Application of Technological Control Measures on Vehicle Pollution: A Cost-Benefit Analysis in China

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Summary

For the past two decades, China has experienced strong, continuous economic growth. At the same time, the number of motor vehicles in China has rapidly increased. As a direct result of such a phenomenon, China has been registering significant increases in air pollution. In spite of recent advances in air pollution control, it remains a serious problem for China's major cities, and constitutes an important issue in the agenda of its policy makers. The object of this paper is to explore the use of cost-benefit analysis (CBA) to evaluate and rank alternative policy scenarios regarding the control of air pollution emitted by motor vehicles. The empirical analysis carried out relates specifically to the Chinese context, over a twenty year period, from 2001 to 2020, and focuses on emission changes of the following three principal pollutants: CO, HC and NOx.

Keywords: Vehicle, Pollution, CO, HC, NOx, Scenario, Standard, Cost, Benefit, China

JEL classification: O33, O53

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1. Introduction

In recent years, China has experienced continuous economic growth. Moreover, there has been a substantial increase in the demand for transportation. The number of vehicles in China has increased at an average annual rate of 15% since 1981. In 2002 and 2003, sales of passenger cars increased by 50% and 75%, respectively. It is predicted that within two years, China will be the world's second-largest new car market. [1].

A direct result of the rapid growth in vehicle numbers is the significant increase in air pollution. In big cities like Beijing, Shanghai and Guangzhou, it was coal combustion that used to cause most air pollution; today the chief source is heavy vehicle pollution. There are three main characteristics of air pollution in China's largest cities (i.e. cities with a population of over two million) nowadays. First, over 50% of NOx is emitted from vehicles in large cities. Second, CO exceeds the national standard in the most traffic congested areas in most large cities. Third, there is a rising potential threat of photochemical smog in large cities [2]. Consequently, controlling air pollution produced by vehicles is now near the top of the policy agenda of Chinese central and local governments in the country's larger cities.

The purpose of undertaking a Cost-Benefit Analysis (CBA) of air pollution produced by vehicles is to apply hard economic reasoning based on an assessment of the efficient allocation of scarce financial resources, aimed at pinpointing and ranking the most effective strategies for controlling pollution. Today, many international policy institutes conduct CBA to assess the relative degrees of efficiency of alternative measures to curb vehicle emission pollution. The main purpose is to identify and assess the economic significance of costs and benefits of unit reductions in pollutants for different vehicle models with regard to the various (cleaner) air policy scenarios under consideration. In the present analysis, we consider the direct costs and expenditure incurred with the use of technological equipment and hardware applied to different vehicle models in order to achieve given air quality standards. In addition, on the benefit side we consider the gains in reduced oil consumption obtained from improved efficiency in different motor models as a direct result of adopting the above mentioned hardware. Owing to lack of data, this paper does not address other benefits such as health benefits in its cost-benefit analysis. Before computing the cost and benefit of controlling vehicle pollution, some essential data and assumptions should be first defined. These will be discussed in detail in the next section.

2. Data and Basic Assumptions

2.1 Identification of the Different Vehicle Models and Respective Characteristics

MOBILE5 model, which is based upon the US Environmental Protection Agency (EPA) DOS-based Mobile5 emission factor model, is used to classify the different vehicle types that will be under analysis in this paper (see Table 1). Because of the efficient control scenario of motorcycles currently in China, it is not necessary for us to design an alternative scenario to substitute the current one. [3] Therefore, we do not take the motorcycle into consideration in this study.

