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Cost-Benefit Analysis of Yellow-label Vehicles Elimination Policy in the Beijing-Tianjin-Hebei Region

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Foreword »

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Since its opening-up and reform, China has been in the process of rapid economic development with its people enjoying an increasingly improved standard of life. Meanwhile accompanying this dramatic economic growth is the degradation of environment which has, to some extent, damaged the gains of the opening-up and reform and prevented the economy from a healthy and sustainable development. The Chinese government is increasingly aware of that without addressing the environmental issues it is facing now, will jeopardize its long term goal of the great rejuvenation of the Chinese nation. Given the magnitude and complexity of the environmental issues in China, there is no easy way in addressing them and the solution to them entails an equal priority being given to environmental protection, ecological conservation and economic development or even higher than the latter by mainstreaming the former into the overall socio-economic decision-making process. As a matter of fact, China has been in the struggle against environmental pollution since the very beginning of its economic take-off and trying to explore a pathway that could help address China's environmental issues in the way most suitable to China's specific circumstances.

In recent years, especially since the 12th Five-Year Plan period, the enhanced measures including legislation, policy, regulatory and economic means have been taken by the Chinese government in dealing with environmental problems, of which environmental policies have played an important role in this regard. Corresponding to this situation and in meeting the demand of governments at different levels for environmental policy tools, the environmental policy research projects on topics of a wide range have been conducted by some Chinese environmental research institutions including the Chinese Academy for Environmental Planning (CAEP).

CAEP founded in 2001, is a research advisory body supporting governments in the development of key environmental planning, national environmental policies, and major environmental engineering projects. In the past more than 10 years, CAEP has accomplished the development of the overall planning of national environmental protection for the 10th, 11th and 12th Five-Year Plan periods; water pollution prevention and control planning for key river basins; air pollution prevention and control planning for key regions; soil pollution prevention and control planning; and some regional environmental protection plans. In the same period of time, CAEP also actively engaged in research on such topics as green GDP, environmental taxation, emission trading, ecological compensation, green financing, etc. By so doing, CAEP has become an indispensable advisory body in the environmental decision-making in mainland China. According to *2013 Global Go To Think Tanks Report and Policy Advice* published by University of Pennsylvania, CAEP was ranked 31 in the field of environment in the world. Many of CAEP's research results and project outcomes regarding environmental policies have drawn great attention of decision makers and international institutions, and have been utilized to contribute to the formulation of national environmental policies concerned.

The Chinese Environmental Policy Research Working Paper (CEPRWP) is a new internal publication produced by CAEP for the purpose of facilitating the academic exchange with foreign colleagues in this field, in which the selected research papers on environmental policies from CAEP are set out on the irregular basis. It is expected that this publication will not only make CAEP's research results on environmental policies be known by foreign colleagues but also serve as a catalyst for creating opportunity of international cooperation in the field of environmental policies, and environmental economics in particular, with a view of both the academic research and practical policy needs.

Cost-benefit analysis is an important means for policy formulation, implementation and adjustment. The study presents a cost-benefit analysis of the policy to eliminate yellow-label vehicles in the Beijing-Tianjin-Hebei region. It estimates the costs and environmental and health benefits of scrappage subsidy program and ban program under the baseline scenario and the controlled scenario, compares results between the two programs and analyzes the economic impact of scrappage subsidy program. It calculates the costs based on the social cost method, the environmental benefits based on the emission factor method and air quality model, the health benefits based on method of environmental health assessment, and the economic and social benefits based on the input-output method. The results show the policy played an important role in reducing pollutant emissions and improving environmental quality in the region during 2008–2015. It reduced the concentration of NO_x by 2.5% and $PM_{2.5}$ by 0.84% in Beijing, 3.2% and 1.15% in Tianjin and 7.98% and 0.78% in Hebei, respectively. The net benefits derived from scrappage subsidy program reached 20.34 billion yuan and from ban program 92.722 billion yuan, and totaled 113.06 billion yuan. The policy also exerted a positive impact on the macro economy. It approximately increased the vehicle consumption by 182.25 billion yuan, total output 829.01 billion yuan, gross domestic product 234.42 billion yuan, and residents' income 981.0 billion yuan, and created about 14.2 million jobs.

Contents

1. INTRODUCTION

China's motor vehicle population is rapidly growing year by year. The consequent exhaust emissions have become an important cause of air pollution, particularly haze and photochemical smog [1–3]. Vehicles contributed about 30% of $PM_{2.5}$ in mega-cities such as Beijing and Shanghai and densely populated eastern areas, and even more than 50% in extremely adverse weather conditions [4]. At the same time, motor vehicle emissions pose a direct threat to public health as most of the motor vehicles travel in densely populated regions [5–7]. In 2014, there were 9.842 million yellow-label vehicles (YLVs) in China. They represented 6.8% of the national motor vehicles, but emitted 45.4%, 49.1%, 47.4% and 74.6% of the carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_x) and particulate matter (PM) respectively [8]. The Action Plan for Air Pollution Prevention and Control considered eliminating YLVs as an important measure in 2013. Yet, the policy evaluation remains blank despite overall studies on the Action Plan [9–11]. Through a case of the Beijing-Tianjin-Hebei region, this study uses cost-benefit analysis to quantify the policy impact in a comprehensive and objective manner, covering costs, benefits and economic impact.

2. METHODOLOGY AND DATA SOURCES

2.1 Research scope

The YLV elimination policy mainly encompasses scrappage subsidy program and ban program, so cost-benefit analysis is conducted for each program. Provinces (autonomous regions and municipalities) across the country have launched their respective YLV elimination policies, which differ widely in many aspects, such as date of entry into force of scrappage subsidy program and ban program, subsidy standards and ban coverage. The Beijing-Tianjin-Hebei region is identified as the study area, because the earliest policy of its kind has yielded the greatest pollutant emission reductions and environmental quality improvements through the most complex process.

2.1.1 Scrappage subsidy program

It is a natural process to purchase, use and phase out motor vehicles. The scrappage subsidy program accelerates the entire process and serves to scrap motor vehicles early (by shortening the service life). Therefore, two scenarios are set. The baseline scenario is the natural elimination of motor vehicles, and the scenario I is YLV scrappage subsidy program (including natural elimination of motor vehicles). This study as an ex-post assessment uses the real-time data from the Beijing-Tianjin-Hebei region for natural obsolescence of motor vehicles. Table 1 describes the YLV subsidy scenarios and Table 2 outlines the impact matrix of scrappage subsidy program for analyzing the impact of scrappage subsidy program on different groups.

Table 1 YLV elimination scenarios

Classification	Description
Baseline scenario	Natural elimination
Scenario I	Scrappage-involved early elimination

Table 2 Impact matrix of scrappage subsidy program

Target	Positive impact	Negative impact
Government	—	Costs for subsidies; management costs
Residents	Income from subsidies Environmental (health) benefits	Loss of YLV residual values New-vehicle purchase costs
Businesses	New-vehicle sales	—
Society	Environmental (health) benefits	Management costs; YLV residual values

The government formulated and implemented the scrappage subsidy program to reduce YLVs emissions. It meant different costs and benefits for different groups. For the whole society, the costs included the supervision & management costs (government expenditure) and the residual values of scrapped vehicles (personal expenditure), and the benefits included environmental benefits and consequent health benefits. The government needed to provide subsidies and cover management costs. Residents borne the costs of YLV residual values and new-vehicle purchases, but enjoyed the subsidies and environmental and health benefits. Businesses also benefited from the scrappage subsidy program through the purchase of new cars by residents.

2.1.2 Ban program

Ban program was an important component of the YLV elimination policy. In order to control air pollution, we must restrict or even ban such high emission vehicles on road. Beijing, Tianjin and Hebei separately analyzed the costs and benefits of the ban policy, in light of the sharp differences in the prescribed time and scope of and compliance with such ban. Table 3 shows the impact matrix of the ban program for analyzing the impact of scrappage on different groups.

