesel are low by international standards (see Table 2.3), nor do they reflect the real cost of the fuel[9].

[8] Much of the unleaded gasoline is contaminated by leaded fuel at storage terminals due to lack of a dedicated storage and a distribution system. Refineries are not responsible for distribution fuel, so most fuel is transported by truck or rail car rather than by pipeline. Since few of these vehicles transport only unleaded fuel and refueling sites generally have only one holding tank, unleaded gasoline is often contaminated with lead. Even small amounts of lead inactivate catalytic converters (the World Bank, 1997).

[9] Real cost (including externalities), the costs that should be covered by the purchaser of a commodity, should include all costs imposed; including such elements as the cost of any environmental pollution caused by the production or consumption of the good or service (Stares and Liu, 1996).

Table 2.3   China's fuel prices are low by international standards, second quarter 1997

Countries	Premium gasoline (unleaded where available) cents per liter	Diesel
China	25	22
Japan	97	65
Thailand	37	34
Germany	101	72
Mexico	38	30
United States	36	31

Source: The World Bank (1997)

- Unreasonable city planning
  - The high population density and high traffic density in the old urban core make the ambient air quality there even worse.
  - In Guangzhou, industrial land occupies the largest share of serviced urban real estate (more than 30 percent), and the concentration of factories is very high: more than half of all industrial enterprises in Guangzhou are located in the urban area (Yusuf and Wu, 1997).
  - In some districts, there are many areas that mix together industrial manufactures, commercial centers and residential areas, making air pollution more difficult to be under control.

These are the main reasons why the concentrations of several pollutants were very high in the residential and commercial areas, and even higher in the mixed areas (see Figure 2.2).

- Low investment in urban infrastructure and public transportation
  - Improvement of the urban transportation and the infrastructure facilities lagged behind the rapid economic growth, urbanization, and the growing motor vehicle fleet. During 1990-1994, the total population increased by an average rate of 1.8% per year (see Table 1.3), motor vehicle fleet increased by an average rate of 13 % per year (see Figure 1.5), while the road area per vehicle decreased by an average rate of 5 % per year (see Table 2.4). This deteriorates traffic congestion and air pollution from road traffic.
  - In particular, there is a lack of class 1 and 2 roads, as well as expressways. This will become a critical issue as car ownership increases.
  - Public transportation is bad (though it has been improved) in the urban Guangzhou. the congested roads also result in unreliable services, with long delays between buses and unpredictable travel times.

Table 2.4 The infrastructure status in urban Guangzhou

	1980	1988	1990	1991	1992	1993	1994
Road length (km)	391	545	945	951	964	1379	1404
Growth rate (%)		4.2*	31.6*	0.63	1.37	43	1.8
Road area (km^2)	3.49	6.51	10.85	10.93	11.18	13.78	14.69
Growth rate (%)		8.1*	29*	0.7	2.3	23.3	6.6
Road area per vehicle (m^2/vehicle)[1]		34	43	36	33	37	35
growth rate (%)			12	-16	-8	12	-5

Notes: *: The data are average annual growth rates.

1: the data on this row are my own calculation

Source: The Guangzhou Planning Committee (1996)

2.4 Future Forecast

- By 2010 there will be about 1.7 million motor vehicles in Guangzhou, resulting in more vehicles traveling more kilometers, burning more fuel and producing more emissions. The problems of air pollution and photochemical pollution will become more severe.
- The concentration of TSP, soot and dusts will still keep at a high level due to the growing vehicle fleet and the increasing construction activities in the urban area, which causes air to be dusty and to decrease total sunshine hours.

Due to lack of relevant data, I can not provide a future forecast of vehicle exhaust emissions for Guangzhou. Fortunately, the World Bank has studied such future forecast for China as a whole. The main results are summarized in Table 2.5.

Table 2.5 Future forecast of fuel demand and pollution emissions for China

Fuel or pollutant	Base year 1993	Automobile-based strategy without improvements, 2020
Gasoline (millions of tons)	29	789
Diesel (millions of tons)	8	144
Carbon monoxide (thousands of tons)	8,389	215,359
Nitrogen oxide (thousands of tons)	956	22,305
Volatile organic compounds (thousands of tons)	1,138	22,895
Particular matter (thousands of tons)	80	1838

Source: The World Bank (1997)

We see that the demand for fuel and vehicle-related air pollution in China will be skyrocketing without control.

3 Valuing the Health Effects of Air Pollution in Guangzhou

The purpose of this chapter is to describe methodology used to estimate health damages associated with air pollution in the urban Guangzhou, and to value these damages in monetary terms.

3.1 Methodology and Baseline Assumptions for Estimating Health Effects

3.1.1 Methodology

To estimate the health damages associated with air pollution, and to value these damages in monetary terms, four factors must be determined: (i) dose-response function (ii) susceptible population, (iii) relevant change in air pollution, and (iv) economic valuation of various health endpoints.

The first step is to develop estimates of the effects of air pollution on various health endpoints. Dose-response functions that relate health impacts to ambient levels of air pollution are often adopted from the published epidemiological literature. This step involves calculating the slope of the dose-response function, which provides an estimate of the change in prevalence of a given health effect associated with a change in outdoor air quality.

The next step involves multiplying this slope by the relevant population that is believed to be exposed and susceptible to the air pollutant effect under consideration. For certain pollution-related health effects this may include the entire exposed population; for other effects there may be particularly sensitive subgroups such as children or asthmatics.

The third step involves the change in air quality under consideration. One may think of an actual change, e.g. a change from current air pollution level to some ambient air quality standard, either the CNAAQ standard or the WHO air quality guideline. One may also think of a given percent reduction, say 10 percent, as the relevant change considered.

With this information, the estimated health impact can be represented as follows:

Equation 3-1 $dH_i = b * POP_i * dA$

where:

dH_i = change in population at risk of health effect i

b_i = slope from dose-response function

POP_i = population at risk of health effect i

dA = change in air pollution under consideration

To complete the benefit estimation for health effects, one would calculate the economic valuation of this effect as well. The valuation could be developed from estimates of the willingness to pay for reducing the risk. Thus, the total social value of health effects due to the change in air pollution under consideration is the summation of all effects and can be represented by:

Equation 3-2 $dT = \Sigma V_i * dH_i$

where:

dT = total social value of all health effects

V_i = economic valuation of health effect i

3.1.2 Baseline Assumptions for Applying the Dose-Response Functions to Guangzhou

- An important question in all of the health effects estimates is whether a threshold level exists, below which health effects no longer occur, or whether the slope of the dose-response function changes significantly at lower concentrations. The studies adopted here have estimated linear functions suggesting a continuum of effects down to the lowest levels, and have not specifically identified a threshold level.
- A basic assumption is the transferability of dose-response functions in the cited studies to Guangzhou. The use of international health studies implicitly assumes a similar distribution of baseline factors, such as health status (e.g. incidence of chronic disease), chemical composition of pollutants, occupational exposures, seasonality, time spent out of doors and general activity. Since the baseline health status in Guangzhou tends to be poorer than that experienced in the developed countries, this assumption will likely lead to an underestimate of the health effects.

3.2 Dose-Response Functions

Epidemiological studies provide dose-response relationships between ambient air pollution and several morbidity endpoints (hospital admissions, emergency room visits, asthma attacks, restricted activity days, etc.) and mortality. Due to lack of such direct studies on Guangzhou, I will adopt results of the World Bank's recent study (1997) on China, which in turn are based on other studies carried out on China, other countries and the assumptions of transferability. The dose-response functions used to estimate mortality and morbidity effects of air pollution (PM_{10}) are shown in Table 3.1.

Table 3.1 Dose-response functions for PM_{10} pollutant

Health impacts	Number of additional deaths, cases, or days per 1 million people for every 1 $\mu g/m^3$ increase in ambient concentration of PM_{10}.
Mortality (deaths)	6
Respiratory hospital admissions (cases)	12
Emergency room visits (cases)	235
Restricted activity days (days)	57,500
Lower respiratory infection / child asthma (cases)	23
Asthma attacks (cases)	2,608
Chronic bronchitis (cases)	61
Respiratory symptoms (cases)	183,000

Source: The World Bank (1997)

The reasons why I only look at the health impacts of PM_{10} pollutant are as follows:

- As discussed in chapter 2, ambient SO_2 concentration has decreased in the past years in the urban Guangzhou (see Figure 2.1 and Figure 2.2). Thanks to industrial emission control, the total SO_2 emission has also been under control. Moreover, the SO_2 emission is not as traffic-related.
- By the contrast, ambient TSP or PM_{10} concentration is quite high and significantly above their respective CNAAQ standards and WHO guidelines everywhere in the urban area. Besides, the TSP/PM_{10} emission is more traffic-related than the SO_2 emission.
- Studies on China have found a statistical significant relationship between health outcomes and both particulates (TSP and PM_{10}) and sulfur dioxide. The interpretation is that sulfur, generated primarily by coal combustion in China, is a good proxy for fine particulates, and that a portion of the fine particulates are formed from sulfur in the atmosphere. Therefore, it is difficult to separate their impacts on health from each other. Hence I will only look at the effect that PM_{10} pollutant has on human health.
- Ambient NO_x and ozone concentrations also contribute significantly to air pollution (see chapter 2) in the urban Guangzhou. However, the effects of NO_x on human health are not certain, and there is little reliable monitoring data on ozone in Guangzhou.

- According to an incomplete statistics, blood-lead levels[10] in traffic policemen in the urban Guangzhou exceed 11.6 microgram per deciliter (μg/dl), and in children living in industrial and heavy traffic areas average 14.2μg/dl to 16.7μg/dl (these data are offered by Yi Ge). They have far exceeded the U.S. standard - 10μg/dl - above which adverse health effects occur. As mentioned in Chapter 2, lead pollution stems mainly from the use of leaded gasoline by motor vehicles. Since China has already introduced unleaded gasoline in Beijing, Shanghai and Guangzhou and is going to phase out leaded gasoline throughout the country by 2000, this pollution problem in Guangzhou is going to be less severe in the future.
- Concerning other motor vehicle exhaust emissions such as CO and CO_2, no quantitative effects relating to them are presented in my thesis. The reasons are as follows:
  - There is little quantitative dose-response information linking CO exposure to a meaningful health endpoint. Part of the difficulty in estimating dose-response is due to the nature of CO itself. CO dissipates rapidly in the air and while it may exist at high concentration near a source, such as a highway, much lower concentrations may exist only a short distance away. Therefore, the use of fixed-site monitors to indicate population exposure is often inappropriate.
  - In recent years, there has been increasing concern about man's potential to alter the earth's climate through the emissions of gases that may result in a "greenhouse effect". CO_2 is one of the greenhouse gases which is associated with a rise in global temperature. However, China is not required to reduce CO_2 emissions at present.

3.3 Valuing Health Effects

The most common approach to economic valuation of air pollution is the willingness-to-pay approach. What are individuals willing to pay to reduce the risk of injury or death, or willing to accept to take on a limited risk? A mid-range estimate of the willingness to pay to avoid a premature death in the United States is about $3 million per statistical life[11] (The World Bank, 1997). Given the current transition from a planned to a market economy, markets for risk in China are still in their infancy, and no known willingness-to-pay surveys have been carried out. Therefore, I will adopt Ostro's hypothesis that the relative willingness-to-pay to save one statistical life is independent of income, which implies the following equation:

10 Blood-lead levels are the most common index of lead exposure.

11 A statistical life saved refers to saving the life of a person who remains unidentified (Wells, Xu et al., 1994).

Equation 3-3 $\Delta W_{US} / GDP_{US}\, per\ capita = \Delta W_{GZ} / GDP_{GZ}\, per\ capita$

where the ΔW_i is the willingness-to-pay to save one statistical life in the U.S. and Guangzhou respectively. The data on GDP, total population and GDP per capita are given in Table 3.2.

Table 3.2 Basic Statistics of the U.S. and Guangzhou in 1994

	GDP (billion dollars)	Population (million)	GDP per Capita (Dollar)
United States	6738.4	260.65	25852
Guangzhou	11.32	6.37	1777.8

Note: The exchange rate (mid-point rate) was US$1 = RMB8.62 in 1994

Source: Chinese Statistical Yearbook (1996) and Guangzhou Statistical Yearbook (1995)

The value of preventing one statistical life in the urban Guangzhou is hence equal to $206,305 by Equation 3-3. This is much lower than that in the U.S. A major contributing factor to this difference is the impact of income. As income rises, an individual is willing to pay more for reducing the risk of death.

The unit valuation of other health impacts are summarized in Table 3.3 based on the same willingness-to-pay approach.

Table 3.3 Unit valuation of mortality and morbidity

Health impacts	Dollars per occurrence
Mortality	206,305
Respiratory hospital admissions	284
Emergency room visits	23
Restricted activity days	2.32
Lower respiratory infection / child asthma	13
Asthma attacks	4
Chronic bronchitis	8,000
Respiratory symptoms	0.60

Source: The World Bank (1997)

3.3.1 Current Situation in Guangzhou

Assume that the current ambient concentration of TSP is 350 $\mu g/m^3$ in the urban Guangzhou, and use a relationship of $1PM_{10} = 0.6$ TSP (Ostro,1994), the ambient concentration of PM_{10} is hence equal to 210 $\mu g/m^3$. Assume that the total population exposed is about 5 million (80 percent of the total population of Guangzhou). With this information, I can work out the number of additional deaths, cases, or days and their economic valuation at the current situation based on Equation 3-1, Table 3.1 and Table 3.3. The results are summarized in Table 3.4.

Table 3.4 Current situation

Health impacts	Number of additional cases	Economic valuation (million dollars)
Mortality	6300	1299.7
Respiratory hospital admissions	12600	3.58
Emergency room visits	246,750	5.68
Restricted activity days	60,375,000	140
Lower respiratory infection / child asthma	24,150	0.31
Asthma attacks	2,738,400	10.95
Chronic bronchitis	64,050	512.4
Respiratory symptoms	192,150,000	115.3
Sum of total economic valuation of morbidity		788.28
Sum of total economic valuation		2,088
Percentage of 1994 Guangzhou's GDP		18%

3.3.2 What if Guangzhou Met the Class II of CNAAQ Standard for PM_{10} Pollutant

If Guangzhou met that standard (see Table 2.2), a 10 percent of its GDP in 1994 could be saved. The results are summarized in Table 3.5.

Table 3.5 A heavy annual toll in both physical and economic damages could be avoided if Guangzhou met the Class II of CNAAQ standard

Health impacts	Number of cases averted	Economic valuation (million dollars)
Mortality	3300	680.8
Respiratory hospital admissions	6600	1.87
Emergency room visits	129,250	2.97
Restricted activity days	31,625,000	73.37
Lower respiratory infection / child asthma	12,650	0.16
Asthma attacks	1,434,400	5.74
Chronic bronchitis	33,550	368.4
Respiratory symptoms	100,650,000	60.39
Total economic valuation for morbidity		412.9
Total economic valuation for both mortality and morbidity		1,093.7
Percentage of 1994 Guangzhou's GDP		9.7%

3.4 Summary

In addition to the well known respiratory diseases from smoking in China, recent studies have also demonstrated a dose-response relationship between ambient air pollution from road traffic and a few health endpoints.

