Modeling the social acceptance of industrial technologies

— Development of an eco-product diffusion analysis model that incorporates three existing models —

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In order to bring change to society through technological developments, analysis of the social acceptance of a given technology is indispensable. In this research, we developed a model that includes the effects of the diffusion of environmentally conscious products. To analyze the long term diffusions and to analyze the effects of various diffusion promoting measures, we have incorporated three existing models: the Bass diffusion model, the consumer preference model, and the learning curve model. These models have been argued for individually to date. The paper describes the research objective, existing models, the developed model, the related developed tools, and an analysis example.

Keywords **:** Social acceptance of technologies, eco-products, product diffusion model, Bass model, consumer preference

1 Introduction

Technology evolves through interactions with the society. There are periods of nightmare of technologies when new technologies are not accepted readily by the society[1]. To bring in changes on society through technological research and development, it is necessary to understand and formulate a model for the interaction between technology and society. This study is an attempt to create a model for the relationship between them. Needless to say, there are several phases and diverse facets in the relationship of technology and society. We aim to tackle related topics and to build a comprehensive and multi-faceted model by building up corresponding models one at a time.

This paper describes the research on building a model for the social diffusion of environmentally- conscious products or "eco-products" that we position as part of building up a corresponding model. This research was conducted as part of Global Warming Countermeasure Survey of the Japan Ministry of Economy, Trade and Industry (METI)[2][3].

The research processes were as follows:
1. Clarification of research goal (chapter 2)
2. Survey of existing models (chapter 3)
3. Formulation of Model (chapter 4)
4. Data collection (chapter 5)
5. Tool development (chapter 6)
6. Analysis (chapter 7)

In this research, three existing models were integrated to achieve the research goal. One of the models was Bass model that was a representative product diffusion model, second was conjoint analysis that was related to consumer preference model, and third was learning curve model that describes the cost reduction in the course of technological advancement. The foundation was the Bass model. The above processes will be described in the following chapters. Chapter 2 explains the objectives of the research, and chapters 3 outlines the existing studies on product diffusion analysis. Chapter 4 introduces the model that we developed in this research. Chapter 5 presents the collected data, and chapter 6 demonstrates the tool that we created to enable easy use of the model and data. Chapter 7 shows the example in which the model was applied to the assessment of diffusion of energy-saving air conditioners, and the final chapter states the conclusion and future issues.

In the course of research, the above six processes did not necessarily progress in one direction. Particularly, the discussions to and from 1 and 3 were repeated several times. In considering the model, the research goal was reviewed and the model was rebuilt and reviewed several times. The details of this process are described in Section 4.

2 Clarification of research objective

This study was conducted as part of Global Warming Countermeasure Survey of the METI. Some of the goals of the research were clear from the beginning, while others took shape during the process of the research. Both will be described as follows.

The goal of the survey was projection and analysis of diffusion of eco-products. The subjects of the diffusion analysis were following products:

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(1) Products that contributed to countering global warming (reduction of CO_2 emission)
(2) Products purchased by general consumers.
Specifically, they included energy-saving vehicles (hybrid cars etc.), energy-saving appliances (air conditioners, refrigerators, etc.), high-efficiency water heater, high-efficiency lighting, solar power generation system for home, and others.

In terms of whose viewpoint the analysis should take, it was
(3) Diffusion analysis useful to policymakers.
The objectives of the survey were to answer the following questions.
− To what level would the target eco-products diffuse at what speed?
− What would be the effect on diffusion when subsidy is granted to the eco-product?
− What would be the effect on diffusion if the energy-saving performance of the eco-product improves further in the future?

We call the first question as basic analysis, and the following two questions as factor-change-effect or sensitivity analysis.
(4) We develop a model that enables basic and sensitivity analyses.
(5) We create an analysis tool so that analysis could be conducted readily.

Finally, the period of diffusion analysis was set as follows:
(6) Analysis would involve the long-term spanning several decades.

While the first two points (target products) were determined at the beginning of the research, the following four points were unclear. It became apparent that clarifying the remaining four points was necessary in determining the appropriate model for the analysis. This will be addressed in chapter 4.

3 Survey of existing models

The models for diffusion analysis of products can be roughly divided into two categories. One is logistic curve model (Bass model) and the other is consumer preference model. Their characteristics are described below. Also, learning curve model that describes the long-term price reduction of new technology is often used as model of technological and production innovations. The three models are described below.

3.1 Bass model [4]-[6]

Diffusion curve of a product often presents S-shape. Figure 1 shows the diffusion curves of major products in Japan. Frank Bass formulated the diffusion model by applying the logistic curve model, which was originally employed in physics and biology, to the dynamics of product diffusions[4].

Mathematical formulation is as follows. When X_t is number of new purchases during period t, N is final number of diffusion, and n_t is diffusion rate during period t (percentage against N), the equation will be as follows:

$$X_t = (p + r \cdot n_t) \cdot (1 - n_t) \cdot N \quad (1)$$

p is called coefficient of innovation and r is called the coefficient of imitation. In Fig. 1, $N{\cdot}n_t$ is the vertical axis while X_t is the incline of the curve. Equation (1) can also be expressed as follows:

$$\frac{dn_t}{dt} = (p + r \cdot n_t) \cdot (1 - n_t) \quad (2)$$

When the boundary condition is set at $n_{t=0}=0$, n_t can be expressed as follows[2][6]:

$$n_t = \frac{1 - e^{-(p+r)t}}{1 + {}^{r}/_{p} \cdot e^{-(p+r)t}} \quad (3)$$

When the three parameters p, r, and N are determined, the temporal transitions of X_t and n_t are determined.

