# Prediction of Diffusion Speed of EV by Characteristics Analysis of Key Devices

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## Abstract

*Predicting how the electric vehicle (EV) market will develop is important not only to countries, such as Japan, that have been leading the car market but also for developing countries. Thus, in order to predict the diffusion of electric vehicles, this study quantitatively analyzes the diffusion speed and price transition of existing cars and clarifies the optimum prediction method for cars' diffusion rates. A prior study examined the diffusion speed and price transition of new products after the commencement of sales using consumer electronics products and cars. It demonstrated the key roles played by engineering development and a key device's production and sales for each product. This study applies that result to other new products and embodies the predictive method as a general formula. It also increases predictive accuracy by extending the subjects of investigation the home electric appliances. The results show that the development speed of the key devices and the diffusion speed of the products are strongly correlated; this fact is expressed as an empirical equation. Furthermore, the general formula for predicting the transition of diffusion rates and prices was produced through an analysis of the empirical equation. By predicting the diffusion speed of an electric vehicle through the empirical equation and its general formula, the study shows that an EV similar to a compact car will have a 20 % household penetration rate in about 15 years after sales commence and that EVs smaller than a mini car will achieve 20 % in 8.7 years.*

## Keywords

*diffusion prediction, price prediction, key device, electric vehicle, consumer electronics*

## 1. INTRODUCTION

Usually, demand- and price-fluctuation predictions for a new product require the use of a model based on previous cases, while accounting for the transition of key parameters after sales of the target product begin [Sakai, 2005]. Therefore, the result tends to become an adaptation of the conventional case. Recently, however, the diffusion speed and price decline of new consumer electronics products have begun to occur much more quickly than in the past, making it necessary to establish a better prediction method. The analysis of Utterback and Rogers were one of precedence researches which analyzed the diffusion process of new products through society [Utterback, 1994; Rogers, 1995]. Refer to these researches, it has been proven possible to predict the diffusion speed of a consumer electronics product or a passenger vehicle by analyzing its development, production, and sales conditions [Yamaguchi, 2009]. Initially, the method focused on the period from the commencement of sales to the achievement of a 20 % diffusion rate. Subsequent research designed to improve the universality of this prediction method analyzed the correlations among the characteristics of the key device, diffusion speed, and price transition in the consumer electronics field [Yamaguchi, 2010, 2011]. This paper applies those results to other products and coordinates them into a simple general formula. In order to enhance its predictive accuracy, the study extends its object of investigation to an electric home appliance. Its method will then be applied to an electric vehicle with a developing market in order to predict its diffusion speed and price transition.

This research does not discuss the contents of the development or sales strategies of new products. Rather, it estimates the diffusion speed and price transition of the market establishment process for new products in order that companies may strategize for optimal timing.

## 2. RESULT

### *2.1 Application result to electric home appliance*

A prior study was carried out on the basis of the following assumptions. The most important factor in the early diffusion stage is product price. The following items were investigated: "the period $Y$ required to attain a 20 % diffusion rate from sales commencement (i.e., 20 % diffusion period)"; "the development style and development period $X$ of a key device in this product"; "the numbers of development cycle n until it reaches a 20 % diffusion rate"; "the real price ratio $P$ compared to sales commencement and a 20 % diffusion rate (i.e., 20 % real price ratio)"; and "real price decrease rate $Z$ of each development cycle."