- For China as a whole, respiratory disease was the third leading cause of death after cerebrovascular disease and malignant tumors, accounting for 15.73 percent of all mortality (China Statistical Yearbook, 1995). In the U.S., diseases related to respiratory tract inflammation account for only 4.4 percent of all mortality.
- According to a currently incomplete statistics, the incidence of respiratory (lung) disease in Guangzhou was almost 10 times higher than that in 1979. Particularly, the incidence of pharyngitis (respiratory) for traffic policemen in the old urban core is as high as 72.3 percent (offered by Yi Ge at Guangzhou Research Institute of Environmental Protection).
- In Guangzhou, it is estimated that about 6300 excess premature deaths will occur each year if the current PM_{10} emission is kept to be the same level in the years to come. Premature deaths caused by PM_{10} pollutant is estimated to cost about $1.3 billion a year in the current situation. It is absolutely the largest cost burden on the society. The total economic loss associated with PM_{10} pollutant is estimated to account for about 18 percent of Guangzhou's GDP in 1994.
- It is also estimated that about 3300 premature deaths (or 52% of today's premature deaths) could be avoided each year if Guangzhou met Class II of CNAAQ standard for PM_{10} pollutant. Valued in the monetary term, it is $681 million saved.
- Urban air pollution's toll on other aspects of human health is also severe. Hospital admissions due to respiratory illness are estimated to be 6600 higher per year because of excess pollution. Moreover, high pollution causes an estimated 129,250 emergency room visits each year. And some 32 million days are estimated to be lost because of illness associated with pollution levels that exceed standards.
- The total economic valuation of the avoided morbidity and mortality cases is estimated to be $1 billion or 10 percent of Guangzhou's GDP in 1994. What a heavy toll an urban air pollution has on the economy!

3.5 Improving the Estimates of Air Pollution Damages: Uncertainties and Future Needs

As mentioned in section 3.1.2, the current estimates of the health benefits are based on other international studies and fairly simple assumptions. Nevertheless, they do provide information about the health effects that can be quantified. These effects can, in turn, be valued in order to provide a range for the economic value of controlling air pollution. These estimates can then form the basis for prioritization when choosing several air pollution control measures. Additional uncertainties arise when applying these numbers to other countries, particularly those that are less developed. This section aims at providing a brief review of the major areas of uncertainty in the estimates, and describing tasks that could be undertaken to reduce these uncertainties.

- One of the major uncertainties is related to the assumptions of transferability. As we know, most of the dose-response functions provided in the literature are based on research conducted primarily in the U.S. Extrapolating these results to countries in very different stages of development adds uncertainty to any estimate of benefits associated with reduced air pollution. For example, consider one of the baseline factors: time spent out of doors. This may vary from country to country, even from city to city in the same country depending on the different geographical location. Ideally, the dose would reflect the ambient air quality and the amount of time spent *outdoors*. Studies of populations in the U.S. suggest that people spend about 90 percent of their time indoors (Ostro 1994). Many of these indoor environments are well sealed and dramatically reduce the penetration of outdoor pollutants into the indoors. Therefore, the estimated dose-response relationships between ambient air pollution and health, by necessity, incorporate the large proportion of time spent indoors by most people. This aspect will lead to a significant underestimate of dose when applying the existing dose-response functions to warm climates such as Guangzhou. An underestimate is likely because residents in these climates will probably spend a greater portion of their time outdoors, both on a daily and on an annual basis. In addition, indoor pollution in Guangzhou also appears to be high. If this is the case, it is likely that a given level of air pollution, everything else remaining constant, would generate much greater health effects in Guangzhou.
- Other disparities between countries may result in different baseline health status. For example Guangzhou may have a greater proportion of individuals with chronic respiratory disease. This could increase the health impacts of a given level of air pollution.
- As a result, there is a great need for developing a comprehensive epidemiological study for Guangzhou.
- Air pollution has also been associated with non-health effects, including material damage, visibility degradation, soil erosion, land degradation, etc. But these are outside the scope of my thesis.

Part II

4 Analytical Framework

This chapter aims at giving a theoretical analysis on how to deal with air pollution. If the city planner were to possess data on how much pollution each individual vehicle caused through a year, then a direct year-end tax bill based on emissions would provide appropriate incentives for pollution reduction. When continuous monitoring of individual emission is not applied, (actually it is not yet feasible for motor vehicles), the planner needs to apply indirect policy instruments to mimic the incentives that would have been provided by an emission fee. This is the topic of this chapter.

4.1 Assumptions

- In order to focus on cost efficiency, the model used here is one with a representative consumer and a representative pollutant
- For the sake of simplicity, I assume that public transportation vehicles do not emit at all
- Absence of economies of scale in public transportation sector

4.2 Description of the Model

4.2.1 Model Equations

Equation 4-1 $W = U(x) - C_a(a) - C_x(x)$

Equation 4-2 $e = m * x$

Equation 4-3 $m = m(a)$

$m'(a) < 0$

Equation 4-4 $e \leq \bar{e}$

Endogenous variables: x, e, a, and m;

Exogenous variable: $\bar{e}$

The model is determined since it has 4 equations and 4 endogenous variables.

4.2.2 Symbol List

x = the representative consumer's use of his/her private motor vehicles (he/she may, of course, own more than one vehicle), where the use is measured by total driving mileage (kilometer)

e = emission of the representative vehicle exhaust pollutant

a = abatement or technical control that can reduce emission

m = emission factor of the representative pollutant measured by gram per driving mileage (g/km)

C_a = costs of using abatement measures

C_x = costs of using private motor vehicles

U = utility function

W = net utility function

$\bar{e}$ = emission target for the representative pollutant set by the city planner; it may be, for example, the CNAAQ standard or the WHO guideline

' denotes the first derivative and " denotes the second derivative

4.2.3 Interpretation of the Model

Equation 4-1: The representative consumer's net utility function function

It equals the difference between the representative consumer's utility and the costs associated with it.

- The consumer's preference is represented by a utility function, with utility depending on the use of his/her own vehicle, where the use is measured by total driving mileage x.
- Assumptions for the utility function are as follows:
  - It is strictly concave, continuous and twice differentiable, i.e. $U_x'(x) > 0$, $U_{xx}''(x) < 0$. A positive first derivative means that the more the consumer drives, the more the utility he/she will get.
  - The total driving mileage is constrained to a non-negative value so that the optimal solution does not involve the corner solution, e.g. x = 0.
  - It is cardinal, i.e. it is measured in money so as to be consistent with the unit of cost functions.
  - It is additively separable from other consumption.

- $C_a(a)$ is the cost function of abatement measures which is convex, continuous, and twice differentiable, i.e. $C_a'(a) > 0$, $C_a''(a) > 0$. It is measured in money.
- $C_x(x)$ is the cost function of using private motor vehicles which is convex, continuous, and twice differentiable, i.e. $C_x'(x) > 0$, $C_x''(x) > 0$. It is measured in money.

Equation 4-2: Emission function for the representative pollutant

It is equal to the emission factor of the pollutant multiplied by the total driving mileage.

Equation 4-3: Emission factor of the representative pollutant

It is a function of the abatement measures. The reason for a negative first derivative is that the more the abatement measures are applied, the less the emission factor (the less the emission per unit of driving mileage) becomes.

Equation 4-4: Emission target for the pollutant

It is set by the city planner. The maximum emission of the pollutant is constrained to not greater than the target level.

4.3 Analysis of the Model

I will use the Lagrange method to solve this maximization problem.

The Lagrangian function is

Equation 4-5 $$L = U(x) - C_a(a) - C_x(x) - \lambda * (m * x - e) - \mu * [m(a) - m] - \gamma * (e - \bar{e})$$

The first-order conditions are found by setting the first derivatives of Equation 4-5 with respect to each endogenous variable zero.

Equation 4-6 $\partial L/\partial x = \partial U/\partial x - \partial C_x/\partial x - \lambda * m = U_x'(x) - C_x'(x) - \lambda * m = 0$

Equation 4-7 $\partial L/\partial e = \lambda - \gamma = 0$

Equation 4-8 $\partial L/\partial a = -\partial C_a/\partial a - \mu * \partial m/\partial a = -C_a'(a) - \mu * m'(a) = 0$

Equation 4-9 $\partial L/\partial m = -\lambda * x + \mu = 0$

4.3.1 Abatement Measures

Abatement measures or technical controls, aiming at reducing emissions per driving mileage, include cleaner cars, cleaner fuels, etc. (for more detailed description of each available measure, see section 5.1).

Determination of optimal value of the abatement, a^{opt}:

Equation 4-7 gives

Equation 4-10 $\lambda = \gamma$

Equation 4-8gives

Equation 4-11 $C_a'(a) = -\mu * m'(a)$, *which is positive since* $m'(a) < 0$

Equation 4-9 gives

Equation 4-12 $\mu = \lambda * x$

By putting Equation 4-10 into Equation 4-12, and then substituting for μ in Equation 4-11, I get the following equation that determines the optimal value of the abatement, a^{opt}:

Equation 4-13 $C_a'(a^{opt}) = - \gamma * x * m'(a^{opt})$, *which is positive since* $m'(a^{opt}) < 0$

Equation 4-13 shows that the marginal cost of abatement is equal to the marginal benefit of emission reduction solely through abatement. The marginal benefit is a product of two terms:

- (i) γ, shadow price of the emissions, can be interpreted as the marginal cost of tightening the constraint slightly.
- (ii) $x * m'(a^{opt})$, total emission reduction, is again a product of total driving mileage, x, and marginal emission factor, $m'(a^{opt})$. The latter can be interpreted as how much the pollutant from a vehicle could be reduced if the abatement measures were applied slightly more stringent.

Note that the Lagrangian function - Equation 4-5 - is concave since it is a summation of several concave functions, hence the value of a^{opt} determined by Equation 4-13 is in fact a maximum value of the function.

4.3.2 Demand Management Measures

The demand management measures, aiming at reducing the total driving mileage, include fuel taxation, parking controls, toll roads, etc. (for more detailed description of each measure, see section 5.2).

Determination of optimal value of the total driving mileage, x^{opt}

By rearranging Equation 4-6 and substituting for λ from Equation 4-10, I get

Equation 4-14 $U_x'(x^{opt}) = C_x'(x^{opt}) + \gamma * m$

Or equivalently,

Equation 4-15 $U_x'(x^{opt}) - C_x'(x^{opt}) = \gamma * m$

Equation 4-14 says that the marginal utility of driving the private cars is equal to the marginal cost of driving plus an additional cost associated with each car's environmental cost per kilometer driven. The vehicle's environmental cost per kilometer driven is a product of the shadow price of the pollutant and its emission factor. In other words, the difference between marginal utility and marginal cost is equal to the vehicle's environmental cost per km driven (Equation 4-15).

Note again that the value of x^{opt} determined by Equation 4-14 or Equation 4-15 is in fact a maximum value of the Lagrangian function - Equation 4-5 - since it is concave.

4.3.3 Relationship Between the Two Measures

By solving Equation 4-13 for γ, I get an expression of the marginal cost of emission reduction through abatement:

Equation 4-16 $- C_a'(a) / [x * m'(a)] = \gamma$

The corresponding marginal cost of emission reduction through demand management is found by solving Equation 4-15, I get

Equation 4-17 $[U_x'(x) - C_x'(x)] / m = \gamma$

There is one important observation to make. The expressions of the marginal cost of each instrument, per unit of emission reduction, are valid even if the other instrument is not used optimally.

- (i) Thus, if the abatement measures were not optimally designed, Equation 4-17 would still inform us of how much it costs to get the same emission reduction through demand management measures. But the value of the emission factor, m, must reflect the actual application of the abatement measures and the value of γ is likely to be higher because the absence of optimal abatement measures induces higher marginal costs.

In order to look at the problem in detail, I will introduce a predetermined target level for abatement measure, $\bar{a}$, which is not optimal, and a new parameter η in the Lagrangian function - Equation 4-5 - and modify it as follows:

Equation 4-18 $$L = U(x) - C_a(a) - C_x(x) - \lambda * (m * x - e) - \mu * [m(a)-m] - \gamma * (e - \bar{e}) - \eta * (a - \bar{a})$$

By taking the first derivative of Equation 4-18 with respect to x, and using Equation 4-10, I get the following first order condition for determining the value of driving mileage:

Equation 4-19 $$U_x'(x) - C_x'(x) = \gamma * m(a)$$

Compared with Equation 4-15, the discrepancy between the marginal benefit and the marginal cost of driving is larger than that in Equation 4-15 because a lack of optimal abatement has resulted in an increased value of $\gamma * m$. In order to get the same emission reduction as before the demand management measures have to be stricter, for example, by increasing the tax rate on fuels.

- (ii) Similarly, if we were not able to use a demand management measure such as a gasoline tax, or unable to adjust it optimally, Equation 4-16 would still inform us of what it costs per unit to obtain emission reduction through abatement measures.

The Lagrangian function - Equation 4-5 - can be modified as follows:

Equation 4-20 $$L = U(x) - C_X(x) - \lambda * (m * x - e) - \mu * [m(a) - m] - \gamma * (e - \bar{e}) - \beta * [U_X'(x) - C_X'(x) - 0]$$

where the last term refers to the lack of proper demand management measures, and it is derived from Equation 4-15 by setting the value of γ*m zero.

By taking the first derivative of Equation 4-20 with respect to "a" and using Equation 4-10 and Equation 4-12, I get,

Equation 4-21 $$C_a'(a) = - \gamma * x * m'(a)$$

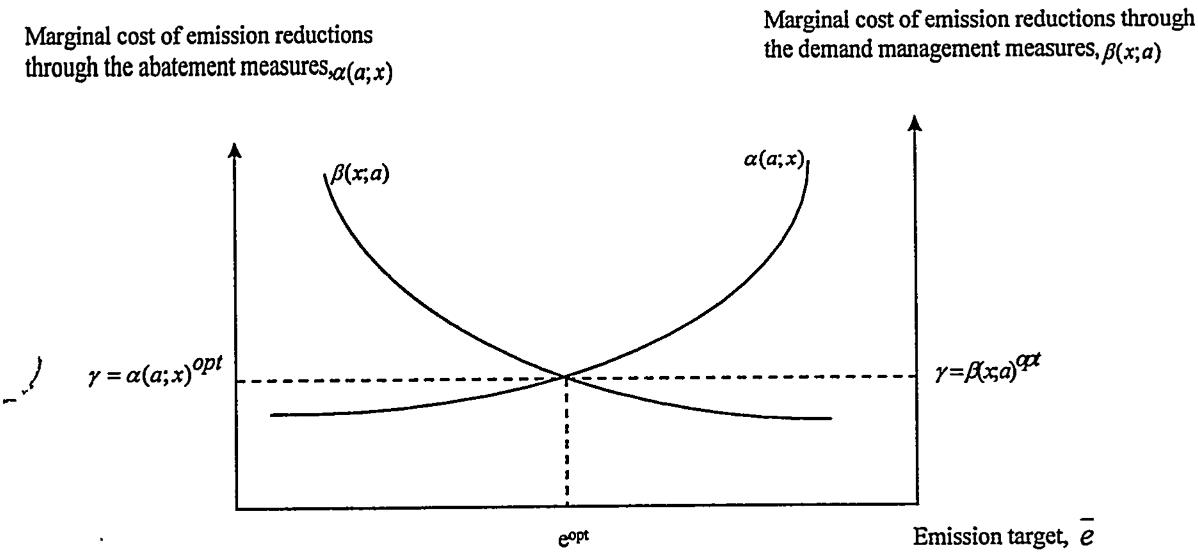
Since the demand management measures have failed to be applied optimally, the consumer receives incentives to drive more at a given level of "a", and the value of γ and x increase because of this failure. These cause the value of right-hand side of Equation 4-21 to increase, which in turn leads an increase of the value of left-hand side. In order to get the same emission reduction as before, more abatement should be applied (since the cost function is convex).

Based on the above analysis, a cost-effective control program requires that the marginal cost per unit of emission reduction through the abatement measures equals the marginal cost per unit of emission reduction through the demand management measures in optimum (Equation 4-22).

