論　文

Non-Traceable Genetic Engineering-Biohazards Generated by Genetically Modified Crops: An Economic Analysis

Kimitoshi Sato†

ABSTRACT: This paper verifies the necessary conditions for efficient quality attributes of Genetically Modified(GM) crops. The genetic characteristics of their seeds are engineered by agrochemical makers which simultaneously provide the pesticides complementary to the seeds they supply. Some farms use GM seeds and insecticides, and some food manufacturers utilize GM plants. Consumers cannot choose but eat foods which may be made from GM crops and they are faced with an optimization problem under uncertainty. Symbiosis with GM crops is impossible, since their biological invasions cannot be artificially stopped. Once they are released into the ecosystem, they will proliferate indefinitely. Hence, terrestrial biota will be decisively and irreversibly modified, and natural species survival will come into question. Non-traceable genetic engineering-biohazards have already begun to spread, since some bacteria embedded in plants create an endotoxin which confers resistance to insects and pesticides.

Journal of Economic Literature classification number: D6, D11, D13, I12, I31.

Key Words: bacteria embedded into plants, biofoods, biological invasions, endotoxin, genetically modified crops, non-traceable genetic engineering-biohazards, pesticides complementary to the seeds, resistence to insects and pesticides, substantial equivalence, terrestrial biota.

† Graduate School of Business Design, Rikkyo University, 3–34–1, Nishi-Ikebukuro, Toshima-ku, Tokyo 171–8501, Japan

1. INTRODUCTION

1.1. Rachel Carson seems to be the first person who sent out a stern warning to the unwise use of pesticides such as DDT in her notable book, *Silent Spring* (1962). DDT was invented to decrease insect-borne diseases in humans, and to increase the production of foods. At the beginning, it was successful, however, this pesticide created the tedious effects upon ecological system. Recently, the situation is more and more deteriorating because of the discovery of endocrine disrupting chemicals like PCB, DDT, and dioxins. It has already been reported that these hormonally active agents in the environment are able to disorder hormones' workings, once they enter the human body. Mimicking estrogens, they are threatening health and well-being of ecosystems and populations, and even individual people and animals. Ominous and suspected toxicologic mechanisms and the effects in wild life and humans are now vigorously examined all over the world.[1]

An "endless domino theory" may be applicable to the issue of genetic engineering-biohazards which could be generated by the "genetically modified(GM) crops," or genetically recombinant(GR) crops." They have already been penetrating the markets under the disguise of "substantial equivalence" insisted by the seed developers of GM crops and the governments which have decided to accept them. They stand firm of the safey of the GM plants which are suspicious from the viewpoints of our human health and of our irreplaceable ecological system.

It is already reported that pesticide resistant weeds were discovered in the periphery of GM canolas in Denmark, and weedicide resistant weeds were also found in South Australian orchards. They can achieve some measure of resistence in a variety of ways. Insecticide resistible pests were also detected by the Department of Insects at the University of North Carolina in April 1997. There are evidence for cross-resistence (e. g., resistance of one type of insecticide creating resistance to others).

Symbiosis with gene recombinant crops is impossible since their ecological invasions cannot be artificially stopped. Once they are released into the ecosystem, they will proliferate indefinitely. Hence, terrestrial biota will be decisively and inevitably modified, and natural species survival will come into question. Some plants and animals as indicators of ecosystem health are already on the way of extinction.

Foods produced by gene recombination are already being sold in supermarkets all over the world. It is impossible to distinguish whether products were made by gene recombination or not. It is possible, however, to identify at a cargo booking who has produced GM crops because one can observe which farms buy gene-recombinant seeds and their complementary insecticides. People, particularly housewives, are worried about the safety of the biofoods which are resistant either to herbicides or to harmful insects. A campaign against foods produced by biotechnology is being conducted to boycott them. Also, a campaign for the labeling of biofoods began to grow in Europe. There are several European governments which have made it obligatory for companies to put special labels on GM foods. They are already exported into Japan from the U. S. and Canada. Certain food manufacturing companies say that they had no intention of attaching clear labels on products engineered by genetic recombination. The Japan Consumer Union is worried about the detrimental effects of biofoods on our bodies because gene-recombinant crops involve plants with a substance to kill weeds and/or insects themselves. In August 1999, the Japan Ministry of Agriculture, Forestry and Fisheries decided to make it obligatory to label on thirty genetically modified foods from April 2000.

1.2. The New Consumer Theory, which was initiated by Gorman(1956/1980)[2] and followed by Lancaster(1966), was rigorously analyzed by Drèze and Hagen(1978). Fundamental theorems of welfare economics state that any competitive equilibrium is Pareto optimal that holds for each amount of goods, but not for each attribute or characteristic with which goods are composed. This observation was verified by Hagen (1975) in his new consumer theoretical framework. Drèze and Hagen(1978) subsequently developed a model using the new consumer theory, drove necessary conditions (or conditions for Pareto stationary points) for optimal product quality in a general equilibrium system, and established both quantitative and qualitative efficiency. They also proved that producers who maximize their profits have an incentive to select the most desirable combination of characteristics which maximizes a consumer's utility. That is, they showed that the production of goods having Pareto optimal product quality is compatible with the profit maximizing behavior of producers. They analyzed two equilibrium concepts : monopolistic Nash equilibrium and competitive profits equilibrium. Moreover, they drove a Slutsky equation for quality changes.

Sato(1998) seeked to characterize nutritionally optimal individual diets resulting in an optimal composition of attributes in foods. More precisely, modern dietetics has already established an optimal fat intake rate for people of each race, as well as seven prerequisite nutritive elements as follows: vitamin A(beta carotin), vitamin B_6, folic acid, pantothenic acid as vitamins, as well as calcium, magnesium, and iron as minerals. Modern dietetics has also shown that there must be optimal rates among micronutrients. The famous biochemist, the late Dr. Roger J. Williams, named a chain of micronutrients such as vitamins, minerals, and amino acids as the Chain of Life, assuring proper health. For example, the optimal metabolic rate between calcium and phosphorus is 1 : 1. In economic terms, all nutritive elements can be considered as Gorman-Lancasterian attributes or characteristics to be explained below that can assure healthy living conditions for the people.

This paper shows that each consumer can maximize his/her 'happiness function' by eating even gene-recombinant crops to establish Individual Super Health to be formulated below. For this purpose, we extend and modify the analyses of Sato(1998) which we will be using as a basis for our discussion.

One may consider two sorts of consumers: those who are prudent and those who ignore the possible risks in their everyday consumption of foods. Therefore, we must roughly distinguish these two types of consumers in a world with food safety precautions. To put it differently, regarding food safety, we have those who are unconscious and those who are well-informed according to their Ecologically-Conscious Levels to be formally defined below. If we wrote a paper in the seventies, we could confine ourselves to the characteristics that were innocuous to the lifelong health of consumers, limiting the scope of the study. As is well known, agricultural chemicals are persistent in the human body after consumption of foods; many food additives which begin to work as cancer initiators or promoters inside the body can result in illness or ultimately, death. Hence, we have to discuss attributes which are injurious to human health, including the probability of illness and death in the 'lifetime happiness functions' to be defined below. That is, foods which have harmful effects on individual maximization should be attended, and this problem is postponed to Section 4.

The objective facets of the risky foods problems should also involve subjective considerations, since immunity and risk resistance are very personal matters. Hence, we utilize Amartya Sen's Capability Approach, which is used to define a person's health to value individual well-being via his or her optimal human diet in the presence of gene-recombinant crops. According to Sen, health is an important functioning(or being) of a person. Owing to the available characteristics embodied in goods, people can live a life which consists of beings and doings. Our aim is to show that any consumer can maximize his or her happiness function by eating foods including those with hazardous attributes, thus composing an optimal human diet which establishes one of the maximal elements in his/her capability set in the sense of Sen.

1.3. Let us combine good 'attributes' of the above strains of research to establish efficiency conditions for the products compounded of characteristics, some of which may be harmful ones. To accomplish this, we adopt an analytical framework involving producers whose works result in noxious activities. As a result, we derive the necessary conditions for Pareto optimal food quality represented by characteristics in this risky world. More precisely, we deduce the necessary conditions for agrochemical makers, farms, and food manufacturers to maximize their profits by providing Pareto optimal food quality attributes.

This paper proceeds as follows. Section 2 presents the Attributes/Functionings model and discusses the valuation of health related to the genetic engineering-biohazards. Section 3 discusses the model of an economy with agrochemical firms, farms, and food makers to produce goods which have possibly hazardous attributes such as agrochemicals and food additives. The necessary conditions for a nutritionally optimal human diet with gene-recombinant or transgenic crops as a composition of genetic attributes are derived in Section 4. Four figures are presented in the Appendix, where we graphically illustrate our issues in the new consumer theoretical framework.

