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Quantitative Research on the Diffusion Speed of EV based on Diffusion Process Analysis of New Consumer Electronics Products

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Abstract

Predicting how the electric vehicle market will develop in the future is an important issue, not only for countries that have been leading the car market, such as Japan, but also for developing countries. Thus, in order to predict the diffusion of electric vehicles, the diffusion speed and price transition of existing cars were analyzed quantitatively, and research was performed to clarify the optimum prediction method for the diffusion rate of a car. In a prior study, the diffusion speed and price transition of new products after the commencement of sales were studied using consumer electronics products. The key roles played by the engineering development and the production and sales of a key device for each consumer electronics product were established. Furthermore, the obtained results could be extended to the auto industry, where the same tendency is observed. In this study, the results were expressed by a quantitative pattern and applied to the prediction of the diffusion speed and price transition of an electric vehicle. First, in relation to the diffusion, it was found that the countrywide establishment of quick charge stations has priority over a reduction in the price of an electric vehicle. Next, in order to predict the diffusion speed, electric vehicles were divided into compact EVs (replacements for compact cars) and micro-EVs (think of a product category between a compact car and a motorcycle), and were analyzed individually. Each key device was specified, and estimations were made of its development, production, and supply. The use of this method revealed that the diffusion rate for compact EVs will reach 20% approximately 14 years from the commencement of sales and that the diffusion speed for micro-EVs is dependent on the battery development speed.

Keywords— “diffusion speed,” “key devices,” “infrastructure,” “electric vehicle,” “consumer electronics”

1 Introduction

Usually, demand-or price-fluctuation predictions for a new product require the use of a model based on previous cases, with respect to

the transition of these parameters after the commencement of the sale of the target products [1]. Therefore, the result tends to become an adaptation of the conventional case. However, in recent years, the diffusion speed and price decline

of new consumer electronics products have sometimes occurred much faster than in the past. This makes it necessary to establish a better prediction method to cope with this new situation. It has been shown that it is possible to predict the diffusion speed of a consumer electronics product or a passenger vehicle by technically analyzing of its development, production and sales conditions [2]. Initially, the developed method focused on the period from the commencement of sales to the achievement of a 20% diffusion rate. In subsequent research to improve the universality of this prediction method, the correlations between the characteristics of the key device, diffusion speed, and price transition were analyzed in consumer electronics field [3].

This paper further expands the research to a car by quantitatively analyzing the correlations between the engine development period and the diffusion speed and price transition for a car. This method accordingly is employed to predict the vehicle diffusion speed and price transitions for electric vehicles, the market for which is expected to grow in the future.

2 Results

2.1 Grouping of Products

In previous research, it was assumed that in the early diffusion stage the biggest factor for the number of sales was the price of a product. This assumption was used when analyzing the price transition and diffusion speed of consumer electronics products and cars. In order to study this mechanism quantitatively in this paper, the results of the previous investigations of consumer electronics products and passenger cars were combined, as shown in Fig. 1. The horizontal axis represents the diffusion speed (shown as a period), the vertical axis represents the price transition (shown as a price ratio), and the figure indicates the corresponding positions of products. As far as possible, products with the same functional level were chosen and monitored for an accurate analysis. The penetration ratio for households was obtained using the consumer behavior forecasting survey results from the Japan Cabinet Office. The prices used for this figure were the suggested list prices indicated by Japan makers. The products in this figure can be divided into four groups, group A (B&W TVs, LCD

TVs, DVD recorders, cellular phones, CD players); group B (color TVs, IC color TVs, VHS tape recorders, VHS-C video cameras, DVD players); group C (passenger cars in Germany, Japan, and South Korea); and group D (portable music players, digital cameras). The real price ratio is the product's price ratio adjusted by the growth of the per capita GDP [4]. The formula is given below.

Real price ratio = $(X/Y) \times 100 (\%)$, X = (Price when penetration rate for households becomes 20%) / (Price at the time of a sale commencement), Y = (GDP per person when the penetration rate for households becomes 20%) / (GDP per person at the commencement of sales).

The average values and standard deviations of "group A," "group B," and "group C," shown in this figure are listed in Table 1. The standard deviations for the periods from the commencement of sales to the time when a 20% diffusion rate is achieved are about 10% of the respective averages, and are included within the solid line limits shown in Fig. 1.