Table 3 Impact matrix of the YLV elimination policy

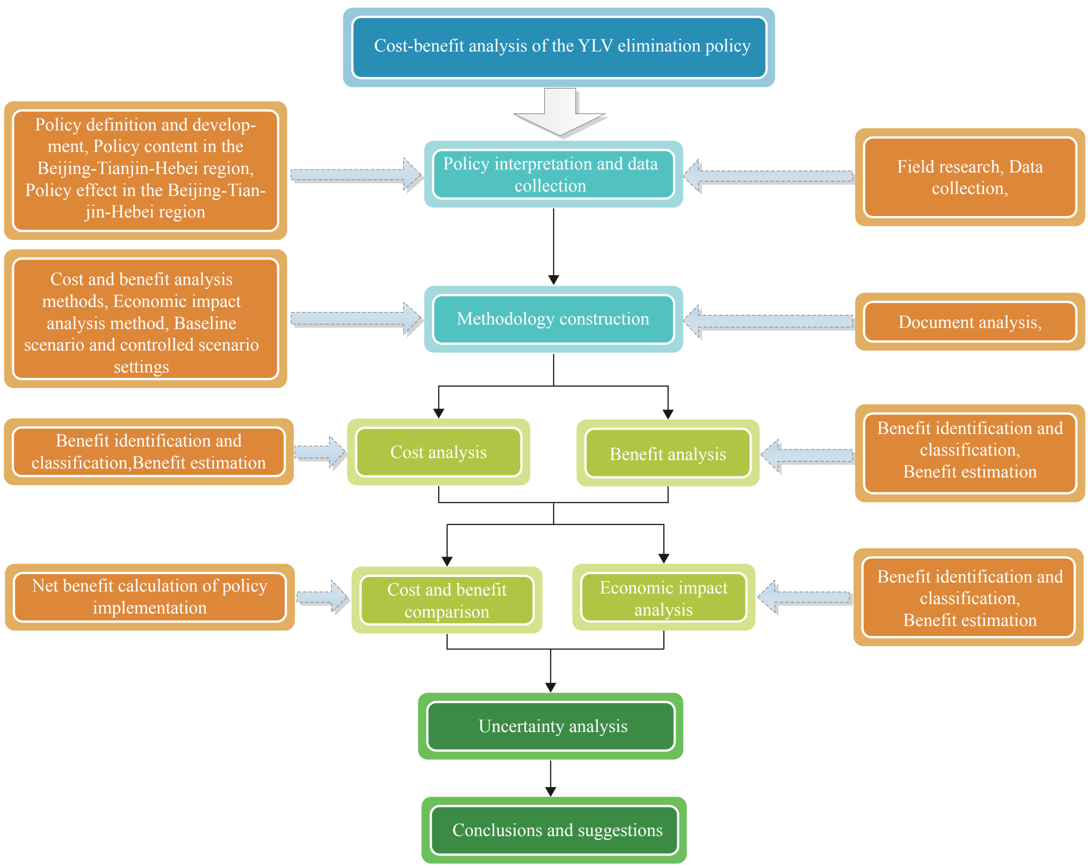
Target	Positive impact	Negative impact
Government	—	Supervision & management costs
Residents	Environmental (health) benefits Ban-related transportation savings	Expenses on changing to other means of transportation
Businesses	—	—
Society	Environmental (health) benefits; Ban-related transportation savings	Supervision & management costs; expenses on changing to other means of transportation

The social costs of the ban policy covered supervision & management, and transfer to other means of transportation; while the social benefits included environmental benefits (health benefits) and travel cost savings derived from the ban program. The government borne the cost of supervision & management. Residents payed for transportation by other traffic patterns. However, Residents saved YLV-based transportation expenses and obtained environmental benefits and health benefits. The ban program had no effect on enterprises, regardless of costs or benefits.

2.2 Technical roadmap

Under the technical framework of cost-benefit analysis of environmental policy, the cost effectiveness and economic impact of the YLV elimination policy in the Beijing-Tianjin-Hebei region are evaluated, including the scrappage subsidy program and ban program. The costs are calculated based on the social cost, environmental benefits based on the emission factor and air quality modeling, health benefits based on environmental health assessment, and economic and social benefits based on the input and output. The technical roadmap is as shown in Figure 1.

Figure 1 Framework for cost-benefit analysis of the YLV elimination policy



2.3 Analytical methods

2.3.1 Costs

(1) Residual value of YLVs (C_{cv}): The residual value of medium and small-sized YLVs is the corresponding amount of subsidies for phasing out such vehicles, and the residual value of large YLVs, the amount of such subsidies at higher standards in order to better meet the real market.

$$C_{cv} = P_{sm} \times V_{sm} \times (1-\sigma) + P_{bc} \times V_{bc} \times (1-\sigma) \quad (2\text{-}1)$$

Wherein C_{cv} is the residual value of YLVs (yuan). C_{sm} and C_{bc} represent the residual values of medium and small-sized YLV models and large YLV models respectively (yuan). P_{sm} and V_{sm} denote the subsidy standard (yuan per vehicle) and number of medium and small-sized YLV models respectively and P_{bc} and V_{bc}, large YLV models. σ stands for natural elimination rate of motor vehicles.

(2) Natural elimination rate of motor vehicles (σ):

$$\sigma = \frac{V_{i-1} + V_x - V_i}{V_i} \qquad (2\text{-}2)$$

Where σ is the natural elimination rate of motor vehicles; V_{i-1} and V_i represent the motor vehicle population in the year i-1 and V_i in the year i respectively; V_x denotes the number of newly registered motor vehicles in the year i.

(3) Amount of subsidies in the Beijing-Tianjin-Hebei region C_{pi}:

$$C_{pi} = \sum_{t=1} \sum_{j=1} P_{tji} \times V_{tji} \qquad (2\text{-}3)$$

Wherein C_{pi} is the amount of subsidies for phasing out YLV early in the region i (yuan), P_{tji} represents the subsidy standard for the model j in the region i during the period t (yuan per vehicle) and V_{tji} the number of eliminated YLVs in the region i during the period t; i denotes Beijing, Tianjin and Hebei respectively.

(4) Number of YLV models in the Beijing-Tianjin-Hebei region:

$$V_{jt} = V \times \frac{H_{jt}}{H} \qquad (2\text{-}4)$$

Wherein V_{jt} means the number of eliminated model j YLVs during the period t and H_{jt} the total number of model j YLVs during the period t; V represents the total number of eliminated YLVs and H, the total number of motor vehicles in the environment statistics.

(5) New-vehicle purchase cost (Cn): It equals to the product of the vehicle purchase coefficient and the average new-vehicle purchase cost minus the amount of subsidies received.

$$C_n = \alpha \times C_g - C_p \qquad (2\text{-}5)$$

Wherein C_n is the new-vehicle purchase cost (yuan); α is the vehicle purchase coefficient after receiving subsidies and C_g average new-vehicle purchase cost after receiving subsidies (yuan); C_P indicates the amount of subsidies received (yuan).

(6) Average new-vehicle purchase cost after receiving subsidies (C_g):

$$C_g = \sum_{i}^{1} C_i \times \lambda_i \times V \qquad (2\text{-}6)$$

Wherein C_n represents the cost of purchasing vehicle i (yuan per vehicle) and λ_n the scale factor for such cost; i can be 1, 2, 3; V indicates the total number of eliminated YLVs.

(7) Ban-related transportation cost (C_d): also the cost of **changing to other means of transportation.** It equals to the product of the number of banned YLVs, the average occupancy of motor vehicles, and the expenses of transportation by other means.

$$C_d = \theta \times V_d \times P_b \times M \qquad (2\text{-}7)$$

Wherein C_d is the ban-related transportation cost (yuan); θ is the average occupancy of motor vehicles (persons per vehicle); V_d represents the number of YLVs banned from road; P_b means the average annual expenses on public transportation per person (yuan per person per kilometer); M indicates the average annual mileage of motor vehicles (kilometer).

2.3.2 Benefits

2.3.2.1 Environmental benefits

(1) Total pollutant emission reductions

The total pollutant emission reductions are pollutant emissions reduced through the implementation of the YLV elimination policy in the Beijing-Tianjin-Hebei region. They are calculated according to the Technical Guidelines for Compiling Air Pollutant Emission Inventory of On-road Vehicles (Trial) (hereinafter referred to as the Guidelines) [12] and the Methods for Measuring Air Pollutant Emissions from Motor Vehicles in Urban Areas (hereinafter referred to as the Methods). In line with the Guidelines, the emission factor is used to calculate the standard YLV pollutant emissions, which are deemed as emission reductions of such eliminated vehicles.