2. GENE-RECOMBINANT CROPS AS A COMPOSITION OF GENETIC CHARACTERISTICS

2.1. *Genes as Genetic Attributes*

We present the attributes/functionings model in this section. The two terms: attributes and characteristics, are used interchangeably throughout this paper. All genes can be interpreted as *genetic characteristics* in our framework, since they can create organisms of flora and fauna. So we can represent a DNA of species s:

$$\gamma_s = \left(\gamma_{s1}, \ldots, \gamma_{sG}\right) \tag{1}$$

where $\gamma_{sg} \geqq 0$, $\forall g = 1, \ldots, G \in \mathbf{G}$, signifies a gene g that sth plants naturally possesses, and $\mathbf{G}$ is the set of genes which composes species. Whereas, Gene-Recombinant

Crops can be shown by

$$\gamma_s^{G+1} = \left(\gamma_{s1}, \ldots, \gamma_{sG}, \gamma_{sG+1}\right) \tag{2}$$

where γ_{sG+1} represents a gene of microorganism (e. g., Bacillus thuringiensis : Bt) which is introduced by an agrochemical firm to create an endotoxin confering a plant insecticide resistance as a functioning in an enlarged sense of Sen (1985), because the term, functioning, was applied only to humans in his book.

Herbicides have been developed as a result of great losses to farm crops every year because of viruses affecting plants. GM crops are able to resist viruses by injections of a stronger form of viruses. Geneticists can improve plants and even produce new species that have never lived on the earth. Some of the crops that they developed can resist pests because they are poisonous themselves. It is already reported that insects are agonized to death due to the damages in their intestines, after they eat GM crops such as potatoes.

2.2. *Crops and Characteristics*

Let there be N consumers indexed by $i \in \mathbf{N} = \{1, \ldots, N\}$: the set of individuals. We consider plants which are composed of C characteristics indexed by $c = \{1, \ldots, C\} \in \mathbf{C}$, that is the set of attributes. Denote q_{hc} as an amount of attribute c embodied in one unit of good x_h. Let $\mathbf{H} = \{1, \ldots, H\}$ be the set of products. Define q as the $H \times C$ (variable) "technological matrix" with typical element, q_{hc}. x_{ih} is a person i's consumption of good h, and $x_i = \left(x_{i1}, \ldots, x_{ih}, \ldots, x_{iH}\right)$. The initial resources of individual i are defined by a nonnegative vector $\omega_i = \left(\omega_{i0}, \omega_{i1}, \ldots, \omega_{iH}\right)$. The sale or purchase of the commodities by individual i is x_{i0}. As in Drèze and Hagen (1978), every good is assumed to have at least one characteristic indexed by h', hence other attributes are measured per unit of characteristic h'. We impose $q_{hh'} = 1$ for size normalization. The index h' differs among different goods.

Let z_{i0} be an individual i's numèraire characteristic that he/she possesses, by which every attribute is utilized. Amounts of each attribute embodied in goods consumed by person i is given by

$$z_i = \left(z_{i0}, z_{i1}, \ldots, z_{ic}, z_{ic+1}\right) = \left(x_{i0}, x_i' q\right)' \tag{3}$$

where

$$z_{ic} = \sum_{h=1}^{H} x_{ih} q_{hc} \tag{4}$$

and z_{ic+1} represents, for example, an endotoxin which can selectively kill the Coleoptera or beetles such as gold bugs and ladybirds. Colorado beetles are natural enemies to potatoes and they have been vexing U. S. farms for a long time. Equation (4) may be interpreted as the nominal characteristics availability function, which converts commodities into attributes. We can regard q_{hc}, $\forall h \in \mathbf{H}$, $\forall c \in \mathbf{C}$, as parameters which are objective and common to all consumers, i. e., they have a public-good property. Only producers can vary q_{hc} by their production technologies to a vector of genetic attributes, γ_s. Consumers therefore must behave as "quality takers," and they can only change their consumption of z_{ic} via the choice of x_i. $q_{hc}(\gamma_s)$ is assumed hereafter, which means that any attribute embodied in a product h is a function of genetic characteristics engineered only by the agrochemical makers.

The Gorman-Lancasterian characteristics theory is most suitable to analyze foods which are perfectly divisible and decomposable into nutritive elements as characteristics. Equation (4) may be applied to any consumer whose utilizations, however, differ from person to person. Consequently, we have to introduce each person's functionings as one of Sen's concepts to fully appraise the value of goods or characteristics. Each person's metabolism and physiology are different, so we must introduce the substantial attributes availability function represented in Eq. (5) below.

2.3. *Beings and Functionings*

Before rushing into our analysis of gene-recombinant crops, let us introduce some basic concepts introduced by Sato (1998), originally due to Sen (1985). A person's state of beings is representable as a vector of functionings. The set of feasible vectors of functionings for any person is the capability set.

An individual i's being generated by his/her functioning f_{ik}, $k = 1, \ldots, K_i$, may be represented by a vector

$$b_i = b_i\big(f_{i1}(z_i), \ldots, f_{ik}(z_i)\big), \ \forall f_i \in \mathbf{K}_i, \tag{5}$$

where $\mathbf{K}_i$ is person i's set of functionings vectors. Let us give an example to paraphrase Eq. (5). When a person is practicing exercises, he or she simultanesouly utilizes several functionings such as his/her feet, hands, legs, heart, and other muscles. The number of $\mathbf{K}_i$ varies according to an individual. Let $\mathbf{K}_i$ be his/her set of functionings.

Assumption 1 : For any $i \in \boldsymbol{N}$, f_{ik} is strictly concave and twice continuously differentiable, with $\partial f_{ik}/\partial z_i \neq 0$, $\forall f_{ik} \in \mathbf{K}_i$.

Remark 1 : We suppose that an infinitesimal change in the numéraire attribute z_i can vary person i's functionings. For example, maintaining regular exercise could strengthen physical functionings such as the system of circulation. The sign of $\partial f_{ik}/\partial z_i$ depends upon what characteristic c is, i. e., it can take a sign $\{+, -\}$ according to attribute c which is good, irrelevant, or bad, respectively, for person i's health. If c is an endotoxin created by the Bt bacteria, then the sign must be minus for individuals who lexicographically prefer the safety of foods. If the safety is lost, the well-informed consumers may not buy them.

2.4. *Happiness Function and Valuing Individual Well-Being*

According to Sen (1985), person i's 'Happiness Function' is assumed here to depend upon his/her beings, which has to be maximized. Thus, we have individual i's 'Happiness Function' given by

$$H_i = H_i\left(b_i\right). \tag{6}$$

In order to obtain our desired results, we need the differentiability assumption.

Assumption 2 : For any $i \in \mathbf{N}$, H_i is strictly quasi-concave and twice continuously differentiable, with $\left(dH_i/db_i\right)\left(\partial b_i/\partial f_{ik}\right) \neq 0$, at least for one $\forall f_{ik} \in \mathbf{K}_i$.

Here we introduce a definition. Denote π_{ic} as individual i's shadow price of attribute c or characteristic c's marginal contribution to person i's marginal happiness through his/her functionings in terms of the numéraire characteristic z_i as :

$$\pi_{ic} = \frac{\sum_k \left(\frac{dH_i}{db_i}\right)\left(\frac{\partial b_i}{\partial f_{ik}}\right)\left(\frac{\partial f_{ik}}{\partial z_{ic}}\right)}{\sum_k \left(\frac{dH_i}{db_i}\right)\left(\frac{\partial b_i}{\partial f_{ik}}\right)\left(\frac{\partial f_{ik}}{\partial z_i}\right)}, \ \forall i \in \mathbf{N}, \ \forall c \in \mathbf{C} \cup \{C+1\}. \tag{7}$$

It can be interpreted also as a marginal willingness to pay which corresponds to a marginal rate of substitution between characteristic c and the numéraire characteristic

z_i in the utility theoretical context, π_{ic} can take whatever sign $\{+, 0, -\}$ from the above discussion. Remark that our 'MRS' is different from that of Drèze and Hagen (1978), because our concept surely involves the functionings *à la* Sen. Hence, we have had to replace a happiness function for a utility function.

The fact that person i has some level of 'happiness', and the value he or she puts on that level are totally different. In order not to confuse these two things, we introduce one of the concepts of Sen (1985) and (1992) as follows.

Person i's valuation function for his/her beings reads

$$v_i = v_i(b_i). \tag{8}$$

An example of a valuation function may be given by

$$v_i(b_i(t)) = \int_0^t H_i(b_i(\theta))d\theta \tag{9}$$

which signifies that 'an accumulation of happiness' until time t is a valuation function at time t. Note that H_i and v_i are completely different concepts, because the former signifies the measure of 'happiness' and the latter is the value that person i puts on that measure. A shift from a current health level to a much healthier state may be motivated by the valuation function which gives a person an incentive to have better health. For example, starting to ingest nutritionally-balanced foods as required by modern dietetics is a role of the valuation function to value many aspects of person i's life. Eating foods which may be made from GR crops make consumers feel uncomfortable about health risks. A sense of feeling uneasy about GR crops may be given by the valuation function.