**Table 1** Diffusion rate, price transition, and key device development period of electric home appliances

| Products | 20 % diffusion period (year) $Y$ | Development style of key device | Development period of key device (year) $X$ | The numbers of development cycles until 20 % (time) $N$ | 20 % real price ratio (%) $P$ | Real price decrease rate of each development cycle (%) $Z$ |
|---|---|---|---|---|---|---|
| Vacuum cleaner | 5.5 | Cooperation | 1.5 | 3.6 | 49 | 18 |
| Electric washing machine | 7 | Cooperation | 2 | 3.5 | 56 | 15 |
| Electric refrigerator | 9.5 | Cooperation | 2.5 | 3.8 | 39 | 22 |
| Room air conditioners | 15 | Cooperation | 5 | 3 | 21 | 41 |
| Microwave ovens | 11 | Cooperation | 4 | 2.8 | 25 | 40 |

The results revealed a proportional relationship between $Y$ and $X$. It became clear that the proportionality was similar to the real product development process for consumer electronics and cars [Yamaguchi, 2010]. For constructing an empirical equation, though, the data on the key device development period were insufficient. This investigation therefore extends the analysis to the electric home appliance market, which has been producing new products over a comparatively long period. Specifically, focus was placed on vacuum cleaners, washing machines, refrigerators, room air conditioners, and microwaves. These electric home appliances were commercialized in Japan after World War II, and the penetration rate for households was started from almost zero [Ohnishi, 2010]. Table 1 shows the results. Within the column of "Development style of key device", "Cooperation" means that a key device was developed with cooperation of a supply side and a purchase side.

### *2.2 Tendency of diffusion speed*

This study combined the results of the consumer electronics and car analysis [Yamaguchi, 2010] with those of the home appliance analysis. The scatter chart of the key devices development period $X$ and the 20 % diffusion period $Y$ is shown in Figure 1. It shows a clear primary type relationship between $X$ and $Y$. The coefficient of the correlation between $X$ and $Y$ is 0.98. This result produces a dashed line in quest of a regression line. This straight line can be denoted by equation (1):

$$Y = 2.5\,X + 2.5 \qquad (1)$$

Y: 20 % diffusion period (year)
X: Development period of a key device (year)

Since key device development is preceded by the product's sales commencement, $X$ can be determined comparatively easily by the development engineer.

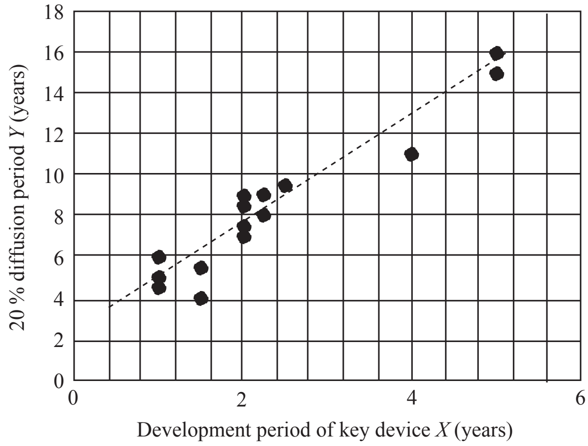


**Fig. 1** A scatter chart of the development period of key device $X$ and 20 % diffusion period $Y$

With empirical equation (1), the 20 % diffusion period $Y$ can be predicted.

### *2.3 Tendency of price transition*

Similarly, the 20 % diffusion period $Y$ and 20 % real price ratio $P$ are shown in Figure 2 (scatter chart).

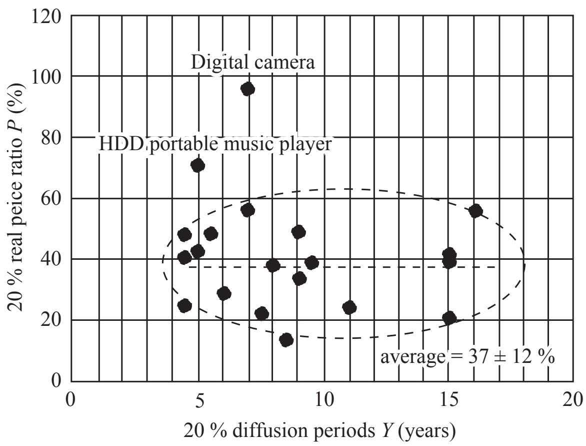


**Fig. 2** The 20 % diffusion period $Y$ and 20 % real price ratio $P$

Note: the dashed straight line is the average of $P$ in the circle

Aside from digital cameras and HDD portable music players, all products lie in the oval. The average is 37 ± 12 % of constant value with $Y$, showing that the quick diffusion products have a high price decrease rate; if the 20 % diffusion period $Y$ can be estimated, the price decrease rate can also be estimated.
In the case of digital camera and HDD portable music player, the supply side and the purchase side had a very close relation to sale of a key device, and the tendency of price decline completely differed from other products.