Equation 4-22 $- C_a'(a^{opt}) / [x * m'(a^{opt})] = [U_x'(x^{opt}) - C_x'(x^{opt})] / m = \gamma$

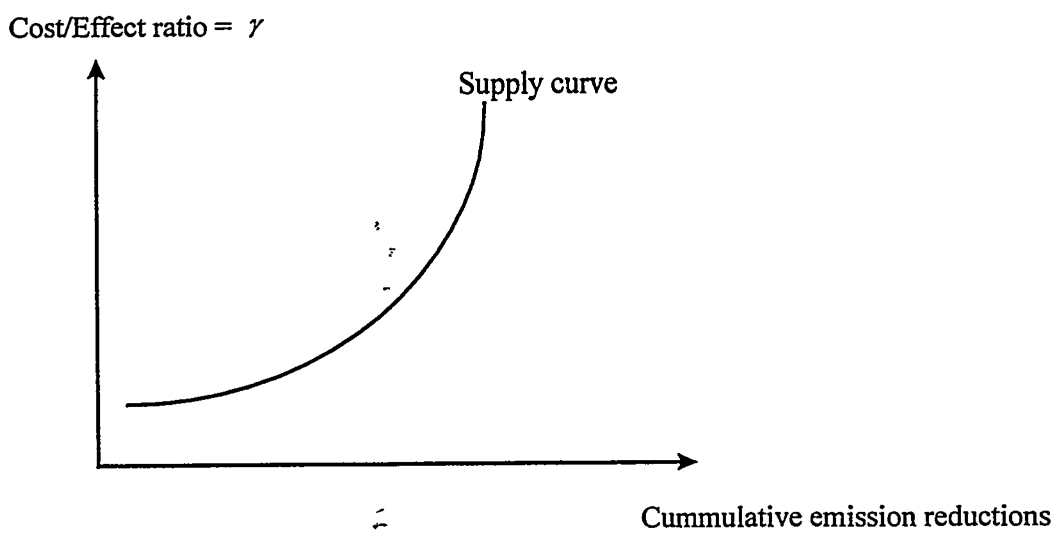
In order to draw a simple and clear figure of the optimal emission-control program, I call the left-hand side of Equation 4-22 α(a; x), and the right-hand side of Equation 4-22 β(x; a).

Figure 4.1 How to reach the emission target by a cost-effective control program



When I apply this conclusion to the case study in chapter 6, I actually need to work out the value of γ (or cost/effect ratio) for each measure and draw a supply curve of all the measures based on their γ-value (or their cost-effectiveness) (see Figure 4.2).

Figure 4.2 Supply curve of measures based on their cost-effectiveness



4.3.4 Measures of Improving Public Transportation

These measures design to make the best use of space to accommodate demand with minimal investments in new infrastructure. For example, it can be investment in new buses and mass rapid transit (for more detailed description of each measure, see 5.3).

Let me now introduce a new variable, y, which can represent the availability of public transportation in the representative consumer's utility function. I assume that the marginal utility of introducing such measures would be greater than the associated marginal costs if there was no public transportation in the beginning, i.e. $U_y'(x, y_0) > C_y'(y_0)$ ("0" refers to the absence of such measures). In other words, it is not allowed for a corner solution.

Then the Lagrangian function - Equation 4-5 - can be modified as follows:

Equation 4-23 $L = U(x, y) - C_a(a) - C_x(x) - C_y(y) - \lambda * (m * x - e) - \mu * [m(a) - m] - \gamma * (e - \bar{e})$

where the term $C_y(y)$ is the cost function associated with the measures, which is assumed to be convex, continuous, twice differentiable, i.e. $C_y'(y) > 0$, $C_y''(y) > 0$. It is also measured in money.

The first-order conditions for this maximization problem can be derived from by setting the partial derivative of the Equation 4-23 with respect to each endogenous variable zero.

Equation 4-24 $\partial L/\partial x = U_x'(x, y) - C_x'(x) - \lambda * m = 0$

Equation 4-25 $\partial L/\partial y = U_y'(x, y) - C_y'(y) = 0$

Equation 4-26 $\partial L/\partial a = - C_a'(a) - \mu * m'(a) = 0$

Equation 4-27 $\partial L/\partial e = \lambda - \gamma = 0$

Equation 4-28 $\partial L/\partial m = -\lambda * x + \mu = 0$

Determination of Optimal Value of the Public Transportation, y^{opt}

Equation 4-25 gives me the following equation for determining y^{opt}:

Equation 4-29 $U_y'(x^{opt}, y^{opt}) = C_y'(y^{opt})$

which says that the marginal benefit of introducing the public transportation, given the other two measures are applied optimally, is equal to the marginal cost associated with it in optimum. Note that there is no element concerning environmental effect in Equation 4-29.

This equation also gives a guideline for the city planners to set price for the public transportation rationally.

Determination of Optimal Value of the Driving Mileage, X^{opt}

By rearranging the Equation 4-24 and substituting for λ from the Equation 4-27, I get the following equation which determines x^{opt}:

Equation 4-30 $U_x'(x^{opt}, y^{opt}) - C_x'(x^{opt}) = \gamma * m$

Equation 4-30 says that the demand management measures should be applied until the difference between the marginal benefit and marginal cost of driving private cars, given the other two measures are applied optimally, equals the car's environmental cost per kilometer driven. The interpretation of this equation is just slightly different from that of Equation 4-15, but the value of x^{opt} is quite different.

It is reasonable to assume $\partial^2U/\partial x\partial y < 0$, indicating that the consumer's marginal utility of driving decreases with an improving of the public transportation.

As a consequence, as long as $y^{opt} > 0$, the value of x^{opt} determined by Equation 4-30 is smaller than that by Equation 4-14 or Equation 4-15. That is to say the total driving mileage is reduced. The intuitive explanation is as follows: the value of y increases from zero to its optimal value, for given values of "a" and "γ" (therefore a given value of γ*m), reduces the value of U_x' (since $U_{xy}'' < 0$), and only a reduced value of x can be consistent with this, since the utility function is concave.

Determination of Optimal Value of the Abatement Measures, a^{opt}

By rearranging the Equation 4-26 and substituting for μ from Equation 4-27 and Equation 4-28, I get the following equation which determines the optimal abatement:

Equation 4-31 $C_a'(a^{opt}) = - \gamma * x^{opt} * m'(a^{opt})$

The optimal driving mileage has now reduced just as discussed above, and the value of γ has also reduced because the new measures have come into effect. These result in a decrease in the value of the right-hand side of Equation 4-31, which also leads to a reduction in the value of the left-hand side (marginal cost of abatement). As a consequence, the value of optimal abatement measures is reduced (since the cost function is convex) and is lower than that without public transportation (cf. 4.3.1).

Relationship Between These Three Measures

- (i) The relationship between the abatement measures and the demand management measures

The relationship between them, as discussed in 4.3.3, is still valid disregarding the optimality of the public transportation. The cost-effective program still requires that the marginal cost per unit of emission reduction through the abatement measures equals the marginal cost per unit of emission reduction through the demand management measures in optimum. However the value of them could be smaller in case with optimal public transportation.

Equation 4-32 $-C_a'(a^{opt}) / [x^{opt} * m'(a^{opt})] = [U_x'(x^{opt}, y^{opt}) - C_x'(x^{opt}, y^{opt})] / m = \gamma^{new}$

- (ii) When demand management measures could not be applied optimally, while the other two are applied optimally

The Lagrangian function - Equation 4-23 - can be modified as follows:

Equation 4-33 $L = U(x, y) - C_a(a) - C_x(x) - C_y(y) - \lambda * (m * x - e) - \mu * [m(a) - m] - \gamma * (e - \bar{e}) - \theta * [U_x'(x, y) - C_x'(x) - 0]$

where the last term refers to the absence of proper demand management measures, for instance, no fuel taxation, and it is derived from Equation 4-30 by setting the value of γ*m zero.

By setting the first derivatives of the Equation 4-33 with respect to each endogenous variable zero, I get the following equations:

Equation 4-34 $\partial L / \partial x = U_x'(x, y) - C_x'(x) - \lambda * m - \theta * [U_{xx}''(x, y) - C_{xx}''(x)] = 0$

Equation 4-35 $\partial L / \partial a = - C_a'(a) - \mu * m'(a) = 0$

Equation 4-36 $\partial L / \partial e = \lambda - \gamma$

Equation 4-37 $\partial L / \partial y = U_y'(x, y) - C_y'(y) - \theta * U_{xy}''(x, y) = 0$

Equation 4-38 $\partial L / \partial m = - \lambda * x + \mu = 0$

How much should the city planner abate now?

Equation 4-35, Equation 4-36 and Equation 4-38 give me:

Equation 4-39 $C_a'(a) = - \gamma * x * m'(a)$

which determines how much the city planner should abate now.

Although it is exactly the same expression as Equation 4-13, it does not mean that the city planner could abate the same as before. Attention should be paid that the total driving mileage and the value of γ have increased due to lack of the optimal demand management measures. These cause the value of left-hand side of Equation 4-39 to increase, therefore requiring more abatement measures (since the cost function is convex).

How much should the city planner supply of the public transportation?

From Equation 4-34

Equation 4-40 $\lambda * m + \theta * (U_{xx}'' - C_{xx}'') = U_x'(x, y) - Cx'(x) = 0$

$\Rightarrow$

Equation 4-41 $\theta * (U_{xx}'' - C_{xx}'') = - \lambda * m$

$\Rightarrow$

Equation 4-42 $\theta = - \gamma * m / (U_{xx}'' - C_{xx}'')$

which is positive.

The parameter θ may be interpreted as the benefits, including both social and individual, gained from introducing the demand management measures. The benefits decrease as these measures become more optimal.

By substituting for θ in Equation 4-37 with Equation 4-42, I get:

Equation 4-43 $U_y'(x, y) = C_y'(y) - \gamma * m * [U_{xy}''(x, y) / (U_{xx}'' - C_x'')]$

From the early analysis, I know that the Equation 4-44 given below holds (cf. 4.3.3).

Equation 4-44 $U_x'(x, y) = C_x'(x)$

By totally differentiating this equation, I get

Equation 4-45 $U_{xx}''dx + U_{xy}''dy = C_{xx}''dx$

$\Rightarrow$

Equation 4-46 $-U_{xy}'' / (U_{xx}'' - C_{xx}'') = dx / dy$, *which is negative*

By putting Equation 4-46 into Equation 4-43, I get

Equation 4-47 $U_y'(x, y) = C_y'(y) + \gamma * m * dx / dy$

or equivalently,

Equation 4-48 $U_y'(x, y) - \gamma * m * dx / dy = C_y'(y)$

This equation gives a main result of the cost-effectiveness analysis, i.e. the marginal utility of introducing the public transportation plus the associated environmental benefit are equal to its marginal cost.

The environmental benefit is equal to the production of dx/dy and $\gamma * m$. The former is the marginal effect of public transportation on total driving mileage (how many driving mileage could be reduced due to a better public transportation). It is negative because I assumed that $U_{xy}''(x, y) < 0$. The latter is the environmental benefit per kilometer driven.

4.4 Conclusions

- A cost-effective control program of air pollution requires that the marginal cost of emission reduction from either abatement measures or demand management measures is equal to each other and is equal to the shadow price of emission, γ (see Equation 4-22).
- When both the abatement and the demand management measures are applied optimally, measures of improving public transportation do not take into account the environment (see Equation 4-29). In other words, the environmental benefits gained from the public transportation should be considered only when the other two measures are failed to be applied optimally (see Equation 4-48).
- Given that some of the cost-effective measures are not undertaken, some measures that are not cost-effective originally should be undertaken.

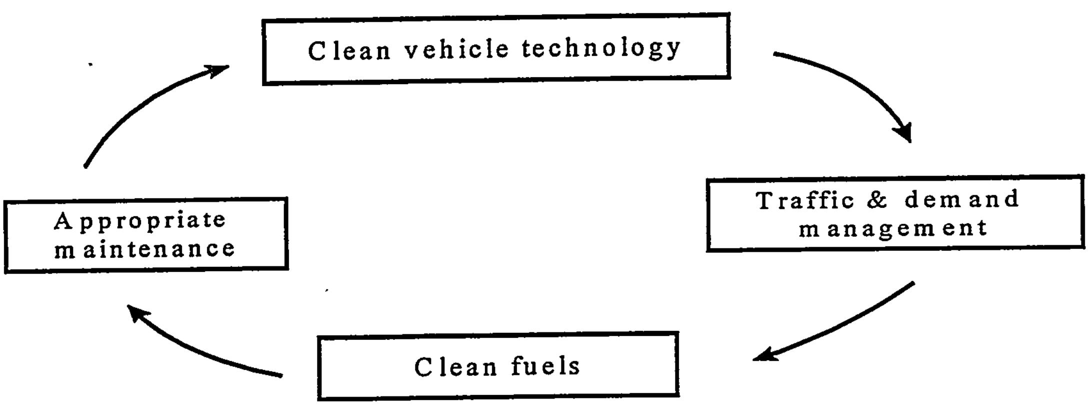
Part III

5 Measures to Control Motor Vehicle Pollution

The purpose of this chapter is to summarize possible measures that could be used to ameliorate air pollution from road traffic based on experience worldwide.

Strategies include both lowering emissions per kilometer driven and reducing actual driving. Some of these strategies - introducing alternative fuels, vehicle inspection and maintenance, vehicle demand management, etc. - are cost-effective.

Figure 5.1 Elements of a comprehensive vehicle pollution control strategy



Source: Stares and Liu (1996)

5.1 Reducing Emissions Per Kilometer Driven

All of the measures discussed below are consistent with those abatement measures mentioned in the previous chapter (see 4.3.1).

5.1.1 Fuel Modification and Alternative Fuels

Conventional vehicle fuels have undergone substantial modification in recent decades and will likely to be improved even more in the future; in parallel, alternative fuels such as ethanol, methanol, natural gas and liquefied petroleum gas (LPG) continue to receive attention.

Gasoline

- The major trend underway worldwide is the gradual reduction of lead in gasoline, both to reduce lead emissions and to facilitate the use of pollution control technologies such as catalytic converter. China already introduced unleaded gasoline in Beijing, Shanghai and Guangzhou in 1997 and has decided to gradually phase in unleaded gasoline throughout China by 2000. This measure involves also providing an infrastructure for distribution of unleaded gasoline (see footnote 8 on page 26). In line with carrying out this measure, the Guangzhou Government has promulgated a penalty rule that aims at charging a RMB3,000 - RMB10,000 ($348 - $1160) fine on each filling station if it is found to be selling leaded gasoline; and charging a RMB200 ($23) fine on owners of the gasoline-fueled cars if they are found to be using leaded gasoline (People's Daily, Overseas Edition).
- Other planned improvements in gasoline fuel quality include eliminating low-octane gasoline (82 RON production), raising the octane level by increasing the use of reformate, oxygenates, alkylates, and other high-octane blending components, and using detergents to control deposits in gasoline-fueled engines. These will allow the use of modern engines.

Diesel Fuel

Modifications to diesel fuel composition have now also drawn considerable attention as quick and cost-effective means of reducing emissions from existing vehicles. The two modifications that show the most promise are a reduction in sulfur content and a reduction in the fraction of aromatic hydrocarbons in the fuel.

Although the sulfur content in domestically produced diesel fuel is already low, its quality is still poor due to low stability and a high aromatic content. Therefore, it will not be difficult to control sulfur dioxide emission from diesel-fueled vehicles, but it will be difficult and expensive to achieve proper particulate emission standards.

Alternative Fuels (for buses)

Alternative fuels can make a significant contribution to improve air quality (some 70 percent reduction in vehicle exhaust gases, People's Daily, Overseas Edition) and are increasingly playing a role in urban areas. Most often, these fuels are used by special groups of vehicles that can have a large impact on the environment (such as transit buses or taxicabs) and can be fueled at central locations, thus minimizing the need for a widespread fueling infrastructure.

Guangzhou is one of the first three Chinese cities[12] that has attempted to phase into use so called "green cars" (cars fueled by alternative fuels). According to

12 The other two cities are Shengzhen in Guangdong Province and Haikou in Hainan Province.

Eskeland's study (1996), alternative fuels are definitely the cheapest measures to reduce emissions from transport in Mexico City. Therefore, Guangzhou has to keep the tempo and try to take the lead in using alternative fuels to curtail air pollution in China.