Define the set of functionings vector slightly different from Sen as :

$$P_i(x_i) = \left\{b_i \,\middle|\, b_i = b_i\left(f_{i1}(z_i), \ldots, f_{ik_i}(z_i)\right), \text{ for some } f_i \in \mathbf{K}_i\right\}. \tag{10}$$

Let $\mathbf{X}_i$ denote the set of person i's consumption of goods. Given $\mathbf{X}_i$, we can represent the set of feasible functionings vector, or the capability set of person i as :

$$\begin{aligned} B_i(\mathbf{X}_i) = \Big\{b_i \,\Big|\, b_i = b_i\left(f_{i1}(z_i), \ldots, f_{ik_i}(z_i)\right),& \\ \text{for some } f_i \in \mathbf{K}_i \text{ and for some } x_i \in \mathbf{X}_i\Big\}.& \end{aligned} \tag{11}$$

The set of the values of well-being is given by

$$\mathbf{V}_i = \{v_i | v_i = v_i(b_i), \text{ for some } b_i \in \mathbf{B}_i(\mathbf{X}_i)\}. \tag{12}$$

2.5. *The Individual Chain of Life*

One of our issues is that if the highest value v_i^* in $\mathbf{V}_i$ is chosen, then what is the composition of z_i in terms of nutrition as a characteristic embodied in foods? v_i^* corresponds to the value with the highest ranking and assures the nutritionally optimal individual diet z_i^* in the presence of GR crops. We can say that our issue is to find an optimal attributes mix, z_i^* such that $H_i^* = H_i(f_{i1}(z_i^*), \ldots, f_{ik}(z_i^*))$, for some b_i in $\mathbf{B}_i(\mathbf{X}_i)$ and for some $v_i(b_i) \in \mathbf{V}_i$.

Limiting our analysis to an individual's health risk aspect of living, menaced by ingredients of foods including GM Crops as well as activities undertaken in his/her personal time. One may interpret b_i as a 'Well-Being Index,' since b_i, ceteris paribus, corresponds to some wellness level. Also, f_{ik} is a continuous function of characteristics composition, z_i. In our context, a person enjoys his/her health, which enhances his/her functionings. The point is that health is not an ultimate objective but just a means that permit a person to experience a healthy lifestyle. Sen(1992, p.40) wrote that "[w]hether a person is well-nourished, in good health, etc., must be intrinsically important for the wellness of that person's being." Moreover, examples of functionings introduced by Sen, which are relevant for our analysis are as follows: being able to know and to choose, avoiding premature mortality and escapable morbidity, etc.

In the $z_{ic}-z_{ic'}$ space, we can represent the relationship between any two nutrients as an angle $\delta_{cc'}$ between a horizontal $Z_{ic'}$-axis and a ray from the origin. The index $\delta_{cc'}$ must be 45° for c(Ca) and c'(P), since Ca : P = 1 : 1 should be kept in the healthy blood, hence $\tan \delta_{cc'} = 1$. Both R_{ic} and $R_{ic'}$ are values that are given by the Recommended Dietary Allowances(RDA) in the United States. Therefore, one can easily choose foods by checking the "Nutrition Facts" that are attached on the food products. For example, 30mg/day is a recommended intake for Zn, 18mg/day for Fe, 5000IU/day for vitamin A, 100mg/day for vitamin C, etc. Hence, the following condition applies to all pairs of nutrients. Knowing an amount of each nutrient contained in each food as well as optimal rates between nutritive elements is also regarded as a functioning related to knowledge. We can say that the facts in modern dietetics fit very well to be formulated in a mathematical economic fashion. We must go further to represent the dietetic optimality which is supported by the chain of life introduced in the Section 1. Here we present its representation as :

CONDITION **ICOL(Individual Chain of Life)** :

$$z_{ic} = R_{ic'} \tan \delta_{cc'}, \ \forall c, \ c' \in \mathbf{C}, \ c \neq C+1, \ c' \neq C+1. \quad (13)$$

Whether a person considers a commodity as good, irrelevant, or bad to his/her functionings verified by the sign of $\sum_c \pi_{ic} x_{ih}$ for each good h. Whether a good is socially optimal or not may also be examined by summing the value as $\sum_i \sum_c \pi_{ic} x_{ih}$ for each good h. Thus we can deduce the necessary conditions for nutritionally optimal individual diets in terms of characteristics, including endotoxin. Distinct from the Drèze and Hagen's analysis, we must add a 'dietetic constraint' based on Condition **ICOL** to confirm balanced nutritional intake to maximize a person's happiness function, which depends upon his/her functionings as required by modern dietetics. The next section shows the results.

3. OPTIMIZATION WITH GENE-RECOMBINANT CROPS HAVING DELETERIOUS ATTRIBUTES

3.1. *Profit Maximization by Agrochemical Makers Spreading Hazardous Biohazards*

Sato(1998) assumed that every food is composed of nutrients as good attributes, and then generalized his model by introducing harmful characteristics such as food additives and agrochemicals, e. g., pesticides, weedicides, fertilizers, preservatives, hormones, antibiotics, colorants, food antioxidents, etc. Our analysis below is applied to the case where agrochemical makers produce gene-recombinant seeds and their complementary insecticides as risky attributes.[3]

A similar framework of Sato(1998) is employed with some modifications to involve the phenomenon of persistant and non-traceable engineering-biohazards caused by GM Crops and hurtful agrochemicals released by multinational agrochemical makers. This section is devoted to present the optimizations by the profit maximizing producers : i. e., agrochemical makers, farms, food manufacturers to supply goods with efficient product quality to ill-informed consumers with or without ecology-consciousness to be formulated below in the next section. In our economy, there are M agrochemical makers, J farms, and F food manufacturers indexed respectively by, $m \in \mathbf{M} = \{1, \ldots, M\}$, $j \in \mathbf{J} = \{1, \ldots, J\}$, and $f \in \mathbf{F} = \{1, \ldots, F\}$: the set of agrochemical makers, farms, and food manufacturers. Each producer h produces a good h by using an input x_{h0}, with the constraint :

$$\sum_{h \in \mathbf{M} \cup \mathbf{J} \cup \mathbf{F}} x_{h0} \leqq \sum_{i \in \mathbf{N}} z_{i0} \tag{14}$$

where z_{i0} is a positive amount of numéraire characteristic initially given to individual i. The price of x_{h0} is normalized to be unity.

We assume that each agrochemical maker m genetically modifies only one crop, i. e., $\gamma_s = \gamma_m$. The production function of an agrochemical maker is represented by $\phi_m(y_m) \leqq 0$, $y_m \geqq 0$, where y_m is an input-output vector given by

$$y_m = \left(x_{mB},\ x_{m0},\ x_m,\ x_{m'},\ q_{m1}(\gamma_m),\ \ldots,\ q_{mC}(\gamma_m),\ q_{mC+1}(\gamma_m)\right) \tag{15}$$

with $x_m \geqq 0$, and $q_{mc} \geqq 0$, $\forall m \in \mathbf{M}$, $\forall c \in \mathbf{C} \cup \{C+1\}$. Suppose that product m has at least one attribute labeled μ and that $q_{m\mu} = 1$. x_{mB} denotes an amount of Bt bacterium that maker m uses as one of the inputs, and q_{mC+1} is a quantity of endotoxin created by the bacterium contained in x_m. x_{m0} is an amount of labor to jointly produce GR seeds, x_m, and complementary insecticide, $x_{m'}$. There is a tie-in between GR seeds and complementary insecticides. A vector $(q_{m1},\ldots,\ q_{mC},\ q_{mC+1})$ represents ingredients involved in x_m and $x_{m'}$. Let p_m and $p_{m'}$ be the unit price of the GR seeds and that of the insecticide.

Then, we have the agrochemical maker's monopolistic profit maximization problem :

$$\text{Max} \quad P_m = \sum_{j \in \mathbf{J}} \{p_m(x_m)x_{jm} + p_{m'}(x_{m'})x_{jm'}\} - (x_{m0} + C_m(x_{mB})) \tag{16}$$

over the set

$$\begin{aligned} \{y_m \mid \phi_m(x_{mB},\ x_{m0},\ x_m,\ x_{m'},\ q_{m1}(\gamma_m),\ \ldots,\ q_{mC}(\gamma_m),\ q_{mC+1}(\gamma_m)) \leqq 0, \\ q_{mc} \geqq 0,\ \forall c \in \mathbf{C} \cup \{C+1\}\} \end{aligned} \tag{17}$$

where $C_m(x_{mB})$ is a cultivation cost of the bacterium. x_{jm} ($x_{jm'}$, resp.) denotes an amount of GR seed (insecticide, resp.) that farm j buys from the agrochemical maker m to use as its inputs. The production function may not be convex, but the problem arising from nonconvexities are not treated here. We suppose that p_m and $p_{m'}$ include patents of monopolistic agrochemical maker m.

Here we need to make an assumption.