Table 1: Classification of the vehicles

Type	Motor Model
LDGV	Gasoline-fueled light-duty vehicles
LDGT1	Gasoline-fueled light-duty trucks up to 6,ooo pounds
LDGT2	Gasoline-fueled light-duty trucks between 6,001 to 8,500 pounds
HDGV	Gasoline-fueled heavy-duty trucks over 8,500 pounds
LDDT	Diesel-fueled light-duty trucks
LDDV	Diesel-fueled light-duty vehicles
HDDV	Diesel-fueled heavy-duty vehicles over 8,500 pounds

Source: EPA

Table 2 shows the data on annual traveling mileage of motor vehicles in China. The figures are based on the data from the *Regulations on the Management of Motor Vehicles* drawn up by the China Transportation Police Bureau. For instance, the maximum mileages of LDGVs is 500 000 km and the maximum life of LDGVs is 20 years. Therefore the average annual mileage covered by LDGVs is 25 000 km.

Table 2: Average Travel Mileage (per year)

Vehicle Type	LDGV	LDGT1	LDGT2	HDGV	LDDT	LDDV	HDDV
Km	25 000	22 500	20 000	20 000	15 000	15 000	20 000

Source: China Transportation Police Bureau

The unit of efficiency in fuel use is measured in terms of the reduction in oil consumption per mile traveled. Fuel efficiency is the yardstick in assessing the relative benefits of alternative policy strategies. Table 3 gives average fuel economy for each vehicle type. The data are based on the results obtained in the B-9-3 program, an investigation carried out by Tsinghua University, China in 1997. [4] Based on the prices of gasoline and diesel oil in China's domestic market in 2003, we adopt 0.4 UD dollar/liter as the average price of both gasoline and diesel. [5]

Table 3: Average Fuel Economy of Each Vehicle Type (L/100km)

Vehicle Type	LDGV	LDGT1	LDGT2	HDGV	LDDT	LDDV	HDDV	MC
Consumption	9	10.5	12.5	25	13	12	22	2.5

Source: B-9-3 Project

2.2 Identification of the alternative policy scenarios under consideration

Our analysis considers three alternative policy scenarios, namely the standard, middle and strict control scenarios. The standard scenario is based on the regulations of the

Emission Standard for the Pollutants from Vehicles laid down in 1999 by the State Environmental Protection Administration of China. [6] The middle scenario is based on the second control plan of the Beijing Vehicle Exhaust Control Comprehensive Scenario Design drawn up by the Beijing local government authority. [7] It is more stringent than national standards because of the critical situation of vehicle pollution in Beijing and the city's importance as the capital of China. China has been chosen to host the 2008 Olympic Games and owing to the rapid growth in vehicle numbers, many environmental experts are calling upon Beijing to implement stricter control scenarios. The strict scenario in this paper is one of the practical design proposals put forward by the Beijing Gasoline Oil Association. [8] Table 4 shows the details of each scenario.

Table 4: Three Scenarios for the Control of Emissions from New Vehicles

Vehicle Models	Standard Scenario			
	EURO1	EURO2	EURO3	EURO4
LDGV, LDGT1	1/1/1999	1/1/2005	n.a.	n.a.
LDGT2, LDDT, LDDV	1/1/2000	1/1/2005	n.a.	n.a.
HDGV, HDDV	1/1/2000	1/1/2005	n.a.	n.a.
	Middle Scenario			
	EURO1	EURO2	EURO3	EURO4
LDGV, LDGT1	1/1/1999	1/1/2003	1/1/2007	n.a.
LDGT2, LDDT, LDDV	1/1/2000	1/1/2003	1/1/2007	n.a.
HDGV, HDDV	1/1/2000	1/1/2003	1/1/2007	n.a.
	Strict Scenario			
	EURO1	EURO2	EURO3	EURO4
LDGV, LDGT1	1/1/1999	1/1/2003	1/1/2005	1/1/2008
LDGT2, LDDT, LDDV	1/1/2000	1/1/2003	1/1/2005	1/1/2008
HDGV, HDDV	1/1/2000	1/1/2003	1/1/2005	1/1/2010

Source: State Environmental Protection Administration of China, China Energy Foundation and Beijing Gasoline Oil Association.