In applying the diffusion analysis to eco-products, in the 1980s, International Institute for Applied Systems Analysis (IIASA) of Europe used it for diffusion projection of renewable energy. While the Bass model could approximate the long-term temporal transition of diffusion, it was unable to analyze the effect on diffusion in case there were changes in the factors. For example, it was difficult to analyze the effect of product price changes due to subsidy policy on the diffusion, or the effect of change in consumer preferences on the diffusion. While attempts were made to incorporate the effects of price changes and advertisements to the model by extending the Bass model[5][6], it was only possible under assumption that sufficient statistical data were available.

3.2 Consumer preference model

There exists an approach of analyzing diffusion by constructing a model of consumers' product preferences[Note 1]. In the simple consumer preference model, hypothesis is set that

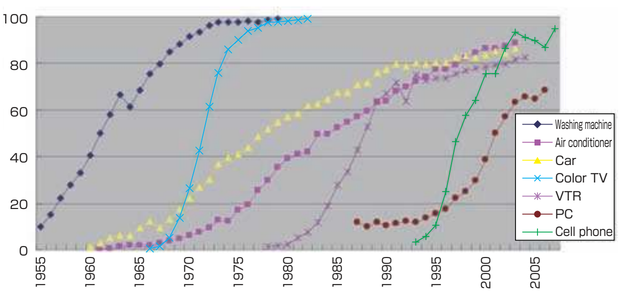

Fig. 1 Diffusion transition curve for past major products.
Vertical axis represents the household diffusion rate. Source: For items other than cell phones, *Trend of Household Consumption – Annual Report of Consumption Trend Survey*, Economic and Social Research Institute, Cabinet Office, Government of Japan. For cell phones, *Report on Communication Usage Trend Survey for Households*, Japan Ministry of Internal Affairs and Communication.

consumers select the most economically rational technologies and products. There are finer models of consumer preference and decision-making, and conjoint analysis is often used for fine modeling[7][8]. Since this approach allows fine analysis of effects on consumer preference brought on by changes in price or product performances, it enables analysis of effect of the factor changes on diffusion. However, since this model basically has no temporal dimension, it is unable to analyze temporal transition of diffusion, particularly for long-term.

3.3 Learning curve model

The learning curve model is used to analyze the cost reduction of industrial products[9][10]. New products tend to decrease in cost with mass production. Learning curve model describes this trend. Figure 2 shows the transition of production volume and price of solar cell. From past data, there is empirical rule "when the cumulative production doubles, the production cost and time required for production decreases by certain percentage." The observed percentage of reduction is 15~30 % in semiconductor industry and 5~20 % in machine assemblies[10].

3.4 Characteristics of existing models

The characteristics of the above models are summarized in Table 1.

4 Model formulation

4.1 Process of model determination

Three existing models were described in the previous chapter. Long period of trial and error was necessary in figuring out how to utilize (or not utilize) and to integrate the models. The research goal was clarified at this point, and the model was created based on whether it was persuasive or not. There were three types of persuasiveness selected for this research: (1) persuasiveness of result, (2) persuasiveness of logic, and (3) persuasiveness of analogy. (1) is the persuasiveness gained from the match between the result of modeling and the reality, and it is naturally the most convincing item. However, in many cases, the actual result of a projection is not available (for example, we do not know the "diffusion 20 years from now"), and this standard cannot be applied. However, it can be used as counter-evidence when the model fails to explain the state of diffusion, or the non-adequacy of the model. (2) is persuasion through the adequacies of assumption and logic of the model, and (3) is persuasion through referencing the similar cases in the real world.

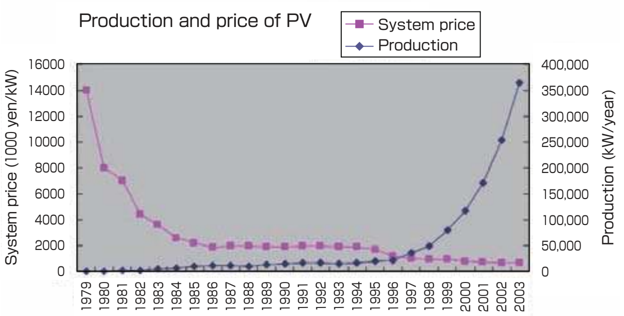

Fig. 2 Production and price of photo voltaic (PV) in Japan.

Based on these points, Fig. 3 shows the process of determining the model for this research. Initially, we thought understanding consumer preference was primary concern, and tried to build the diffusion model based on consumer preference model. However, we were unable to draw the diffusion curve that matched reality (failure of (1)). We attempted to create something that resembled reality through numerous revisions, but were unable to obtain sufficient level of persuasion in the logic of the revisions (failure of (2)). At this point we reconsidered the model. The key of reconsideration was whether the subject of diffusion analysis was long-term (several decades) or short-term (few years). We realized that consumer preference model was effective in short-term while Bass model was good for long-term. This point was not indicated in existing literature. Confirming that our study was for long-term, we set Bass model as the foundation of our model. In the Bass model, it was possible to reference the diffusion coefficients of similar products (section 3.1). For example, it could be seen that 40 to 50 years would be required for diffusion of hybrid cars in reference to past automobile products (such as automatic transmission cars), and similar number of years would be necessary for diffusion of energy-saving appliances in reference to similar appliances. This is (3) persuasiveness of analogy.