Assumption 3 : (i) For any m, ϕ_m is convex and twice continuously differentiable, with $\partial\phi_m/\partial x_{mB} < 0$, $\partial\phi_m/\partial x_{m0} < 0$, $\partial\phi_m/\partial x_m > 0$, $\partial\phi_{m'}/\partial x_{m'} > 0$, and $\partial\phi_m/\partial q_{mc} > 0$, $\forall c \in \mathbf{C} \cup \{C+1\}$, $c \neq \mu$. Furthermore, $x_m > 0$ implies $x_{m0} > 0$, $x_{mB} > 0$, and $\forall \Lambda \in \mathbf{R}_+$, $\{y_m | \phi_m(y_m) \leqq 0,\ x_{m0} \leqq \Lambda,\ x_{mB} \leqq 0\}$ is compact.
(ii) For any m, q_{mc} is twice continuously differentiable with respect to γ_m.
(iii) For any m', $q_{m'c}$ is twice continuously differentiable with respect to $\gamma_{m'}$. For any x_{mB}, C_m is convex and twice continuously differentiable, with $dC_m/dx_{mB} > 0$, and $d^2C_m/dx_{mB}^2 > 0$.

Notice that the arguments in Eq.(16) and (17) are all functions of genetic characteristics, $\gamma_{mg}, \forall g \in \mathbf{G}$, that each agrochemical maker m can manipulate to maximize its profit. Thus, we can state the following :

PROPOSITION 1 : *Necessary conditions for Pareto optimal product quality of Genetically Modified Seeds and Pesticides in terms of genetic attributes are :*

$$\left(\frac{\partial x_m}{\partial \gamma_{mg}}\right)\left(p_m + x_m \frac{dp_m}{dx_m}\right) + \left(\frac{\partial x_{m'}}{\partial \gamma_{mg}}\right)\left(p_m + x_{m'} \frac{dp_{m'}}{dx_m}\right) = \frac{\partial x_{m0}}{\partial \gamma_{mg}} + \left(\frac{dC_m}{dx_{mB}}\right)\left(\frac{\partial x_{mB}}{\partial \gamma_{mg}}\right), \tag{18}$$

$$\forall m \in \mathbf{M},\ m \neq \mu,\ \forall g \in \mathbf{G} \cup \{C+1\}$$

$$\left\{\left(\frac{\partial x_m}{\partial \gamma_{mg}}\right)\left(p_m + x_m \frac{dp_m}{dx_m}\right) + \left(\frac{\partial x_{m'}}{\partial \gamma_{mg}}\right)\left(p_m + x_{m'} \frac{dp_{m'}}{dx_m}\right) - \frac{\partial x_{m0}}{\partial \gamma_{mg}} - \left(\frac{dC_m}{dx_{mB}}\right)\left(\frac{\partial x_{mB}}{\partial \gamma_{mg}}\right)\right\} \gamma_{mg} = 0, \tag{19}$$

$$\forall m \in \mathbf{M},\ m \neq \mu,\ \forall g \in \mathbf{G} \cup \{C+1\}$$

Remark 2 : These are the Kuhn-Tucker necessary conditions which mean the equality of marginal revenue [L.H.S. of Eq.(18)] and marginal cost [R.H.S. of Eq.(18)] of the agrochemical maker that can maximize by modifying genetical attributes, $\gamma_{mg}, \forall g \in \mathbf{G}$.

3.2. *Profit Maximization by Farms Producing Gene-Recombinant Crops*

We can easily generalize our model to incorporate many agrochemicals, so we extend Eq.(3) as

$$z_i = \left(z_{i0},\ z_{i1},\ \ldots,\ z_{ic},\ z_{ic+1},\ \ldots,\ z_{ic+A}\right) \tag{20}$$

where z_{ic} is a consumption of characteristic c which may be hazardous if $c \in \boldsymbol{A} = \{C+1,\ \ldots,\ C+A\}$: the set of endotoxin and agrochemicals.

Remark 3 : We also assume hereafter that π_{ic} covers both nutrients and the harmful attributes, e. g., the endotoxin. Note that the analysis of Drèze and Hagen (1978) allows for negative MRSs of some consumers, with an additional assumption that $\sum_i \pi_{ic} > 0$ as expressed in our notation. This means that even if one puts negative valuations $\pi_{ic} < 0$ on some characteristic c, the aggregate value of MRSs over consumers can still be positive, i. e., socially accepted. It is this forced or coercive social acceptance that gives rise to growing public discussion. Even if consumers know that some GRCs are contained in foods, they cannot identify them because of their same taste and appearance. Moreover, there are mixed supplies of GRCs and ordinary vegetables or non-GRCs.

We assume that each farm produces only one output such as corn to maximize its profit over the set

$$\begin{aligned}\left\{y_j \,\middle|\, \phi_j\left(x_{jm},\ x_{jm'},\ x_{j0},\ x_j,\ q_{j1},\ \ldots,\ q_{jC},\ q_{jC+1},\ \ldots,\ q_{jC+A}\right) \leqq 0,\right.\\ \left. q_{jc} \geqq 0,\ \forall c \in \mathbf{C} \cup \mathbf{A}\right\}\end{aligned} \tag{21}$$

where x_{j0} is an input of labor used by farm j, and x_j is farm j 's output. $\left(q_{j1},\ \ldots,\ q_{jC}\right)$ is a vector of attributes including nutritive elements embodied in crop j. Whereas, $\left(q_{jC+1},\ \ldots,\ q_{jC+A}\right)$ is a vector of deleterious characteristics and q_{jC+1} is a persistant amount of endotoxin contained in x_j. We assume that $q_{jC+1} = \rho_{mj}\, x_{jm}$, where $0 < \rho_{mj} \leqq 1,\ \forall m \in \mathbf{M},\ \forall j \in \mathbf{J}$, is a degree of persistence of the endotoxin as a hazardous attribute in the human body.

Assumption 4 : For any $j \in \mathbf{J}$, ϕ_j is convex and twice continuously differentiable, with $\partial \phi_j / \partial x_{jm} < 0$, $\partial \phi_j / \partial x_{jm'} < 0$, $\partial \phi_j / \partial x_{j0} < 0$, $\partial \phi_j / \partial x_j > 0$, and $\partial \phi_j / \partial q_{jc} > 0$, $\forall c \in \mathbf{C} \cup \mathbf{A}$, $c \neq j'$. Furthermore, $x_j > 0$ implies $x_{j0} > 0$, $x_{jm} > 0$, and $x_{jm'} > 0$, and $\forall \Lambda \in \mathbf{R}_+$, $\left\{y_j \middle| \phi_j\left(y_j\right) \leqq 0,\ x_{j0} \leqq \Lambda,\ x_{jm} \leqq \Lambda, \text{ and } x_{jm'} \leqq \Lambda\right\}$ is compact.

To define the producer's profit function, we follow Drèze and Hagen (1978, p.

510) who wrote that "the implicit price could be computed... and they would in equilibrium be the same for all consumers. So we do not have to make price differentiation among consumers." This statement follows from their assumption of non-singularity of the technological matrix. If the matrix q is non-singular, then it has an inverse matrix. When $x_{ij} > 0$, p_j could be computed as represented below. This observation is applied in the same manner for the food manufacturers below. Then, the profit maximization problem for competitive GR farms are given by :

$$\text{Max} \quad P_j = \sum_{c \in \mathbf{C} \cup \mathbf{A}} q_{jc} \sum_{i \in \mathbf{N}} \pi_{ic}\, x_{ij} + \sum_{f \in \mathbf{F}} x_{fj}\, p_j - \left(x_{j0} + p_m x_{jm} + p_{m'}\, x_{jm'} \right) \tag{22}$$

over the set represented by Eq.(21), where x_{fj} is an amount of farm j's crop that food maker f uses as an input. Thus, we have the following theorem.

PROPOSITION 2 : *Necessary conditions for Pareto optimal product quality of Gene-Recombinant Crops in terms of attributes including deleterious ones are :*

$$\sum_{i \in \mathbf{N}} \pi_{ic}\, x_{ij} + \sum_{f \in \mathbf{F}} p_j \frac{\partial x_{fj}}{\partial q_{jc}} \leqq \frac{\partial x_{j0}}{\partial q_{jc}} + p_m \frac{\partial x_{jm}}{\partial q_{jc}} + p_{m'} \frac{\partial x_{jm'}}{\partial q_{jc}}, \quad \forall j \in \mathbf{J},\ \forall c \in \mathbf{C},\ c \neq j' \tag{23}$$

$$\left(\sum_{i \in \mathbf{N}} \pi_{ic}\, x_{ij} + \sum_{f \in \mathbf{F}} p_j \frac{\partial x_{fj}}{\partial q_{jc}} - \frac{\partial x_{j0}}{\partial q_{jc}} - p_m \frac{\partial x_{jm}}{\partial q_{jc}} - p_{m'} \frac{\partial x_{jm'}}{\partial q_{jc}} \right) q_{jc} = 0, \quad \forall j \in \mathbf{J},\ \forall c \in \mathbf{C},\ c \neq j'. \tag{24}$$

Remark 4 : These are the Kuhn-Tucker Conditions for the above optimization problem. Eqs.(23) and (24) establish a Pareto optimality for an amount of each attribute and determine a vector of optimal quality characteristics, q_{jc}^{*}, $\forall j \in \mathbf{J}$, $\forall c \in \mathbf{C}$, that farms can choose to supply GR crops. The L.H.S. in Eq.(23) is the marginal revenue which is the aggregate of consumers' and food makers' marginal evaluations of an infinitesimal change in an attribute embedded in x_j. The R.H.S. is the marginal cost composed of three terms : the first term is the marginal cost of the numéraire attribute, and the second and third terms are those of seeds and insecticides. Eqs.(23) and (24) signify the marginal social value of the seeds and the pesticides in terms of the numéraire characteristics, where the marginal social value is the sum of the personal evaluations of an infinitesimal change in each deleterious attribute persistent in x_j.