There are three kinds of patterns that explain how the products became popular. The real price ratios of all the groups are similar. They have average values between 30 and 50% and standard deviations between 7 and 11%. Independent of the type of product, the real price ratio falls by 30 to 50% from the commencement of sales until a penetration rate of 20% is reached for households. From another viewpoint, it can be seen that the diffusion speed and price transition have a fixed relationship. The products with an early price decline have an early diffusion. The products with a slow price decline have a slow diffusion.

With the portable music players and digital cameras of Group D, in every new model the makers tended to increase the amount of music that could be recorded, or the number of pixels for photographs, without reducing the prices of the older models. As a result, the products with the older specifications disappeared one after another. Therefore, unlike the other groups, it was not possible to track the prices of products with the same functional level. Because this has previously been reported, and does not affect the analysis of Groups A, B, and C, it will not be reported at this time [3].

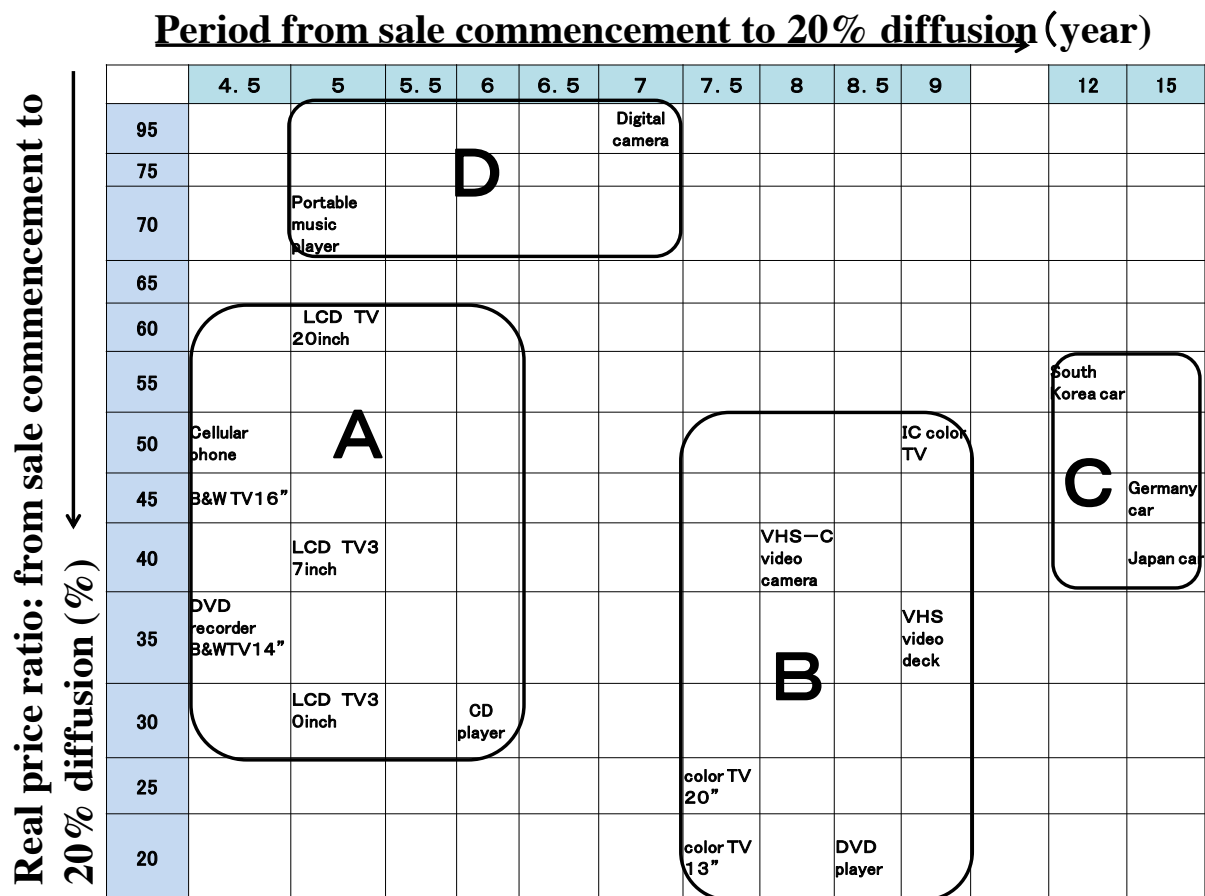


Figure 1: Diffusion rates for various products and distribution map of price transitions

2.2 Classification of Characteristics of Key Devices

In previous researches, the characteristics of the key devices in electronics products were classified into the following two types: (1) the engineering development of the key device is independently performed by the supply side and (2) the engineering development of the key device is performed by cooperation between the supply side and the user side of the key device. Furthermore, the development periods for the key

devices of (1) and (2) were evaluated. In this study, the development period of a key device was defined as the day when the design commenced to the publication date for the approval document, which did not include the time needed to develop the basic technology. Since the approval document is generally published just before production starts, the development period for a key device is almost the same as the product development period.