Next, to enable sensitivity analysis that was difficult to accomplish using the Bass model, we attempted to incorporate the consumer preference model. The integration method will be described in the following section. We determined that it was most convincing among considered integrated models (superior in (2)). However, we do believe that there is room for more discussion for this integrated model.

4.2 Formulation of model

In this research, the original equation (1) for the Bass model was modified, and the model was formulated as follows:

$$X_t = (p + r \cdot n_t) \cdot (1 - n_t) \cdot N \cdot \frac{H_t}{H^0} \quad (4)$$

H_t/H^0 is multiplied to equation (1). H_t and H^0 are values

Table 1 Characteristics of current models.

Model	Characteristic
Bass model	Macro-model where diffusion transition is seen as a whole. Appropriate for long-term diffusion transition analysis. Sensitivity analysis is difficult.
Consumer preference model	Micro-model for looking at diffusion by consumer preference. Appropriate for short-term diffusion transition analysis and sensitivity analysis. Long-term diffusion analysis is difficult.
Learning curve model	Model for transition of cost reduction of industrial products.

calculated in reflection of the consumer preference model, and have the following definition. Consumers are assumed to have two choices: eco-product (EC) and traditional or "trad-product" (TR). The distribution of difference of consumer's preference for eco-product and trad-product ($U_{i,EC} - U_{i,TR}$) is calculated. Definition of U will be given in section 4.4. H is the percentage of consumers who prefers eco-products to trad-products (percentage of consumer i that satisfies $U_{i,EC} - U_{i,TR} > 0$). The value of H calculated according to current level (current s value) is H^0, and H value during period t is H_t. Since the H value changes according to policies (e.g. subsidy) and technological advances (e.g. increased performance), in equation (4), when percentage H_t of consumers who prefer eco-product changes during period t, the new purchases X_t during period t changes in proportion to the percentage of the change. If H_t is same value as H^0 throughout t, the curve will be same as the one for the Bass model.

4.3 Setting the diffusion coefficient (p, r, and N of equation (4))

The diffusion coefficients (p, r, and N) for products targeted for analysis are set as follows according to the status of diffusion of the products[6]. (1) If the product is already diffused to some level, p, r, and N are estimated from past diffusion transitions (actual past values of X_t and n_t). (2) If the product is newly launched on market or has not been launched yet, p, r, and N values for diffusion of past similar products are applied.

In principle, for this research, we use the latter method.

4.4 Setting the consumer preference model (H of equation (4))

Consumer i's preference to product k, that is U_{ik}, is defined as sum of item of preference factor j as follows:

$$U_{ik} = \sum_j w_{ij} \cdot s_{kj} \tag{5}$$

j is preference factor (attribute), and s_{kj} is value (level) of attribute j of product k. In the example of energy-saving air conditioner described in chapter 7:

k = {conventional air conditioner, energy-saving air conditioner}

j = {initial price, annual electricity bill, eco-image, others}

This is one example of the setting. w_{ij} is weight of preference of each factor, and conjoint analysis is used for quantification. U_{ik} is quantified, and H value of equation (4) is calculated based on these values. Examples will be shown in sections 5.2 and 7.2.

4.5 Flow of analysis

Figure 4 shows the flow of the analysis. First, basic settings were determined. The years in which the diffusion analysis would be started and completed were set. Next diffusion coefficients p, r, and N of the subject product were set (method shown in section 4.3). Next, consumer preference model was set. Using equation (5) as format of consumer preference model, attribute j of the equation was determined, and

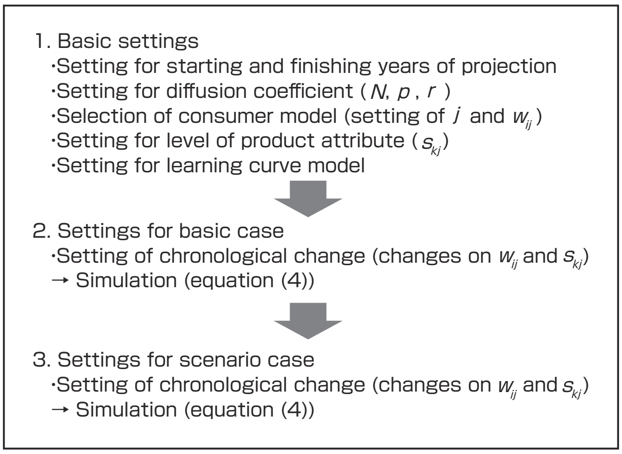

Fig. 4 Flow of analysis.