5.1.2 Improving Car Quality

Applying Catalytic Converters (especially for in-use cars)

Widespread use of unleaded fuel will permit the introduction of new environmental standards that can only be met by requiring motor vehicles to be equipped with catalytic converters. Although the rest of the world uses vanadium and similar rare minerals as the catalyst, China has an abundance of lower-priced alternative minerals that could function almost as well, so the increase in initial vehicle costs will be negligible (The World Bank, 1997).

The Guangzhou Government has to compel the owners of gasoline-fueled cars (both new and old cars) to have their cars equipped with catalytic converters since cars without them will make the engines fueled by unleaded fuel work inefficiently.

Stringent Standards (for all new cars)

Emission tests of new vehicle models should be carried out by an agency that is independent of vehicle manufacturers and is responsible for air quality, such as the Chinese National Environmental Protection Agency. Emission standards should be revised more frequently, giving manufacturers incentives to improve the emissions performance of their products. Once a system for distributing unleaded gasoline is in place, much stricter standards requiring the use of the catalytic converters should be introduced. Testing of in-use vehicles needs to be more stringent and uniform, at least in the urban areas.

Inspection and Maintenance

Today's vehicles in the urban Guangzhou are absolutely dependent on properly functioning emission controls to keep pollution levels low. The Inspection and Maintenance (I/M) programs have demonstrated to reduce emissions from existing vehicles in two ways:

- By lowering emissions from the vehicles that fail the test and are required to be repaired.
- By encouraging the owners to take proper care of their vehicles and to avoid the potential cots of repairing the vehicles that have been tampered with or misfueled.

Stares and Liu (1996) estimated that a well-run I/M program would result in significant emission reductions, in the order of 25 percent for HC and CO and about 10 percent for NO_x.

In this respect, the Guangzhou Government can learn from Hong Kong. Since the air pollution problem in Hong Kong is primarily excess particulates, a trained small group of smoke inspectors patrol the streets, identifying vehicles with excess smoke and requiring them to be repaired or paid a fine. Such a program requires minimal capital investment and resources.

Scrapping the Old Cars

This policy aims at encouraging car owners to replace their old cars by paying them an amount of money or allowing them to avoid some registration fees when they buy new cars. The Guangzhou Government has already carried out this measure and they also may learn something more from Singapore.

5.2 Reducing Actual Driving: Demand Management

Demand management should be aimed at making the best use of an existing infra-structure, incorporating environmental costs, and responding to the demand for new facilities. The tools of demand management, pricing and regulatory measures are designed to make people's travel choices take into account the economic consequences of their actions. They aim to manipulate demand by avoiding both excess use and overloaded infrastructure on the one hand and unnecessary duplication and underuse of capacity on the other.

All of the measures discussed below are consistent with those demand management measures mentioned in the previous chapter (see 4.3.2).

5.2.1 Vehicle Ownership Controls

Vehicle ownership controls seek to limit the size of the vehicle fleet by either fiscal or regulatory means, in an attempt to restrict the number of vehicles accessing the road system. Several approaches are possible.

Vehicle Ownership Taxation

Taxes are commonly raised on vehicles both at the time of vehicle purchases, and annually or monthly thereafter for all vehicles maintained in use. These taxes and fees are independent of the amount of usage - they apply equally to all vehicles, whether they are used every day or once a month. The principal function of the taxation is to raise government revenue, but they also have the effect of making ownership of vehicles more expensive, thereby making it cost prohibitive for some.

Additional vehicle ownership-related purchase fees, annual licensing fees and residential parking fees can be imposed with the objective of making the owner-ship of a vehicle even more expensive and thereby further restricting the total size of the vehicle fleet. This policy has been used very successfully in both Hong Kong and Singapore.

Since today's private ownership of passenger cars is low in the urban Guangzhou, and most cars are enterprise-owned, a discriminating ownership taxation is absolutely necessary.

Box 1 Experience of Singapore: vehicle registration and licensing

1. The expense of owning and operating a vehicle in Singapore has served as a dampener to the growth in the vehicle fleet. The car owners wishing to register their cars must pay a 45 percent import duty on the car's open-market value (OMV), a registration fee of $1,000 for a private car ($5,000 for a company-registered car) and an Additional Registration Fee (ARF) of 150 percent of the OMV.
2. In addition, car owners pay annual road taxes based on the engine capacity of their vehicle. The road tax of company-registered cars is twice as high as for individuals.
3. For diesel vehicles, a diesel tax that is 6 times the road tax of an equivalent gasoline vehicle is paid.
4. To encourage people to replace their old cars with newer, more efficient models, a Preferential Additional Registration Fee (PARF) system was introduced in 1975.

- Private car owners who replace their cars within 10 years are given PARF benefits that they can use to offset the registration fees they have to pay for their new cars.
- For cars registered before November 1, 1990, a fixed PARF benefit would be given upon deregistration based on the engine capacity of the car.
- For cars registered on or after Nov. 1, 1990, the PARF benefits would vary according to the age of the vehicle at deregistration.
- To provide a higher PARF benefit to car owners who deregister their cars before 10 years, all PARF-eligible cars registered on or after November 1, 1990 receive higher fees if the vehicle is newer.

Source: Stares and Liu (1996)

Vehicle Quotas

Vehicle quotas can be used to restrict growth of the vehicle fleet to a fixed number of vehicles per year. Quotas are currently used widely in Chinese cities to control the number of motorcycles, taxis, and enterprise-owned vehicles in use. In the urban Guangzhou, the number of new motorcycles is now capped at 12,000 vehicles per year.

Singapore successfully combines quotas and pricing to restrict the growth of the motor vehicle fleet to 3 percent per year. Purchasers of new vehicles must first obtain a Certificate of Entitlement, of which a fixed number are auctioned to the highest bidder each month. This, combined with other duties, taxes and fees, increases the cost of cars to about five times their CIF value (all are imported).

Box 2 *Experience of Singapore: vehicle quota system*

As high taxes alone would not ensure that the vehicle fleet grow at an acceptable rate, a vehicle quotas system was introduced to achieve that objective. Since May 1, 1990, any person who wishes to register a vehicle must first obtain a vehicle entitlement in the appropriate vehicle class, through bidding. Tender for specified number of vehicle entitlement is conducted monthly. Successful bidders pay the lowest successful bid price in the respective category in which they bid. A vehicle entitlement is valid for 10 years from the date of registration of the vehicle. On expiration of the vehicle entitlement, if the owner wishes to continue using the vehicle, he needs to revalidate the entitlement for another five or ten years by paying a revalidation fee (pegged at 50 percent or 100 percent of the prevailing quota premium, respectively).
Source: Stares and Liu (1996)

5.2.2 Controls on Vehicle Use

Controls on vehicle use offer the opportunity to be more discriminating in the management of traffic demand. A large number of methods are available, which vary greatly in their sophistication. For ease of discussion, they are grouped into four overall classifications: non-pricing access controls, basic pricing, parking controls, and area pricing; but in reality there are many overlaps between them.

Non-Pricing Access Controls

A widely used method of eliminating unwanted traffic is simply to ban vehicle use. The scope of such bans varies greatly, ranging from time-based restrictions on selected vehicles on parts of some streets, to complete and permanent areawide bans. A range of such measures are discussed below.

Traffic management measures

Traffic management measures are designed to make the best use of space to accommodate demand with minimal investment in new infrastructure. Using traffic engineering, traffic control, and traffic enforcement to manage traffic flow, the traffic management gives priority to the movement of people rather than vehicles. Street capacity in Guangzhou can be increased by installing junction improvements and traffic signals, creating bus lanes, controlling on-street parking, and introducing one-way streets and other traffic flow measures.

Bus services are particularly vulnerable to traffic congestion and need protection. Bicycles which play an essential role in the city-center transport should not mix with motorized traffic. Therefore, it makes sense to divide the existing road space among road users, segregating buses, bicycles and other road vehicles to the extent possible. This means protecting specific roads or sections of roads for exclusive use by buses or bicycles, at least for critical periods in the day. At the same time, all of the motorists and bicyclists have to obey the traffic rules and drive or ride well in their respective lanes. A fine should be charged on those who break the rules.

The Guangzhou Government should also have an overall control on its city planning, considering all aspects when they planning to construct a new commercial center, a new residential area or a new public infrastructure project. They must learn the lessons that poor city planning has caused on the environment (see chapter 2).

Areawide bans

Bans on certain types of vehicles entering the city center during daytime hours are quite common. For example, Milan in Italy bans private cars from the city center between 7:30 am and 4:30 pm. In Hong Kong, goods vehicles of any type are banned from the Mid-Levels, a major residential area, during the morning and evening peak hours when passenger vehicle flows are greatest. In Guangzhou, access to the center by heavy goods vehicles is generally restricted to night time hours.

Odd-even number plates

Several cities, including Athens, Lagos, and Mexico City, impose restrictions on the days on which selected vehicles can operate, based on the date and the number plate: Vehicles with even-number plates operate on even dates, and vehicles with odd-number plates operate on odd dates. It is currently applied in some larger Chinese cities (such as Guangzhou) as a means of limiting the access of light goods vehicles to the city centers.

Basic Pricing

Fuel and related car use taxes

Virtually all countries impose duties and taxes on fuel as a general revenue-raising measure. Increasing these duties is an administratively simple traffic control measure, directly affecting the cost of using vehicles and thereby reducing usage.

Overall, however, fuel taxes are very low in China compared to most of the other countries in the world and there are excellent arguments for increasing them from current levels. The impact of curbing excessive vehicle usage would be a useful side benefit.

Toll roads

In many countries, including China, tolls are commonly charged on expressways, bridges and tunnels in both urban and rural areas in order to collect revenues for financing construction and maintenance. Tolls also affect traffic volumes using the tolled facilities, and can be used to control the volume of traffic demand.

The Guangzhou Government has already introduced such tolls on a few river bridges[13]. It should also introduce them on main roads which run toward

13 Guangzhou Municipality imposed differential tolls in 1990 to adjust traffic levels between five river bridges. Two new bridges with tolls built outside the main city center in the 1980s supplemented three

downtown in order to control traffic volume to the downtown area and therefore make traffic flow better. Tolls as means of controlling traffic demand in the urban areas are most effective when the tolled facilities cross a natural barrier with no parallel non-tolled routes.

Prices for passing through toll roads could be differentiated according to vehicle types. For example, prices for passing through toll roads by public transportation (with the possible exception of taxis) could be set lower than for other types. Since the Guangzhou Government currently puts emphasis on controlling growth of the motorcycle fleet, they can set the price for passing through toll roads for this vehicle type much higher than for other types. In this way, the growth of the motorcycle fleet could be controlled in a more effective and market-oriented manner than by enforcement measures alone. The possibility of establishing a black market for the quotas would be low and it would be difficult to obtain a motorcycle through bribery. For enterprise-owned cars, the price for passing through toll roads should be set higher since the price elasticity for such cars is possibly low.

Singapore was the first country that introduced the toll system and was also the only country by 1994 that did not use the collected toll money primarily for financing the infrastructure, but merely to control traffic volume. The Singapore scheme, as modified over time, has been very successful (for more detailed information on this, see Stares and Liu, 1996). The traffic volumes in the central area have been reduced so that average speeds in the central area are around 30 km/h (Stares and Liu, 1996).

Parking Controls

The areas of highest traffic congestion tend to be major business and shopping districts. Therefore, controls on vehicle parking could be used to limit the number of trips made to these districts by cars. However, the parking capacity in the urban Guangzhou is low, so the Government is actually planning to build more parking spaces. The Government must also strictly control parking so that its adverse effects will not be significant in the years to come.

Area Pricing

Area pricing aims to charge motorists for the use of roads in selected districts, with the highest charges for the most congested districts. Frequent users of busy roads would accumulate high charges, but the more casual motorists, by careful selection of times and routes, could avoid road charges altogether. The practical effects should be less traffic on busy roads as motorists avoid the higher-priced congested districts.

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older bridges inside the city center that were untolled. Finding that traffic on the two new tolled bridges was very light, they imposed tolls on all five bridges, thereby shifting traffic to the new bridges. Overall, traffic on the old bridges reduced by 25 percent, and overall cross-river travel by 12 percent.

Although there are many overlaps between toll and area pricing measures, the principal difference between them lies in how the collected money is used. The former aims at using the collected toll money for financing new road projects. The latter aims at paying the social-economic costs the traffic causes which are not covered by other taxes imposed on road-users (Silborn, Solheim et al,1996).

Singapore has demonstrated the benefits of area pricing. Furthermore, what they have accomplished thus far has made little use of advanced technology, demonstrating that technology need not be the driving force behind effective area pricing, even if it has the potential to make it more efficient. All of this would give good arguments for initiating area pricing schemes in Guangzhou.

5.3 Public Investment and the Supply of Infrastructure

All of the measures discussed below are consistent with the public transportation measures mentioned in the previous chapter (see 4.3.4).

5.3.1 Investment in Public Transportation

Due to poor public transportation, the Guangzhou Government has planned to invest about RMB1.1 billion ($0.13 billion) in public transportation by the end of 2000. It has also planned to invest RMB3.1 billion ($0.36 billion) during 2001-2010 to avoid further deterioration in travel speeds and an increase in congestion-induced pollution. Among the total investment, RMB1.9 billion ($0.22 billion) will go to investment in new buses, aiming at improving service quality and frequency so that commuters will not be attempted to turn to the use of cars. The Government plans also to invest RMB1.2 billion ($0.14 billion) in timing traffic signals according to the flow of traffic in the urban Guangzhou during 2001-2010 (The Guangzhou Planning Committee (1996)).

The Government must keep the service of the Metro Line One to a high standard, and should fulfill the proposed construction plans of the Metro Line Two and Three according to its 21 century-blueprint.

5.3.2 The Road Building Measure

In general, new road construction on its own will not solve the traffic congestion problem - traffic will tend to fill up all available road space. The overwhelming conclusion from all experience of motorization to date is that if the road system is made more efficient, or of greater capacity, yet more motorists will be attracted to using it until congestion once again in the results. Since most transport improvements are incremental, the effect is that any new capacity gained is swallowed up by new traffic sooner or later, seeming to render all efforts (and particularly small-scale efforts) useless.

Hence, the conclusion is that the road transport demand will always exceed the supply of road space, no matter how well managed and how efficiently used. Therefore, the Guangzhou Government has no alternative but considering ways of controlling and managing the demand for road space.

6 A Case Study

This chapter gives an application of the theoretical framework through a case study. I will choose five measures among those discussed in chapter 5: a reduction of sulfur content in diesel fuel measure, bus lane measure, taxation measure, toll road measure and metro measure, and study their cost-effectiveness regarding PM_{10} emission reductions. I will also attempt to draw a supply curve of the selected measures based on their cost-effectiveness.

6.1 Calculation of the Cost-Effect Ratios of the Selected Measures

In order to work out the cost-effect ratios of these measures, I have to have access to both the cost of carrying out the measures and the accompanying effects. However, China is at an early stage in curtailing ambient air pollution problems, and it is very difficult for me to find relevant data to fulfill the cost-effective evaluation. I hope readers still remember those assumptions of transferability mentioned in chapter 3 where I adopted results of studies worldwide on valuing health damages of PM_{10} pollutant. Therefore, I may use the same arguments for adopting the relevant data from other countries, for example from Norway, to my cost-effective evaluation of the selected measures here.

Of course, Norway and China are quite different in many respects. The results I will receive by using the Norwegian data may be not reliable. For instance, they may give misleading information that it could make a measure more expensive to carry out than it actually is. However, it does give us some interesting results of those measures which are relatively cost-effective and should be carried out with first priority.

In the case study, I will only look at the effects on reducing PM_{10} emission because I only looked at the health damages of PM_{10} in Chapter 3. This will of course have a negative effect on accuracy of the cost-effect ratios, since the health benefits of reducing PM_{10} emissions are only a small part of the total benefits that those measures will bring.

Under the calculation of cost-effect ratios which are given in section 6.1.1 to section 6.1.5, I will disregard exchange rate between Norwegian Kroner and Chinese Ren Min Bi. The reason for this is that the exchange rate between these two currencies is almost equal to 1 (Norwegian Kroner is worth slightly more than

Chinese Ren Min Bi). By using an exchange rate of 1 to 1, I counteract the tendency caused by using Norwegian data to overstate the costs.