Table 1: Period until a 20% penetration rate achievement for households, and real price ratios of groups A, B, and C

Group	Period to 20% diffusion			Real price ratio		
	The number of samples	Average (year)	Standard deviation (year)	The number of samples	Average (%)	Standard deviation (%)
A	5	4.9	0.583	8	40.7	9.2
B	5	8.46	0.605	6	31	11
C	3	14	1.4	3	46	7.4

Moreover, since product development is performed continuously, a new model change cycle period is also the same as a key device development period. In this paper, these three periods are called the “new product development periods.” In the case of consumer electronics products, a new product’s development period was about one year in the case of (1), and about two years in the case of (2). This difference was thought to be based on the repetition cycles for the key device development work. Although in case (1) this was one cycle, in case (2) two or more cycles were involved because of frequent demands from the user side. As shown in Fig. 1, group A is type (1) and group B is type (2).

Until now, the key device for a passenger car has been the engine. There are many more parts in an engine than in the key devices of consumer electronics products. This makes a long development period necessary. Moreover, because engine performance has the biggest influence on the entire passenger car, the problem solving phase during product development usually involves engine adjustments. A passenger car has a total of 30,000 parts, which is more than 10 times the number in parts of color TV of consumer electronics products. Because of this, an average of five years was required to change to a new model when the TOYOPET CROWN was first placed in the market in Japan. This is Group C.

3 Analysis of Mechanism

The diffusion speeds for new products, the characteristics of the key devices, and the new product development periods are combined in Table 2. Table 2 also shows the number of development cycles before a product reaches a 20% diffusion rate and the real price decrease per development cycle.

This calculation assumed that product development advances without a pause and cost

reduction progresses at the same rate. As a result, it was found that there is a nearly proportional relationship between the product development period and diffusion period, and it was proved that the development speed of the key device determines the product’s diffusion speed.

After the sales of a new product begin, competition from other manufacturers eager to get their share of the market begins as soon as possible, which eventually lower the price of the product. Consequently, product development advances nonstop. In groups A and B, 4 or 5 development cycles took place before the products reached a diffusion rate of 20%. A passenger car in Group C had 2.8 development cycles.

Moreover, before a diffusion rate of 20% was reached, the rate of real price decrease per cycle became 16.7% in group A, 24.1% in group B, and 29% in group C. Generally, since Japanese consumer electronics makers employ a cost reduction target of 15% for projects with one-year development cycles and about 20 to 30% for those with two-year development cycles, the results shown in Table 2 satisfy the actual operation conditions. Although these cost reduction targets are not announced by automakers, an investigation report showed that around 1993, the development of a car in Japan took 43 months from the concept creation to the commencement of sales [5]. In this period automakers had to manage the improvement of cost and performance of a new model at same time. It can thus be estimated that a rate of 29% for the real price decrease is appropriate. This is the mechanism by which the key devices of groups A, B, and C determine the diffusion speeds of products.

The above discussion of the characteristics of the key device makes it clear that the diffusion speed and price transition of a new product can be predicted. The procedure is as follows.

(1) Specify the key device.

Table 2: Development cycles and rate of price decrease for consumer electronics and car

Product group	<i>The time to reach a diffusion rate of 20% (year)</i>	<i>Engineering development of a key device</i>	<i>New product development period (year)</i>	<i>The number of development cycles</i>	<i>The real price ratio at the time of 20% diffusion (%)</i>	<i>The rate of real price decrease per cycle, assumed to progress at the same rate (%)</i>
A	4.9	Independent	1	4.9	40.7	16.7
B	8.4	Cooperation	2	4.2	31	24.1
C	14	Cooperation	5	2.8	46	29

(2) Determine the relationship between the user side and supply side of the key device. When it has a close relationship, it is commodity group D.

(3) Check the style of the engineering development of the key device, and the development period. Determine whether it is group A, B, or C based on the result.

(4) Apply Table 2. The number of development cycles and the rate of real price decrease per cycle can then be determined during the new product development.

