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Optimal Subsidizing Policy to Promote Electric Vehicles in Hong Kong

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Abstract

In this paper, we propose a framework to optimize the subsidizing policy by taking into account all the lifecycle costs and the environmental benefits of electric vehicles. First, the barriers of commercialization of electric vehicles are discussed. Models are developed to estimate the damages costs of vehicular emissions. Optimal subsidizing rules are derived to maximize the saving in government expenditure. The optimization framework for Hong Kong is developed. Numerical analysis is conducted to illustrate the effectiveness of the optimal subsidizing policy. Benefits of electric and hybrid electric vehicles are compared. The hybrid electric vehicle is found to be more cost effective in Hong Kong.

Keywords

transportation systems, policy

1. INTRODUCTION

Vehicle emissions cause serious air pollution problems in many metropolitan cities. The intensity of vehicle usage is high. The intensity of vehicle usage grows continuously. In Hong Kong, the urban setting and tall buildings are dense such that the dispersion of pollutants is poor. Electric vehicles (EVs) and hybrid electric vehicles (HEVs) have higher fuel economy and produce less pollutions, hence, they have been propelled as the alternative vehicles to substitute internal combustion engine vehicles (ICEVs) to reduce air pollution.

EVs have the advantages of zero tailpipe emissions, flexible chassis design, and silent motor operations. However, there are pollutions from EVs because of the emissions from the power plants, which supply the electricity. Hence, the net reduction of emissions due to the use of EVs depends on the source of the fuel for electricity generation.

The market share of EVs and HEVs is low. Not only the vehicle performances but also the high prices hinder the commercialization of EVs and HEVs [Kamioka, 2003]. There are certain numbers of paper dealing with the estimation of transport externalities of alternative fuel vehicles. Some papers also highlight the necessity to provide subsidy to promote EVs and HEVs. Subsidy is essential for the commercialization of EVs and HEVs [Kamioka, 2003, Borger et al., 1998]. This paper aims to propose a framework to integrate both the tangible and intangible parameters of EVs, HEVs and ICEVs. Hence, environmental benefits of EVs and HEVs are quantified to optimize the cost effectiveness of the subsidizing policy.

2. THEORETICAL MODEL

The basis for evaluating the cost effectiveness of a subsidizing policy is the estimation of the lifecycle costs (LCCs) and the quantification of the environmental benefits of EVs and HEVs. Figure 1 shows the flows to optimize the subsidizing policy. First, LCCs are estimated to determine the marginal amount of subsidy, which is the LCC difference between an EV and an ICEV or the difference between a HEV and an ICEV by assuming that people buy EVs or HEVs if the LCCs of EVs or HEVs are less than or equal to that of ICEVs. The subsidizing policy changes distribution of vehicle population, which in turn changes the emissions of pollutants and greenhouse gas (GHG) in the city. The damage of gas pollutants and GHG emissions is quantified into damage cost (DC) [Kirby, 2000, Ogden et al., 2004].

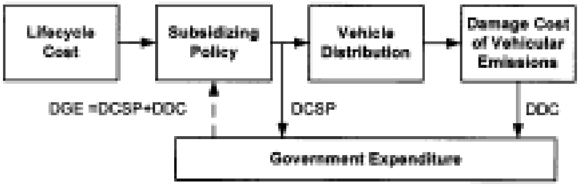

Fig. 1 Framework of optimization

Government policy correlates the costs of vehicles [Dhakal, 2003, Smokers, 2002]. Existing subsidizing policies can be found in a transportation system. The cost of subsidizing policy is defined as CSP in this paper. The proposed framework is to estimate the impact to the government expenditure (GE) while the optimization scheme is to minimize the government expenditure by controlling the total amount of subsidy. The impact to CSP due to this new policy is defined as DCSP, while the impact to DC is defined as DDC. Finally, the impact to GE is defined as DGE.

Historical statistics are used to determine the parameters in this framework. In the following subsections, the modeling approaches will be discussed while the statistics in Hong Kong are applied to demonstrate the application of the framework. Finally, a numerical simulation with reference to the scenario in Hong Kong is conducted to illustrate the effectiveness of the optimization scheme.