I also assume that all gasoline-fueled cars have already been equipped with catalytic converters. But this may not be the case necessarily, hence resulting in an underestimate of emission reductions.

6.1.1 Measure of Reducing Sulfur Content in Diesel Fuel

Reducing the sulfur content in diesel fuel leads to a proportional decline in sulfur dioxide emission (approximately 17,000 tons in 1992). PM_{10} emission also decreases because a part of the particulates comes from sulfur in the fuel (Larssen et al., 1997). How dose this measure help curtail air pollution problems in the urban Guangzhou? The following steps give a detailed description of the way I worked out the cost-effect ratio.

Step I: Converting investment cost into average annual cost

The Institute of Norwegian Petroleum (INP) estimated that the investment cost of reducing the sulfur content from 0.2 percent to 0.05 percent in diesel fuel was about NOK1.3 billion (the data was offered by Inger Lise Nøstvik at INP by telephone). Since such investment will usually have greater effects over the years, I have to convert the investment cost into an average annual cost under the calculation of cost-effect ratio. The average annual cost can be roughly worked out by Equation 6-1:

Equation 6-1 $q = (r + \delta) * P$

where

q is user cost of capital

r is interest rate

δ is rate of depreciation

P is total investment cost

Assume that r is equal to 10 percent and δ is equal to 5 percent, then the average annual cost of reducing sulfur content in diesel fuel is about NOK195 million or RMB195 million for the sake of simplicity.

Step II: Calculating total emission reductions

The reduction of sulfur content in diesel fuel is estimated to result in a 13 percent reduction in PM_{10} emission for heavy-duty cars (>3.5 ton) and a 2.5 percent reduction for light-duty cars (<3.5 ton) (The data was offered by Inger Lise Nøstvik at INP by telephone).

Therefore, the total emission reductions of PM_{10} pollutant a year by the diesel-fueled cars (include only minibuses, buses and goods vehicles) due to carrying out this measure can be calculated by the following equation:

Equation 6-2 *Total emission reductions of PM_{10} pollutant a year =*

$$\sum_{i=1}^{3} \textit{Emission factor of vehicle type}_i * \textit{percentage reduction of } PM_{10} \textit{ by a vehicle of type}_i * \textit{driving mileage of the vehicle of type}_i * \textit{total number of vehicles of type}_i$$

i = 1 for minibuses, 2 for buses and 3 for goods vehicles

STEP III Working out cost-effect ratio

The cost - effect ratio is equal to the quotient between the results of Step I and II.

The result of the cost-effect ratio is shown in Table 6.1 (the results of Step I and II are summarized in Table A.1 in Appendix 3).

Table 6.1 *Cost/effect ratio of reducing sulfur content in diesel fuel*

	Diesel-fueled cars (minibuses, buses and goods vehicles)
Cost/effect ratio (thousands of RMB per ton)	1590

6.1.2 Taxation Measure

How does this measure help curtail air pollution problems in the urban Guangzhou? The following steps are required to calculate the cost-effect ratios under alternative scenarios by varying the tax rate.

Step I: Calculating total costs imposed on owners of each vehicle type

Demand for fuel oil by each vehicle of $type_i$ can be expressed by Equation 6-3:

Equation 6-3 $F_i = U_i * P^{\varepsilon_i}$

where: F is consumption of the fuel oil by a vehicle of $type_i$ a year (liter/year)

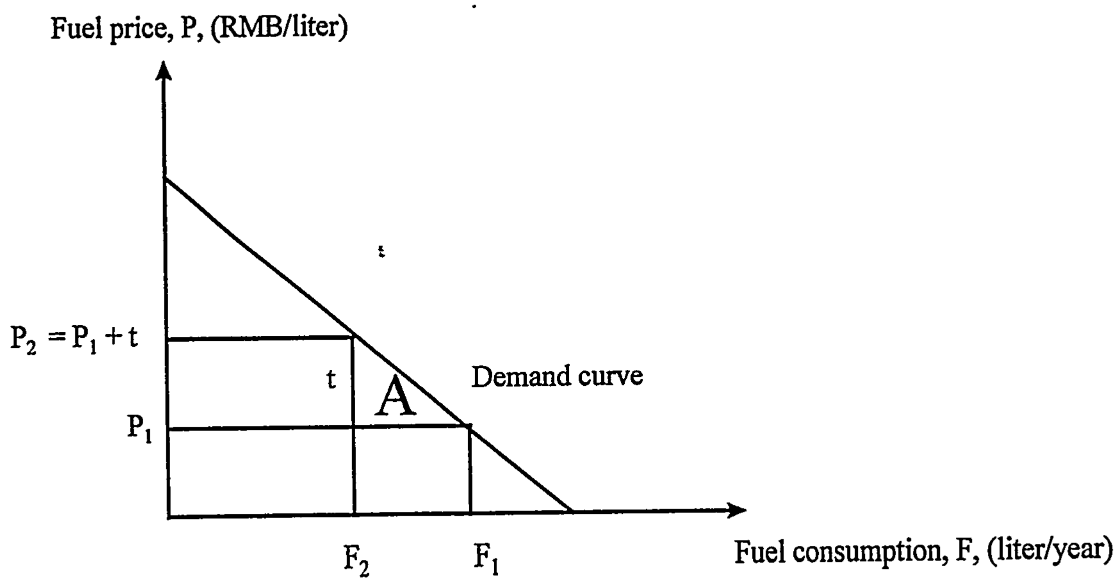
P is price of the fuel oil, (RMB/liter)

ε is fuel price elasticity

U is a constant

i = 1 for taxis, 2 for motorcycles, 3 for passenger cars, 4 for minibuses, 5 for buses and 6 for goods vehicles

Figure 6.1 A demand curve for fuel consumption



Cost of levying a tax rate on fuel oil imposed on each owner of vehicle $type_i$ is equal to the size of triangle "A" under the demand curve in Figure 6.1. It can be calculated by Equation 6-4.

Equation 6-4 $$A = \int_{P_1}^{P_2} U_i * P^{\varepsilon_i} dP - F_{2i} * t = \frac{U_i}{\varepsilon_i + 1}\left(P_2^{\varepsilon_i+1} - P_1^{\varepsilon_i+1}\right) - U_i * P_2^{\varepsilon_i} * t$$

where: $P_{1,\,gasoline} = 2.55$ RMB/liter

$P_{1,\,diesel} = 2.35$ RMB/liter

$t = 0.5$ RMB/liter (t is the tax rate)

The fuel price elasticities for taxis, motorcycles, passenger cars, minibuses, buses and goods vehicles are assumed to be -0.3, -0.5, -0.3, -0.1, -0.1, and -0.1, respectively[14].

By altering the tax rate and therefore the value of P_2, I can calculate the costs imposed on each owner of vehicle $type_i$ under the different tax rate scenarios.

The results of Equation 6-4 under the different scenarios are summarized in Table A.2 in Appendix 3. Care should be taken that the figures calculated above are the annual costs imposed on one owner of vehicle $type_i$ under the different scenarios, and they should be multiplied by total number of vehicles of $type_i$ in order to get the total annual costs imposed on all of the vehicle owners (since all of the owners are affected by this measure).

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14 Here I also assume that the cross price elasticities are zero.

Step II: Calculating total emission reductions

Equation 6-5 *Total emission reductions of PM_{10} pollutant by vehicles of $type_i$ = emission factor of vehicle $type_i$ * reduction in driving mileage by a vehicle of $type_i$ due to this measure * total number of vehicles of $type_i$ = emission factor of vehicle $type_i$ * (reduction in annual fuel consumption by the vehicle of $type_i$ / fuel consumption per km by the same vehicle) * total number of vehicles of $type_i$*

Step III: Working out cost/effect ratio

The cost-effect ratio for each vehicle type is simply equal to the quotient between the total costs imposed on the owners of vehicle $type_i$ and the total emission reductions by the vehicles of $type_i$.

The results of the cost-effect ratios under the different tax rate scenarios are summarized in Table 6.2.

Table 6.2 Cost/effect ratios of the taxation measure

	Gasoline-fueled cars with catalytic converters			Diesel-fueled cars		
				Light-duty cars	Heavy-duty cars	
	Taxis	Motor-cycles	Passenger cars	Mini-buses	Buses	Goods Vehicles
Cost/effect ratio under Alt.1 (thousands of RMB per ton)	5767	2388	5768	107	74	56
Cost/effect ratio after Alt1 has come into effect (thousands of RMB per ton)	17803	7405	17803	330	228	171
Cost/effect ratio after Alt.2 has come into effect (thousands of RMB per ton)	29829	12418	29829	553	383	287

6.1.3 Toll Road Measure

How does the toll road measure help curtail air pollution in the urban Guangzhou?

Costs imposed on the vehicle owners of introducing toll roads are two-fold: The first one is a share of the annual construction cost of such road composed of several toll houses that each owner of vehicle $type_i$ has to bear; the second one is an extra driving cost of passing through the toll roads.

I will give a detailed description of the way I worked out the cost-effect ratio for the passenger cars (enterprise-owned cars) below. The way I worked out the cost-effect ratios for the other vehicle types is similar. For the sake of simplicity, I assume that there is one and only one toll house located on a most used trunk road running toward downtown area of the urban Guangzhou.

Step I: Calculating total passing trips by passenger cars a year

1. Assume that one passenger car passes through the toll road once a day (no matter which direction), and there are 250 (working) days that this car is in use, then the total passing trips made by this car are 250 a year. If it costs RMB5 ($0.58) per trip to pass through the toll road, the annual cost imposed on this owner is hence equal to RMB1250 ($145).

2. By multiplying the result calculated above by total number of passenger cars, I get the total trips that all of the passenger cars pass through the toll road a year.

Step II: Working out consumption of fuel oil by passenger cars

Suppose that a passenger car uses 0.12 liter gasoline per kilometer on average (the data is estimated by Eirik Wærness at ECON), and its driving mileage averages 15,000 kilometer a year, then the average annual consumption of gasoline by this car is 1800 liter. If the gasoline costs RMB2.55 ($0.30) per liter, then the annual cost of gasoline consumption is RMB4590 ($532).

Step III: Working out a percentage increase in driving cost (ΔP/P) caused by this measure

ΔP is the extra driving cost the owner (of a passenger car) has to pay for passing through the toll road and is equal to RMB1250 ($145) a year. P is the gasoline cost imposed on the owner disregarding the toll road and is equal to RMB4590 ($532). Therefore the percentage increase in driving cost that each passenger car owner incurs is equal to 1250/4590=27%.

Step IV: Calculating cost of passing through the toll road imposed on the owners of passenger cars

- The cost imposed on each owner can be calculated by Equation 6-6 (in the same way as levying a tax on fuel oil):

Equation 6-6 Cost of passing through the toll road imposed on each owner of the passenger car a year =

$$\int_{P_1}^{P_2} U_i * P^{\varepsilon_i} dP - (P_2 - P_1) * F_{2i} = \frac{U_i}{\varepsilon_i + 1}\left(P_2^{\varepsilon_i+1} - P_1^{\varepsilon_i+1}\right) - (P_2 - P_1) * F_{2i}$$

Assume that the price elasticity for passenger cars is -0.3, $P_{1,\text{ gasoline}} = 2.55$ RMB/liter, and $P_{2,\text{ gasoline}} = P_{1,\text{ gasoline}} + P_{1,\text{ gasoline}} * 27\%$.

- Then, the total costs of passing through the toll road imposed on all of the owners of passenger cars are equal to Equation 6-6 multiplied by the total number of passenger cars.

Step V: Calculating construction cost of the toll road and a share the passenger car owners incur a year

1. The average annual construction cost of one toll road is equal to the total investment cost corrected by interest rate and depreciation rate. Based on the total investment costs of 19 toll roads in Oslo, Norway, I can easily work out the average annual construction cost of one toll road. It is equal to NOK 255 million multiplied by 15% and then divided by 19 toll roads (the investment cost is quoted from Silborn, Solheim et al., 1996).

2. The purpose of this measure is to restrain the vehicle owners from driving, then all of them have to incur a share of this physical construction cost which can be calculated by the following equation:

Equation 6-7 *The share of construction costs imposed on the passenger car owners a year = the average annual cost * percentage of the passing trips made by the passenger cars a year to the total passing trips made by all of the vehicles of each type a year*

Step VI: Calculating the total costs imposed on all of the passenger car owners due to carrying out this measure

The total costs are equal to sum of the results of Step IV and V.

Step VII: Calculating total emission reductions

Equation 6-8 *Total emission reductions of PM_{10} (by passenger cars)= emission factor * reduction in driving mileage by a passenger car a year* total number of passenger cars = emission factor * (reduction in annual fuel consumption by this car / fuel consumption per km) * total number of the passenger cars*

Step VII: Working out the cost/effect ratio

The cost - effect ratio is equal to the quotient between the total cost (result of Step VI) and the total emission reductions (result of Step VII).

Similarly important assumptions for working out the costs imposed on owners of the other vehicle types are as follows:

- The trips that one taxi passes through the toll road are 10 a day, and the driving days are 365 a year. It costs RMB5 per passing trip.
- The trips that one motorcycle passes through the toll road are 2 a day, and the driving days are 365 a year. It costs RMB5 per passing trip.
- The trips that one minibus passes through the toll road are 2 a day, and the driving days are 365 a year. It costs RMB1 per passing trip.
- The trip that one bus passes through the toll road is 1 a day, and the driving days are 365 a year. It costs RMB1 per passing trip.

- The trips that one goods vehicle passes through the toll road are 2 a day, and the driving days are 250 a year. It costs RMB5 per passing trip.
- The price elasticities for taxis, motorcycles, mini-buses, buses and goods vehicles are -0.3, -0.5, -0.1, -0.1 and -0.1, respectively.

The results of the cost-effect ratios are shown in Table 6.3.

Table 6.3 Cost/effect ratios of the toll road measure

	Gasoline-fueled cars with catalytic converters			Diesel-fueled cars		
				Light-duty cars	Heavy-duty cars	
	Taxis	Motor-cycles	Passenger Cars	Mini-buses	Buses	Goods vehicles
Cost/effect ratio (thousands of RMB per ton)	11688	18174	8276	104	60	71

6.1.4 Metro Measure

A 18.4-kilometer-long Metro Line One opened to traffic in Guangzhou on October 1, 1997. The total investment cost was around RMB12.715 million ($1.41 million) (The Guangzhou Planning Committee, 1996) and the estimated passenger traffic is 362 millions of people a year (this data is actually an estimate of Shenzhen metro made by a research group on Pricing the Chinese Natural Resources, 1997).

How does the metro measure help tackle air pollution problems in the urban Guangzhou?

Let me calculate the cost-effect ratio by the following steps:

Step I: Where do the Metro passengers come from?

Based on the current urban transportation mode (see Figure 1.4), I assume that 7 percent of the metro passengers come from people who take taxis today, 10 percent from today's motorcyclists, 20 percent from people who take buses today, 20 percent from people who take mini-buses today, 40 percent from today's bicyclists, 2 percent from people who walk and 1 percent from people who take passenger cars (enterprise-owned cars).

Step II: Driving mileage saved per Metro passenger because of his/her changing to the Metro

1. Assume that the length of a trip each passenger could take by metro is about half of the total length of the metro, e.g. 10 kilometers. If the passenger does travel by metro instead of by other transportation means (except bicycle and

walk), the driving mileage saved per trip by this passenger is then 10 kilometers.

2. How many passengers share a taxi, a motorcycle, a passenger car, a minibus, and a bus, respectively?
   - It is quite usual that more than one person sits on a motorcycle in the urban Guangzhou. Suppose that half of the motorcyclists drive alone and the other half drive with a friend, the average is hence 1.5 persons per motorcycle.
   - Assume that a minibus carries 15 passengers on average and a bus carries 40 passengers on average.
   - Assume that a taxi or a passenger car takes only 1 passenger each.