## 3. PREDICTION METHOD ESTIMATING DIFFUSION SPEED OF PRODUCTS FROM CHARACTERISTICS OF KEY DEVICE

### *3.1 Prediction method*

The above discussion makes clear that, by observing the characteristics of a key device, the diffusion speed and price transition of new products can be predicted experientially. The process is as follows.

(1) Specify a key device
(2) Check the relationship between the purchase side and the supply side of the key device. If they have the usual independent relationship, the 20 % real price ratio is 37 ± 12 %. If they have a close relationship, the price will not fall.
(3) Survey the development style of the key device, and check the key device development period $X$.
(4) Calculate the 20 % diffusion period $Y$ using equation (1)

### *3.2 General formula*

The following general formula is based on the investigation results. Two equations calculate the household penetration rate and real price ratio after the product's sales commencement. It is assumed that the model change cycle repeats without a pause. Development cycle $n$ is expressed by equation (2). Furthermore, the real price decrease rate $Z$ assumes that the cost reduction progresses by a fixed ratio, as shown by equation (3).

$$n = Y / X \qquad (2)$$

$$Z = \left(1 - 10^{\frac{\log \frac{P}{100}}{n}}\right) \times 100 \qquad (3)$$

The following general formula shows the household penetration rate $d$ and the real price ratio $p$ using $Y$ and $Z$. In addition, it is assumed that the volume of production increases at the same rate every year according to market expansion.

$$d = 20\left(\frac{t}{Y}\right)^2 \qquad (4)$$

$$p = \left(1 - \frac{Z}{100}\right)^{\frac{t}{x}} \times 100 \qquad (5)$$

$d$: The penetration rate for households after $t$ years (%)
$p$: The real price ratio of t years after (%)
$t$: The years from sale commencement (year)

These equations can be used to calculate the household penetration rate and real price ratios for any period.

## 4. APPLICATION TO PREDICTION OF EV DIFFUSION SPEED AND PRICE TRANSITION

### *4.1 Estimation of compact EV diffusion speed and price transition*

For to estimate compact EV diffusion speed and price transition, the engineering development progress of a hybrid car and a Lithium ion battery were investigated [Yaguchi, 2009; Maruyama et al, 2009]. It was considered that a compact EV's key device is the power unit, including the battery, the PCU (power control unit), the motor, and the gear assembly [Yamaguchi, 2009]. Using the evaluation method outlined in chapter 3, the price transition was estimated as the diffusion speed of the compact EV. First, since the development period of the key device is five years, equation (1) calculates 15 years for the 20 % diffusion period. Since the key device is produced in-house, the 20 % real price ratio is 37 ± 12 %. In order to calculate the standard price ratio at the 20 % diffusion rate threshold, the object market is set as Japan, and compensation is tied to the growth of per capita GDP. Statistics from the Ministry of Internal Affairs and Communications (MIC) show that real GDP (expenditure side) increased 1.08 times between 2003 and 2008 [MIC, 2010]. For a 20 % diffusion period of 15 years, the rate will increase 1.24 times if the rate's duration is multiplied by 3. The 20 % diffusion standard price ratio will then be 46 %. Equations (2) and (3) calculate the number of product development cycles n until the diffusion rate hits 20 % and the real price decrease rate $Z$ for each product development. Table 2 is the result.
In 2009, the world's first compact mass production EV, the i-MiEV, was placed on the market by Mitsubishi Motors for 4,600,000 yen. In Table 2, equation (1) calculates that the household penetration rate will be 20 % and will change to 2,120,000 yen at the standard price by 2024. When the growth of per capita GDP is taken into consideration, the real price will be 1,700,000 yen. Japanese consumers would accept this real price, because the car is currently about 2 million yen. The calculation results for the household penetra-