2.1 Assumptions

The vehicles studied here are representatives of 1800cc or power equivalent passenger cars. The life cycle is assumed to be 9 years while the annual mileage is assumed to be 1000 km. Three types of vehicles are studied, namely the battery EV, HEV and ICEV. The notation used is listed in Table 1. The cost of vehicles is an essential factor which affects the road users' purchase decisions. Table 2 lists the key vehicle figures and assumptions for economic analysis.

Table 1 Notation of vehicle types

Superscript	Vehicle Type
0	Passenger car –ICEV
1	Passenger car – Battery EV
2	Passenger car – HEV

Table 2 Estimation of lifecycle costs

Vehicle Type	EV	HEV	ICEV
Fuel converter power (kW)	63	63	63
Life cycle (year)	9	9	9
Annual mileage (km)	9000	9000	9000
Annual energy use (kWh)	3800	6370	9100
Petrol price (US$/kWh)	N.A.	0.155	0.155
Electricity price (US$/kWh)	0.122	N.A.	N.A.
Vehicle cost (US$)	26667	22564	20513
First registration tax (US$)	0	7897	7179
Vehicle price (US$)	26667	30462	27692
Annual expenses:			
Lease of battery (US$)	1538	0	0
License fee (US$)	81	743	743
Compulsory insurance (US$)	513	513	513
Maintenance (US$)	513	385	256
Fuel tax (US$)	0	544	777
Fuel cost (US$)	463	446	637
Subtotal annual expense (US$)	3108	2630	2926
Running cost (US$)	25873	21897	24362
Lifecycle cost (US$)	52540	52359	52054

N.A. : Not applicable

2.2 Estimation of Lifecycle Cost

The lifecycle cost is given by

$LCC^i = lcc(P^i, RC^i)$ for i=0,1,2 (1)

where lcc calculates the lifecycle cost of vehicle i (LCC^i). P^i and RC^i represent the price and the running cost of vehicle i. P^i includes the first registration fee. Running costs is the present value of the lifecycle costs with an interest rate of 2%.

In Hong Kong, the first registration tax of EVs is waived as a promotion of EVs. On the other hand, the first registration tax for HEVs and ICEVs is assumed to be 35% of the vehicle cost. Vehicle cost of the HEV is assumed to 10% more expensive than that of an ICEV, while the vehicle cost of the EV, excluding the battery, is assumed to be 30% more expensive than that of an ICEV. Battery cost for the battery EV is not included in the price. The LCCs of different vehicles are listed in Table 2.

2.3 Determination of Subsidizing Level

The amount of subsidy (S) is given by

$S^i = LCC^i - LCC^0$ for i = 1,2 (2)

where S^i is the subsidy paid for an vehicle i. The DCSP is given by

$DCSP^i = VP^i * S^i$ for i = 1,2 (3)

where VP^i is the population of vehicle i. The population of ICEV is given by

$VP^0 = V - VP^i$ for i = 1,2 (4)

where V is the total number of passenger cars in the city. In Hong Kong, passenger cars dominate more than 64% of licensed motor vehicles. In 2000, there were 332379 licensed passenger cars. In February 2003, there were 339459 petrol passenger cars, 2202 diesel passenger cars and 9 electric passenger cars. In this paper, the total number of passenger cars is assumed as 332379.

2.4 Estimation of Damage Cost

There were significant correlations between the concentrations of air pollutants and the mortality rates of certain types of respiratory and cardiovascular diseases. In this paper, only the damage costs of air pollutants on health is quantified as the damage cost of vehicular emissions. Monetary values associated with the morbidity and mortality caused by the rise of individual criteria ambient pollutants, namely the nitrogen dioxide (NO_2), sulphur dioxide (SO_2), respiratory small particulate (RSP), are evaluated according to the relative risk (RR) factor provided by the Environmental Protection Department (EPD). The damage cost is given by

$DC^i = dc(VP^i, FAEF^i, M^i, E_{COI}, E_{WTP})$ for i = 0,1,2 (5)

where dc calculates the damage cost of vehicles, E_{COI}, E_{WTP} are economic costs calculated by cost of illness (COI) and willingness-to-pay (WTP) respectively, M^i is the annual mileage of vehicle i, and $FAEF^i$ is the fleet

Table 3 Modified emission factors of passenger cars

Pollutants	EV	HEV	ICEV
SO_2 (g/km)	0.6625	0	0
NO_2 (g/km)	0.185	0.319	0.455
RSP (g/km)	0.0385	0.0272	0.0388

average emission factors of vehicle i. Table 3 shows the FAEFs of the EV, HEV and ICEV in Hong Kong.