Let x_{jm}^{+} be a product of farm $j \in \mathbf{J}^{+}$, and denote also x_{jm}^{-} as a product of organic farm $j \in \mathbf{J}^-$, where $\mathbf{J}^+$ and $\mathbf{J}^-$ are the sets of GR and non-GR farms. Organic farms may generally require more labor than GR farms, so we suppose that $x_{j0}^+ - x_{j0}^- < 0$. Let us compare the profits of two types of behaviors that any farm j can choose. Use of GR seeds and its complementary pesticides may result in more agricultural products produced by the farms, so we assume that $\sum_i x_{ij}^+ - \sum_i x_{ij}^- > 0$. Moreover, under the assumption of $\sum_i \pi_{ic} x_{ij}^+ > 0$, i. e., food j is reluctantly accepted without exact knowledge of whether GR crops are contained in the foods or not. Hence, we observe

$$\begin{aligned} P_j^+ - P_j^- = & \sum_{c \in \mathbf{C} \cup \mathbf{A}} q_{jc} \sum_{i \in \mathbf{N}} \pi_{ic} x_{ij}^+ + \sum_{f \in \mathbf{F}} x_{ij}^+ p_j - \left(x_{j0}^+ + p_m x_{jm} + p_{m'} x_{jm'} \right) \\ & - \left(\sum_{c \in \mathbf{C}} q_{jc} \sum_{i \in \mathbf{N}} \pi_{ic} x_{ij}^- + \sum_{f \in \mathbf{F}} x_{ij}^- p_j - x_{j0}^- - p_n x_{jn} \right) \end{aligned} \tag{25}$$

where P_j^+ is a profit when farm j behaves as a GR farm : the sum of the first and the second terms is its revenue and the third term is its cost. x_{jn} is an amount of organic seeds with its unit price p_n, and P_j^- is an organically behaved farm j's profit when it does not use GR seeds nor their complements. Food manufacturers do not have to differentiate GR or non-GR foods in the existing circumustances without strict regulations on the gene-recombinant crops. This fact results in the differentiation of not using implicit prices in calculating the revenue from food makers. Whereas, consumers evaluate crops via their functionings. The sign of Eq.(25) depends upon the magnitudes of positive and negative terms, hence, is indeterminate. Thus, an incentive not to use GR seeds and pesticides cannot necessarily be given to farms, provided that the above situation is realized. This is a contrasting result compared with that Sato (1998) presented.[4]

3.3. *Profit Maximization by Food Manufacturers Using Gene Recombinant Crops*

Suppose we consider a food maker who produces tomato juice by using GM tomatoes.[5] Then we can obtain the model to many deleterious attributes possibly provided by the production function represented by

$$\begin{aligned} \Big\{ y_f \,\Big|\, \phi_f\big(x_{fj},\ x_{f0},\ x_f,\ q_{f1},\ \ldots,\ q_{fC},\ q_{fC+1},\ \ldots,\ q_{fC+A}\big) \leqq 0, & \\ q_{fc} \geqq 0,\ \ \forall c \in \mathbf{C} \cup \mathbf{A} \Big\} & \end{aligned} \tag{26}$$

with $q_{fc} = \rho_{jf} x_{fj}$, where $0 < \rho_{jf} \leqq 1$, $\forall f \in \mathbf{F}$, $\forall c \in \mathbf{A}$, is a degree of persistence of each food additive. We may put $\rho_{jf} = 1$ for additives such as preservatives and food flavorings because these amounts used in the manufacturing process are not necessarily digestible and persist in human bodies by possibly the same quantities. x_{f0} is an input of numéraire that food maker f uses, and x_f is an output of that producer. $\left(q_{f1}, \ldots, q_{fc}\right)$ is a vector of attributes of food f, mainly, nutrients. The assumption as in Assumption 4 is valid for any food manufacturer.

Let p_{fc}, $\forall j \in \mathbf{J}$, $\forall c \in \mathbf{A}$, be a unit price of harmful input in the food manufacturer's optimization problem

$$\text{Max} \quad P_f = \sum_{c \in \mathbf{C} \cup \mathbf{A}} q_{fc} \sum_{i \in \mathbf{N}} \pi_{ic} x_{if} - \left(x_{f0} + \sum_{c \in \mathbf{A} - \{c+1\}} p_{fc} x_{fj} \right) \tag{27}$$

subject to the above production function represented by Eq.(26), then, in the presence of risky attributes, we can state the following theorem.

PROPOSITION 3: *Necessary conditions for Pareto optimal product quality of manufactured foods including possibly risky attributes are*:

$$\sum_{i \in \mathbf{N}} \pi_{ic} x_{if} \leqq \frac{\partial x_{f0}}{\partial q_{fc}}, \left(\sum_{i \in \mathbf{N}} \pi_{ic} x_{if} - \frac{\partial x_{f0}}{\partial q_{fc}} \right) q_{fj} = 0, \quad \forall c \in \mathbf{C}, \ \forall f \in \mathbf{F}, \ c \neq f' \tag{28}$$

$$\sum_{i \in \mathbf{N}} \pi_{ic} x_{if} \rho_{jf} \leqq \frac{\partial x_{f0}}{\partial x_{fj}}, \left(\sum_{i \in \mathbf{N}} \pi_{ic} x_{if} \rho_{jf} - \frac{\partial x_{f0}}{\partial x_{fj}} \right) x_{fj} = 0, \quad \forall c \in \mathbf{A}, \ \forall f \in \mathbf{F}, \ c \neq f'. \tag{29}$$

Remark 5: Eqs.(28) are the necessary conditions for Pareto optimal product quality in terms of characteristics (or Pareto stationary conditions) which are not hazardous to human health. The left-hand side of the first equation of (29) is the marginal social value in terms of the numéraire characteristic, where the marginal social value is the sum of the personal evaluations of an infinitesimal change in a harmful characteristic persistent in x_{if}.

4. OPTIMIZATION BY CONSUMERS SUFFERED FROM FOOD CONTAMINATION DUE TO GENETIC BIOHAZARDS

4.1. *Optimization by Ill-Informed Consumers Still Aiming at Individual Super Health*

Let us assume that consumers are ill-informed but they have an incentive to consume an optimal human diet in order to aim at an 'individual super health,' to be defined below. Therefore we have to solve our consumers' maximization problem. The maximand we have chosen is the 'daily happiness function', since some nutrients such as vitamin B complex cannot be reserved for the next day. We must take them daily, preferably by eating natural foods. Consumers must maximize his/her daily happiness function without knowing which goods are made from GR crops.

$$\text{Max} \quad H_i = H_i\left(b_i\right) \tag{30}$$

$$\text{s. t.} \quad b_i = b_i\left(f_{i1}\left(z_i\right),\ \ldots,\ f_{ik}\left(z_i\right)\right) \in \mathbf{B}\left(\mathbf{X}_i\right), \quad \forall f_i \in \mathbf{F}_i \tag{31}$$

$$Z_{ic} = \sum_{j \in \mathbf{J}} x_{ij}\, q_{jc} + \sum_{f \in \mathbf{F}} x_{if}\, q_{fc}, \quad \forall c \in \mathbf{C} \tag{32}$$

$$Z_{ic} = R_{ic} \tan \delta_{cc'} \quad \forall c,\ c' \in \mathbf{C},\ c \neq C+1,\ c' \neq C+1 \tag{33}$$

$$Z_{ic} = \xi_{ic}, \quad \forall c \in \mathbf{A} \tag{34}$$

$$\sum_{h \in \mathbf{J} \cup \mathbf{F}} \rho_h\, x_{ih} = Z_{i0} \tag{35}$$

$$x_{ih} \geqq 0, \quad \forall \mathbf{J} \cup \mathbf{F}. \tag{36}$$

Remark 6: The above equations are similar to those of **PROPOSITION 1** in Sato (1998) except for Eq.(34) which is related to the amount of endotoxin as well as food additives and agrochemicals, and ξ_{ic}, $\forall c \in \mathbf{A}$, is regarded as a tolerable daily intake (TDI) of an additive or an agricultural chemical that person i may consume. We assume that ξ_{ic} is known for any $c \in \mathbf{A}$.