3. By taking the quotient between 10 kilometers and the number of passengers sharing their respective vehicles, I get the driving mileage saved per metro passenger. For example, the driving mileage saved by a motorcyclists would be 6.67 kilometers if he/she stopped driving and changed to the Metro.

Step III: Total driving mileage saved a year

Equation 6-9 *Total driving mileage saved by passengers from transportation mean$_i$ a year = driving mileage saved per passenger from transportation mean$_i$ (solution of Step II) * number of passengers from transportation mean$_i$ changing to the metro (solution of Step I)*

Step IV: Total emission reductions of PM_{10} pollutant

Equation 6-10 *Total emission reductions of PM_{10} pollutant = $\sum_{i=1}^{5}$ emission factor of vehicle type$_i$ * total driving mileage saved by passengers from transportation mean$_i$ a year (solution of Step III)*

where, i = 1 for taxis, 2 for motorcycles, 3 for passenger cars, 4 for minibuses, and 5 for buses.

Step V: Calculating the cost/effect ratio

The result of the cost-effect ratio is shown in Table 6.4

Table 6.4 *Cost/effect ratio of the metro measure*

	Sum of taxis, Motorcycles, passenger cars, minibuses and buses
Cost/effect ratio (thousands of RMB per ton)	39813

6.1.5 Bus Lane Measure

How does the bus lane measure help curtail air pollution in the urban Guangzhou?

Step I: Converting the investment cost of marking existing roads into the average annual cost

- The estimated investment cost of marking existing roads so that they can be exclusively used by transit buses is RMB30,000 ($3480) per kilometer based on a similar Norwegian data (Silborn, Solheim et al., 1996).
- If there is a need for expanding an existing road, the cost is estimated to be one third of the cost of building a new road (for example, it is estimated to cost NOK3-5 million per kilometer road in Norway!) (Silborn, Solheim et al., 1996). However, I will not look at this case here.
- Suppose that the total length of such bus lanes is 50 km.

The average annual cost of marking the existing roads is therefore calculated by Equation 6-11:

Equation 6-11 *Average annual cost of marking the existing roads = total investment cost per km * 50 km * 0.15*

Step II: Calculating total emission reductions of PM_{10} pollutant

A relationship between a bus' driving speed and its emission factor was found by a Danish study. It shows that, on average, a bus emits 1.4 g/km at a speed of 15 km/h and 1.1 g/km at a speed of 20 km/h (Silborn, Solheim et al., 1996). Suppose that the average driving speed for a bus can be increased from 15 km/h to 20 km/h due to carrying out the bus lane measure[15]. This results in 0.3 gram (or 300 mg) reduction of PM_{10} emission per kilometer driven. Therefore, the total emission reductions in PM_{10} pollutant can be worked out by the following equation:

Equation 6-12 $\textit{Total emission reductions of } PM_{10} = \sum_{i=1}^{2} \textit{emission reduction of } PM_{10} \textit{ per kilometer driven by a vehicle of type}_i * \textit{driving mileage of the vehicle of type}_i * \textit{total number of vehicles of type}_i \textit{ using the bus lanes}$

where, i = 1 for minibuses and 2 for buses

Here I assume that the number of minibuses using the bus lanes as a major part of their routes is only one tenth of the total number of minibuses. The same proportion holds for buses.

Step III: Calculating the cost/effect ratio

The result of the cost-effect ratio is summarized in Table 6.5.

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15 For the sake of simplicity, I assume that, on average, buses' driving speeds increase from 15 km/h to 20 km/h. It means that the driving speeds increase to 20 km/h not only on the bus lanes but also on other mixed lanes, therefore I can use Equation 6-12 to calculate the emission reductions by buses. Otherwise, I have to have data for the mileage that the buses drive on the bus lanes, which is difficult to find.

Table 6.5 Cost/effect ratio of the bus lane measure

	Diesel-fueled cars (minibuses and buses)
Cost/effect ratio (thousands of RMB per ton)	43

6.2 Rank of the Selected Measures Based on Their Cost-Effectiveness

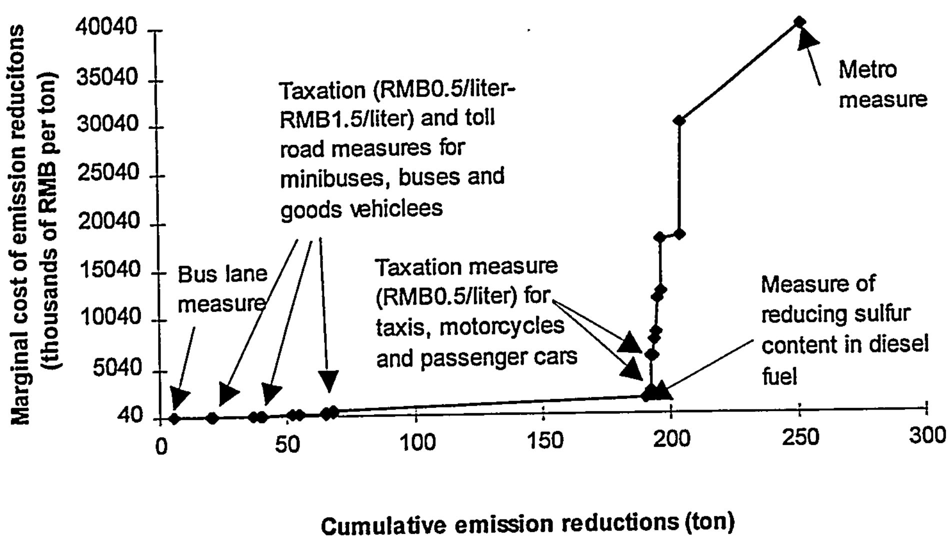
Table 6.6 and Figure 6.2 show the rank of the five selected measures and a supply curve of emission reductions based on their cost-effectiveness, respectively.

Table 6.6 Rank of the selected measures by their cost-effectiveness

	Cumulative emission reductions (ton)	Marginal cost (thousands of RMB per ton)	Emission reduction (ton)	Cumulative cost (thousands of RMB)
1. Bus lane measure	5	43	5.30	226
2. Taxation measure under Alt.1 (e.g. t_1=0.5RMB/liter) for goods vehicles (GV)	20	56	15.00	1061
3. Toll road measure for buses	20	60	0.11	1068
4. Toll road measure for goods vehicles (GV)	36	71	16.00	2208
5. Taxation measure under Alt.1 (e.g. t_1=0.5RMB/liter) for buses	40	74	3.30	2452
6. Toll road measure for minibuses	40	104	0.07	2460
7. Taxation measure under Alt.1 (e.g. t_1=0.5RMB/liter) for minibuses	40	107	0.37	2499
8. Taxation measure after Alt.1 has come into effect (e.g. t_2=1 RMB/liter) for goods vehicles (GV)	52	171	12.00	4556
9. Taxation measure after Alt.1 has come into effect (e.g. t_2=1 RMB/liter) for buses	55	228	2.70	5173
10. Taxation measure after Alt.2 has come into effect (e.g. t_3=1.5 RMB/liter) for goods vehicles (GV)	65	287	10.00	8043
11. Taxation measure after Alt.1 has come into effect (e.g. t_2=1 RMB/liter) for minibuses	65	330	0.30	8142
12. Taxation measure after Alt.2 has come into effect (e.g. t_3=1.5 RMB/liter) for buses	67	383	2.30	9022
13. Taxation measure after Alt.2 has come into effect (e.g. t_3=1.5 RMB/liter) for minibuses	68	553	0.30	9188
14. Measure of reducing sulfur content in diesel fuel	190	1590	122.65	204188
15. Taxation measure under Alt.1 (e.g. t_1=0.5 RMB/liter) for motorcycles (MC)	192	2388	1.54	207865
16. Taxation measure under Alt.1 (e.g. t_1=0.5 RMB/liter) for taxis	192	5767	0.47	210576
17. Taxation measure under Alt.1 (e.g. t_1=0.5 RMB/liter) for passenger cars	193	5767	0.24	211960
18. Taxation measure after Alt.1 has come into effect (e.g. t_2=1 RMB/liter) for motorcycle (MC)	194	7405	1.20	220846
19. Toll road measure for passenger cars	194	8276	0.33	223577
20. Toll road measure for taxis	195	11688	0.86	233629

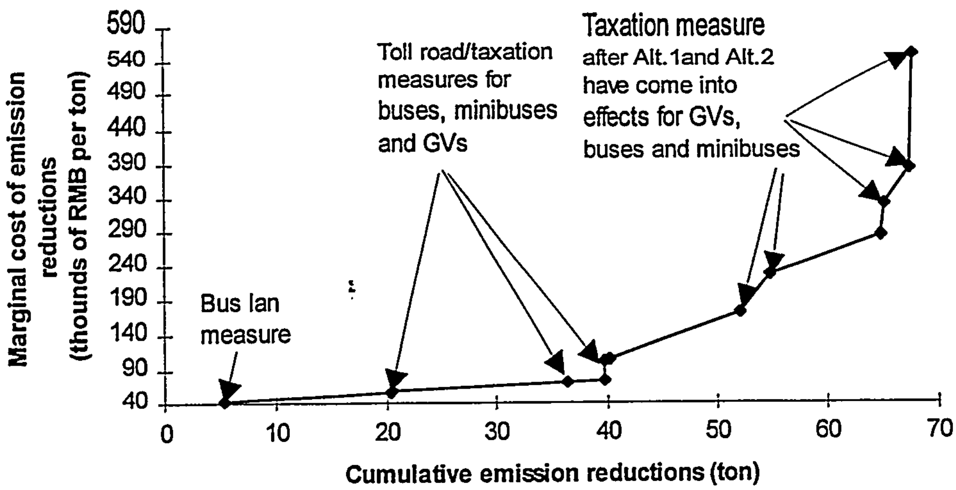
21. Taxation measure after Alt.2 has come into effect (e.g. t_3=1.5 RMB/liter) for motorcycles (MC)	196	12418	0.97	245674
22. Taxation measure after Alt.1 has come into effect (e.g. t_2=1 RMB/liter) for taxis	196	17803	0.40	252795
23. Taxation measure after Alt.1 has come into effect (e.g. t_2=1 RMB/liter) for passenger cars	197	17803	0.20	256356
24. Toll road measure for motorcycle (MC)	204	18174	7.42	391207
25. Taxation measure after Alt.2 has come into effect (e.g. t_3=1.5 RMB/liter) for taxis	204	29829	0.32	400752
26. Taxation measure after Alt.2 has come into effect (e.g. t_3=1.5 RMB/liter) for passenger cars	205	29829	0.16	405525
27. Metro measure	253	39813	48.00	2316570

Figure 6.2 Supply curve for emission reductions from transport in the urban Guangzhou

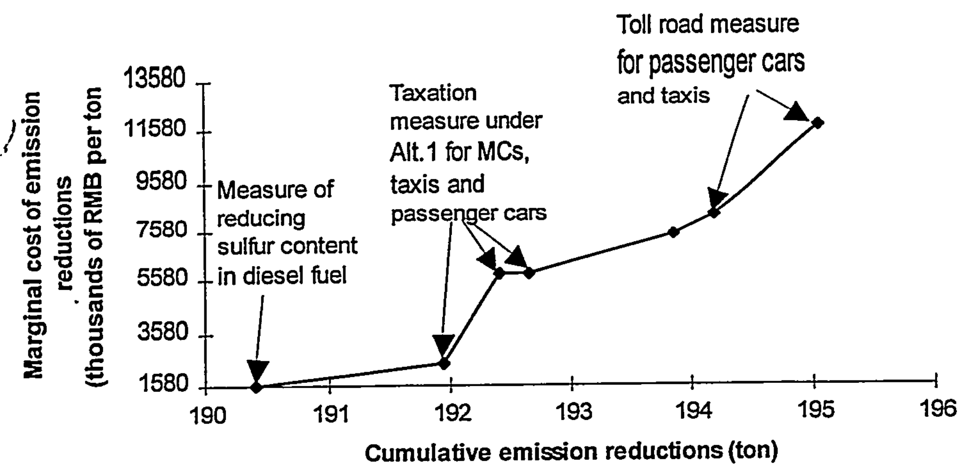


Since these measures are very expensive and their marginal costs of emission reductions vary very much, I will therefore divide the measures into three groups according to their marginal costs and draw a supply curve for each group in order to give the readers a better understanding of the measures.

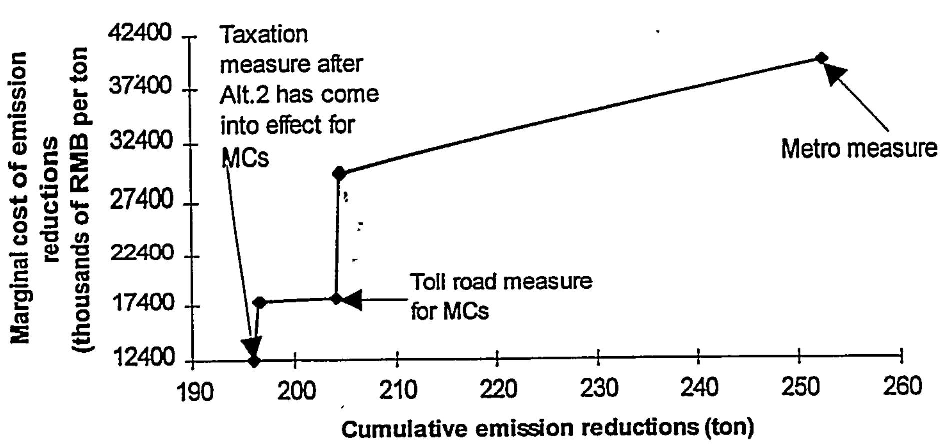
a: Marginal cost < RMB 553,000 per ton



b: Marginal cost between RMB 1,590,000 to RMB 11,688,000 per ton



c: Marginal cost between RMB 12,418,000 to RMB 39,816,000 per ton



6.3 Summary of the Five Selected Measures

Based on the results shown in Table 6.6 and Figure 6.2, I find the following interesting results:

Bus lane measure for both minibuses and buses is the most cost-effective measure

- The reasons why this is true are two-fold: first of all, I assumed under the calculation, that the Government does not expand any roads, but only mark the existing roads so that they can be exclusively used by the transit buses. Therefore the annual cost of this measure is definitely the lowest one among all of the measures listed in Table 6.6 (also compare with Tables A.1 - A.5 in Appendix 3). Secondly, I supposed that the average driving speed for 10 percent of the buses and 10 percent of the minibuses could be increased from 15 km/h to 20 km/h not only on the bus lanes, but also on other mixed lanes. However, this should not be the case necessarily and will likely overestimate the emission reductions.
- No matter what, this measure is the most cost-effective one based on my calculation (under certain simplified assumptions), therefore it should be carried out with first priority.
- This measure has also other positive effects:
  - Traffic security is improved. Information on 91 bus lanes in residential areas in Sweden shows that the buses have a 25 percent lower risk of traffic accidents per million kilometers driven on the bus lanes than on the mixed lanes. Traffic security for bicyclists also improves (Silborn, Solheim et al., 1996).
  - Better traffic flow for public buses will improve the public transportation and will also reduce operation costs for the public transportation companies. Calculations from Oslo show that a 20 percent higher driving speeds for buses can reduce the operating costs in an order of NOK100 million a year (Silborn, Solheim et al.,1996).
- However, this measure will have a negative impact on other motorized traffic, for example, the average driving speeds for passenger cars could be reduced, which may result in more emissions. This impact will be disregarded.

The cost-effective evaluation of this measure gives us an indication that measures of improving traffic flow are likely to be very cheap.

Toll road measure for buses, minibuses and goods vehicles is the next cost-effective measure

Under the calculation of the cost-effect ratio of this measure, I assumed that there is one and only one toll house located on the most used trunk road running towards downtown area in the urban Guangzhou. Of course, if there are many toll roads spreading on all of the trunk roads which run towards downtown area, vehicles will pass through them more often, and it will also improve the cost effectiveness of this measure.