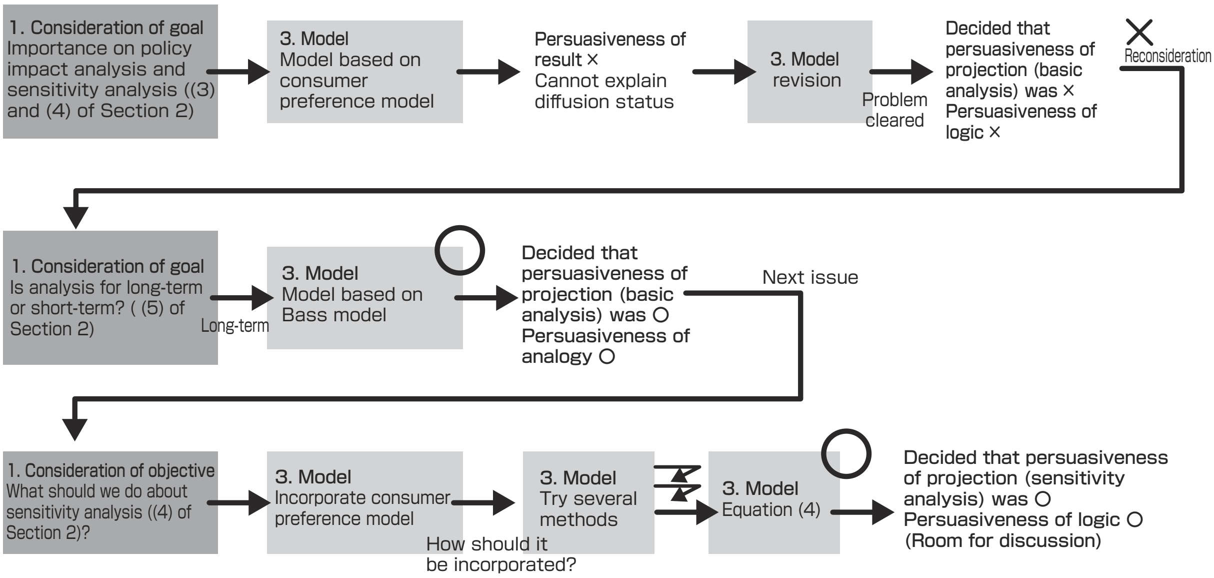

Fig. 3 Process of model construction.

coefficient of preference weight w_{ij} was set based on the result of conjoint analysis. Level s_{kj} of product attribute was set. Also, learning curve model was set to set the price reduction transition of eco-product in the basic case. The change of level of attribute in basic case was set. Other price change factors (such as subsidy), if any, were set. Based on the above settings combined with basic setting, the diffusion was simulated by equation (4). This was the diffusion projection of basic case.

Next, the scenario case was set to conduct the scenario analysis. Change of levels of attributes that were different from basic case was set. For example, future changes of attribute levels due to technological advances or government policies such as subsidy and carbon tax were set as scenario. As in basic case, diffusion was simulated by equation (4).

5 Data collection

5.1 Diffusion coefficient of past products

To refer to the diffusion coefficients of past products, the diffusion curves of past products were collected and their diffusion coefficients were extracted. Figure 5 shows the diffusion transition of washing machines and the approximated curve by Bass model. In this research, diffusion curves of 28 products were collected. Table 2 shows the diffusion coefficients of 20 products. As guideline of speed of diffusion, the rightmost column of the table shows the years required for the diffusion rate to increase from 10 % to 50 %. It generally took four to five times as long as the years specified in the rightmost column from launch of product to saturation in market. For automobiles, it was 40 to 50 years, while it was about 10 years for home appliances such as television that diffused very fast in the 1960s.

5.2 Conjoint analysis

In this research, three conjoint analyses were conducted. They were conducted for 1) home electric appliances about 100,000 yen, 2) home installations about 1 million yen (for home photo voltaic system, in particular), and 3) automobiles. The methods and results of conjoint analysis for 1) home electric appliances at around 100,000 yen will be presented here.

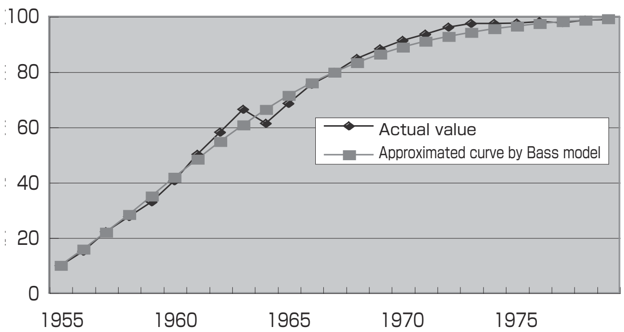

Fig. 5 Transition (actual) of household diffusion of washing machine and approximated curve by Bass model (p = 0.044, r = 0.165, N = 101.2).

The analysis was conducted for 1,112 respondents who were sampled and selected statistically on the web. Attribute j was set as four attributes including initial price, annual electricity cost, product reliability, and environmental performance. Figure 6 is an example of the profile. The two profiles in the figure have different levels of “product price” and “environmental performance.” Twelve profiles were shown to each respondent who were asked to indicate his/her preference of each profile according to seven-step scale. Based on the responses, coefficient of preference weight (w_{ij} of equation (5)) for each attribute j of each respondent i was calculated. Each attribute was calculated as having the following values as average of respondents when converted to product price:

・ Annual electricity cost is 1,000 yen less → Same value as product price being 5,500 yen less

・ Product reliability is high → Same value as product price being 10,000 yen less

Choice 1			
Product price	100,000 yen	Annual electricity cost	15,000 yen
Product reliability	High	Environmental performance	Average

Not attractive at all — Don't know — Very attractive

① ② ③ ④ ⑤ ⑥ ⑦

Choice 2			
Product price	120,000 yen	Annual electricity cost	15,000 yen
Product reliability	High	Environmental performance	Good

Not attractive at all — Don't know — Very attractive

① ② ③ ④ ⑤ ⑥ ⑦

Fig. 6 Example of profile by conjoint analysis.

Table 2 Diffusion coefficient values of past products.