It is believed that this method will become a powerful weapon when creating a timetable for the strategy for new products.

4 Adaptation to Electric Vehicle

4.1 Key Device of Electric Vehicle

There are two types of electric vehicles, a compact EV equivalent to a common passenger car and a micro-EV, whose range is further limited [6]. First in order to investigate the key devices of compact EVs, the development process for a hybrid car was investigated, which demonstrated the method of shifting from a traditional passenger car to an electric vehicle. Fig. 2 shows the different generations of the Prius, a hybrid car from Toyota, along with the years of commencement of its sales, photographs of its power unit, the output of the power unit, body weight, etc. The model was changed every six years. In the third generation of the Prius, the following three points were the major areas of development: (1) improvement in fuel consumption; (2) smaller size, lighter weight, and higher power for the power unit; and (3) exhaust gas improvement. Therefore, improvements were made in the entire power unit [7]. The results can be seen in the power unit photographs of Fig. 2. The improvements involved the entire power unit, including the battery, PCU, electric motor, engine, and gears. Thus, dynamic-force performance improvement and cost reduction were realized simultaneously. In this case, the key device of a compact EV should be the entire power unit. The car manufacture led the key device development, with cooperation from the parts supply side.

The storage capacity of the battery of a compact EV already on the markets is 15 or more times that of the Prius, and it was estimated that the cost of this battery made up the largest part of the cost of the entire EV [2]. Therefore, the key device for a compact EV seems to be just the

battery. However, since the typical performance of the power unit of a passenger car should be the same as that of the Prius, the key device for a compact EV is the entire power unit, which includes the PCU, motor, and gears, in addition to the battery, but excludes the engine. The car manufacturer has expertise in power units, and the development period would be five years, just as with the Prius. When the above results are applied to Table 2, a compact EV belongs to group C, and it can be expected that the real price ratio will be 46%, and the period needed to reach 20% diffusion will be 14 years.

In the case of the hybrid car, sales commenced in 1997, and 2,800,000 had been sold worldwide by 2009. It is expected that in 2011, 14 years after sales commenced, 20% of the volume of new car registrations in Japan will be for a hybrid car [8].

The key device of the micro-EV is next examined. Since there is no definition for a micro-EV, in this paper it is defined as smaller than a compact EV or mini-EV, and has restrictions involving the areas that it can be used and its operating conditions. Some trial developments have already been made. Example specifications are shown in Table 3, alongside an electric motorcycle with similar specifications [9]. The main uses of a micro-EV are shopping around town, traveling around the neighborhood, etc., rather than highway use. Therefore, it does not require improvements in power consumption efficiency, miniaturization, and high performance like compact EVs. Rather, the main development target is a cheap and easy-to-use product. As seen in Table 3, the battery capacity is about 1.2 kWh ($57.6 \text{ V} \times 10 \text{ Ah} \times 2$), which is comparable to a hybrid car.

If the body cost is about 30% of a hybrid car, the cost ratio of the battery becomes more than 20% of the entire vehicle. Therefore, in this case, the key device is the battery. In order to reduce the price rather than increase the performance, ready-made components will be used for the motor and PCU. In this case, battery makers will develop a battery by themselves, and supply it to an automaker. Today, joint ventures between automakers and battery makers are being established, which are often exclusive relationships. However, in the case of micro-EVs, the battery will be standardized and a battery maker will supply standardized goods to two or more automakers without exclusivity.

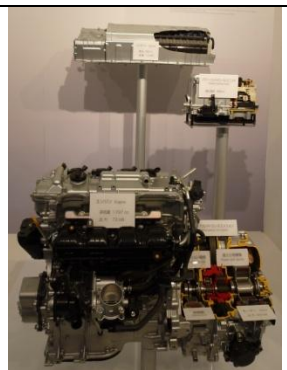
	<i>The 1st generation</i>	<i>2nd generation</i>	<i>3rd generation</i>
Commencement of sales	1997	2003	2009
Power unit (Battery) — (PCU) — (Engine) — (Motor) — (Gears) —			
Engine	1500 cc (56 kW)	1500 cc (57 kW)	1800 cc (73 kW)
Battery	1.5 kWh	1.1 kWh	1.1 kWh
Motor	33 kW	50 kW	60 kW
PCU relative power density	1	1.4	2.0
Body weight	1.2 tons	1.2 tons	1.3 tons

Figure 2: Transition of power unit of Prius (2009 Tokyo Motor Show exhibitions)