The most interesting results here are that the toll measure for taxis, passenger cars and motorcycles are very expensive. The main reasons for this are as follows:

1. Vehicles of each of these three types pass through the unique toll road much more often than those of the other three types through a year, which results in:
   - (i) higher share of the annual construction cost that owners of each of these three vehicle types have to bear
   - (ii) higher costs of passing through the toll road imposed on the owners (the differentiated prices for passing through the toll road for these vehicles also contribute to the higher costs).
   - (iii) However, the costs of fuel consumption they incur are not high because these types of vehicles use less fuel than the others. Reasons (ii) and (iii) cause higher percentage increases in the driving costs to the owners of each of these three types, and hence lower cost-effectiveness.
2. Different price elasticities for different vehicle types.
   - The price elasticity will affect the slope of the demand curve. Under the calculation procedure, I assumed that the price elasticities for taxis, passenger cars and motorcycles are -0.3, -0.3 and -0.5 respectively, which are higher than those for the other three vehicle types (-0.1 for each). A higher price elasticity implies a flatter demand curve, therefore a higher cost imposed on the owner (see Figure 6.1), and then a lower cost-effectiveness.
   - The reason why I assumed a low price elasticity for the passenger cars is that the private ownership of passenger cars is quite low (see chapter 1), while the ownership of the enterprise-owned cars is high. Usually the enterprises consider the prices less important when they buy cars than the private owners do. The reason why I assumed a high price elasticity for motorcycles is that most of them are privately owned.

Taxation measure for buses, minibuses and goods vehicles under three alternatives by raising the tax rate from RMB0.5 /liter to RMB1.5/liter is the third cost-effective measure.

The most interesting results here are the same as the toll measure reveals, i.e. the taxation measure for taxis, passenger cars and motorcycles even under Alternative One is quite expensive. I think the main reason for this is that the price elasticities for different vehicle types affect the slope of the demand curve.

Because the marginal cost of raising the tax rate increases as the tax rate raises, so does the cost-effect ratio of each vehicle type under the different alternatives.

The taxation measure and toll measure indicate that the basic pricing measures are cost-effective, especially for minibuses, buses and goods vehicles.

Measure of reducing the sulfur content in diesel fuel is an expensive measure

This result seems to be reasonable since Eskeland (1996) and Larssen (1997) found the similar results in their respective studies. As the number of vehicles increases in Guangzhou, the cost-effect ratio will likely to decrease.

Metro measure is the most expensive measure

The main reasons lie in where the metro passengers come from (see 6.1.4). Based on my assumption, there are few metro passengers from people who take the "polluting transportation means" such as passenger cars, taxis and motorcycles. However, there are many people who walk or use bicycles as the alternative. This results in less emission reductions. As the car ownership increases in the future, there will be probably more passengers from the "polluting transportation means", particularly from private-owned cars (enterprise-owned cars), changing to the metro, which will result in greater emission reductions and improve the cost effectiveness of the metro measure.

Another reason could be that the main purpose of the metro measure sometimes aims at making the city more modern and flexible rather than merely making the city cleaner. Hence I can not merely rank this measure based on its cost-effectiveness concerning emission reductions in the short term. Its effect on air pollution could be a side effect, and is likely to be more significant and last over the decades.

6.4 A Comparison with the Theory

- The value of $-C'_a / X * m'(a)$ in the theory is just the cost-effect ratios of various technical abatement measures in the case study; for instance, a reduction of sulfur content in the diesel fuel.
- If, for example, the World Bank found that the utility of emission reductions would be, say RMB1,500,000 per ton, then all of the abatement measures with cost-effect ratios less than RMB1,500,000 are good. The value of shadow price, γ, in the theory is just RMB1,500,000 in the case study.
- The metro measure is only relevant when neither the abatement measures (for example, reducing sulfur content in the diesel fuel) nor the demand management measures (for example, taxation measure) could be applied optimally. This is consistent with the theory (cf. Equation 4-29 and Section 4.4).

A similar argument applies for the demand management measures and the traffic management measures.

Part IV

7 Concluding Remarks

This chapter attempts to give the Guangzhou Government a recommendation on those measures which are the most cost-effective and should be carried out with first priority (based on my calculation under certain simplified assumptions). I will finish the thesis with suggesting some further improvements of the results.

7.1 Recommendation to the Guangzhou Government

Based on the cost-effect analysis of the five measures, I will give the Guangzhou Government the following recommendations:

- The first priority action should be to mark the existing roads so that they can be used exclusively by the transit buses.
  - Other similar measures can be to separate bicycles completely from today's mixed traffic lanes. Although this measure is already in use in the urban Guangzhou, it is not as effective as it should be, partly due to the enormous bicycle fleet, bad behavior in riding, and also bad behavior in driving the motorized cars by motorists. Therefore, a more stringent fine system for bicyclists and motorists who break the rule must come into effect.
- The second priority action should be to build toll roads and levy a tax rate on fuel oils. These measures have not been used in Guangzhou so far, while they are extensively used in other countries around the world. For example, the fuel taxation in Norway, a country with a rich resource of crude oil, is among the highest in the world at 46 percent of 1997 market price (The Institute of Norwegian Petroleum, 1997). These measures will have greater effects in a well-functioned market. Since Guangzhou is one of the leading cities in China which has succeeded in transitioning to a market-oriented economy, the Government can take huge advantages of implementing these measures.
- Development of an efficient public transportation is of great need. The Guangzhou Government has to implement a public transportation strategy rather than build more roads or use an automobile-based strategy. A new study on China (The World Bank, 1997) showed that the public transportation option would be about 17 percent less costly than the automobile-oriented strategy. The experience of Singapore proves this. Singapore's

success in controlling the motor vehicle fleet and air pollution is in large part dependent upon the support of many initiatives in urban transport planning - strong traffic management, good public transportation including both buses and metros, effective infrastructure provision for a clear plan that include bypasses around the designated area, and effective pricing policies.

- Cleaner fuel and introducing alternative fuels in Guangzhou should be considered in the long term.

7.2 Further Improvements of the Results

- More precise emission factors for cars must be estimated
  - Under the calculation of the cost-effect ratios, I applied Norwegian emission factors for cars models from 1980s. This will not be a proper application for Chinese cars and will likely lead to underestimates of the emission reductions.
- Comprehensive environmental benefits including noise, material damage, vegetable damage, ecosystem, etc. brought about by the measures must be estimated.
- More precise investment costs of implementing the measures must be available.
- More precise price elasticities for fuel oil and car ownership must be estimated.
- Other non-market benefits and costs should be estimated, such as the effects on road congestion.
- Time to build and future costs and benefits should be estimated; for example, for the metro measure.
- More measures should be considered and evaluated by their cost-effectiveness.

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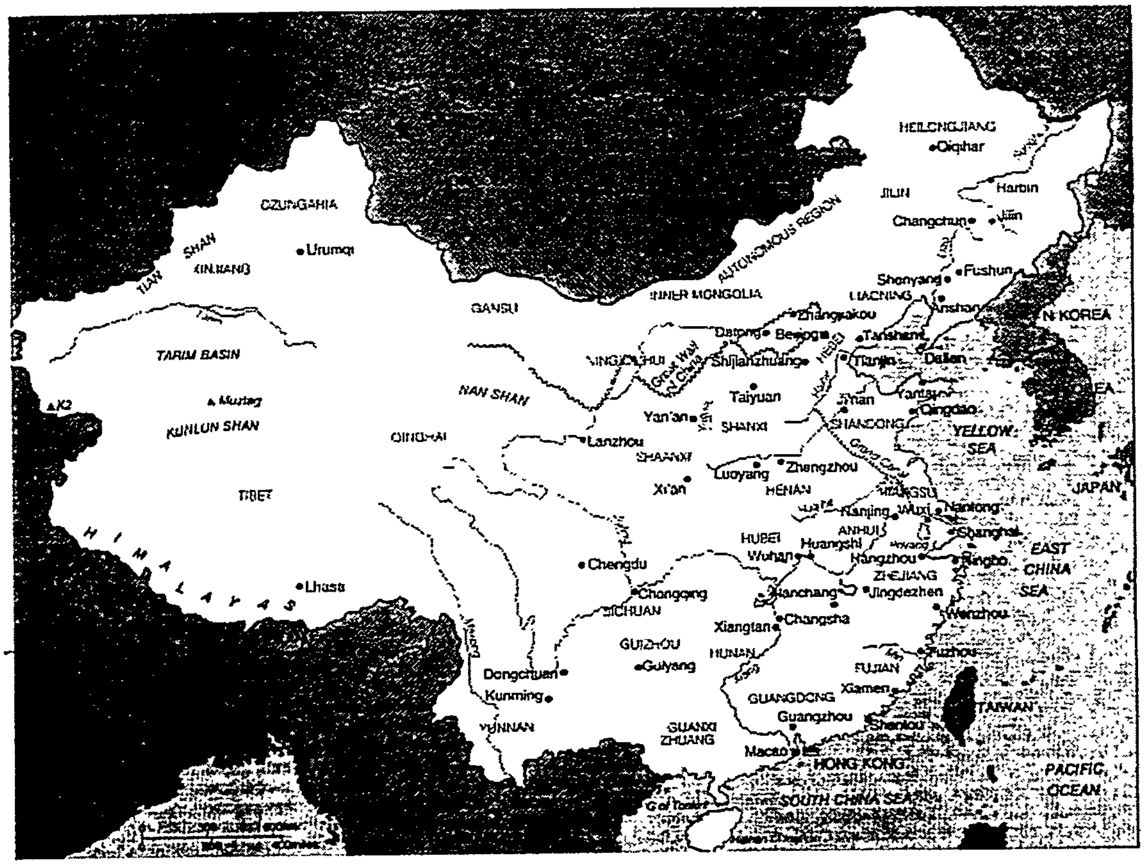
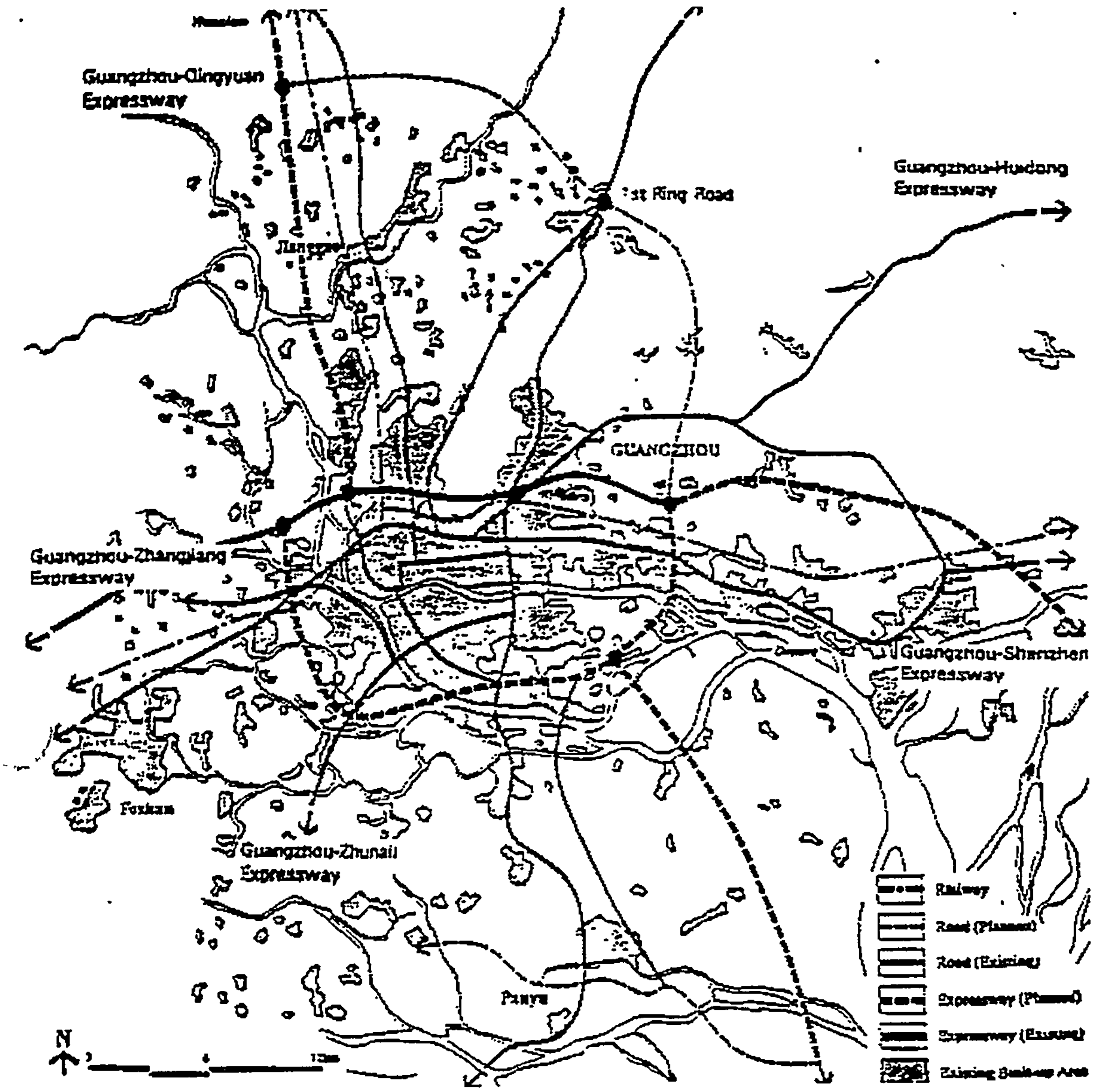
Appendix I: Maps

Figure A.1 A map of China



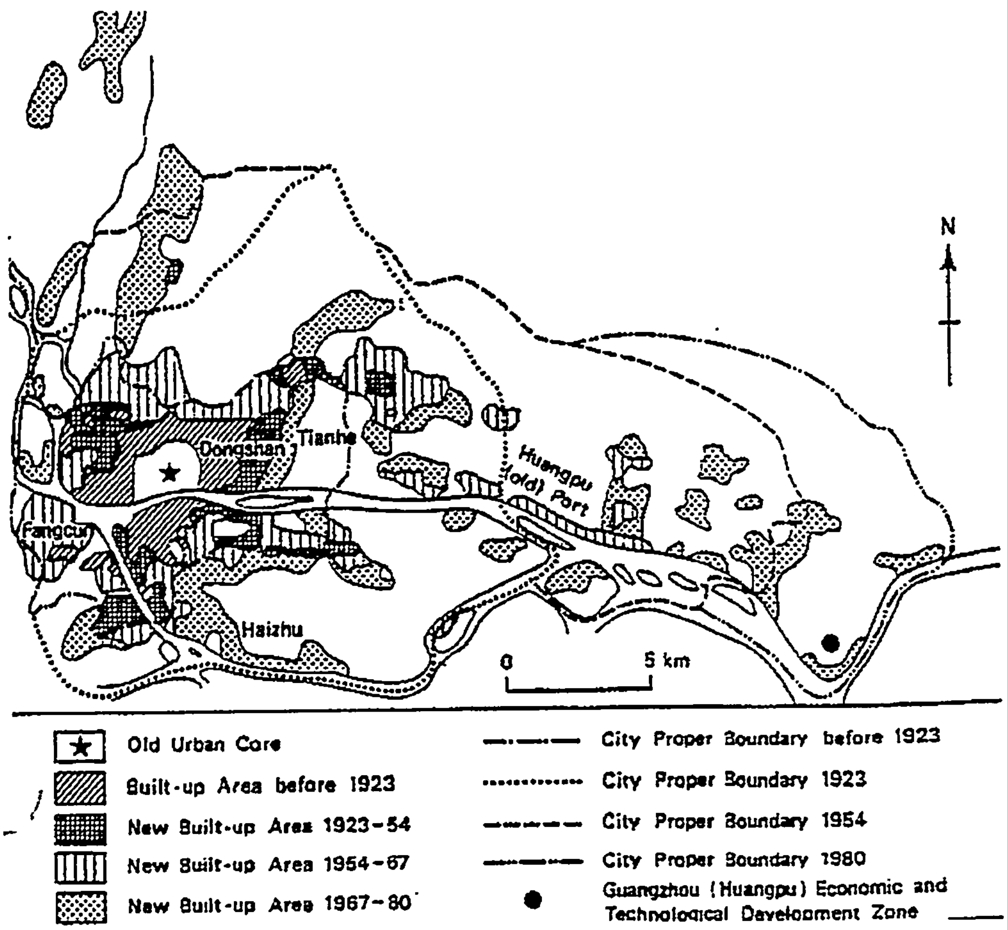
Source: Briggs (1992)

Figure A.2 Transport network of Guangzhou



Source: MacPherson and Cheng (1996)

Figure A.3 Spatial expansion of Guangzhou



Source: MacPherson and Cheng (1996)

Appendix II: Migration and Floating Population

Over the past decades greater employment opportunities and higher living standards have lured China's peasants to the cities in unprecedented numbers. This migration creates new challenges for China's rural and urban economics.