Product	Period	N	p	r	Speed
Flushing toilet	1964-2003	118.1	0.12	0.133	17
AT car (excluding light car)	1958-2005	87.8	0.00042	0.182	14
AT car (light car)	1959-2005	87.8	0.00053	0.182	13
Microwave oven	1970-2004	100.5	0.0059	0.151	13
PC	1987-2006	76.5	0.011	0.190	13
Fluorescent lamp	1953-2005	76	0.021	0.099	13
Air conditioner	1961-2003	92.3	0.0069	0.148	12
Stereo	1961-2004	65.9	0.041	0.145	12
Washing toilet seat	1992-2006	112.2	0.023	0.067	12
Automobile	1960-2003	90	0.011	0.120	11
Facsimile	1964-2006	118.1	0.0095	0.142	10
Automatic washing machine	1983-2004	77.8	0.00014	0.313	9
Gas water heater	1966-1981	80	0.038	0.260	8
CD player	1987-2004	62.3	0.012	0.530	6
Washing machine	1955-1979	101.2	0.044	0.165	6
VTR	1978-2004	84	0.0042	0.410	5
Refrigerator	1955-1982	98.1	3.6×10^{-7}	0.429	5
Black & white TV	1955-1968	95.9	0.013	0.681	4
Color TV	1967-1982	99.2	0.00023	0.638	3
Cell phone	1993-2007	92	0.00042	0.709	3

The source of diffusion transition data is taken mostly from *Trend of Household Consumption – Annual Report of Consumption Trend Survey (for FY2004 and FY2006)*, Economic and Social Research Institute, Cabinet Office, Government of Japan. Rightmost column shows the years required for the diffusion to increase from 10 % to 50 %.

・ Environmental performance is good → Same value as product price being 32,900 yen less

Preference function (U_{ik} of equation (5)) was formulated from this result (w_{ij}) and product specification (s_{kj}) to calculate the H value of equation (4), and this was used in diffusion analysis. Specific example will be presented in section 7.2.

6 Tool creation

A tool that allows the analysis to be done easily was created based on the above model and data. Figure 7 shows the screen of the tool. Basic setting and Bass model setting are done on the upper left section of the screen. The diffusion coefficient is set by directly entering the figures or by selecting the past products. The settings for consumer preference model and scenario case are done in the right part. Result is displayed in center left and lower left.

7 Analysis

Using the tools and methods shown in the above section, diffusion analyses of energy-saving air conditioner, energy-saving refrigerator, hybrid car, high-efficiency water heater, compact (bulb-type) fluorescent lamp, and solar power generation system were conducted. This section will describe the diffusion analysis of energy-saving air conditioner.

Air conditioners consume about 25 % of total power consumption at home[Note 2)], and as their energy-saving performance has improved over the past 10 years or so[Note 3)], diffusion of energy-saving air conditioner is expected to be effective countermeasure for global warming.

7.1 Settings

In the analysis, it was assumed that there were two types of air conditioners, traditional (TAC) and energy-saving (EAC). Consumers selected one or the other. Assuming that energy-saving air conditioner started diffusion from year 2000, the analysis period was set from 2000 to 2040. The consumer preference function was set up as follows:

$$\begin{aligned} U_{i,\ \mathrm{EAC}} = &\ w_{i,\ \text{initial price}} \cdot t_{\mathrm{EAC},\ \text{initial price}} \\ &+ w_{i,\ \text{annual electricity cost}} \cdot t_{\mathrm{EAC},\ \text{annual electricity cost}} \\ &+ w_{i,\ \text{eco image}} \cdot t_{\mathrm{EAC},\ \text{eco image}} \\ &+ w_{i,\ \text{others}} \cdot t_{\mathrm{EAC},\ \text{others}} \\ U_{i,\ \mathrm{TAC}} = &\ w_{i,\ \text{initial price}} \cdot t_{\mathrm{TAC},\ \text{initial price}} \\ &+ w_{i,\ \text{annual electricity cost}} \cdot t_{\mathrm{TAC},\ \text{annual electricity cost}} \\ &+ w_{i,\ \text{eco image}} \cdot t_{\mathrm{TAC},\ \text{eco image}} \\ &+ w_{i,\ \text{others}} \cdot t_{\mathrm{TAC},\ \text{others}} \end{aligned} \quad (6)$$

The product specifications of energy-saving air conditioner and traditional air conditioner were set according to the model case shown in the homepage of the Energy Conservation Center, Japan[Note 4)]. They are shown in Table 3.

Table 3 Settings for diffusion analysis of energy-conserving air conditioner.

Item	Setting
Start of projection	2000
End of projection	2040
Final number of diffusion	130 million (current diffusion)
Innovation coefficient (p)	0.0069 (p value of air conditioner)
Imitation coefficient (r)	0.148 (r value of air conditioner)
Initial price	Trad-product: 84,000 yen Eco-product: 134,000 yen
Price segment that is affected by the learning curve	50,000 yen
Learning curve constant	0.1
Annual electricity cost	Trad-product: 27,000 yen/year Eco-product: 19,000 yen/year
Eco-image	Trad-product: 0 Eco-product: 1
CO_2 reduction effect	115 kg-CO_2/conditioner・year