1) Annual YLV pollutant emissions

The equation for calculating pollutant emissions from motor vehicles based on the emission factor is written as follows:

$$E_i=\sum_i P_i\times EF_i\times VKT_i\times 10^{-6} \qquad (2\text{-}8)$$

E_i denotes the corresponding annual emissions of CO, HC, NO_x, $PM_{2.5}$ and PM_{10} of model i vehicles in the Beijing-Tianjin-Hebei region, expressed by tons (emissions before the adoption of China I standards are considered as YLV emission reductions in this study). EF_i represents the amount of pollutants discharged by model i vehicles per unit of mileage, namely the emission factor, expressed by grams per kilometer (the emission factor is determined based on the data measured in Beijing, Tianjin and Hebei. If there are no measured data, the method described below is used with consideration to the actual situation of natural climate and motor vehicles). P means the population of model i vehicles in the region (number of YLVs eliminated in Beijing, Tianjin and Hebei in this study). VKT_i means the average annual mileage traveled of model i vehicles, expressed by kilometer per vehicle. i indicates the model of motor vehicles with different levels of pollution control.

2) Emission factor (EF_i)

The emission factor EF_i is determined according to vehicle models. It varies depending on regions, pollution control levels and vehicle models.

$$EF_{ij}=BEF_i\times\Psi_j\times\gamma_j\times\lambda_i\times\theta_i \qquad (2\text{-}9)$$

EF_{ij} represents the emission factor of model i vehicles in the region j and BEF_i the integrated baseline emission factor of model i vehicles. Ψ_j is the environmental correction factor for region j, γj the correction factor for average velocity in the region j, λi the correction factor for degradation of model i vehicles, and θi the correction factor for other conditions of model i vehicles (such as load factor and oil quality). This study only needs to determine the corrected emission factor of YLVs (before the adoption of China I standards) based on the actual situation of Beijing-Tianjin-Hebei region.

(a) Integrated baseline emission factor (BEF)

The integrated baseline emission factor (BEF) of gasoline, diesel and other fuels is provided by the Guidelines. It takes into account the average mileage travelled of motor vehicles of different kinds in 2014 and also the typical urban traffic conditions (30 km/h), weather conditions (temperature of 15 ℃ and relative humidity of 50%), fuel quality (sulfur content of gasoline and diesel at 50 ppm and 350 ppm respectively and no ethanol content for gasoline) and load factor (50% for diesel vehicles in typical traffic conditions). Targeted emission factors can be determined based on field research in cities of the Beijing-Tianjin-Hebei region or relevant materials and literature.

(b) Environmental correction factor (Ψ_j)

The environmental correction factor includes the correction factors for temperature, humidity and altitude, written as follows:

$$\Psi_j=\Psi_{Temp}\times\Psi_{RH}\times\Psi_{Height} \quad (2\text{-}10)$$

Ψ_{Temp} represents the temperature correction factor, Ψ_{RH} humidity correction factor, and Ψ_{Height} altitude correction factor. Multi-year mean temperature and humidity are used herein as the vehicle emission inventories are calculated on a yearly basis.

(c) Correction factor for traffic conditions (γ_j)

The correction factor for traffic conditions is determined according to the local average velocity of vehicles, which is divided into four intervals (<20, 20–30, 30–40, 40–80 and >80 km/h). The average velocity is calculated according to the field survey or statistical data of each city in the Beijing-Tianjin-Hebei region. The average velocity for buses is usually modified to <20 km/h.

(d) Degradation correction factor (λ_i)

The degradation correction factor is used to correct the degradation of vehicles during 2015-2018 based on 2014.

(e) Correction factor for other conditions (θ_i)

The correction to other conditions of use mainly consider the impact on motor vehicle emissions brought by sulfur content of fuels, ethanol content of ethanol-gasoline blends, and load of diesel vehicles. No correction is made in this study considering the low SO_2 emission of motor vehicles, unavailability of data about ethanol-gasoline blends, and little effect of diesel vehicle load on emission factors.

3) Level of activity

The level of activity considers the number and average annual mileage travelled (VKT) of YLVs eliminated in the cities of Beijing-Tianjin-Hebei region. The calculations are separate for different models and fuels. The numbers of eliminated YLVs by fuels are estimated based on model-specific numbers. The average annual mileage traveled (VKT) uses the value of experience provided by the Guideline.

(2) Environmental quality improvements

The benefits of environmental quality improvements are estimated based on the MEIC inventories and the pollutant emission inventories established on the basis of regional environmental statistics, WRF three-dimensional meteorological fields, and Models-3 Community Multiscale Air Quality (CMAQ) model.

2.3.2.2 Health benefits

According to the theory of environmental health assessment, the health benefits of air pollution control are assessed typically through two steps: first to analyze and estimate the endpoint-specific health effects (environmental health risk assessment) brought by the reduction of air pollutant concentrations, and then to monetize such health effects (environmental health valuation) and calculate the economic benefits of health improvements.

In view of the differences in policy content and results, the health benefits of the YLV elimination policy are examined separately for Beijing, Tianjin and cities in Hebei Province, covering the period from the year of starting policy implementation to 2015. In specific, the $PM_{2.5}$ concentrations of cities each year are modeled and measured in the baseline scenario and the controlled scenario. According to exposed population, the health effects are identified using the exposure-response model and further monetized. The sum of health benefits in various cities is the overall health benefits of the YLV elimination policy in the Beijing-Tianjin-Hebei region.

(1) Environmental health risk assessment

1) Air pollution factors that affect health

The exhaust emitted by motor vehicles contains 150 to 200 compounds 0.3 to 2 meters near ground within the range of human breath. These emissions, particularly CO, HC, NO_x and PM emissions, pose a serious threat to human health. A large number of epidemiological studies at home and abroad confirm that PM is the most harmful air pollutant for human health. PM can damage the respiratory and cardiovascular systems of exposed population. With a smaller diameter, $PM_{2.5}$ is even more harmful as it can adsorb heavy metals and microorganisms on the surface and penetrate into the cell and blood circulation. Therefore, $PM_{2.5}$ is chosen as the pollution factor to evaluate health effects in this study.

2) Health endpoints

In order to evaluate the economic loss caused by long-term chronic health effects of air pollution, respiratory diseases and cardiovascular diseases, which have strong correlation with air pollution, are selected as health endpoints according to the principles of selection. The measurable indicators mainly include mortality, inpatient attendance, outpatient attendance, unexplained attendance and sick leave, as detailed below:

Table 4 Health endpoints of air pollution

Category	Indicator
All-cause mortality	Mortality under chronic effects
	Mortality under acute effects
Hospitalization	Respiratory diseases
	Cardiovascular diseases
Sick leave	Chronic bronchitis

3) Exposure–response relationship

The dose (exposure)–response function is used to characterize the impact of air pollution on human health. It indicates that the level of air pollution is statistically associated with exposed population. After controlling for other confounders, regression analysis is conducted to estimate the coefficient of correlation (β) between unit change of concentration of major pollutants and health endpoints of exposed population.

The existing studies suggest that the relative risk (RR) of health endpoints of air pollution basically has a linear or logarithmic linear relationship with the concentration of a specific pollutant [13].

The linear relationship is expressed as:

$$RR = \exp[\beta(C - C_0)] \qquad (2\text{-}11)$$

The logarithmic linear relationship is expressed as:

$$RR = \exp[\alpha + \beta \ln(C)] / \exp[\alpha + \beta \ln(C_0)] = (C / C_0$$

In order to avoid the case that C_0 equals 0, both the numerator and the denominator are added 1:

$$RR = [(C+1)/(C_0+1)]\beta \quad (2\text{-}12)$$

Wherein C represents the current concentration of a specific atmospheric pollutant and C_0 the baseline (clean) concentration (threshold); RR is the relative risk of human health effects of air pollution; β is the exposure-response coefficient, indicating the percentage (%) of increase in mortality or prevalence specific to health outcome for each unit of increase in atmospheric pollutant concentration.

(2) Environmental health evaluation

Regarding the valuation of environmental health, the willingness-to-pay (WTP) approach is favored in the western developed countries, while the cost of illness approach and the revised human capital approach are adopted in developing countries with incomplete market economy. In this study, environmental health is valuated based on income loss and direct medical cost. The economic loss from premature deaths associated with pollution is estimated using the revised human capital approach, and the medical cost using the cost of illness approach. The result obtained should be the minimum health losses caused by air pollution.