Here we modify the concept of "distance" introduced by Sato(1998) to distinguish any pair of crops with different genetic characteristics. In our context, it reads as follows:

Definition 1 **Genetic Distance(GD)** is denoted as

$$d_{ss'} = d_{ss'}\left(\gamma_s,\ \gamma_{s'}\right),\ \forall s \in \mathbf{S} \tag{37}$$

where γ_s($\gamma_{s'}$, resp.) represents DNA of species s(s', resp.) and the set of species is denoted $\mathbf{S}$. $d_{ss'}$ is a norm or a metric which measures the distance between the two related varieties of any crop.

Definition 2 **Genetical Equivalence(GE)** states that the genetic distance between the two crops is zero : more precisely, **GE** is attained if and only if **GD** equals to zero :

$$\gamma_s = \gamma_{s'} \;\Leftrightarrow\; d_{ss'}(\gamma_s, \gamma_{s'}) = 0. \tag{38}$$

It is obvious that

$$\gamma_s \neq \gamma_{sG+1} \;\Rightarrow\; d_{ssG+1}(\gamma_s, \gamma_{sG+1}) \neq 0.$$ [6] (39)

Definition 3 **Individual Nutritional Distance(IND)** is given by

$$d_i = d_i(z_i^*, z_i) \tag{40}$$

which is a distance between z_i^* and z_i : the former means a consumer's individually optimal attributes mix, and the latter signifies his/her currently preferred nutrients mix, that is not necessarily good for the proper health of that person. More precisely.

$$z_i^* = \underset{\mathbf{x}_i}{\operatorname{argmax}} \;\; H_i(b_i). \tag{41}$$

IND signifies how far from optimal composition of nutrients given by current diets of an individual.

Definition 4 **Individual Super Health (ISH)** is not only just a healthy state but it also combats diseases, and even slows aging. More precisely, **ISH** is attained if

$$z_i^* = z_i \;\Leftrightarrow\; d_i(z_i^*, z_i) = 0. \tag{42}$$

Definition 5 A Nutritionally Optimal Individual Diet(NOID) under uncertainty is a diet which satisfies the dietetic constraint represented by CONDITION **ICOL**. The optimal rates among nutritions composing the individual chain of life, assuring successful aging and the highest health level for each person, viz., his/her Individual Super Health. However, consumers cannot have choices but to eat GR Crops, which involve genetic attributes that are made recombinant by agrochemical firms. Hence, consumers have to face food-related risks in their everyday consumption.

Thus, we can assuredly state the characterization theorem.

Theorem 1 : *Nutritionally Optimal Individual Diets with Genetically Modified Crops as a composition of Gorman-Lancasterian attributes are characterized as :*

$$\sum_{c \in C \cup \mathbf{A}} \pi_{ic} q_{hc} \leqq p_h, \left(\sum_{c \in \mathbf{C} \cup \mathbf{A}} \pi_{ic} q_{hc} - p_h \right) x_{ih} = 0, \quad \forall h \in \mathbf{J} \cup \mathbf{F} \tag{43}$$

$$b_i = b_i\big(f_{i1}(z_i), \dots, f_{ik}(z_i)\big) \in \mathbf{B}(\mathbf{X}_i), \quad \forall f_i \in \mathbf{F}_i \tag{44}$$

$$Z_{ic} = \sum_{j \in \mathbf{J}} x_{ij} q_{jc} + \sum_{f \in \mathbf{F}} x_{if} q_{fc}, \quad \forall c \in \mathbf{C} \tag{45}$$

$$Z_{ic} = R_{ic} \tan \delta_{cc'}, \quad \forall c,\ c' \in \mathbf{C},\ c \neq C+1,\ c' \neq C+1 \tag{46}$$

$$Z_{ic} = \xi_{ic}, \quad \forall c \in \mathbf{A} \tag{47}$$

$$\sum_{h \in \mathbf{J} \cup \mathbf{F}} p_h x_{ih} = Z_{i0} \tag{43}$$

$$x_{ih} \geqq 0, \quad \forall h \in \mathbf{J} \cup \mathbf{F}. \tag{49}$$

Remark 7: The proof is almost the same as for **PROPOSITION 1** in Sato(1998) except for the inclusion of hazardous attributes. The above conditions are not only necessary but also sufficient from the assumptions on the functions. If tomato juice is made from GR tomatoes, then the ingredients of the juice is dependent on the genes of recombinant tomatoes. In the above equations, π_{ic} signifies a 'shadow price' of a nutrient or a food additive as an attribute acquired by i's functionings. The left-hand side of the first equation in (43) is the sum of values of nutrients and food additives, as well as the endotoxin embodied in one unit of a food. The equations in (43) mean that the unit price of the food is equal to the sum of marginal contributions of attributes generated by individual i's functionings to his/her health. The conditions in Eqs. (43) assure a Pareto optimality for a quantity of each food, and give a basis upon which consumers choose to buy certain foods. The above formulae are a natural extention of the conditions shown in **PROPOSITION 1** in Sato(1998).

4.2. *Happiness Functions with Food-Related Risks due to the Gene-Recombinant Crops*

Roughly speaking, there are two types of consumers: those who are prudent about the foods they eat and those who are apt to ignore the possibility of risks in foods which are hazardous to them. Therefore, we may roughly distinguish the types of consumers in an uncertain and hazardous world without food safety precautions. However, neither type of consumers can necessarily avoid the risks that foods may involve. The problem that the people faces is the overflow of pollutants in their bodies by eating deleterious foods including gene-recombinant crops.[7]

Each consumer faces an uncertainty arising from genetic engineering-biohazards and entailing food contamination. One has to maximize expected happiness generated by his/her functionings to utilize attributes, including harmful ones embodied in foods. Hereafter, let all variables be a function of time t.

Thus we have person i's expected happiness

$$EH_i(t) = \sum_{d \in \triangle(t)} p_{id}\big(b_i(t)\big) H_i\big(b_i(t)\big) \tag{50}$$

where E is an expectation operator. $p_{id} \geqq 0$ is the probability of his/her suffering from some disease $d \in \triangle(t) = \{0, 1, \ldots, D\}$ in period t where 'D' means 'death,' and $p_{iD} \geqq 0$ is the probability of person i's death caused by some disease(s) due to the accumulating food additives and agrochemicals in the body. The survival rate, $1-p_{iD}$, depends on the rate, p_{iD}, from food-related diseases and other causes(exogenous), as well as p_{i0} which is a probability of being healthy without any disease. Thus, we have $\sum_{d \in \triangle(t)} p_{id} = 1$. Since a probability varies according to what state a person is in, we need an assumption.

Assumption 5: For any $i \in \mathbf{N}$, $p_{id}(\cdot)$ is twice continuously differentiate, where p_{id} represents p_{iD}, p_{id}, and p_{i0}.

One of the problems in the lifelong 'food fight' is how to avoid an accumulation of persistant agrochemicals and food additives. Let r be a discount factor. Then we have person i's optimization problem to maximize his/her lifetime expected happiness function discounted at the rate r. In this paper we assume a fixed discount factor, but we can easily generalize it to a flexible age-dependent time preference. Ignoring the constraints, our issue is to maximize:

$$v_i\big(b_i(t)\big) = \int_0^{\infty} EH_i(t)e^{-rt}dt. \tag{51}$$

As for food pollutants, according to their Eco-Conscious Levels(E.C.L.) to be formulated below, there are two kinds of consumers: ignorant or unconscious risk takers, and conscious or informed risk averters. For ease of notation, let us omit the argument of time. Solving the above problem and rearranging terms, we have therefore

$$\sum_{d\in\triangle}\sum_{k\in\mathbf{K}_i}\int_0^\infty\left(\frac{\partial p_{id}}{\partial f_{ik}}\right)\left(\frac{\partial f_{ik}}{\partial Z_{ic}}\right)H_i\left\{\left(\frac{\partial H_i}{db_i}\right)\left(\frac{\partial b_i}{\partial f_{ik}}\right)\left(\frac{\partial f_{ik}}{\partial Z_{ic}}\right)\right\}^{-1}e^{-rt}dt$$
$$=\sum_{d\in\triangle}\sum_{k\in\mathbf{K}_i}\int_0^\infty\left(\frac{\partial p_{id}}{\partial f_{ik}}\right)\left(\frac{\partial f_{ik}}{\partial Z_{ic}}\right)\Omega_{ic}e^{-rt}dt=-1 \tag{52}$$

where

$$\Omega_{ic}\equiv H_i\sum_{k\in\mathbf{K}_i}\left\{\left(\frac{dH_i}{db_i}\right)\left(\frac{\partial b_i}{\partial f_{ik}}\right)\left(\frac{\partial f_{ik}}{\partial Z_{ic}}\right)\right\}^{-1}. \tag{53}$$

Remark 8: Ω_{ic} may be called individual $i's$ "a marginal willingness-to-pay for food safety or avoiding diseases from food contamination due to attribute c through his/her kth functioning." This concept was inspired by Drèze(1992). The sign of Ω_{ic} varies according to what category a characteristic belongs to. If, for example, c is an endotoxin, then $(\partial p_{id}/\partial f_{ik})(\partial f_{ik}/\partial Z_{ic})>0$, i. e., an increase in the probability of death due to an accumulation of the endotoxin, and $\Omega_{ic}<0$ is resulted. The same result applies to an additive like OPP or TBZ(frequently used for imported lemons, oranges, and grapefruits to remain fresh). While, $(\partial p_{id}/\partial f_{ik})(\partial f_{ik}/\partial Z_{ic})<0$ may be assumed for a nutritive element such as calcium, because an increasing nutritional intake could decrease the risks of many diseases, and $\Omega_{ic}>0$ follows. We may call a person with Eco-Conscious Level related to attribute c, if the above inequalities of Ω_{ic} are preserved, and vice versa. To achieve individual happiness maximization, Eq.(52) must be fulfilled, which means that consumers have to know the sign of each partial derivative in the equation. Hence, individuals with E. C. L. only can maximize their happiness.