**Table 2** Calculation result of diffusion speed and price transition applied to compact EVs in Japan

| Market | 20 % diffusion period (year) *Y* | 20 % diffusion price ratio (%) | | Key device development period (year) *X* | The number of development cycles (time) *n* | The price decrease rate of each development cycle (%) | |
|---|---|---|---|---|---|---|---|
| | | Real price *P* | Standard price | | | Case of real price *Z* | Case of standard price |
| Japan | 15 | 37 ± 12 | 46 | 5.0 | 3.0 | 29 | 23 |

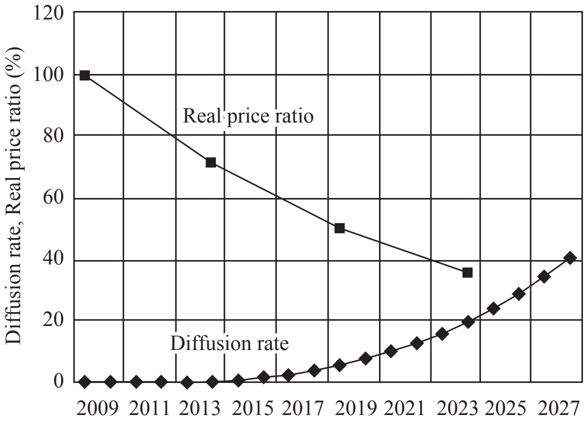


**Fig. 3** Diffusion and price estimation for EVs in Japan

tion rates and real price ratios from 2009 to 2024 are shown in Figure 3. The diffusion rate was calculated with the assumption that the production volume would be extended by a constant ratio every year. The real price ratio was calculated with the assumption that *Z*, as shown in Table 2, would be repeated every five years.

Table 2 shows that the standard price ratio will be 46 % at the 20 % diffusion point. This result has serious implications for the product development process. Development must be completed within five years, including that of the battery. Unlike conventional cars, an EV's parts are all made with new technology. Development will also require a significant increase in the workload, management control of machinery, and electronics and chemical technology refinements. Furthermore, although the model's overall cost reduction will be 23 %, the cost reduction of the power unit is not guaranteed. Efforts to reduce the cost of the whole vehicle are needed. This will require fundamental innovation in the car's entire development process.

### *4.2 Estimation of micro EV's diffusion speed and price transition*

The micro EV stands between the compact EV and the electric motorcycle [Chen, 2010]. A trial micro EV has been announced (ZMP, 2010). In the latest investigation, it became clear that the Japanese mini car users were interested to this EV [Kudoh et al., 2009]. A prior study took the battery as the micro EV's key device [Yamaguchi, 2009]. This product is purchased more for its low price than its performance; thus, its motor and PCU use ready-made parts. Although the automaker and the battery maker have founded many joint corporations, micro EV production is still "independent." The car's battery will become standardized, and many battery makers will sell their own batteries. It became clear that the cost of a lithium ion battery is mainly determined by the material cost and production facility investment [Paul et al., 2009]. If diffusion is successful, like that of liquid crystal panels, new large-scale production facilities will emerge, lowering costs. No announcement on standardized car batteries' development period has been made. Research on similar key devices suggests, though, that development periods change with development styles. Empirical analyses have shown that an "independent" development style takes half the time of a "cooperative" style. Accordingly, it is assumed that the development period of the micro EV's battery will be 2.5 years. Equation (1) thus calculates the 20 % diffusion period as 8.7 years. The main development purpose is cost reduction, and, since the relationship between the supplier and the user is one of independence, the 20 % real price ratio is 37 ± 12 %. As a result, the real price decrease rate *Z* per model change will be 25 %. These results are shown in Table 3. The price falls 25 % every 2.5 years. This sharp decline has not yet been experienced. Although most of the reduction should be realized by the lithium ion battery, the costs of other parts will fall as well. Figure 4 shows the household penetration rate and the real price ratio. The horizontal axis represents the years from sales commencement.