1) Cost of illness approach

The cost of illness refers to all disease-related direct and indirect costs, including medical expenses for outpatient, emergency and inpatient visits, medical expenses of self-treated unaccounted patients, loss of income (converted by daily per capita GDP) due to sick leave, and indirect costs such as transportation and accompanying expenses.

2) Revised human capital approach

The revised human capital approach uses per capital GDP to measure the contribution to GDP in statistical life year when estimating the economic loss from premature deaths caused by pollution. Unlike the human capital approach, this approach examines the contribution of human resources to social and economic growth from the perspective of whole society rather than individuals (avoiding the problem of whether human beings are healthy laborers or the elderly and the disabled). Premature deaths from pollution reduce human resources and further their contribution to GDP during the statistical lifetime. Therefore, for the entire social economy, the loss of a statistical life year means a loss of GDP per capita. The revised loss of human capital is equivalent to the sum of GDP per capita in the lost life years.

The economic loss of premature deaths associated with pollution is calculated as follows:

Per capita human capital (HC_m) is calculated as follows.

$$HC_m = \frac{C_{ed}}{P_{ed}} = \sum_{i=1}^{t} GDP_{pci}^{pv} = GDP_{pc0} \sum_{i=1}^{t} \frac{(1+\alpha)^i}{(1+r)^i} \quad (2\text{-}13)$$

Wherein C_{ed} represents the economic loss from premature deaths associated with pollution. P_{ed} denotes the number of premature deaths associated with pollution. And t is the average loss of life years due to premature death associated with pollution. GDP_{pci}^{pv} means the present value of per capita GDP in the year i and GDP_{pc0} per capita GDP in the base year. r is the social discount rate and α is the annual growth of per capita GDP.

(3) Assessment of health benefits of the YLV elimination policy in the Beijing-Tianjin-Hebei region

Combined with the types and characteristics of air pollutants emitted by motor vehicles, the health benefits of air pollution control in this study consist of three parts. a) all-cause premature deaths and associated economic loss caused by air pollution (ECa_1), and the economic loss is measured using the human capital approach. b) Increased inpatient attendances and waiting days for respiratory and cardiovascular diseases resulting from air pollution, and associated economic loss (ECa_2) which is measured using the cost of illness approach. c) new cases of chronic bronchitis associated with air pollution and the economic loss (ECa_3) which is evaluated through disability-adjusted life years (DALY) [14]. As the basic evaluation approach requires a lot of data, funding and time, the reference method can be used due to time and data constraints. The overall health benefits (ECa_{Total}) are calculated as follows:

$$ECa_{\text{Total}} = ECa_1 + ECa_2 + ECa_3 \quad (2\text{-}14)$$

1) Economic loss from all-cause premature deaths associated with air pollution (ECa_1)

The value for current health outcomes (in the controlled scenario) is calculated based on the air pollution levels, health endpoints and exposure- response functions of cities. The hazard of air pollution to human health is the health outcome value of the baseline scenario minus the health outcome value of the controlled scenario).

$$P_{ed} = 10^{-5}(f_p\text{-}f_t)P_e = 10^{-5} \cdot ((RR\text{-}1)/RR) \cdot f_p \cdot P_e \quad (2\text{-}15)$$

$$EC_{a1} = P_{ed} \cdot HC_{mu} = P_{ed} \cdot \sum_{i=1}^{t} GDP_{pci}^{pv} \quad (2\text{-}16)$$

Wherein P_{ed} represents the number of all-cause premature deaths associated with air pollution in the baseline scenario, expressed by 10,000 persons. f_p denotes the all-cause mortality in the baseline scenario and f_t all-cause mortality in the controlled scenario (baseline value). P_e means the exposed urban population, expressed by 10,000 persons. RR stands for attributable relative risk of all-cause mortality associated with air pollution. t is the average loss of life years due to all-cause premature deaths caused by air pollution, which is calculated to be 18 years based on rates of death from air pollution-related diseases by age groups [15]. HC_{ma} means per capita human capital of urban population, expressed by 10,000 yuan per person; GDP_{pci}^{pv} means urban per capita GDP in the year i. The data come from China Statistical Yearbook 2016 [16] and Hebei Economic Yearbook 2016" [17].

2) Economic loss from hospitalization for diseases associated with air pollution (ECa_2)

$$P_{eh} = \sum_{i=1}^{n}(f_{pi}\text{-}f_{ti}) = \sum_{i=1}^{n} f_{pi} \cdot \frac{\Delta c_i \cdot \beta_i/100}{1+\Delta c_i \cdot \beta_i/100} \quad (2\text{-}17)$$

$$EC_{a2} = P_{eh} \cdot (C_h + WD \cdot C_{wd}) \quad (2\text{-}18)$$

Wherein n mean diseases associated with air pollution, such as respiratory diseases and cardiovascular diseases. f_{pi} represent the current inpatient attendances at the current level of air pollution, expressed by 10,000 person-times. β_i is regression coefficient (%) which is the percentage of change in health hazards with unit concentration of pollutants i. Δc_i denotes the difference between the actual pollutant concentration and the threshold pollutant concentration for health hazards (μg/m^3). C_h stands for hospitalization costs, including inpatient hospital costs, transportation costs, and nutrition costs, expressed by yuan per case. WD refers to waiting days. The 5th national healthcare service census conducted in 2013 found three waiting days for respiratory diseases on average. C_{wd} refers to the cost of waiting days, equal to per capita GDP divided by 365 (yuan per day).

3) Economic loss of DALY from chronic bronchitis caused by air pollution (ECa_3)

Foreign researchers believe that chronic bronchitis have extremely great damage to human bodies. Patients with chronic bronchitis will suffer the disease for lifetime and with disease progression, eventually lose the ability to work and enjoy life. Therefore, the DALY approach usually replaces the cost of illness approach for evaluating the economic loss from chronic bronchitis. The related studies have shown the DALY weight of 32% for chronic bronchitis, which means 32% of average human capital.

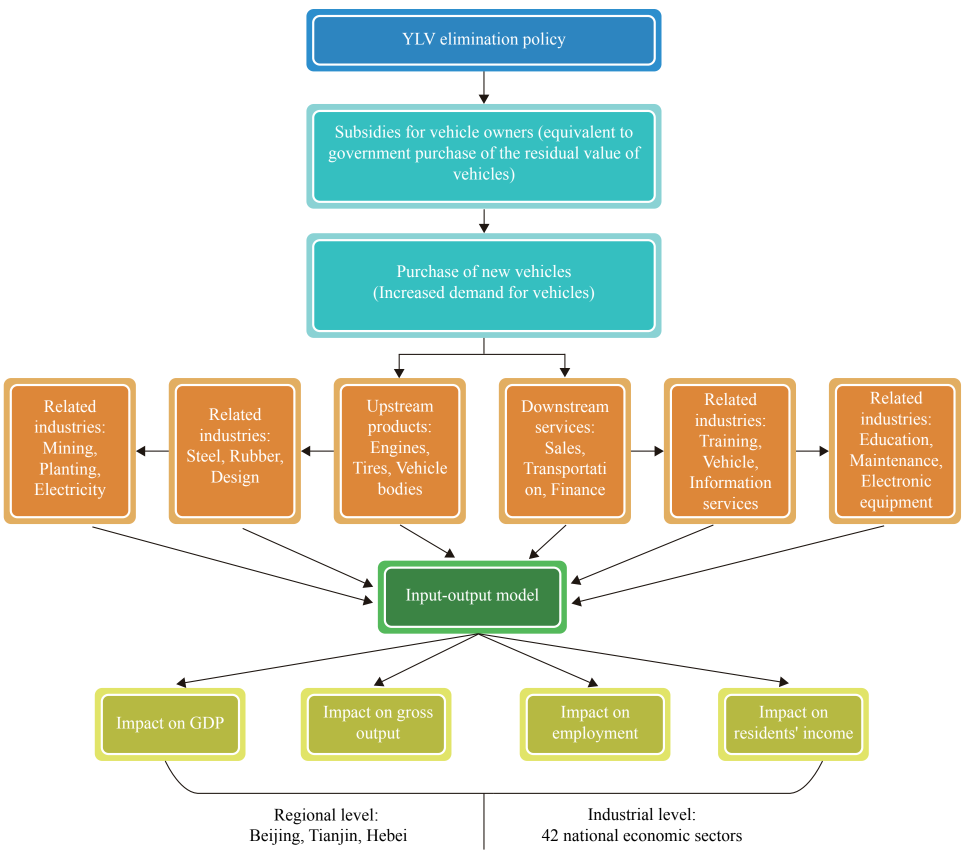
$$EC_{a3} = \gamma \cdot P_{ed} \cdot HC_{mu} = \gamma \cdot P_{ed} \cdot \sum_{i=1}^{t} GDP_{pci}^{pv} \quad (2\text{-}19)$$

Wherein t represents the average loss of life years due to premature deaths from chronic bronchitis associated with air pollution, which is 23 years according to the mortality of chronic bronchitis and emphysema (COPD) by age groups; γ represents the DALY coefficient for chronic bronchitis, which is 0.32.