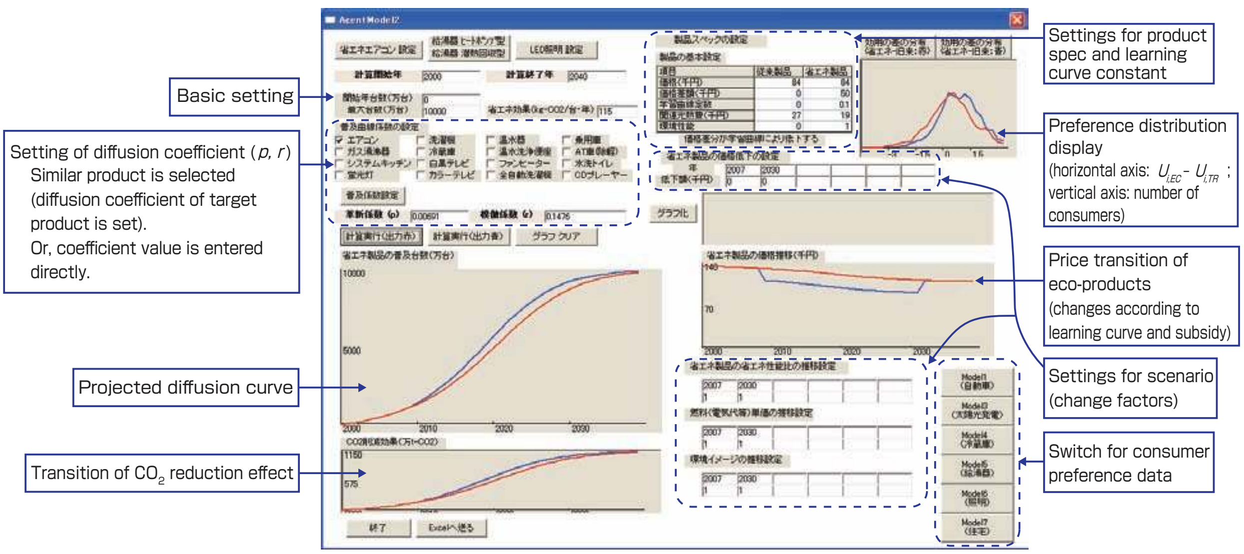

Fig. 7 Screen of diffusion analysis tool.

The maximum number of diffusion of energy-saving air conditioner was set at approximately 130 million, which was the number of current diffusion of home-use air conditioners[Note 5)]. For innovation coefficient and imitation coefficient, coefficient values (Table 2) extracted from past diffusion curves of air conditioners were used. We applied the learning curve model, and assumed that the 50,000 yen price difference between eco-products and traditional products contracts by learning curve constant 0.1. The effect of CO_2 reduction per diffusion of one eco-product was 115 kg-CO_2/year by converting 8,000 yen difference in electricity cost. These are summarized in Table 3.

Three scenarios of granting subsidy money to energy-saving air conditioner were set. We assumed subsidy of 20,000 yen per conditioner. First scenario was provision of subsidy from FY 2008 to 2030, and this was compared with basic case to investigate the effect of the subsidy. Second and third scenarios were subsidy provision period from FY 2008 to 2013 and FY 2015 to 2020, and the effects of periods of subsidy provision were compared.

7.2 Results

Figure 8 shows the distribution of consumer preference in basic case and subsidy provision case. In the basic case, of the 1,112 sample consumers (conjoint analysis respondents), there were 675 consumers who preferred energy-saving air conditioner to traditional air conditions (consumer *i* that satisfied $U_{i,\text{EAC}} - U_{i,\text{TAC}} > 0$) ($H^0$ = 675/1112 = 0.61). About 60 % of the consumers preferred energy-saving air conditioner (Fig. 8). The preference distribution when the product price decreased 20,000 yen due to subsidy was H_t = 751/1112 = 0.68 (Fig. 8).

Using these data in equation (4), the diffusion transition of energy-saving air conditioner was simulated. The result is shown in Fig. 9. In the basic case, eco-product reached 49 % (64 million conditioners) in year 2020, 87 % (110 million conditioners) in 2030, and reached saturation in 2040. The effect of CO_2 reduction by diffusion was 7.4 million ton-CO_2 in 2020, and 14 million ton-CO_2 in 2040. In the subsidy scenario (2008-2030), diffusion was 57 % (74 million conditioners) in 2020 and reached 92 % (120 million conditioners) in 2030.

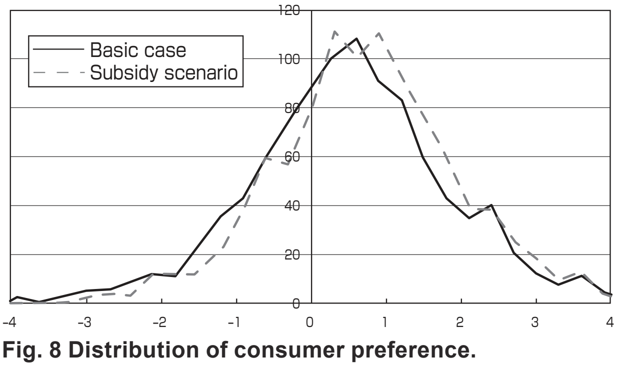

Fig. 8 Distribution of consumer preference.
Horizontal axis: $U_{i,\text{EAC}} - U_{i,\text{TAC}}$; vertical axis: number of people (total 1,112 people).

In case the subsidy period was 2008-2013 and 2015-2020, diffusion reached almost same number for both cases after 2020. However, since diffusion occurred earlier in the former case, the number of subsidized air conditioners would be less than the latter case. The total number of subsidies in former case would be about 2/3 of the latter case, and the burden of cost was also 2/3. The result indicated that the provision of subsidy was more efficient when started in the early stage of diffusion.

