Evaluation on Economic Performance Efficiency of Hybrid Electric Vehicle

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Abstract: Hybrid electric vehicle is the most mature area in the development of new energy automotive industry. This paper employs data envelopment analysis model to analyze the overall economic performance, pure technology efficiency and pure scale efficiency of the five typical hybrid vehicles in Chinese market, and then obtains the improving direction of DEA efficiency. Finally, evaluation results are offered on the economic performance of hybrid vehicles to raise appropriate suggestions.
Key words: HEV; Economic performance; DEA

1 Introduction

The new energy automobile has good energy conservation and environmental protection effect, which may bring long-term benefit to consumers and the society. Moreover, governments issue subsidy to the consumers to stimulate market demand for the new energy automobiles. Japanese government subsidy amounts to about 2000 US dollars to each new energy automobile on average, and American subsidy varies from 500 US dollars to 2000 US dollars. "Tentative Method of the Administration of the Fund Subsidizing Energy Conservation and New Energy Automobile" released in China recently also explicitly stipulates that China will subsidize new energy vehicle [1]. For all this, compared with the traditional fuel automobile, high price of the new energy automobile enables the majority consumers only to keep at a respectful distance to it, making the new energy auto market “game no one played”. What auto buyers’ care most is its economical serviceability, rather than whether it’s energy-saving or not. So the superiority of the new energy automobile often cannot obtain consumer's approval.

In the current technical conditions, there is a big gap between the economical efficiency of the new energy car and market expectations. Its market share is still very low, for example, in 2006, the sales of the new energy vehicle accounted for only 7.9% of total car sales in the United States where the new energy vehicles develop better, while in China less than 1%. But the new energy vehicle technology continues to be mature and industry scale expands, its economical efficiency will inevitably be greatly improved. In recent years, for the aim of analyzing the power and economic of hybrid electric vehicle, some scholars has studied the economical evaluation consisting of the current situation of the manufacture, sale, and prospect, as well as economical analysis and gain and loss analysis of hybrid vehicle in China [2], and some has analyzed and predicted the life cycle cost of HEV in the last three stages, and also compared the cost of HEV with that of the conventional diesel bus (CDB) [3]. They all put forward many innovative viewpoints. Nevertheless, research limitations are still exists because of all these researches are still at the exploration stage. Based on the results of other scholars, this paper analyzes the economical efficiency of the typical hybrid electric vehicles by using data envelopment analysis model to estimate the overall economic performance, pure technology efficiency and pure scale efficiency of the five typical hybrid electric vehicles in Chinese market, so obtaining the improving direction of DEA efficiency. Finally, evaluation results were analyzed on the economic performance of hybrid vehicles to raise appropriate suggestions. This paper is divided into four parts: Part I, Introduction; Part II, Models and Indicators; Part III, Data and Results Analysis; Part IV, Conclusion.

2 Models and Indicators

2.1 Model design

Data envelopment analysis, based on the actual decision making unit of a production system, is built on the concept of "Pareto optimal" of decision making units. It determines the efficiency frontier of the production system (or frontier production function) through the use of linear programming techniques, and then gets the relative efficiency as well as scale benefit of decision making units and other information. For decades in foreign countries, there are a great deal of the research literature of DEA theory and its application in management science and in the field of operations research [4-6]. Chinese scholar Wei Quanling playes an active and important role in the popularization and promotion of DEA in China [7] and in 2000 he published literature on the research progress of DEA [8].

In this paper, the economic performance of the hybrid electric cars can be seen as the activity of producing a certain number of "products" by some decision-making units through the input of a number of production factors. Although the concrete content of inputs and outputs is somewhat different, its purpose is to maximize the economic and social benefits as much as possible. Therefore, firstly, the text uses C^2R model with a non-Archimedean infinitesimal evaluating DMU overall efficiency based on the input.

$$(D_\varepsilon)\begin{cases}\min[\theta-\varepsilon(\hat{e}^T s^- + e^T s^+)],\\ \sum_{j=1}^{n}\lambda_j x_j + s^- = \theta x_0,\\ \sum_{j=1}^{n}\lambda_j y_j - s^+ = y_0,\\ \lambda_j \ge 0, j=1,\cdots,n,\\ s^- \ge 0, s^+ \ge 0.\\ \varepsilon \text{ is non-Archimedean infinitesimal}\end{cases} \tag{1}$$

The overall efficiency used to evaluate technology and scale is called the overall efficiency. Secondly, the text uses BC^2 model with a non-Archimedean infinitesimal evaluating DMU pure technological efficiency based on the input.