As indicated in Table 4, China adopts the same vehicle pollution control standards as the European Union. The Euro Emission Standards were introduced in Europe to progressively reduce the amount of harmful pollutants, such as carbon monoxide, hydrocarbons, nitrogen oxides and particulates. In this context, Euro Emission Standards were first introduced in Germany, on 1 October 1990, establishing that only low-emission commercial vehicles were allowed to register for road use. As the plan was to gradually reduce pollutants, EURO1 and EURO2 limits came into effect on 1 Oct 1993 and 1 Oct 1996 respectively, lowering the amount of pollutants allowed in each limit. On Dec 1998, the European Council of Environment Ministers reached an agreement on the final EURO3 standard and also adopted EURO4 and EURO5 for the year 2005 and 2008. Table 5 shows details of the standard limits of the three main pollutants under alternative standards for different vehicle types.

Table 5: Standard Limits Applied for the Various Vehicles

Model	Standard	Limits			
			CO	HC	NOx
Cars g/km	EURO1		3.16	1.13**	
	EURO2		2.2/1.0*	0.5/0.7/0.9***	
	EURO3		2.3/0.64	0.2	0.15/0.5
	EURO4		1.0/0.5	0.1	0.08/0.25
Commercial Vehicles g/km	EURO1	Class1	2.72	0.97	0.14
		Class2	5.17	1.4	0.19
		Class3	6.9	1.7	0.25
	EURO2	Class1	2.2/1.0	0.5/0.7/0.9	
		Class2	4.0/1.25	0.6/1.0/1.3	
		Class3	5.0/1.5	0.7/1.2/1.6	
	EURO3	Class1	2.3/0.64	0.2/0.56	0.15/0.5
		Class2	4.17/0.8	0.25/0.72	0.18/0.65
		Class3	5.22/0.94	0.29/0.86	0.21/0.78
	EURO4	Class1	1.0/0.5	0.1/0.3	0.08/0.25
		Class2	1.81/0.63	0.13/0.39	0.1/0.33
		Class3	2.27/0.74	0.15/0.46	0.11/0.39
Heavy Diesel Motors g/km	EURO1		4.9	1.2	9
	EURO2		4	1.1	7
	EURO3		2.09/5.53	0.66/0.83	5.04/5.13
	EURO4		2.76	0.41	2.56

Notes: 1. * indicates gasoline/diesel; ** indicates HC/HC+NOx; *** indicates gasoline/non-direct -ejection diesel/ direct-ejection diesel.

2. Class1: weight< 1305kg; class2: 1305kg<weight<1760kg: class3: weight>1760kg

Source: European Union

2.3 Cost and Benefit Data of Different Technological Control Measures

The cost and benefit data of different Euro standards are obtained from the B-9-3 Project and the current motor parts supply market. Table 8 shows the original data on the costs and benefits of different vehicle models under different control standards. In this table, the costs include the hardware cost, which is incurred by using new technology to match the alternative standards and repair costs. The new technological equipments include closed loop electronic control ejection, cold start triple catalytic converter, rarefaction combustion, deoxidization catalytic converter under rarefaction conditions, oxidation catalytic converter and so on. [9] All the hardware costs and repair cost together constitute the total costs incurred during the whole cycle of emission pollutant treatment. The benefit is obtained/gauged from the improvements in economy of fuel when adopting new standards.

Table 6: Original Data on Cost and Benefits of Various Vehicle Models (USD)