2.3.3 Economic and social impact assessment

According to the macroeconomic theory, the YLV elimination policy will spur the demand for new vehicles through subsidies for YLV owners. The new-vehicle production process will simulate the upstream and downstream industries, such as upstream products

Figure 2 Economic impact analysis mechanism for the YLV elimination policy



including engines and tires and downstream services including transportation, marketing and finance. The upstream and downstream industries will then drive other industries such as steel and rubber through industrial chains, which eventually will inject a stimulus to the entire national economy. The input-output model can capture the impact of changes in the demand for final products on different indicators of the national economy (gross output, GDP, residents' income, and employment).

Calculation model

An input-output model is a mathematical method that represents the complex relations between different economic sectors, which can be used for economic analysis, policy simulation, planning demonstration and economic forecasting. An input-output table prepared for input-output analysis is a checkerboard pattern that describes the source and destination of various product inputs. It is formed by intersected input and output tables. The input table reflects the value of various products, including material consumption, remuneration and surplus products, and the output table reflects the distribution and use of various products, including investment, consumption and export. Input-output tables can be used to reveal the quantitative interdependence and mutual restraint between the various sectors of the national economy.

The direct consumption coefficient (a_{ij}), also known as input coefficient or technical coefficient, means the quantity of product i consumed per unit of product j. The total consumption coefficient (b_{ij}), means the quantity of product i consumed indirectly or directly (i.e. completely consumed) per unit of product j.

According to the above balance and direct consumption coefficient, the input-output table is used to set up an input-output model by lines, which can reflect the production and distribution of products among sectors and describe the balance of value between the final products and the total output. The equation is written as follows:

$$\sum_{j=1}^{n} a_{ij} \cdot x_j + y_i = x_i; (i = 1, 2, \dots, n) \qquad (2\text{-}20)$$

It can be further written in matrix:

$$(I - A)X = Y \qquad (2\text{-}21)$$

$$X = (I - A)^{-1} Y \qquad (2\text{-}22)$$

Wherein A represents the direct consumption coefficient matrix, X the total output, and Y the final products. The input-output model reflects the economic mechanism by which the final products drive the total output.

2.4 Data sources

(1) Subsidy standards

The standards for YLV elimination subsidies during different periods in Beijing, Tianjin and 11 cities in Hebei Province are clarified based on the analysis of the national vehicle trade-in policy and national and local YLV elimination policies.

(2) Number of eliminated vehicles

The number of YLVs eliminated with scrappage each year in Beijing, Tianjin and 11 cities in Hebei Province are identified through the analysis of annual local government work reports, annual statistical bulletins of national economic and social development, and news published on the official websites of the ministry of environmental protection and ministry of public security.

3. RESULT ANALYSIS

3.1 Scrappage subsidy program

3.1.1 Costs

From 2008 to 2015, **the costs for subsidies under the scrappage subsidy program (YLV residual values) amounted to 13.687 billion yuan in the Beijing-Tianjin-Hebei region, including 2.62 billion, 2.555 billion and 8.512 billion yuan for Beijing, Tianjin and Hebei respectively.** Government costs (subsidies) attained 10.207 million yuan as a whole, which read 1.519 million, 2.396 million and 6.292 million yuan for Beijing, Tianjin and Hebei respectively. New-vehicle purchase costs reached 182.25 billion yuan, which read 35.806 billion, 39.886 billion and 112.39 billion yuan for Beijing, Tianjin and Hebei respectively.

Figure 3 Costs for the scrappage subsidy program in the Beijing-Tianjin-Hebei region, 2008–2015

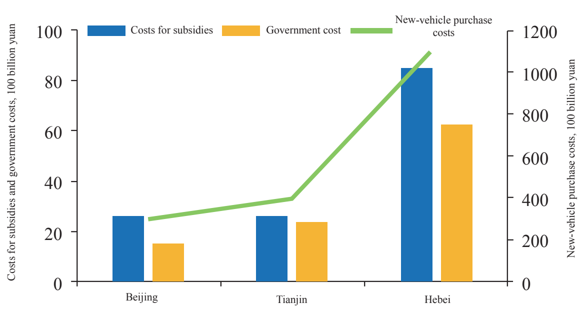


Figure 4 Costs for subsidies under the scrappage subsidy program in Beijing, Tianjin and Hebei, 2008–2015

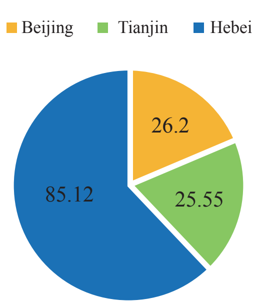
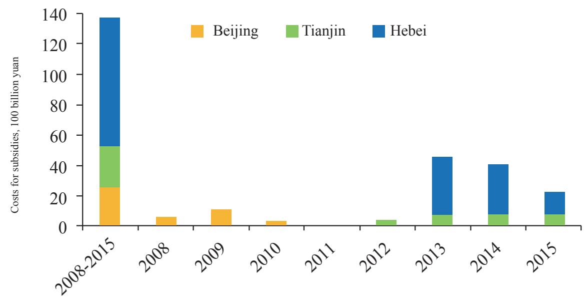


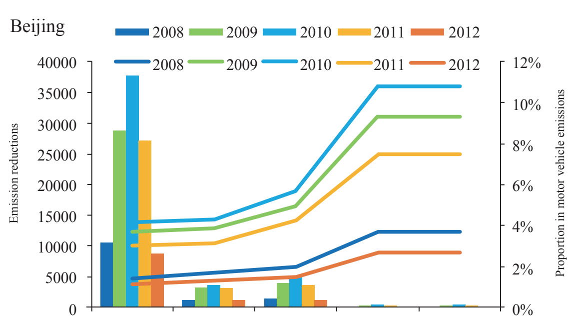
Figure 5 Costs for subsidies under the scrappage subsidy program in the Beijing-Tianjin-Hebei region, 2008–2015

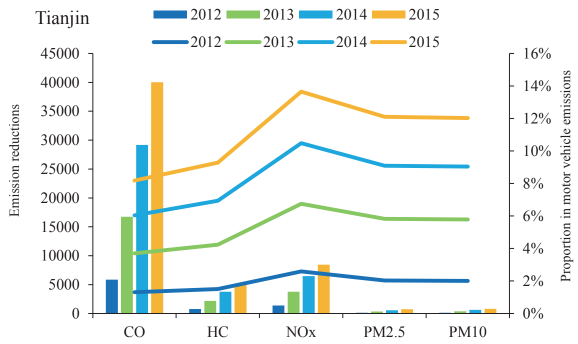


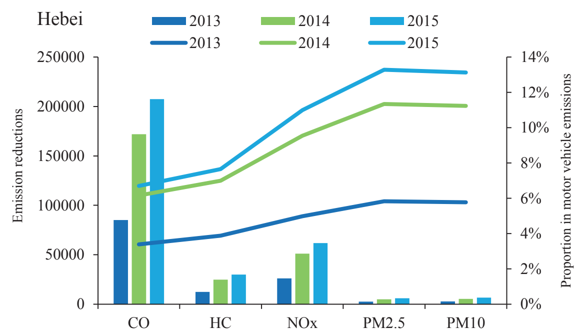
3.1.2 Environmental benefits

Owning to the implementation of the scrappage subsidy program, the CO, HC, NO_x, $PM_{2.5}$ and PM_{10} emissions from vehicles during 2008–2012 were cut by 113,072.60, 12,718.32, 15,239.55, 1,260.48, and 1,392.96 tons in Beijing respectively. The figures read 91,757.03, 11,840.53, 20,046.12, 1,755.30 and 1,938.90 tons for Tianjin during 2012–2015. The emission reductions of these five pollutants during 2013–2015 registered 464,278.80, 67,078.78, 139,149.70, 13,445.15 and 14,791.84 tons in Hebei.