$$(D_\varepsilon)\begin{cases}\min[\sigma-\varepsilon(\hat{e}^T s^- + e^T s^+)],\\ \sum_{j=1}^{n}\lambda_j x_j + s^- = \sigma x_0,\\ \sum_{j=1}^{n}\lambda_j y_j - s^+ = y_0,\\ \sum_{j=1}^{n}\lambda_j = 1, \lambda_j \ge 0, j=1,\cdots,n,\\ s^- \ge 0, s^+ \ge 0.\\ \varepsilon \text{ is non-Archimedean infinitesimal}\end{cases} \tag{2}$$

The DMU efficiency calculated by the model is pure technical efficiency, reflecting the conditions of DMU pure technical efficiency. Finally, it calculates the net scale efficiencies of DMU by formula (3).

$$s^* = \frac{\theta^*}{\sigma^*} \tag{3}$$

2.2 Selection of indicators and analysis

Hybrid cars use both fuel and electric drive. According to the proportion of electric drive, it can be divided into low degree hybrid, moderate degree hybrid and high degree hybrid. The oil saving rate of low degree hybrid vehicles is between 10% -15%. The cost of which is low and the technology is easy to implement. Typical car models home and abroad are Mercedes-Benz Smart, Chery A5 BSG, Besturn B50 HEV, etc.; the oil saving rate of high degree hybrid vehicles is between30%-40%. The cost of which is high and the structure is complex. Typical car models are Mercedes-Benz S400 Hybrid, Toyota Prius, BYD F3 DM. Moderate fuel-efficient hybrid vehicles are between the two in terms of oil-saving, cost and technology. Typical examples are Buick LaCrosse ECO-Hybrid, Honda Civic Hybrid, Junjie Hybrid etc.

This paper selects 5 hybrid cars for sale on Chinese market sales, respectively, Toyota Prius, Civic Hybrid, LaCrosse ECO-Hybrid, BYD F3 DM and Chery A5 BSG, covering low degree hybrid, moderate degree hybrid and high degree hybrid. They are of both foreign and domestic brands, and very typical. The analysis of their economic performance can fully reflect the economic performance and other conditions of hybrid vehicles.

From the entire life-cycle perspective, the cost of hybrid vehicles is mainly the purchase cost and the use cost. For consumers, the purchase cost of hybrid cars is the purchase price, while the use cost includes: fuel costs, maintenance costs, tax costs and government subsidies costs, of which tax and government subsidies costs can be neglected, and maintenance costs depend on the specific vehicle condition which has great randomness and is difficult to have a unified measure. Therefore, the fuel cost is the main concern of the use costs of hybrid cars. Considering the above analysis, the paper decided to choose the following five technical and economic indicators: price, emissions, fuel consumption, oil saving rates and sales of hybrid vehicles to conduct economic analysis, as is shown in Table 1.

Table 1 The Economic Indicators of the 5 Hybrid Electric Vehicles

Hybrid vehicles	Price（0,000 yuan）	Emissions（L）	Fuel consumption（L/100km）	Saving rate（%）	Sales (Units)
Toyota Prius	27.98	1.5	4.3	31.3	3182
Civic Hybrid	26.98	1.3	4.7	16.3	290
Lacrosse ECO-Hybrid	26.99	2.4	8.3	15	313
BYD F3 DM	14.98	1.0	4.0	33	117
Chery A5 BSG	7.48	1.6	5.2	10	250

Selected 5 from the price of hybrid view, which, BYD F3 DM and Chery A5 BSG Both the price of domestic brand cars less than 15 million, the price of Chery A5 BSG is less than 10 million, was 7.48 million. While the other three models priced foreign brands are in between 250,000 to 300,000 yuan, domestic hybrid vehicle compared to the foreign price of hybrid vehicles more obvious advantages.

From the displacement point of view, LaCrosse ECO-Hybrid displacement of 2.4L, 4 other models in the 1.0-2.0L displacement between the emission models are moderate. At the same time, vehicle emissions largely determine how much of its fuel from the fuel consumption indicators, LaCrosse ECO-Hybrid's fuel consumption is one hundred kilometers 8.3L, Chery A5 BSG's one hundred km fuel consumption of 5.2 L, Toyota Prius, the Civic Hybrid, BYD F3 DM of hundred kilometers are between the 4L-5L.

Saving rate of this indicator reflects the general hybrid cars and similar vehicles compared to the ratio of the fuel savings, depending on the electric drive hybrid vehicle technology. At the same time, this indicator is strong by mixing, the mixing, weak mixing three types of hybrid vehicles standards. Toyota Prius, BYD F3 DM models of fuel-efficient mixing of two strong rate of more than 30%; Civic Hybrid, LaCrosse ECO-Hybrid's fuel-efficient models in the mixed two rates were 16.3%, 15%; Chery A5 BSG's saving rate of 10%, mixed models are weak.

Sales reflected the market's level of demand for hybrid vehicles, from 5 models of domestic sales situation of China; its sales are very small. Among them, the sales of the Toyota Prius are the best, listed in the domestic market in early years, sales of just over three years since 3000, and just listed BYD F3 DM, its sales volume in the Shenzhen Municipal Government procurement 80, very few real market sales.