Remark 9: This paper has dealt with individual optimizing behaviors of four economic agents in the economy: i. e., monopolistic agrochemical makers, competitive farms, food manufacturers, and consumers. No governmental regulation on gene-recombinant crops has not been analysed. Neither a dynamic analysis of the intertemporal negative effects of proliferated transgenic newcomer plants has not been treated here and will be postponed to the next occasion.[8]

APPENDIX

Figure 1 represents five vegetables, $x_1 \sim x_5$, e. g., soybean, corn, potato, tomato and canola in the q_{j1}–q_{j2} attribute space, where q_{j1}(q_{j2}, resp.) signifies, for example, vitamin A(calcium, resp.). In the new consumer theory, each good is representable by the half line from the origin, and the angle corresponds to the proportion of attributes' quantities possessed by that good. The kinky line is a budget line : each x_j, $j = 1, \ldots, 5$, signifies the maximal amount one can buy.

Figure 2 explains the income effect when a consumer prefers product x_3 to x_2, and x_1 is produced by using an agrochemical. Whereas, x_3 is an organically grown vegetable. In this chart q_{j1} is some agrochemical, and q_{j2} is some nutrient, i. e., crop x_2 has agrochemical as a deleterious attribute, while x_3 does not. When the income rises, the price of vegetable x_3 becomes relatively cheaper and entails a shift from an initial equilibrium point B where the consumer buys x_2 to a new point A' where he/she changes to buy x_3 instead of x_2. I and I' are indifference curves.

Figure 3 shows an addition of a new plant to an existing group of ordinary vegetables : $x_1 \sim x_3$, and x_G is a gene recombinant crop, say GR potato. q_{j3} is a new attribute representing an endotoxin created by the Bt bacterium. Hence, x_G contains as characteristics q_{j3} as well as q_{j1} and q_{j2}, so that three dimensional representation must be introduced. An attribute q_{j3} confers a crop insecticide resistance as a functioning in the sense of Sen(1985). Let x_2 be an ordinary potato : x_2 and x_G are related varieties. Consumers consider that x_G is a substitute for x_2 as a perfect alternative, i. e., they are indifferent in purchasing the commodity if both vegetables are apparently the same and equally priced ; otherwise, consumers buy the cheaper one. As can be easily seen, however, x_G contains less than a half of nutrients that x_2 involves. In this case, the hyperplane ABCD represents a budget constraint.

In **Figure 4** the tangent point α signifies a consumer's "virtual" choice of crops, x_2 and x_3, without any knowledge about the market situation around the GR crops. That person believes as if he or she buys some proportion of both x_2 and x_3. One thinks that he/she consumes attributes, q_{j1}^v and q_{j2}^v, where a superindex " v " means "virtual." While, another tangent point β shows a consumer's real choice of x_2 and x_G even if the individual does not know that x_G is a gene-recombinant crop with insecticide resistance. Actually, one is to consume the characteristics, q_{j1}^R, q_{j2}^R, and q_{j3}^R, where a superindex "R" signifies "real". The point is that this consumer does take a hazardous

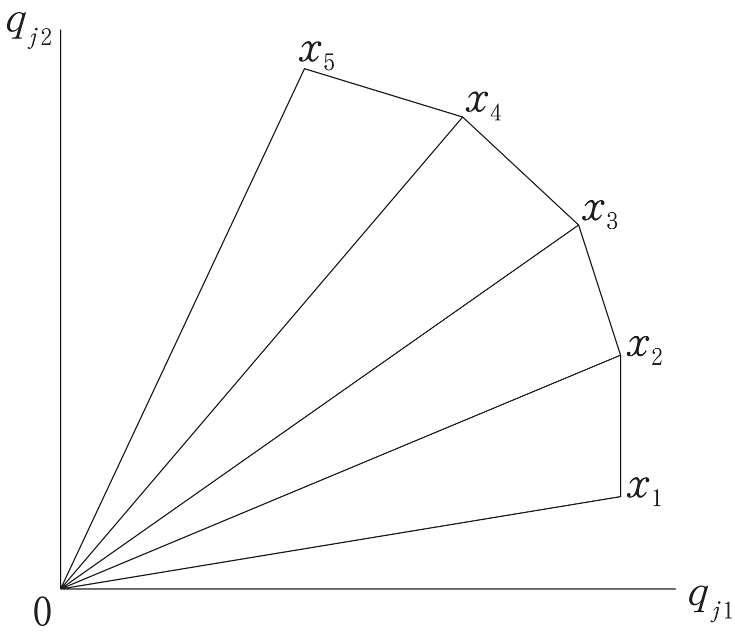

FIGURE 1 Representing Vegetables in the Attribute Space

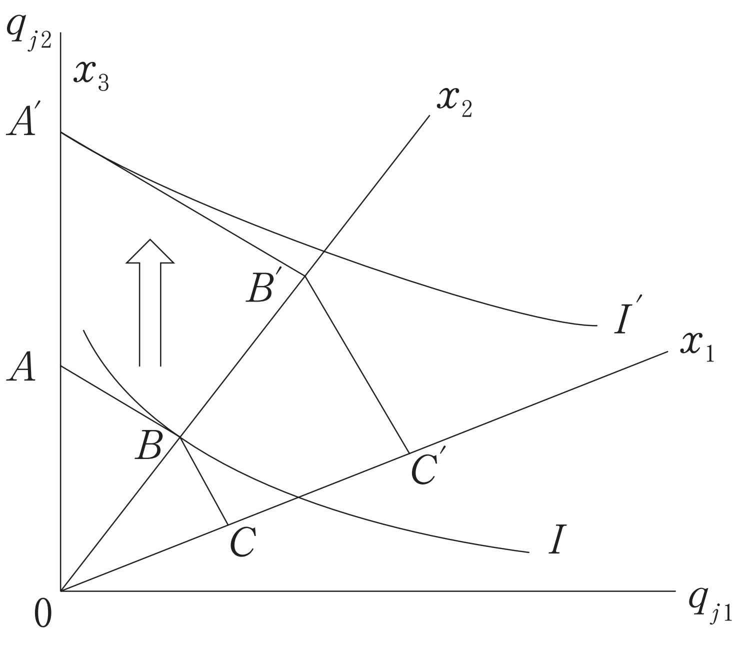

FIGURE 2 The Income Effect when a Consumer Prefers an Organically Grown Vegetable to a Crop using some Agrochemicals

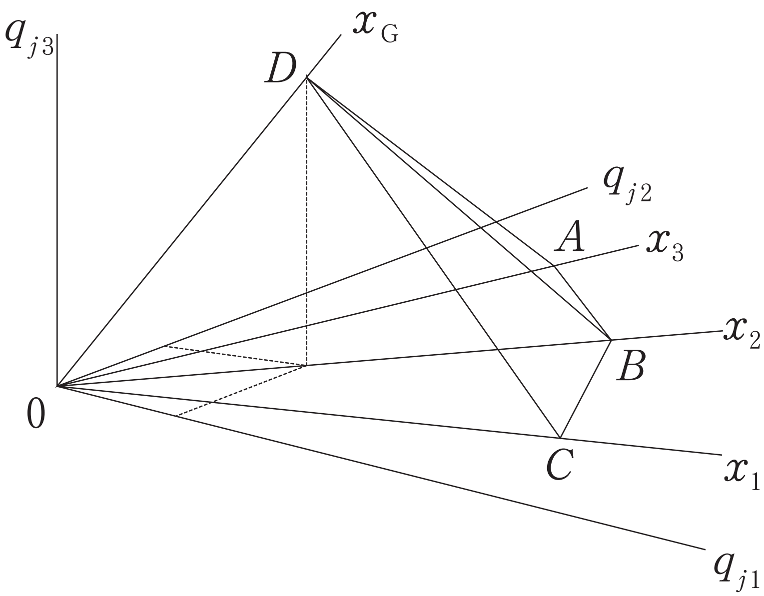

FIGURE 3 Introducing a Gene-Recombinant Crop to an Existing Group of Natural Plants