Figure 6 Emission reductions from the scrappage subsidy program and the proportion in motor vehicle emissions in the Beijing-Tianjin-Hebei region



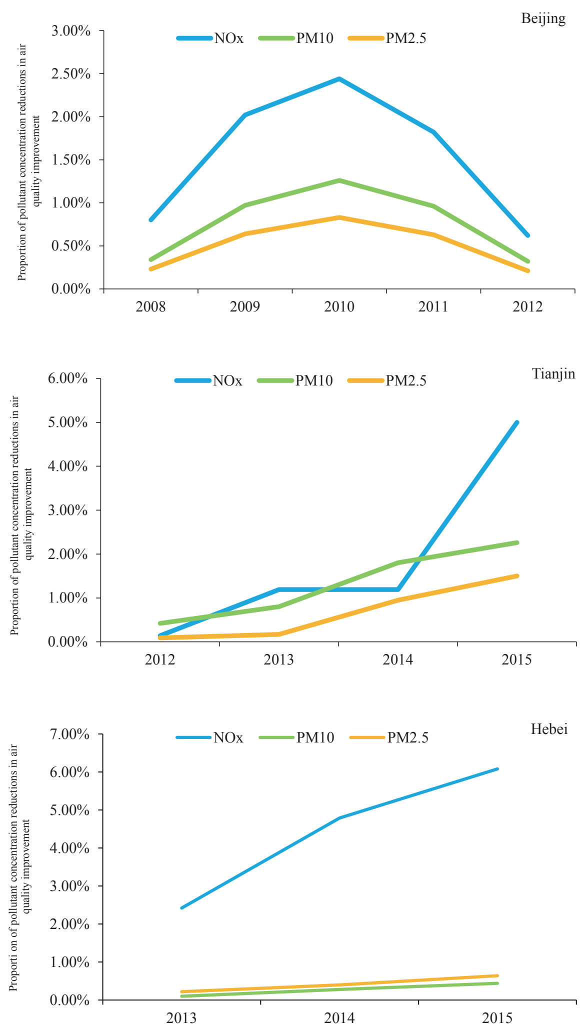




With the implementation of the scrappage subsidy program, the annual NO_x concentration in Beijing were reduced by 0.32–1.39 ug/m^3, $PM_{2.5}$ 0.35–1.52 ug/m^3, and PM_{10} 0.18–0.79 ug/m^3 during 2008–2012. The reductions in Tianjin reached 0.24–2.10, 0.44–2.62, 0.06–1.05 ug/m^3 respectively during 2012–2015. Hebei decreased the annual NO_x concentration by 0.24–7.69 ug/m^3, $PM_{2.5}$ 0.01–1.92 ug/m^3, and PM_{10} 0.02–1.13 ug/m^3 during 2013–2015.

Beijing saw the most significant air quality improvement in 2010 with the NO_x concentration lowered by 2.44%, PM_{10} 1.26% and $PM_{2.5}$ 0.83%. In Tianjin and Hebei, such improvement reached a record high in 2015 when the NO_x, PM_{10} and $PM_{2.5}$ concentrations fell by 5.00%, 2.26% and 1.50% in Tianjin respectively and 6.08%, 0.44% and 0.64% in Hebei.

Figure 7 Proportion of pollutant concentration reductions brought by the scrappage subsidy program in Beijing, Tianjin and Hebei



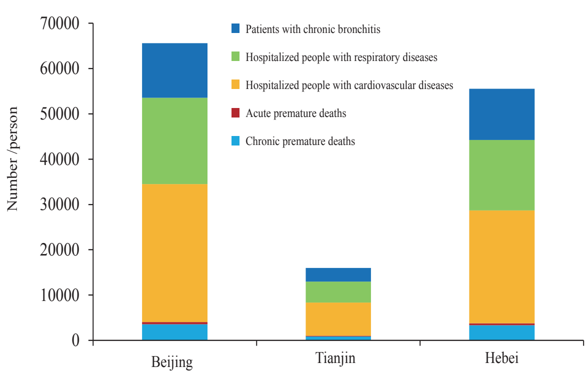
3.1.3 Health benefits

From 2008 to 2015, the number of premature deaths (including chronic and acute deaths) was narrowed by 4,015 in Beijing, representing about 45.7% of the total reduction of the Beijing-Tianjin-Hebei region. The figure read 1,005 in Tianjin and 3,769 in Hebei, accounting for about 11.7% and 42.6% of the regional total reduction respectively.

From 2008 to 2015, Beijing brought down hospitalized people (including with respiratory and cardiovascular diseases) by about 49,500, Tianjin 11,900 and Hebei 40,500, which accounted for 48.6%, 12.0% and 39.4% of the regional reduction of hospitalized people respectively.

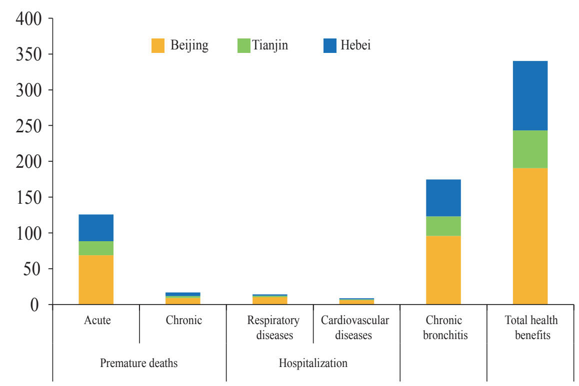
From 2008 to 2015, Beijing lessened the number of patients suffering from chronic bronchitis by 12,000, representing 45.7% of the regional reduction. The number approximately dropped by 11,300 in Tianjin and 3,000 in Hebei on average.

Figure 8 Health endpoints reduced by the scrappage subsidy program in the Beijing-Tianjin-Hebei region, 2008–2015



The health benefits in the Beijing-Tianjin-Hebei region totaled 34.03 billion yuan, 93% of which can be attributed to the reduction of premature deaths and chronic bronchitis. The health benefits associated with less premature deaths, chronic bronchitis and hospitalization registered 14.25 billion, 17.47 billion and 22.9 billion yuan respectively. Generally, the decline of chronic premature deaths generated far greater health benefits than that of acute premature deaths.

Figure 9 Value of health endpoints reduced by the scrappage subsidy program in the Beijing-Tianjin-Hebei region, 2008–2015



3.1.4 Economic and social benefits

The YLV elimination in the Beijing-Tianjin-Hebei region added new-vehicle consumption by 182.25 billion yuan. It drove an increase of 829.01 billion yuan in country's total output, including 182.25 billion yuan in a direct way and 646.76 billion yuan in an indirect way, which accounted for 22.0% and 77.4% respectively. This contributed to a GDP growth of 234.42 billion yuan, of which the direct and indirect impacts attained 371.1 billion and 197.24 billion yuan respectively. As a result, the income of residents rose by 98.10 billion yuan, of which the direct and indirect rises reached 12.61 billion and 85.39 billion respectively. 142,000 jobs were created, 3,000 in a direct way and 13,7000 in an indirect way. Overall, the YLV elimination policy gave a direct stimulus to the automobile industry, and played a positive role in the macro economy by driving national economic growth through the industrial chain.

Table 5 Macro-economic impact analysis of the YLV elimination policy

Indicator	Direct impact	Indirect impact	Total impact
Total output (100 million yuan)	18 22.5	6467.6	8290. 1
Value added (100 million yuan)	371.1	1972.4	2344.2
Residents' income (100 million yuan)	126.1	853.9	981.0
Nonfarm employment (10,000 persons)	0.3	13.7	14.2

3.2 Ban program

3.2.1 Costs

From 2008 to 2015, the social cost for the YLV ban policy amounted to 5.806 billion yuan in the Beijing-Tianjin-Hebei region, which included 1.355 billion yuan in Beijing, 1.694 billion yuan in Tianjin and 2.757 billion yuan in Hebei.