Table 3: Micro-EV and electric motorcycle

	<i>Micro-EV (example)</i>	<i>Electric motorcycle</i>
Range	60 km	35~40 km
Maximum speed	60 km/h	35~45 km/h
Battery capacity	57.6 V, 10 Ahx2	48 V, 20 Ah
Motor output	600 W	600 W
Crew member	1	1
License (Japan)	Standard-sized car	Moped

If full-scale diffusion is expected, as with the case of liquid crystal panels in consumer electronics, large-scale production facilities for batteries will be introduced, and the cost will decline rapidly as the scale increases. Since batteries are still being developed, this speed is not clear. If we suppose that “performance will be increased 1.5 times and the cost will drop to one seventh its initial value from 2006 to 2015,” which are the progress targets for batteries that have been set up by the Japanese government, the possibility that a new low priced battery will be developed every year will be high [8]. On the basis of this assumption, this case is the same as group A in Table 2. In this case, the diffusion rate will reach 20%, 4.9 years after sales begin, and the price will be 40%

compared to the commencement of sales. If the micro-EV product concept is accepted by consumers and complies with the laws, such as the Road Traffic Law, such a result may appear. (In order to be accepted by consumers, a product’s price, functions, performance, and quality must meet the consumers' approval. This paper does not discuss whether this is right or wrong.)

4.2 Relation between Infrastructure and Diffusion

The existence of gas stations to replenish the energy source used by cars is indispensable. Similarly, for the success of electric vehicles, the existence of quick charge facilities is also indispensable. The preparation status of a society's infrastructure will greatly affect the diffusion of electric vehicles. This is especially important since the maximum mileage of a typical EV is only about 160 km per charge. Thus, the infrastructure construction requirements are investigated as a precondition for predicting the diffusion speed. In the consumer electronics field, there have been three examples where the construction of a society's infrastructure had a strong influence on the diffusion of products: "color televisions vs. color broadcasting" "liquid crystal television vs. terrestrial digital broadcasting." and "DVD player vs. DVD movie media." Color television broadcasting stations, terrestrial digital television broadcasting stations, and the DVD movie industry took charge of the infrastructure that supplied content to the visual equipment. The effect of infrastructure construction in the early diffusion stage of these three kinds of products was evaluated. As Chapter 1 explained in relation to the diffusion of new products, a product is not easily popularized until it satisfies many requirements. Hence, the situation for the early diffusion stage of this example was investigated. The results are shown in Table 4. The definition of the diffusion start-up year is the year that the diffusion rate increases rapidly compared with the previous year.

The countrywide diffusion of color televisions started in 1966. One year later a microwave network was completed and a color relay broadcast was made all over the country. As a result, the color broadcasting of NHK, which had been several hours per day, was greatly extended to 11 hours, and was expanded all over the country. A rapid increase in color television purchases occurred after this. This shows that infrastructure construction had a definite influence on diffusion. In fact, at the time, the price of a domestic color television had already fallen sharply, and was 47% of the price when sales commenced. This was because Japanese televisions had been exported to the United States, which had seen the golden age of color television diffusion, and the price fell because of the volume production effect.

However, even this drop in prices did not extend the diffusion very much. After installing the microwave network, the domestic demand for color televisions increased rapidly, and since the maker had enlarged the production factory for mass production, the price fell further. When the diffusion rate became 20%, the real price ratio was also 20%. In order to become completely popularized, it is clear that a countrywide infrastructure needed to be ready. Paradoxically, it also becomes clear that, until then, the diffusion did not progress even when the price fell.

Next, the liquid crystal television and terrestrial digital television are examined. Technically, a liquid crystal television and digital television are different products. In fact, a liquid crystal television was first marketed as a liquid crystal analogue television in 2001. There was a diffusion of only 1% or less until 2003. The market price at that time was 80.3% compared with the time that sales commenced, and the diffusion was not following it. However, terrestrial digital broadcasting started in 2003, the potential households with direct reception increased rapidly over the entire country, and the diffusion rate of liquid crystal digital televisions reached 20% after only a short time.

Terrestrial digital broadcasting has Hi-Vision image quality, a liquid crystal television is thin, and many big screen models are available. The combination of these features made it easier for consumers to accept the concept of liquid crystal digital television, and countrywide diffusion began.