- Floating population
  - Floating population is defined as mainly legal migrants - that is, those with permits or those who commute on a daily basis. This definition excludes/ignores those who migrate illegally (the World Bank, 1997).
  - The floating population in China was less than 10 million in 1985; while it was 60-80 million in 1989.
  - The floating population tends to be concentrated by area and appears to vary widely across counties and even villages. Most of them find their jobs through family and other informal connections, and these connections are mostly at the village level. Only 15% of migrants find jobs through formal channels, such as local labor bureaus and employment offices.
  - Most migrants are young, unmarried, and work in blue-collar and service jobs. The average migrant is less educated than the general population but more educated than the rural population. They migrate because job opportunities are abundant and their migration costs are low. The construction sector absorbs the largest share of migrant workers, followed by manufacturing, light assembly and services.
  - Causes of growth in floating population:
    - √ increasing land fragmentation, growing population, and decline of cultivable land has created large surplus labor (about 200 million people in late 1980s);
    - √ rapid growth of township and village enterprises and other private companies offer economic opportunities for workers;
    - √ rapid growth of cities and attraction of cities for rural workers in terms of employment and living conditions;
    - √ policy biases favoring cities and special economic zones;
    - √ about 65 percent of floating population makes up of temporary migrants.
- Impact on urban areas
  - Migration has had positive effects on both rural and urban economies. Evidence dose not indicate that migration has a negative effect on agricultural productivity, and it is stimulating the rural economy in many ways. While migration's effect on urban infrastructure, congestion, crime, and other problems is clearly negative, in many ways these negative effects are outweighed by the positive contributions migrants make to urban economies.

Appendix III Calculation Results of the Cost-Effect Ratios of the Selected Measures

Table A.1 Measure of reducing sulfur content in the diesel fuel

	Diesel-fueled cars			
	Light-duty Cars	Heavy-duty Cars		
	Mini-buses	Buses	Goods Vehicles	Sum
Emission factor of vehicle type$_i$ (mg/km)[1]	450	1300	1300[a]	
Emission reduction per km driven by vehicle of type$_i$ (mg/km)[2]	11.25	169	169	
Driving mileage of a vehicle of type$_i$ a year (km/year)[3]	40000	60000	15000	
Total number of vehicles of type$_i$ in 1994[4]	1068	2214	39339	
Total emission reductions by vehicles of type$_i$ a year (ton/year)	0.48	22.45	99.72	122.65
Average annual cost of the measure[5] (RMB)				19500000 0
Cost/effect ratio (RMB/ton)				1589826

Note: a. weight composition is: 3.5-10t: 40%, 10-20t: 40% and >20t: 20%

Sources:
1. Larssen (1991)
2. The data were offered by Inger Lise Nøstvik at IPN via telephone
3. A research group on Pricing Chinese Natural Resources (1997)
4. Guangzhou Statistical Yearbook (1995)
5. The data was offered by Inger Lise Nøstvik at IPN via telephone

Table A.2 Taxation Measure

	Gasoline-fueled cars with catalytic converters			Diesel-fueled cars		
				Light-duty cars	Heavy-duty cars	
	Taxis	Motorcycles	Passenger cars	Mini-buses	Buses	Goods Vehicles
Diving mileage of a vehicle of type$_i$ (km/year)[1]	150000	15000	15000	40000	60000	15000
Unit fuel consumption by vehicle of type$_i$ (liter/km)[2]	0.12	0.05	0.12	0.20	0.40	0.30
Total fuel consumption by a vehicle of type$_i$ per year, F_{1i} (liter/year)	18000	750	1800s	8000	24000	4500
Total number of vehicles of type$_i$ in 1994[3]	12000	2309331	62309	1068	2214	39339
$U_i = F_{1i} / P_{1j}^{e_i}$ $P_{1, gasoline}$=2.55 (RMB/liter), $P_{1,diesel}$=2.35(RMB/liter)	23836.06	1197.65	2383.61	8713.58	26140.75	4901.39
$P_{1j}^{e_i+1}$,	1.93	1.60	1.93	2.16	2.16	2.16
$P_{2j}^{e_i+1}$, $P_{2, gasoline}$=2.55+0.5(RMB/liter), $P_{2, diesel}$=2.35+0.5 (RMB/liter)	2.18	1.75	2.18	2.57	2.57	2.57
Fuel consumption after a tax rate of 0,5RMB/liter is levied, $F_{2i} = U_i * P_{2j}^{e_i}$	17058.65	685.77	1705.86	7847.16	23541.47	4414.03
Tax revenue (RMB/year), $t_1 * F_{2i} = t_1 * U_i * P_{2j}^{e_i}$	8529.32	342.89	852.93	3923.58	11770.73	2207.01
Cost imposed on a vehicle owner of type$_i$ under Alt.1, t_1=0.5RMB/liter: $U_i/(e_i+1) * (P_{2j}^{e_i+1} - P_{1j}^{e_i+1}) - t_1 * F_{2i}$	226.21	15.34	22.62	36.86	110.58	20.73
Total cost imposed on all of the owners of vehicle type$_i$ under Alt.1 (RMB/year)	2714563.98	35420749.51	1409514.72	39367.00	244827.34	815655.71
$P_{3j}^{e_i+1}$ $P_{3, gasoline}$=2.55+1 (RMB/liter) $P_{3, diesel}$=2.35+1 (RMB/liter)	2.43	1.88	2.43	2.97	2.97	2.97
Fuel consumption after a tax rate of 1 RMB/liter is levied, $F_{3i} = U_i * P_{3j}^{e_i}$	16299.19	635.65	1629.92	7721.33	23164.00	4343.25
Tax revenue (RMB/year), $t_2*F_{3i}=t_2*U_i*P_{3j}^{e_i}$	16299.19	635.65	1629.92	7721.33	23164.00	4343.25
Cost imposed on a vehicle owner of type$_i$ under Alt2. t_2 = 1RMB/l: $U_i/(e_i+1)*(P_{3j}^{e_i+1}-P_{1j}^{e_i+1}) - t_2*F_{3i}$	789.56	52.46	78.96	130.30	390.89	73.29
Total cost imposed on all of the owners of type$_i$ under Alt.2, (RMB/year)	9474768.19	121141025.61	4919694.42	139155.98	865425.10	2883211.21

$P_{4j}^{e_i+1}$ $P_{4, gasoline}$=2.55+1.5 (RMB/liter) $P_{4, diesel}$=2.35+1.5 (RMB/liter)	2.66	2.01	2.66	3.36	3.36	3.36
Fuel consumption after a tax rate of 1,5 RMB/liter is levied, $F_{4i} = U_i * P_{4j}^{e_i}$	15667.44	595.12	1566.74	7614.66	22843.99	4283.25
Tax revenue (RMB/year), $t_3*F_{4i}=t_3*U_i*P_{4j}^{e_i}$	23501.16	892.68	2350.12	11421.99	34265.98	6424.87
Cost imposed on a vehicle owner of $type_i$ under Alt.3, t_3 = 1.5 RMB/l: $(U_i/e_i+1)*(P_{4j}^{e_i+1}-P_{1j}^{e_i+1})$ - t_3*F_{3i}	1574.74	102.79	157.47	262.95	788.86	147.91
Total cost imposed on all of the owners of $type_i$ under Alt.3, (RMB/year)	18896936	237366054	9812076	280834	1746536	5818681
Emission factor of vehicle $type_i$ (mg/km)[4]	5	5	5	450	1300	1300
One vehicle's emission reduction under Alt.1 (mg/year)	39223.00	6422.53	3922.30	343898.97	1490228.85	372557.21
Total emission reductions by vehicles of $type_i$ under Alt.1 (ton/year)	0.47	14.83	0.24	0.37	3.30	14.66
One vehicle's emission reduction under Alt.2 (mg/year)	70867.03	11435.13	7086.70	627000.36	2717001.56	679250.39
Total emission reductions by vehicles of $type_i$ under Alt.2 (ton/year)	0.85	26.41	0.44	0.67	6.02	26.72
One vehicle's emission reduction under Alt.3 (mg/year)	97189.98	15488.10	9719.00	867007.75	3757033.59	939258.40
Total emission reductions by vehicles of $type_i$ under Alt.3 (ton/year)	1.17	35.77	0.61	0.93	8.32	36.95
Cost/effect ratio under Alt.1 (RMB/ton)	5767372	2388169	5767372	107184	74204	55653
Cost under Alt2 - Cost under Alt1	6760204	85720276	3510179	99788	620597	2067555
Emission reduction under Alt.2 - Emission reduction under Alt.1	0.38	11.58	0.20	0.30	2.72	12.07
Cost/effect ratio after Alt1 has come into effect	17802734	7405166	17802734	330042	228490	171368
Cost under Alt3 - Cost under Alt.2	9422168	116225029	4892382	141678	881111	2935470
Emission reduction under Alt.3 - Emission reduction under Alt.2	0.32	9.36	0.16	0.26	2.30	10.23
Cost/effect after Alt.2 has come into effect	29828753	12417673	29828753	552722	382654	286990

Source: 1. A research group on Pricing Chinese Natural Resources (1997)

2. Eirik Wærness at ECON

3. The Guangzhou Planning Committee (1996)

4. Larssen (1991)

Table A.3 Toll road measure

	Gasoline-fueled cars with catalytic converters			Diesel-fueled cars			
				Light-duty cars	Heavy-duty cars		
	Taxis	Motor-cycles	Passenger Cars	Mini-buses	Buses	Goods vehicles	Sum
Driving mileage of a vehicle of $type_i$ a year[1], (km/year)	150000	15000	15000	40000	60000	15000	
Unit fuel consumption by vehicle of $type_i$ (liter/km)[2]	0.12	0.05	0.12	0.2	0.4	0.3	
Annual fuel consumption by a vehicle of $type_i$, F_{1i} (liter/year)	18000	750	1800	8000	24000	4500	
Trips that one motor vehicle passes through one toll road a year	3650	730	250	730	365	500	
Total number of motor vehicles of $type_i$ in 1994[3]	12000	239331	62309	1068	2214	39339	
Total trips that all of the motor vehicles pass through the toll road a year	43800000	174711630	15577250	779640	808110	19669500	2.6E+08
Cost of passing through the toll road imposed on a owner of $type_i$ a year (RMB/year), It costs RMB1 per trip for transit buses, and RMB5 for others	18250	3650	1250	730	365	2500	
Cost of fuel consumption imposed on a owner of $type_i$ a year (RMB/year), Price for gasoline is 2.55 RMB/liter and for diesel is 2.35 RMB/liter	45900	1912.5	4590	18800	56400	10575	
Percentage increase in driving cost imposed on the owners of vehicle $type_i$ (%)	39.76 %	190.85 %	27.23 %	3.88 %	0.65 %	23.64 %	
$U_i = F_{1i} / P_{1j}^{e_i}$	23836.06	1197.65	2383.61	8713.58	26140.75	4901.39	
$P_{1j}^{e_i+1}$ $P_{1,gasoline}$=2.55RMB/L $P_{2, diesel}$=2.35 RMB/L	1.93	1.60	1.93	2.16	2.16	2.16	

$P_{2j}^{e_i+1}$, $P_{2,\ gasoline}$ =2.55*(1+?%) (RMB/liter) $P_{2,\ diesel}$ = 2.35*(1+?%) (RMB/liter)	2.43	2.72	2.28	2.23	2.17	2.61	
Fuel consumption by a vehicle of $type_i$ after the toll road measure is carried out (liter/year), $F_{2i} = U_i * P_{2j}^{e_i}$	16280	440	1675	7970	23985	4406	
Value of fuel consumption reduced = $(P_{2j} - P_{1j}) * F_{2i}$	16506	2140	1163	727	365	2448	
Cost of passing through the toll road imposed on a vehicle owner of $type_i$ a year (RMB/year): $U_i/(e_i+1)(P_{2j}^{e_i+1} - P_{1j}^{e_i+1}) - (P_{2j} - P_{1j})*F_{2i}$	808.78	558.05	41.30	1.38	0.12	25.23	
Cost of passing through the toll road imposed on all of the owners of $type_i$ a year (RMB/year)	9705341	133559829	2573082	1472	260	992379	
Annual construction cost per toll-road (RMB/year)	345321	1377433	122812	6147	6371	155075	2013158
Total cost imposed on all of the owners of $type_i$ due to this measure (RMB/year)	10050662	134937261	2695893	7619	6631	1147454	
Emission factor of vehicle $type_i$ (mg/km)[4]	5	5	5	450	1300	1300	
Emission reduction by one vehicle of $type_i$ a year (mg/year)	71662.12	31022.86	5227.99	68440.33	50299.86	409448.30	
Total emission reduction by vehicles of $type_i$ a year (ton/year)	0.86	7.42	0.33	0.07	0.11	16.11	
Cost/effect ration (RMB/ton)	11687558	18174024	8275932	104229	59547	71238	

Source: 1. A research group on Pricing Chinese Natural Resources (1996)

2. Eirik Wærness at ECON

3. The Guangzhou Planning Committee (1996)

4. Larssen (1991)

Table A.4 Metro measure

	Taxis	Motor-cycles	Passenger cars	Mini-buses	Buses	Sum
Where do the total metro passengers come from?	2.5E+07	36200000	3620000	7.2E+07	7.2E+07	209960000
Driving mileage saved per passenger due to changing to Metro (km)	10.00	6.67	10.00	0.67	0.25	
Total driving mileage saved a year (km)	2.5E+08	241333333	3.6E+07	4.8E+07	1.8E+07	
Emission factor of vehicle type$_i$ (mg/km)[1]	5	5	5	450	1300	
Total emission reductions a year (ton)	1.27	1.21	0.18	21.72	23.53	47.90
Average annual cost[2] (RMB)						1.907E+09
Cost/effect ratio (RMB/ton)						39813449

Source: 1. Larssen (1991)
2. The Guangzhou Planning Committee (1996)

Table A.5 Bus lane measure

	Diesel-fueled cars		
	Light-duty cars	Heavy-duty cars	Sum
	Mini-buses	Buses	
Driving mileage of a bus[1] (km/year)	40000	60000	
Emission reduction in PM10 per km due to bus lane solution[2] (mg/km)	300	300	
Emission reduction in PM10 per bus (mg/year)	12000000	18000000	
Number of buses in 1994[3]	1068	2214	
Total reduction in PM10 emission a year (ton/year)	1.28	3.99	5.27
Annual cost of marking the bus lanes[4] (RMB)			225000
Cost/effect ratio (RMB/ton)			42720

Source: 1. A research group on Pricing Chinese Natural Resources (1997)
2. Silborn, Solheim et al., (1996)
3. Guangzhou Statistical Yearbook (1995)
4. Silborn, Solheim et al., (1996)