Figure 10 Costs for the ban policy in Beijing, Tianjin and Hebei, 2008–2015

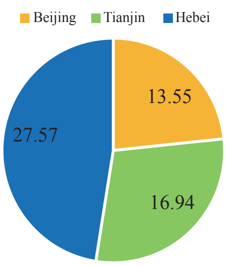
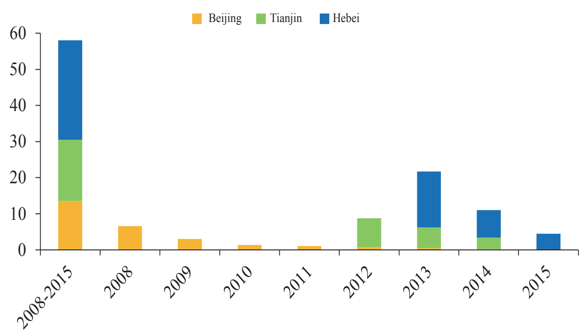


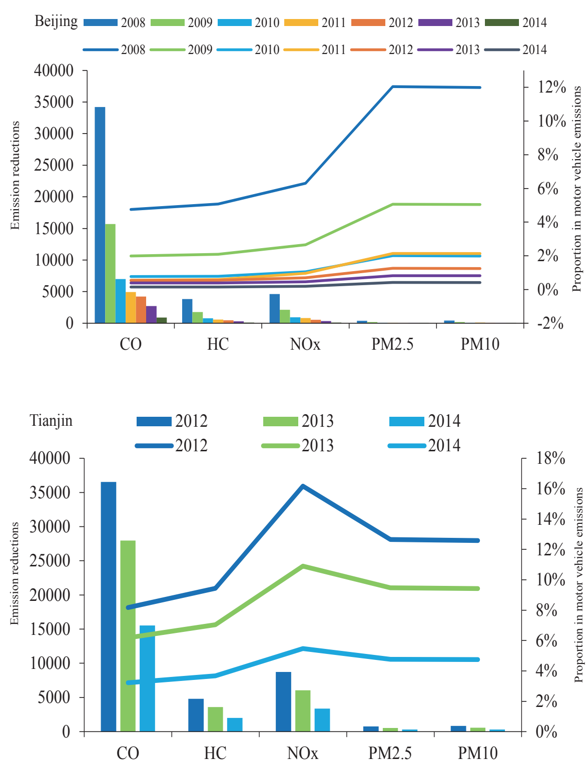
Figure 11 Costs for the ban policy in the Beijing-Tianjin-Hebei region, 2008–2015

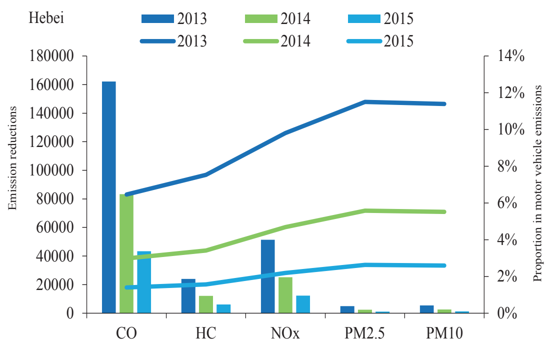


3.2.2 Environmental benefits

Due to the YLV ban policy, CO, HC, NO_x, $PM_{2.5}$ and PM_{10} emissions from vehicles in Beijing were cut by 69,654.87, 7,852.78, 9,531.60, 804.33 and 888.95 tons during 2008–2012 respectively. The numbers read 80,047.6, 10,425.01, 18,178.28, 1,581.95 and 1,747.39 tons for Tianjin during 2012–2015. The emission reductions of these five pollutants in Hebei reached 288,687.30, 42,184.90, 88,812.40, 8,588.65 and 9,448.11 tons during 2013–2015.

Figure 12 Emission reductions from the ban policy and the proportion in motor vehicle emissions in the Beijing-Tianjin-Hebei region

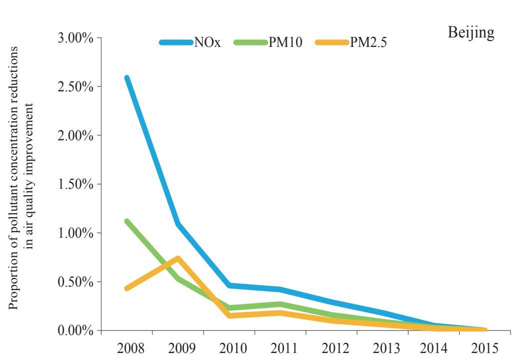


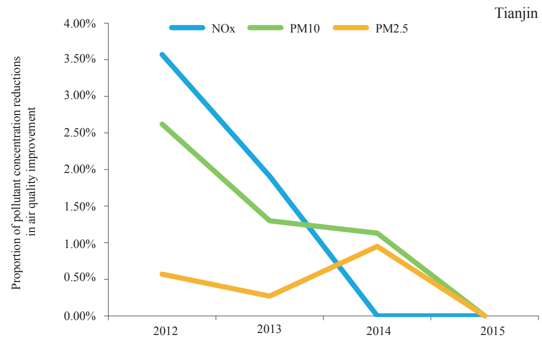


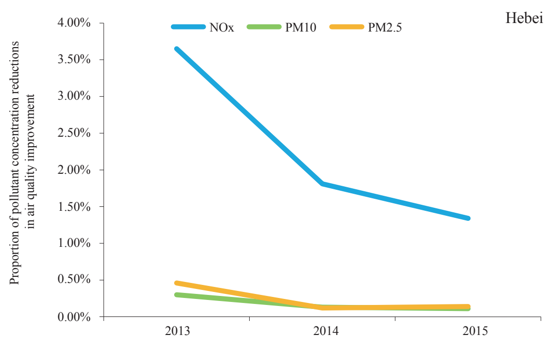
With the implementation of the ban policy, the annual NO_x concentration in Beijing were reduced by 0.03–1.27 ug/m^3, $PM_{2.5}$ 0.04–1.37 ug/m^3 and PM_{10} 0.02–0.41 ug/m^3 during 2008–2012. The reductions in Tianjin reached 1.03–1.50, 1.50–2.75, 0.26–0.79 ug/m^3 respectively during 2012–2015. Hebei decreased the annual NO_x concentration by 0.05–4.04 ug/m^3, $PM_{2.5}$ 0.01–1.70 ug/m^3 and PM_{10} 0.02–1.07 ug/m^3 during 2013–2015.

Beijing saw the most drastic reductions of NO_x and PM_{10} concentrations in 2008 and $PM_{2.5}$ in 2009, which read 2.59%, 1.12% and 0.74% respectively. In Tianjin, the largest magnitude of decline in the NO_x and PM_{10} concentrations registered 3.57% and 2.62% (in 2012) and $PM_{2.5}$ 0.95% (2014). In Hebei, such improvement reached a record high in 2013 when the three concentrations fell by 3.65%, 0.30% and 0.46% respectively.

Figure 13 Proportion of pollutant concentration reductions brought by the ban policy in Beijing, Tianjin and Hebei







3.2.3 Health benefits

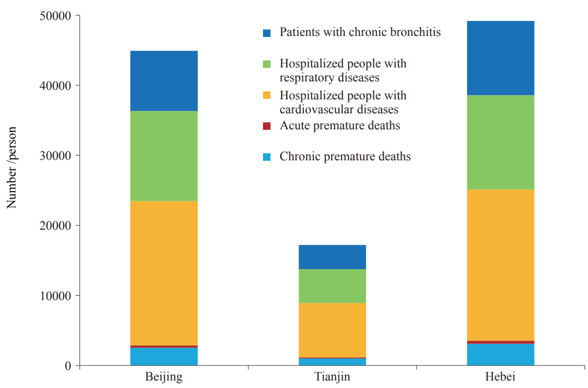
From 2008 to 2015, the number of premature deaths (including chronic and acute deaths) was narrowed by 809–4287 (2,860 on average) in Beijing, representing about 37.9% of the total reduction of the Beijing-Tianjin-Hebei region. The figure read 1,148 in Tianjin and 3,535 in Hebei, accounting for about 15.2% and 46.9% of the regional total reduction respectively.

From 2008 to 2015, Beijing brought down hospitalized people (including with respiratory and cardiovascular diseases) by 8000–42000, Tianjin 12,600 and Hebei 35,100, which accounted for 41.3%, 15.5% and 43.2% of the regional reduction of hospitalized people respectively.

From 2008 to 2015, Beijing lessened the number of patients suffering from chronic bronchitis by 3000–18000 (8,600 on average), representing 47.9% of the regional reduction.