8 Result and issues

A model of social acceptance of eco-products that contribute to global warming countermeasure was constructed. We aim to develop this research further, and to use this model as a component of the larger model of interaction of technology and society.

One of the issues of this research is the investigation of adequacy of the integration method (equation (4)) of the Bass model and consumer preference model that was hypothesized in this research. It is necessary to consider the method to verify the adequacy of the integration method from the perspective of projection accuracy. Second, since the objective of this study was long-term diffusion analysis, the model was created based on the Bass model, and setting of diffusion coefficients (p, r, and N of equation (4)) were done in reference to the diffusion coefficients of past similar products. In this research, the person conducting the analysis selected the similar products, but it is desirable to have a standard for similarity. We shall consider some guideline for selecting products to be references of coefficient values.

In the future, we aim to develop the model of interaction of technology and society by including corporate decision-making, results of government policy on industrial technology, and social impact assessment of public research institutes[11] that were not included in this model.

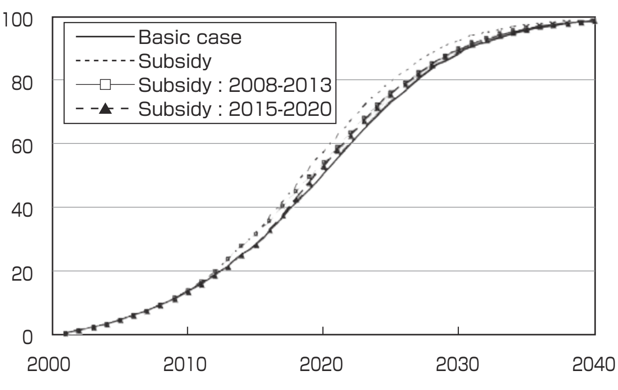

Fig. 9 Result of diffusion analysis for energy-saving air conditioner.
Vertical axis: % (100 % is 130 million conditioners, and CO_2 reduction effect at that moment is about 15 million t-CO_2 (over 1 % of total CO_2 of Japan)).

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Note

Note 1) Examples include AIM end-use model by Morita *et al*.

Note 2) Source: Sources after “Outline of Electricity Demand FY 2004,” Agency for Natural Resources and Energy is taken from the homepage of The Energy Conservation Center, Japan (http://www.eccj.or.jp/catalog/2006s/memo/3.html).

Note 3) Simple average value of annual electricity consumption of major home air conditioners in Japan decreased almost to half, from 412 kWh in 1994 to 227 kWh in 2005. Source: *EDMC Handbook of Energy & Economic Statistics in Japan 2006*, The Institute of Energy Economics, Japan, p. 101.

Note 4) Homepage of The Energy Conservation Center, Japan (http://www.eccj.or.jp/catalog/2006s/memo/13.html).

Note 5) Number of diffusion was estimated to be approximately 130 million air conditioners from number of ownership per 100 households = 255.5 (as of March 2007; source: *Consumer Behavior Forecasting Survey*, Cabinet Office, Government of Japan) and number of households in Japan = 51.71 million (as of March 2007; source: *Basic Resident Register*, Japan Ministry of Internal Affairs and Communications).

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Discussion with Reviewers

1 Clarification of research objective and explanation of process of consideration of the model

Question and comment (Masaaki Mochimaru)

Reading the work as “*Synthesiology*,” I realized that the uniqueness of this paper was the integration of three technologies (particularly Bass model and consumer preference model). It can be considered aufheben type synthesiology (Fig. a). (Kobayashi: *Synthesiology - English edition*, 1(2), 134 (2008))

This paper contains *Synthesiology* information not only on the integration of the two (or three) technologies, but in the process of repeating the revision of research goal and model. The objective of *Synthesiology* is “to archive knowledge system on technological integration to solve problems that are socially significant issues.” The process described in the final paragraph of chapter 1 is worth inclusion in the knowledge archive of *Synthesiology*. Rather than writing simply “it was repeated several times,” I want you to specifically describe the “process of considering the technological integration (or synthesis)” including what objectives were set, which models were considered accordingly, why some were discarded upon evaluating the results, and how the following goals were set. Although it may be too much to explain all of the considerations, by selecting the major consideration processes, I think you will be able to clarify "why the models were selected and combined" and "what are the (current) technological limits of the combined model."

In this case, it becomes difficult to arrange the chapters of the paper. As written in the end of chapter 2 (Clarification of research objectives), you had both clearly decided goals and those with degree of freedom. How about stating how setting goals with freedom was involved in the integration of model in chapter 3, and how you settled the objectives and models after what kind of consideration processes and evaluations in the beginning or the end of chapter 4?

Answer (Mitsutaka Matsumoto)

In modeling a phenomenon, particularly when modeling human and social phenomena rather than natural phenomenon, it is impossible to model every single aspect, so it is important to consider the model by clarifying "which aspect of phenomenon you want to focus (= setting the objective)" at all times. The standard to determine the success or failure of the model in the process is ultimately "persuasiveness." In case of natural phenomenon, the power of persuasion of a model or a theory is how accurately it can explain and recreate the phenomenon. However, it is often impossible to use reproducibility as point of persuasion because experiment cannot be done in human and social phenomena. In that case, it is necessary to consider what should be the scale of persuasiveness of the model. According to your advice, we newly added section 4.1 to describe the processes of objective setting and model consideration (Fig. 3) and added discussion on persuasiveness on which our research depends. For objective, "whether the subject of diffusion projection was short-term (several year span) or long-term (several decade span)" became the key criteria for model selection. For persuasion, we emphasized "persuasion by analogy." In this case, when we are asked, "Why did you get this projection?" in assessing the diffusion speed of eco-products, we made sure we had logical ground to reply, "Because the diffusion speed of the past similar products showed those figures."