Vehicle Models	Emission Standard	Hardware Cost	Repairing Cost	Oil Benefit improvement (%)
LDGV	EURO1	955	80	3%
	EURO2	1075	80	3%
	EURO3	1500	80	5%
	EURO4	4500	90	10%
LDGT1	EURO1	955	80	3%
	EURO2	1075	80	3%
	EURO3	1600	80	5%
	EURO4	5000	90	10%
LDGT2	EURO1	150	80	-3%
	EURO2	1050	80	1%
	EURO3	1600	80	3%
	EURO4	2200	80	3%
LDDT	EURO1	850	80	1%
	EURO2	1175	80	3%
	EURO3	1750	80	3%
	EURO4	2500	90	5%
LDDV	EURO1	955	80	1%
	EURO2	1150	80	3%
	EURO3	1800	80	3%
	EURO4	3100	90	5%
HDGV	EURO1	528	38	-3%
	EURO2	1352	90	3%
	EURO3	2100	90	3%
	EURO4	2750	90	5%
HDDV	EURO1	1125	95	1%
	EURO2	1425	95	3%
	EURO3	2200	95	3%
	EURO4	3885	100	1%

Source: B-9-3 Project and http://www.auto1688.com.cn/

3. Theoretical Approach of the Computing Method

3.1 Basic Formula

The aim of the computing method is to calculate the net benefit of emission reduction of different pollutants in the middle and upper scenarios, so the basic formula is:

$$\left(\overline{NB}_j\right)_i = \Delta\left(NB_j\right) / \Delta\left(E_j\right)_i \qquad (1)$$

Because *NB*=*B*-*C*, We can rewrite the formula into Eq. (2):

$$\left(\overline{NB}_j\right)_i = \Delta\left(B_j - C_j\right) / \Delta\left(E_j\right)_i \qquad (2)$$

Where, *i=1, 2, 3* presents the three different pollutants, CO, HC and NOx, respectively;

j=1, 2 presents the Middle and Strict scenarios, respectively;

C_j is the total cost of a scenario;

B_j is the total benefit of a scenario

$\left(\overline{NB}_j\right)_i$ is the net benefit per ton for one pollutant;

$\Delta\left(NB_j\right)$ is the difference between the net benefit of the current scenario (Middle or Strict) and the standard scenario;

$\Delta\left(E_j\right)_i$ is the difference in the emission of one pollutant between the current scenario (Middle or Strict) and the standard scenario.

3.2 Calculation of $\Delta\left(NB_j\right)_i$

$\Delta\left(NB_j\right)_i$ measures the welfare change associated with the adoption of a stricter pollution emission policy. In other words, it refers to the change in the net benefits from moving from the current (standard) scenario towards the middle or strict scenario. Therefore, it is equal to the difference between the two net benefits of two different scenarios. In this paper, the net benefit of a scenario, *NB*, is the economic benefit of oil, B_{oil}, less the sum of the hardware cost, C_h, and repair costs, C_r. As given by Eq. (3)

$$NB = B_{oil} - (C_h + C_r) \qquad (3)$$

Considering the fact that $NB=-NC$, we can rewrite Eq (3) into Eq (4):

$$NC = -NB = C_h + C_r - B_{oil} \qquad (4)$$

The hardware cost of a scenario, C_h, is based on the accumulated data from the standards for different years. For simplicity sake, we assume that the hardware cost is smoothly/uniformly allocated throughout the life cycle of 20 years. The repair costs for a scenario, C_r, is based on the accumulated data from the standards in different years. Each repair cost is equally distributed across the life cycle of 20 years. Contrariwise, the economic oil, B_{oil}, is based on the consumption of oil every one hundred kilometers and the yearly mileage, multiplied by the improved percentage in oil economy and the average oil prices for 2003. Thus, the total economic benefit of oil in a scenario will be equal to the sum of the whole fuel economy improvement for each year.

3.3 Calculation of $\Delta(E_j)_i$

In order to obtain $\Delta(E_j)_i$, we must calculate pollutant emission, E, first. The computation of E is based on each control scenario and the emission factors. It is obtained by accumulating the multiplication of the emission factor k (refer to Table 5), and annual traveling mileage, L (refer to Table 2), through the twenty year long life cycle of the vehicle, as given by Eq. (5).

$$E = \sum_{n=1}^{20} k_n \cdot L_n \text{ , (n is the year number)} \qquad (5)$$