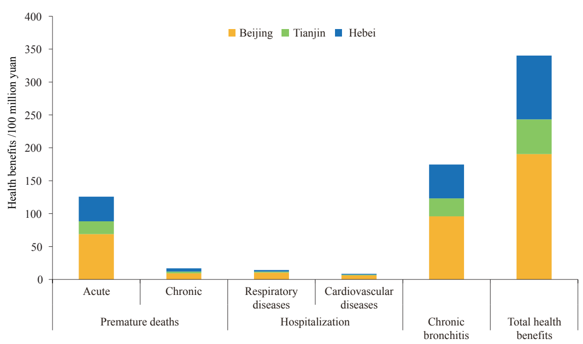
The number approximately dropped by 3,400 in Tianjin and 10,600 in Hebei on average.

Figure 14 Health endpoints reduced by the ban policy in the Beijing-Tianjin-Hebei region, 2008–2015



The health benefits in the Beijing-Tianjin-Hebei region totaled 28.3 billion yuan, 94% of which can be attributed to the reduction of premature deaths and chronic bronchitis. The health benefits associated with less premature deaths, chronic bronchitis and hospitalization registered 11.94 billion, 14.63 billion and 1.73 billion yuan respectively. Generally, the decline of chronic premature deaths created far more health benefits than that of acute premature deaths.

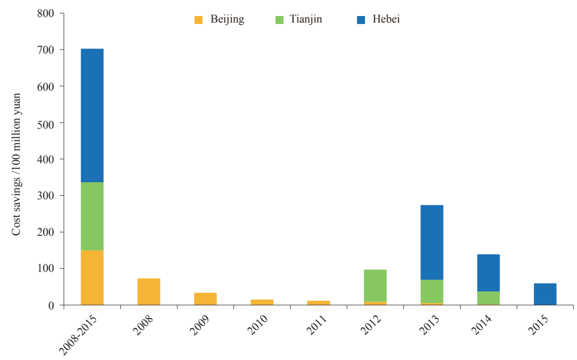
Figure 15 Value of health endpoints reduced by the ban policy in the Beijing-Tianjin-Hebei region, 2008–2015



3.2.4 Cost savings

From 2008 to 2015, the cost savings derived from the ban policy in the Beijing-Tianjin-Hebei region totaled 70.226 billion yuan. To break it down, the figures read 14.938 billion, 18.680 billion and 36.608 billion yuan for Beijing, Tianjin, and Hebei respectively.

Figure 16 Cost savings derived from the ban policy in the Beijing-Tianjin-Hebei region, 2008–2015



3.3 Results

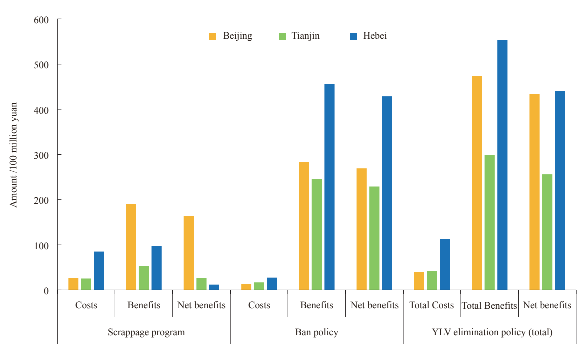
From 2008 to 2015, the YLV elimination policy (including scrappage subsidy program and ban program) in the Beijing-Tianjin-Hebei region involved total costs of 19.49 billion yuan and produced total benefits of 132.55 billion yuan. The net benefits reached 113.06 billion yuan, of which 20.34 billion yuan were derived from the scrappage subsidy program and 92.722 billion yuan from the ban policy. As far as scrappage is concerned, Beijing stayed top in net benefits and cost-effectiveness ratio (7.27:1). As to the ban policy, Beijing presented the highest cost-effectiveness ratio of 20.88: 1, though it failed to maximize the net benefits.

From 2008 to 2015, Beijing's NO_x emission reductions brought by the YLV elimination policy represented 5.97% of motor vehicle emissions in the region, Tianjin 16.40%

and Hebei 14.05%. They accounted for 2.57%, 3.25% and 5.09% of the regional NO_x emissions respectively, contributing to 2.50%, 3.20% and 7.98% of the decline in regional NO_x concentrations. Beijing's $PM_{2.5}$ emission reductions represented 11.15%, of motor vehicle emissions in the region, Tianjin 13.96% and Hebei 16.71%, accounting for 1.02%, 1.34% and 0.80% of the regional $PM_{2.5}$ emissions respectively. They brought down the regional $PM_{2.5}$ concentrations by 0.84%, 1.15% and 0.78% respectively.

The YLV elimination policy in the region added new-vehicle consumption by 182.25 billion yuan, resulting in an increase of 835.17 billion yuan in China's total output, 234.42 billion yuan GDP, 98.10 billion yuan residents' income and 142,000 people employment. The policy contributed to different degrees to economic sectors. It exerted the most impact on the automobile manufacturing industry by adding about 207.2 billion yuan, representing 25% or so of the total output. As a whole, the YLV elimination policy directly boosted China's automobile industry and promoted national economic growth through industrial chain, thus playing a positive role on the macro-economy.

Figure 17 Cost-benefit analysis results of the YLV elimination policy



3.4 Uncertainty analysis

Uncertainties may arise from the following aspects:

(1) Calculation boundary. Given the large scope of the Beijing-Tianjin-Hebei region and limited costs for management and vehicle transformation, administrative costs, indirect costs and benefits are not included in the calculations.

(2) Data. There are wide differences among regions in the quantities and pollutant emissions of YLVs with different models, conditions and standards. Due to data constraint, the number of YLVs eliminated in the cities of the Beijing-Tianjin-Hebei region each year is estimated based on the annual total and the 2012 model ratio in the three places.

(3) Parameter coefficients. There are uncertainties in the proportion of owners that buy new cars and the natural elimination rate, mileage traveled and occupancy of yellow-label vehicles.

(4) Time and scope of the ban policy. Launched at different time, the ban on YLVs on road expanded the scope over time in cities of the Beijing-Tianjin-Hebei region. The policy applies to such vehicles from other areas, and in some cases, it does not cover the whole region or the whole year. Therefore, there may be certain error in the cost-benefit analysis of this policy.

(5) Dose-response factor. A group of parameters from existing studies at home and abroad has been used for calculating environmental and health benefits. This may lead to uncertainty in the results, due to differences in the types and concentrations of air pollutants and the size and characteristics

of exposed population.

(6) Input data for the input-output model. It is assumed that 90% of the YLV owners purchase new cars, which may be inconsistent with the reality in the cities of the Beijing-Tianjin-Hebei region.

(7) Input-output model. The 2012 input-output model has been used for static economic impact assessment of the YLV elimination policy, but the dynamic changes in industrial structure and correlation coefficient among years may add uncertainty in the results. In addition, uncertainties may also arise from such parameters as labor occupancy coefficient. Nevertheless, experiences prove such errors have little effect on the results.

4. CONCLUSIONS AND SUGGESTIONS

4.1 Conclusions

From 2008 to 2015, the YLV elimination policy (including scrappage subsidy program and ban program) in the Beijing-Tianjin-Hebei region involved total costs of 19.49 billion yuan and produced total benefits of 132.55 billion yuan, making net benefits of 113.06 billion yuan. The results show that the policy has played an important role in reducing pollutant emissions and improving air quality in region, and the benefits have far outweighed the costs. Meanwhile, the policy has exerted a positive impact on the macro economy by increasing GDP, income and employment.

4.2 Suggestions

First, economic instruments should be maintained to advance the elimination of old vehicles. The YLV elimination policy will yield greater net benefits if implemented earlier. The results will turn better in urban areas with relatively dense population, large exposed groups and high per capita GDP. Second, the ban and restriction policy should be strictly implemented. It is suggested to improve the legislation, strictly develop, and enforce the ban on on-road YLVs and the restriction on on-road old vehicles in a larger scope. Motor vehicles in violations of such regulations will face serious penalties. Policy instruments such as Fuel-related pollution charges and differentiated parking fees are expected to accelerate the elimination of yellow-label vehicles and old vehicles. Third, it is necessary to raise the standards of subsides for phasing out yellow-label vehicles and older vehicles. Fourth, the YLV management needs to be strengthened, especially considering the transfer of such vehicles to other areas. To address the transfer of pollution with YLVs, the supervision of the used car market should be strengthened and the transaction of such vehicles restricted. Fifth, publicity and education should be intensified to encourage car owners to use energy-efficient low-emission vehicles and public transportation.

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