E_{COI} and E_{WTP} are obtained by

$$E_{COI} = b(d_i) * COI(d_i) * \{RR(p_i, d_i) - 1\} \quad (6)$$

$$E_{WTP} = b(d_i) * WTP(d_i) * \{RR(p_i, d_i) - 1\} \quad (7)$$

where E is economic cost of morbidity and mortality by hospital admission, $b(d_i)$ is the actual hospital admission and out-patient doctor consultation due to a particular disease d_i such as respiratory or circulatory diseases, COI estimates the cost of illness related to hospital admissions and out-patient treatment due to d_i, RR is the relative risk for morbidity and mortality, and p_i is the air pollutant. The available quantitative data of Hong Kong was fitted into these mathematical models to evaluate the economic impact of air pollution with respect to morbidity and mortality.

COI concentrates on the aspects of the value of health that are well-defined with observable and measurable quantities. In COI, people are treated as productive agents and yield a continuing return in the future. The values of any resources used in promoting health are referred to as the direct cost of illness, while the losses of labour earnings due to the sickness and premature death are considered as the indirect cost of illness. The economic impact estimated by COI is listed in Table 4.

Table 4 Estimated economic cost increase in criterion pollutants by COI

Per Microgram Per Cubic Metre Increase	SO_2	NO_2	RSP
Morbidity (million US$)	1.249	2.186	1.249
Mortality (million US$)	0	7.162	2.387
Total (million US$)	1.249	9.347	3.636

WTP is based on methods developed for explicit quantification of the monetary value of health gains and losses. WTP includes market and non-market activities and leisure, and the premium for pain and suffering, which are the intangible aspects of health. WTP values are evaluated from four components, namely loss of wages, additional medical expenses, the monetary value of the disutility of additional illness and the change in defensive expenditures through the quantification of "stated preference" based on market prices which are derived from survey techniques. The economic impact estimated by WTP is listed in Table 5.

Table 5 Estimated economic cost increase in criterion pollutants by WTP

Per Microgram Per Cubic Metre Increase	SO_2	NO_2	RSP
Morbidity (million US$)	2.142	3.750	2.142
Mortality (million US$)	0	9.717	3.238
Total (million US$)	2.142	13.467	5.381

The benefits of EV and HEV are defined by

$$DDC^i = DC^i - DC^0 \text{ for } i = 1,2 \quad (8)$$

2.5 Area of Optimization

The impact of the subsidizing policy is defined by

$$DGE^i = DCSP^i - DDC^i \text{ for } i = 1,2 \quad (9)$$

Both DDC^i and DGE^i depend on $DCSP^i$. Figure 2 shows the variations of DDC^1 and DGE^1 with reference to different values of $DCSP^1$. The DDC^1 is estimated by WTP. The population of EVs is linearly proportional to $DCSP^1$. On the other hand, the increase of $DCSP^i$ decreases the population of ICEVs, hence, emissions of pollutants are reduced such that the DDC^1 is reduced.

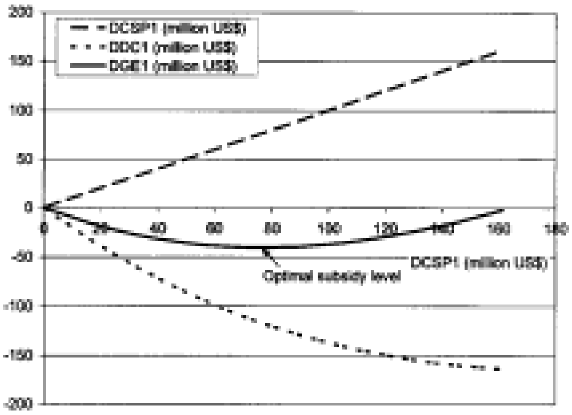

Fig. 2 Optimal subsidizing policy for EVs with damage cost estimated by WTP

The optimal subsidizing level depends on the method of estimating the damage cost. Figure 3 shows the variations of DDC^1 and DGE^1 with reference to different values of $DCSP^1$ when the damage cost is estimated by COI. As shown in Figure 3, the DGE^1 becomes positive when