Even though a liquid crystal television was thin, if it was expensive and the image quality was poor, consumers would not have felt attracted to it. After the countrywide diffusion began, the price fell rapidly. A production system for the large piece of glass needed for a liquid crystal panel was introduced in preparation for the rapid increase in demand. The price of liquid crystal televisions fell by 43.4% several years after that. The infrastructure construction brings the merit of products is the most important items for diffusion. In the case of the DVD player, sales commenced in 1996, but the diffusion only started in 2001. This was because video rental stores began to carry DVDs in 2001. The price had already fallen to 62.1% by 2001. This decrease in price without diffusion was the result of an increase in PC applications of DVD drives. The diffusion progressed only when it was comparatively easy to obtain DVDs. Conversely, as shown, without a supply system for the media, it did not spread

Table 4: Relation between infrastructure and diffusion in consumer electronics field in Japan

Diffusion	<i>Diffusion start-up</i>			<i>From diffusion start-up to 20% diffusion</i>	
	Year (A.D)	Diffusion (%)	Real price ratio (%) (The reason for price decline)	Situation of infrastructure construction	Real price ratio (%)
Color TV receiver	1966	0.3	47 (Volume production effect by export to USA)	Completion of a countrywide micro wave circuit, and the start-up of the color broadcast for 11 hours per day (1955)	20
Liquid crystal TV receiver	2003	1	80.3	Rapid increase in potential households with direct reception of terrestrial digital TV (2003, 24%; 2006, 85%, Ministry of Internal Affairs and Communications investigation)	43.4
DVD player	2001	3	62.1 (Volume production efficiency for PCs)	DVD rentals start around 2000	16.4

even when the price of the players fell. As mentioned above, these three consumer electronics products were examples where infrastructure construction was indispensable. In every case, after the infrastructure construction commenced, full-scale diffusion started. Furthermore, in the cases of the color television and DVD player, even when the prices of the products fell greatly because of other factors, they did not diffuse. This shows the importance of infrastructure construction, compared to price. Moreover, the effect is exhibited by countrywide infrastructure construction. This result will be applied to an electric vehicle. As long as an EV is a car that is powered by electricity, the construction of a charging equipment infrastructure is indispensable. However, installing one charging station requires an investment of about 3 million to 4 million yen, and the amount of electricity sold at a charging station will be low. There are few entrepreneurs who are going to make this investment because there is little diffusion of electric vehicles. Therefore, many now feel that state and local governments should try to meet this challenge. There are also some countries that give a rebate for the purchase of an electric vehicle. However, based on the results presented here, the installation of charging equipment will have a greater effect than rebates.

5 Conclusion

1. It was found that the diffusion speed and price transition of a new consumer electronics

product and a passenger car after the commencement of sales could be estimated according to the procedure described as follows.

(1)First specify the key device of the target product. A key device refers to the parts or module that has the strongest effect on the product's functions, performance, and price.

(2)Determine the relationship between the user side and supply side of a key device, whether it is a closed relationship or an open one.

(3)Determine the new product development period (development period of a key device), apply the following pattern and predict.

2. The pattern is as follows.

(1)When a new product development period (key device development period) was one year, it took an average of 4.9 years from the commencement of sales to reach a 20% penetration rate for households, and the average of the real price ratio adjusted for the growth of the GDP value per person was 40%.

(2)When a new product development period was two years, the real price ratio was 31% and the period was 8.4 years.

(3)When a new product development period was five years, the real price ratio was 46% and the period was 14 years

(4)If the relation between the supply side and user side of a key device was close and exclusive, it did not correspond to the pattern described above. In this case, after the commencement of sales, the functions of the product would be improved and the price would remain the same.

3. The key device for a compact EV (that is, an electric vehicle equivalent to a common passenger car) is the entire power unit containing not only a battery, but also a motor and a PCU. Since a car manufacturer leads the development, which can be assumed to be five years for the key device development, it corresponds to (3), as seen above. From these results, a compact EV requires 2.8 development cycles, and the rate of real price decrease per time is expected to be 29%.

4. A micro-EV was defined as having a size between a compact EV and an electric motorcycle. In this case, the key device is a battery. The battery will be standardized. A battery maker will be responsible for its development, mass production, and sales, and since it is expected to have a new product development period of one year, it should correspond to (1) in point 2 above. If the micro-EV product concept is accepted by consumers, it is expected to have 4.9 development cycles based on the above results, with a rate of real price decrease per time of 16.7%.

5. For the full-scale diffusion of electric vehicles, the preparation of quick charge facilities across the country has priority over a price reduction for an electric vehicle.

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