3 Data and Results Analysis

According to the indicates and data of table 1, by using C^2R model and BC^2 model, it calculates five types of new energy (hybrid electric) vehicles' economic total efficiency θ^*, pure technical efficiency σ^*, and pure scale efficiency s^* calculated by formula (3) and the concrete results will be shown in table 2.

Table 2 The DEA Economic Performance Evaluation Results of Five Types Hybrid Electric Vehicles'

DMU	θ^*	σ^*	s^*	s_1^{*-}	s_2^{*-}	s_3^{*-}	s_4^{*-}	s_1^{*+}	Scale efficiency
Toyota prius	1.000	1.000	1.000	0	0	0	0	0	unchanged
Civic Hybrid	0.175	1.000	0.175	0	0	0	0	0	increasing
Lacrosse ECO- Hybrid	0.205	0.697	0.294	10.896	0.075	0.606	0	0	increasing
Byd F3 DM	0.069	1.000	0.069	0	0	0	0	0	increasing
Chery A5 BSG	0.294	1.000	0.294	0	0	0	0	0	increasing

The s_1^{*-} 、 s_2^{*-} 、 s_3^{*-} 、 s_4^{*-} and s_1^{*+} of table 2 are the numerical values of slack variables respectively which forms under the constraints of C^2R model namely type 1.

Under the condition of existing properties and configuration of the five types of hybrid electric vehicle, Toyota prius is in the forefront of economic performance efficiency. This model is integrated DEA efficient in terms of economic performance. It is technically efficient, that is, has reached the maximum output in terms of relative investment, with the decision-making units in the curve of the production function. It is also effective in terms of scale, that is, the input volume is neither too large nor too small, with returns ranging from increasing to decreasing, which are in the best condition. The economic performance of the hybrid electric vehicle is characterized by: the use of gasoline engine and electric motor to power the vehicle. The working principle of the electric motor is to convert the kinetic energy into electrical energy through the motor when the vehicle decelerates, and store in the nickel-metal hydride battery and release again when starting or speeding up so as to reduce the load on the engine. The engine will automatically shut down when stops so as to save fuel. Toyota prius adopts 1.5 L VVT-i engine and electric motor, the nickel-metal hydride battery and power control unit and so on to compose the second- generation of Toyota hybrid system (THS), using different dynamic combination in different driving conditions. The maximum power and the maximum torque of the engine are 57 kW/4500 RPM and 115 nm/4200 RPM respectively, and the rising power and special power are 38.08kW/L and 0.0422kW/Kg respectively. The power and torque of the electric motor are 50 kW/1200-1540 rpm and 400 nm/0-1200 rpm. The series of 28 6.9 volts cuboid chlorine hydrogenated metal battery forms a volume of 274 volts cuboid compact battery pack. The maximum speed is 165 km/h. And the 53 kW of the 1.5 liters petrol engine power and 50 kW power of the electric motor produce the output of the total power of 106 kW. With the full load up to 1750 Kg, the power of the Prius is not very strong, but the output torque of the mixed power of Toyota Prius is quite amazing. Although in order to be fuel saving and environmental protecting, its engine and electric motor will not output the maximum torque. But due to the motor's 400 nm output torque is between 0-1200 RPM, it is enough to make the Prius have a better ability to accelerate.