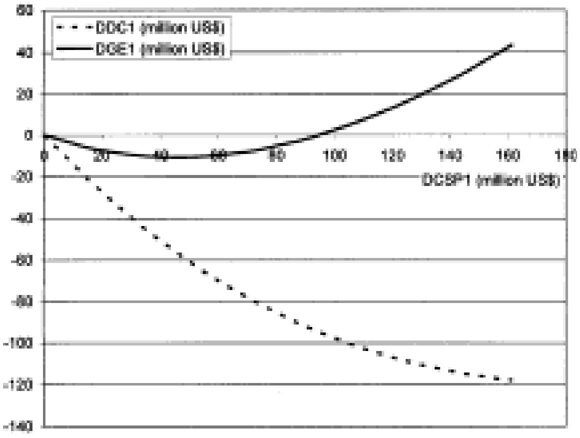

Fig. 3 Optimal Subsidizing Policy for EVs with Damage Cost Estimated by COI

the DCSP^1 is over 96 million US$.

The optimal subsidizing levels for HEVs are found similarly. Figure 4 shows the changes of DDC^2 and DGE^2 when the damage cost is estimated by WTP. Figure 5 shows the changes of DDC^2 and DGE^2 when the damage cost is estimated by COI. Finally, the achievements of optimal policy is summarized in Table 6.

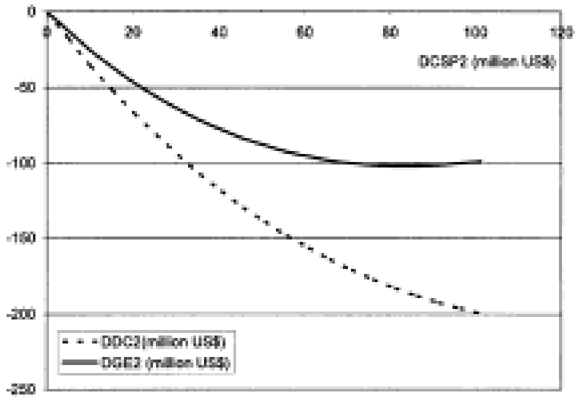

Fig. 4 Optimal subsidizing policy for HEVs with damage cost estimated by WTP

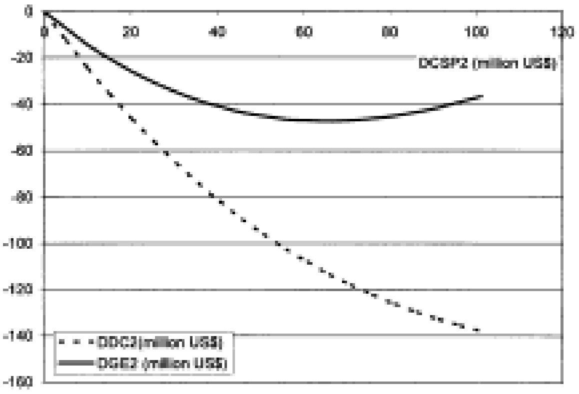

Fig. 5 Optimal subsidizing policy for HEVs with damage cost estimated by COI

Table 6 Achievements of optimal subsidizing policy

	Estimation of Damage Costs	**Optimal Market Share**	**Saving in Government Expenditure (Million US$)**
EV	WTP	45%	40.56
	COI	30%	10.84
HEV	WTP	80%	101.89
	COI	65%	47.46

3. CONCLUSION

A framework was proposed to optimize the subsidizing policy, by taking into account all the lifecycle costs and the damage costs of EVs, HEVs and ICEVs. The optimization scheme aims to minimize the government expenditure by controlling the total amount of the subsidy. Numerical analysis of the scenarios in Hong Kong is conducted to demonstrate the effectiveness of the subsidizing policy. In Hong Kong, the benefits of EVs or HEVs render the subsidies paid. However, it is more cost effective to promote HEVs in Hong Kong.

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