The current micro EV market is unclear. Legal preparation will probably be required before diffusion. A product that solves the many problems in the market, however, will double both its diffusion speed and price reduction. In such a case, the model development period will be 2.5 years. Moreover, many parts, including the battery, should become standardized. In

**Table 3** Diffusion speed of micro EV and analysis output of price transition

| Products | Development style of key device | 20 % diffusion period (year) *Y* | 20 % real price ratio (%) *P* | Development period of key device (year) *X* | The number of development cycles until 20 % (time) *N* | Real price decrease rate of each development cycle (%) *Z* |
|---|---|---|---|---|---|---|
| Micro EV | independent | 8.7 | 37 ± 12 | 2.5 | 3.5 | 25 |

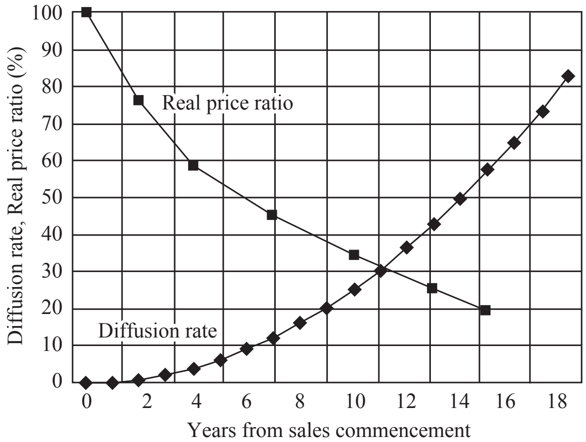


**Fig. 4** Diffusion speed of micro EV and estimation of price transition

order to assemble its parts and produce the micro EV, a fundamental change in auto manufacturing needs to occur. It is very important for Japan's motor vehicle industry to prepare for this event.

## 5. CONCLUSION

(1) This study found that the diffusion speed and price transition of a new consumer electronics product, a home appliance, and a passenger car after the commencement of their sale could be estimated according to the procedure described below.

- Specify the key device of the target product. A key device is the part or module with the strongest effect on the product's functions, performance, and price.
- Determine the relationship between the user and supply sides of the key device (i.e., whether it is a close or open one).
- For an open development style, decide the key device development period *X*. Equation (1) provides the 20 % diffusion period *Y*. Furthermore, the 20 % real price ratio is calculated, as in Figure 2.
- Using equations (2) and (3), calculate the number of development cycles n and the 20 % real price decrease rate *Z* for every model change.
- Calculate the diffusion speed and price transition of the target products through equations (4) and (5) from *Y* and *Z*.
- A relationship between the supply and user sides of the key device that is close and exclusive does not correspond to the pattern described above. In this case, after the commencement of sales, the functions of the product will be improved, and the price will remain the same.

2. The key device in a compact EV (an electric vehicle equivalent to a common passenger car) is the entire power unit, including the battery, motor, and PCU. The leading car manufacturer's development of the device can be assumed to take five years. A compact EV requires 3 development cycles, and the rate of real price decrease per time is expected to be 29 %. Thus, the 20 % diffusion period *X* is 15 years, and the 20 % diffusion real price ratio *Y* is expected to be 37 ± 12 %.
3. A micro EV's size lies between a compact EV's and an electric motorcycle's size. Its key device is a battery, which will become standardized. One battery maker will be responsible for its development, mass production, and sale; its development period is expected to be 2.5 years. Accordingly, the prediction method calculates that the micro EV's development cycle will have 3.5 iterations, that the real price decrease rate will be 25 %, that the 20 % diffusion period will be 8.7 years, and that the 20 % real price ratio will be 37 ± 12 %.

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