Using the calculated values of the pollutant emission $\Delta(E_j)_i$ we can obtain Eq. (6),

$$\Delta(E_j)_i = (E_0)_i - (E_j)_i \qquad (6)$$

Where $(E_0)_i$ is the emission of one pollutant under the Standard Scenario;

$(E_j)_i$ is the emission of one pollutant under the current scenario (Middle or Upper)

For example, in the Standard Scenario, cars will comply to EURO1 standards from 2000 to 2004, and comply to EURO2 from 2005 to 2020, so the emission during 2000 and 2004 is computed by multiplying EURO1 emission standards and annual traveling mileage, while the emission during 2004 and 2020 is computed by EURO2 emission standards. Total emissions for these 20 years is obtained by adding up emission amounts for each year.

4. Valuation Results

4.1 Pollution Levels

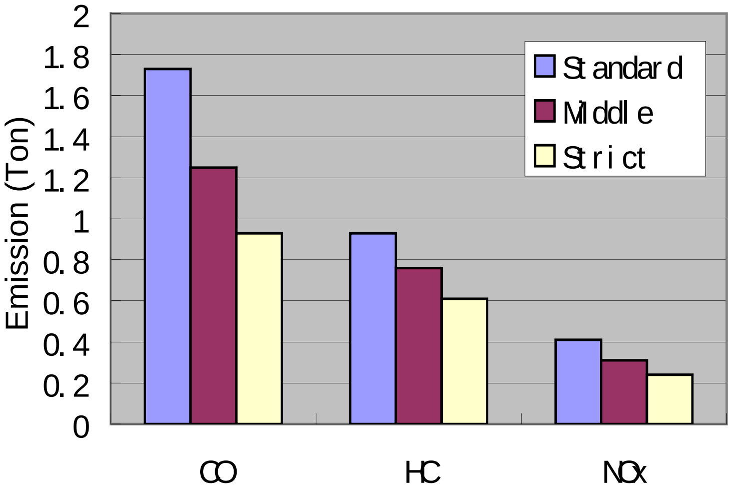
The estimation of the cost benefit results involved the use of (a) six motor models, (b) two control policy scenarios, and (c) three types of pollutants. Furthermore, alternative policy scenarios have different effects on the discharge and cost / benefit of CO, HC, and NOx treatment , because they register different values in the data on pollutants. Valuation results are presented and discussed in detail in the following sub-sections. Table 7 shows the emission of different vehicle models under each control scenario. Accordingly , we can calculate the percentage changes of reduction in CO, HC, and NOx comparing Middle and Strict scenarios with the Standard scenario, without considering cost and benefit.

Table 7: Comparison of the Discharge of Different VehicleTypes (Ton)

Vehicle Model	Scenario	CO	HC	NOx
LDGV	Standard	1.73	0.93	0.41
	Middle	1.25	0.76	0.31
	Strict	0.93	0.61	0.24
LDGT1	Standard	1.18	0.62	0.32
	Middle	1.03	0.47	0.21
	Strict	0.82	0.31	0.18
LDGT2	Standard	1.73	0.93	0.41
	Middle	1.35	0.74	0.31
	Strict	1.02	0.53	0.24
HDGV	Standard	2.35	0.86	0.63
	Middle	2.02	0.72	0.47
	Strict	1.43	0.64	0.28
LDDV	Standard	0.71	0.39	0.31
	Middle	0.62	0.17	0.23
	Strict	0.51	0.12	0.17
LDDT	Standard	1.21	0.72	0.41
	Middle	0.93	0.48	0.31
	Strict	0.67	0.33	0.22
HDDV	Standard	0.73	0.53	2.72
	Middle	0.61	0.37	2.47
	Strict	0.47	0.17	1.73