On the other hand, hybrid electric vehicle with pure technical efficiency in the front of the economic performance are civic Hybrid, Byd F3 DM and Chery A5 BSG. These three models belong to pure technical DEA effectiveness and the output has reached the maximum in terms of input. The decision-making units are located in the curve of the production function, while the scale returns are not in the best state of constant scale returns. These three vehicle models have common characteristics in the economic performance. The thesis will take civic Hybrid as an example, by comparative analysis with Toyota Prius to illustrate the characteristics of such vehicles. Honda civic Hybrid adopts the Second-generation Hybrid Electric System which composes of 1.3L level-3 i-VTEC engine and IMA (electric motor auxiliary system), electric motor, nickel-metal hydride batteries and power control units and so on. According to the vehicle's driving condition, level-3 i-VTEC (cylinder stop system) can be divided into low speed, high speed and cylinder stop——three-stage controlling valve; when the vehicle is in low and constant speed, all cylinders will stop working, with only electric motor providing driving force; when in urgent acceleration, high-speed concave wheels can achieve high power output, while all cylinder will stop when decelerating. The maximum output power of the engine is 71.5KW, maximum output torque is 170nm, rising power is 55kw and the power of the electric motor is 15kw. Combined together, the whole system can reach the same power output and torque output as that from 1.8L gasoline engine. Honda civic Hybrid adopts cylindrical nickel-metal hydride rechargeable batteries, and the voltage can be up to 158V, which ensures the output power 16KW so as to drive the electric motor with power of 15KW. To save the fuel, Honda civic hybrid has given up a quick acceleration and its maximum output power of the hybrid power system is 86.5KW, maximum torque output is 170nm, all of which are much lower than Toyota Prius. Even if compared with the 1.8L gasoline version with maximum power and the maximum torque being 103KW/6300RPM and 174nm/4300RPM respectively, the power of Honda civic Hybrid is much inferior, obviously week. Honda Civic Hybrid's accelerating ability has declined than the Honda Civic with 1.8L, the acceleration capabilities of which are similar with the Toyota Prius. Honda Civic Hybrid's acceleration is obviously weak compared with Toyota Prius. In the aspect of suspension ,Toyota Prius has adopted McPherson front suspension and trailing arm torsion beam rear suspension, while Honda civic Hybrid still uses McPherson and re-adjusts the positional angle and multi-link double wishbone rear suspension，improving the rear suspension shock absorber's installation position of the vehicle which ameliorates the athletic performance of the vehicle. In oil consumption, Toyota Prius can save more oil than Honda Civic Hybrid which is the purpose of Hybrid power vehicles. The manufacturer calibration of the r fuel consumption of Toyota Prius and Honda Civic Hybrid are 4.3 liters and 4.6 liters respectively, which are very economical. However, the Honda Civic Hybrid uses a relatively simple technology to achieve low fuel consumption when compared with Toyota Prius. It consumes only 0.3 liter more oil every one hundred kilometer than Toyota Prius which possesses complex power system, which indicates its brilliant respect.

In addition, Honda Civic Hybrid's hybrid power technological level is lower than Toyota Prius', so is the cost, due to its slight distinction with the current conventional power vehicles, with only additional batteries and electric motors. The utilizing cost will be high with the higher scientific and technological level of the products, which are the causes why foreign consumers will be hesitant to buy Toyota Prius. Toyota Prius and Honda Civic Hybrid fuel consumption contrast will be elaborated in table 3.

Table 3 Fuel Consumption Contrast Between Toyota Prius and Honda Civic Hybrid

Fuel consumption test contrast (L/100KM)		
	Toyota Prius	Honda Civic Hybrid
The AMS standard test field	4.4	4.7
highway	9.3	9.3
Ordinary highways	8.2	9.3
Urban road	3.8	5.8
Integrated oil consumption	6.7	7.3

Non-DEA effective DMU's projection on the production forefront is DEA effective which means through the appropriate adjustments of input and output numerical of non-DEA effective DMU to achieve DEA effectiveness. According to this theory, the author can get the improvement direction of the economic performance of the five types hybrid electric vehicles which will be shown in table 4.

Table 4 Five Types Hybrid Vehicles Improvement Direction of Economic Efficiency

DMU	Improvement Direction	
	X_0	Y_0
Toyota prius	（27.980，1.500，4.300，31.300）	（3182.000）
Civic Hybrid	（26.980，1.300，4.700，16.300）	（290.000）
Lacrosse ECO-Hybrid	（7.920，1.598，5.181，10.458）	（313.000）
Byd F3 DM	（14.980，1.000，4.000，33.000）	（117.000）
Chery A5 BSG	（7.480，1.600，5.200，10.000）	（250.000）

According to table 1 and table 4, in the five types hybrid electric vehicles, Lacrosse Eco-Hybrid model belongs to economic performance non-DEA effectiveness (overall). It helps to find the ascending direction of economic performance. To take Lacrosse Eco-Hybrid as an example, its economic performance of projection points in production forefront is X_0=（7.920，1.598，5.181，10.458），Y_0=（313.000）, all of which show that in order to achieve economic performance (based on the input of the

C^2R model), under the condition of maintaining the output index and sales value of 313,000, cutting its corresponding input value, namely the price reduced to 7.920, gas emission reduced to 1.598, fuel saving rate reduced to 10.458. In addition, table 2 has shown five types hybrid electric vehicles' scale returns of economic performance, with one of the types' scale returns remain the invariable stage, while other four types keep increasing, namely all the five types keep an unchanged or increasing state, all of which show that every type new energy hybrid power vehicle has a strong momentum of development at present. They are still in the stage of cultivation and growth. On the condition of avoiding one-side development of economic improvement, most of the hybrid electric vehicles can have proper expansion to make further improvement of each economic performance.

4 Conclusion

Data envelopment analysis is the effective means to conduct a comparative analysis of economic performance of hybrid vehicles. The method can determine the frontier of experience production, give the DMU overall efficiency, pure technical efficiency, pure scale efficiency, the DMU projection on production frontier, and at the same can determine the scale of the situation, provide a wealth of system analysis tools, provide decision-makers with efficiency evaluation, quantitative management information of scale and other aspects of analysis, making decision-making more scientific and reliable.

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