2 Ultimate goal (dream) of the research

Question and comment (Masaaki Mochimaru)

I understand that the subject of research was the process of acceptance of industrial technology by the society, and I think it is significant that you have constructed a computational model. Here, you took up the survey for METI as specific example, but please indicate the destination of this social acceptance model (researcher's dream and social acceptance) in the beginning. For example, like what you mention in the end of the paper. In an ordinary academic paper, significance and difficulty of the specific issues to be solved are described in the beginning, and then future developments and views in the end. In *Synthesiology*, we recommend presentation of researcher's dream (image of what one wishes to realize in future although it is not totally solved in the paper) in the beginning, and then describe why the subject presented in the paper was selected as a way to realize that dream. This is because we believe the way of thinking (knowledge system) where large dream is realized step by step is part of "*Synthesiology*."

Answer (Mitsutaka Matsumoto)

As dream, I wish to deeply understand the interaction of technology and society. Recently, companies speak of "management of technology" and "management of innovation," and policymakers talk of "science of science policy." Both are pursuit of understanding of relationship of technology and society. Our research is related closely to these. Our research deals with the part close to the market. As approach in pursuing the dream, I think the ideal will be to study the research theme one by one and to accumulate the results toward the large goal. I added the description of the goal in the beginning of the paper.

3 Age dependence of consumer preference model

Question and comment (Masaaki Mochimaru)

I understand that the expression of consumer preference model and the ways to obtain the parameter are effective. I ask the following question with this knowledge. This consumer preference model is age dependent (affected by social consensus). For example, wouldn't changes in society such as "increased environmental consciousness" influence the H_t value?

Answer (Mitsutaka Matsumoto)

As you indicate, there is age dependency in consumer preference. The model selection in Discussion 1 was closely related. The reason why the basic model was changed from consumer preference model to Bass model was because we decided it was difficult to set consumer preference model as base since consumer preference do change with time. In this study, age dependency of consumer preference was handled as scenario. For example, with the rise of environmental consciousness, the importance of consumer's environmental image of a product (in the model, "$w_{i,\ \text{eco-image}}$" of equation (6)) would increase, and it was evaluated in similar manner as the subsidy scenario of the paper. It is very interesting to see how much the consumer's environmental consciousness has changed in the real world.

4 Verification of the model

Question and comment (Masaaki Mochimaru)

Since the model deals with human group behavior in the real world, I understand verification is difficult. Isn't confirmation of parameter sensitivity a possible verification method at this point? In the integrated model, the necessary parameters are determined by similar phenomena and experimental data, but I think simulation analysis can be done to determine which parameter will strongly influence the projection or what level of care is needed to identify the parameter.

As another method, there is verification of to what level reproduction is possible using this model for the social policy intervention and technological diffusion that were actually conducted in the real world. For example, we can see the level of reproducibility of this model for how much the right-of-way priority for hybrid cars, which was conducted in California, affected the technological diffusion, with comparison with nearby states. Although it seems that actual verification is difficult (to obtain data), it will be useful for you to indicate what the actual

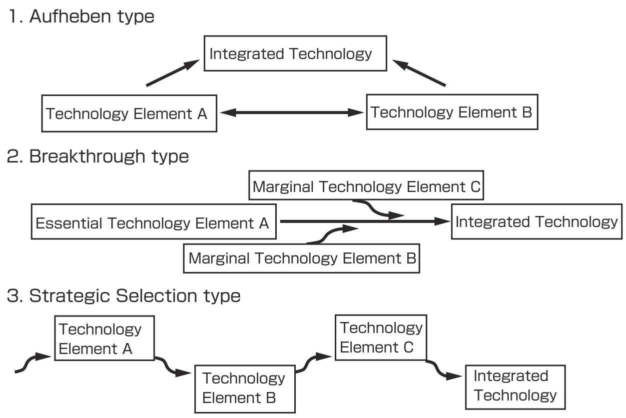

Fig. a Different types of synthesis.

difficulties are.

Answer (Mitsutaka Matsumoto)

Verification is a problem. We attempted statistically extracting product price and changes in diffusion rate using diffusion transition of past product and price change data obtained from price statistics, but failed to obtain statistically significant results. In the point of parameter sensitivity, we worked on seeking influences on product diffusion of shifts in product price, running cost (electricity or gasoline costs), improved environmental performance, and environmental consciousness. Relative sensitivity basically is dependent on the result of conjoint analysis. As result of conducting sensitivity analysis in expected range of change, we obtained result that improvement of environmental performance was effective in promoting diffusion. In terms of absolute sensitivity, our model may be dull in sensitivity. The result (Fig. 9) shows that there isn't much change in diffusions in different scenarios. For the other method that you indicated, consideration of the policy in California is very interesting. Currently, we are conducting survey of policy assessments. As verification material, since the amounts of subsidy differ by local governments for home-use solar power generation system, we can see the relationship between subsidy and diffusion. Powerful diffusion promotion has been conducted for the electronic toll collection (ETC) system for vehicles, though not an eco-product, through discount on expressway costs. It is an interesting case in observing the effect of diffusion promotion policy. Verification is an issue that we are currently working from various perspectives.