For instance, as shown in Figure 1, for gasoline driven light vehicles, if we adopt the Middle scenario, the percentage changes in the reduction of CO, HC, and NOx emissions are 27%, 18%, and 23% respectively; if we adopt the Strict scenario, the percentage changes in the reduction of CO, HC, and NOx are 46%, 35% and 41% respectively. From the calculations of the percentage change in the reduction of CO, HC and NOx, we can rank the seven vehicle models from the results. That is: for LDGV, LDGT1, and HDGV, the efficiency in controlling emissions of the three pollutants under both Middle and Strict scenarios is CO, NOx and HC in descending order. For LDGT2 and HDDV, the efficiency in controlling emissions of the three pollutants in both the Middle and Strict scenarios is CO, HC and NOx in descending order. Finally, for LDDV and LDDT vehicles, the efficiency of controlling emissions of the three pollutants under both Middle and Strict scenarios is HC, NOx and CO, again in descending order.

Figure 1: Emission Comparison of LDGV



4.2 Cost Benefits Results

Taking into account the data on cost and benefits, we can calculate the net benefit of CO, HC, and NOx in the different control scenarios for different vehicle models. Because the net benefits are all negative, all the figures in Table 8 refer to the net costs.

Table 8: Net Benefit under Each Scenario of Various Vehicles (Dollar/Ton)

Vehicle models	Scenario	CO	HC	Nox
LDGV	Middle	191	191	352
	Strict	270	621	1114
LDGT1	Middle	383	1203	3180
	Strict	5213	6314	10713
LDGT2	Middle	138	341	367
	Strict	1171	2050	4729
HDGV	Middle	301	647	503
	Strict	107	410	268
LDDV	Middle	372	189	379
	Strict	4003	2905	5370
LDDT	Middle	201	187	411
	Strict	1671	2801	4002
HDDV	Middle	760	563	310
	Strict	345	321	102

The results in Table 8 may be influenced by some variables such as yearly mileage, fuel consumption rate, changing percentage in oil economy , oil price and discount rate**.**

The yearly mileage can influence the total amounts of emission but make little difference on the net benefit. The oil price and the fuel consumption rate can influence the total benefit. The bigger the discount rate is, the smaller the conversion rate of the cost and the larger the total cost. The changing percentage of economy in oil consumption is very important in this analysis. The greater the percentage , the less time will be needed to absorb the hardware cost and thus achieve better results in cost benefit. This also indicates that economizing on oil is of great importance in controlling emissions.

5. Conclusions

From the preceding calculations and results, we can rank the alternative control scenarios, for the different types of vehicle, as follows:

Table 9: Recommended Controlling Scenarios for Various Vehicles

Model	Control Scenario
LDGV	Middle Scenario
LDGT1	Middle Scenario
LDGT2	Middle Scenario
LDDV	Middle Scenario
LDDT	Middle Scenario
HDGV	Strict Scenario
HDDV	Strict Scenario

It is clear that for light duty vehicles, it is better to opt for the middle scenario. The reason is that these vehicles are already controlled strictly under the standard scenario, therefore if we follow the strict scenario, the costs of the unit pollutant are higher than they would be in the middle scenario. This can also tell us that when standard emission levels reach a certain rate , it is more difficult to further reduce polluting emissions Additional investments would be required to achieve this. For heavy duty vehicles, it is better to choose the strict scenario. Because these vehicles are less controlled under the standard scenario, this can make their control costs per unit discharge in the strict scenario lower than those of the middle scenario, so the strict scenario can bring them more cost benefits. Finally, comparing Table 7 and Table 9, we find that the amount of control over emissions among different vehicle models differs according to the pollution control measure implemented. For instance, for the LDGV, the strict scenario is more effective in reducing the amount of pollutants than the middle scenario. However, from an economic perspective, the strict scenario is not the preferred one since the cost-benefit exercise shows that the net benefit estimates associated to the middle policy scenario are larger compared to the net benefit estimates associated with the strict policy scenario.

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(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003

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(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

(lxxi) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by Fondazione Eni Enrico Mattei and Consip and sponsored by the EU, Rome, September 23-25, 2004

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