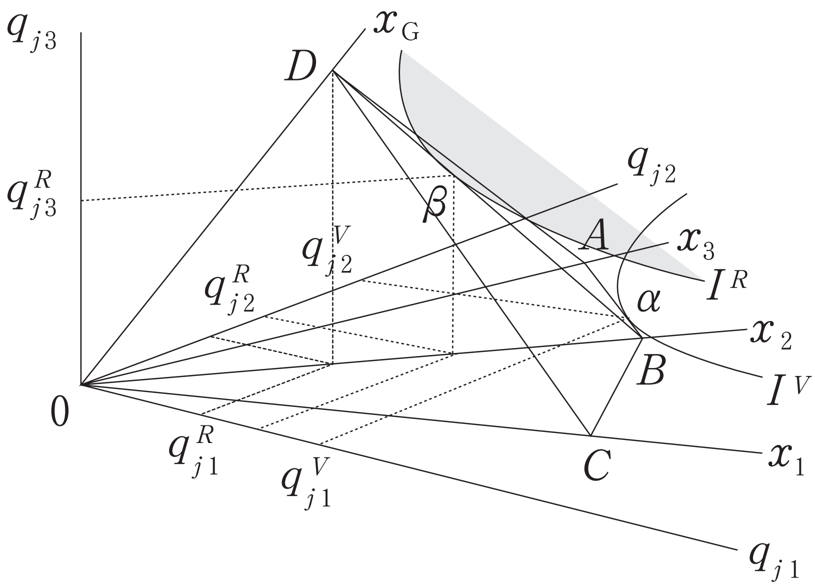

FIGURE 4 Attribute Analysis of Misperception in a Consumer's Choice of Plants under Uncertainty

attribute, q_{j3}^R, which is an endotoxin embedded in GR product, x_G. I^v touching to α is a virtual indifference curve, while I^R tangent to β is a real indifference surface with the shadow signifying that it is not a curve but a hyperplane in the three dimensional space.

† This is a revised version of the paper presented at the annual meeting of the Japanese Economic Association held at Ritsumeikan University, September 12, 1998; also at the annual meeting of the Society for the Environmental Economics and Policy Studies held at Keio University, September 27, 1998. Thanks go to Shinobu Ito for her helpful comments and discussion. Some revisions were made thereafter.

NOTES

1 See Colborn et al.(1996) and Wargo(1996) for this menace. See also Spash(1993) for the ethical issues related to the long-term environmental damages including engineering-biohazards. See also Commitee on Hormonally Active Agents in the Environment, National Research Council(1999).

2 Gorman's famous classic paper was written in 1956, however, it was finally published in 1980. To my knowledge, he was the first to use the term, 'characteristics' to represent ingredients of foods. The delay of the publication of Gorman's paper made well-known the Lancaster's works. See also Gorman and Myles(1987), and Blow et. al. (2008).

3 For example, it was $10 per acre that GM soybeen seeds using farms must pay to a multi-national agrochemical maker in America. This firm developed gene-recombinant soybeans, canolas, corns, potatoes, and their complementary weedicides. For soybeans named ROUND-UP READY SOYBEANS, there is a weed killer called ROUND-UP. There is also this complementarity for the canola. And as a result, the agrochemical maker can behave monopolistically. Its corn, and potato named NEW LEAF POTATO have insecticide resistance.

4 See Henry(1989) for the design of a tax-subsidy scheme which gives farms proper incentive not to use pesticides.

5 That tomato, which stays fresh for a significant amount of time, i. e., the tomato named FLAVR SAVR, was developed by an American maker via the 'anti-sense method' to artificially manipulate genetical activities. A Japanese brewery company, Kirin, also succeeded in developing this type of tomatoes. Moreover, this maker plays both roles of a GR seed developer and food maker to supply tomato juice made from GR tomatoes. There is also 'a method of particle bombardement' for genetic engineering of plants. This is a method via the use of a 'genetic gun' to shoot genes into the plants.

6 "Substantial Equivalence" insisted by the United States, some EU countries and the Ministry of Health and Welfare of Japan is far from equal to our genetical equivalence, because GR Crops have completely different genes which natural plants never possessed. It is clear that they are 'mutants.' Substantial Equivalence is the term made to protect international commercial benefits from the trade of gene-recombinant crops among the countries concerned. Notice that it is not for the sake of the consumers all over the world. See Pudue(2000), Redmem(2000) and Wesseler(2005).

7 Developers of GR seeds and insecticides, and the Ministry of Health and Welfare of Japan insisted that Bt bacteria are a sort of amino acids, and that there is no problem of safety. They never admitted that the bacteria creates an endotoxin confering insecticide resistance to plants. However, the Ministry advised to improve the safety test on the GM crops in Japan. See, for example, Mckenzie(1996) for insecticide resistance, Munro(1997) for the spread of resistance, and Laxminarayan(2001) for antibiotic resistance. See also BRAC et al.(2000), Huber et al.(1995), Jorgensen et al.(1996), and Committee on Food Chemicals Codex(1996).

8 Sato(1999) and (2005) treated dynamic analyses by using the method to formulate the MDP Procedures for optimally providing public goods. See also Sato(2009).

REFERENCES

BLOW, L., M. BROWNING and I. CRAWFORD, "Revealed Preference Analysis of Characteristics Models," *Review of Economic Studies*, 75, 371–389.

BRAC, R. and F. SEURET(2000), *Brave New Seeds : The Threat of GM Crops to Farmers*, Zed Books, London.

CARSON, R.(1962), *Silent Spring, Houghton Mifflin Company*, Boston.

COLBORN, T., D. DUMANOSKI and J. MYERS(1996), *Our Stolen Future : Are We Threatening Our Fertility, Intelligence, and Survival? – A Scientific Detective Story*, Dutton.

COMMITTEE ON FOOD CHEMICALS CODEX(1996) : *Food Chemicals Codex*, 4th Edition, National Academy Press, USA.

COMMITEE ON HORMONALLY ACTIVE AGENTS IN THE ENVIRONMENT, NATIONAL RESEARCH COUNCIL (1999), *Hormonally Active Agents in the Environment*, National Academy Press, USA.

COOPER, A.(2000), *Bitter Harvest : A Chef's Perspective on the Hidden Danger in the Foods We Eat and What You Can Do about it*, Routledge, London.

DRÉZE, J.(1992), "From the "Value of Life" to the Economics and Ethics of Population : the Path is Purely Methodological," *Recherches Economiques de Louvain*, 58, 551–567.

DRÉZE, J. and K. HAGEN(1978), "Choice of Product Quality : Equilibrium and Effici ency," *Econometrica*, 46, 493–513.

GORMAN, W.(1956/1980), "A Possible Procedure for Analyzing Quality Differentials in the Egg Market", *Review of Economic Studies*, 47, 843–856.

GORMAN, W. and G. Myles(1987), "Characteristics," in Eatrvell, J., M. MILGATE and P. Newman (eds.), *The New Palgrave : Dictionary of Economics*, Macmillan, London, 403–406.

HAGEN, K.(1975), "On the Optimality of the Competitive Market System in an Economy with Product Differentiation," *Swedish Journal of Economics*, 77, 443–458.

HENRY, C.(1989), "Polluter–Pays and Other Principles : Alleviating External Effects," in *Microeconomics for Public Policy : Helping the Invisible Hand*, Clarendon Press, Oxford, Chapter 2.

HUBER, J., M. NOTEBORN and H. KUIPER(1995), "Safety Evaluation of Transgenic Tomatoes Expressing Bt Endotoxin," *Report of a WHO Workshop* : 51–61.

JORGENSEN, R., T. HAUSER, T. MIKKELSEN and H. OSTERGARD(1996), "Transfer of Engineered Gene from Crop to Wild Plants," *Trends in Plants Science*, 1, 356–358.

LANCASTER, K.(1966), "A New Approach to Consumer Theory," *Journal of Political Economy*, 74, 132–157; reprinted in LANCASTER(1991), Chapter 2.

LANCASTER, K.(1971), *Consumer Theory*: A New Approach, Columbia U. P., New York.

LANCASTER, K.(1991), *Modern Consumer Theory*: Edward Elgar, London.

LAXMINARAYAN, R.(2001), "Economics of Antibiotic Resistance: A Theory of Optimal Use," *Journal of Environmental Economics and Management*, 42, 183–206.

MCKENZIE, J.(1996), *Ecological and Evolutionary Aspects of Insecticide Resistance*, Academic Press, U.S.A.

MUNRO, A.(1997), "Economics and Biological Evolution," *Environmental and Resource Economics*, 9, 429–449.

PURDUE, D.(2000), *Anti-genetiX: The Emergence of the Anti-GM Movement*, Ashgate Studies in Environmental Policy and Practice, Ashgate Pub. Ltd., London.

REDMAN, N.(2000), *Food Safety: A Reference Handbook*, ABC-Clio, London.

SATO, K.(1998), "Weil-Being and an Optimal Human Diet as a Composition of Characteristics à la Gorman-Lancaster," presented at the spring meeting of the Japanese Economic Association held at Aoyama-Gakuin University, June 13, 1998; also delivered at the TCER Microworkshop held at The University of Tokyo, June 30, 1998.

SATO, K.(1999), "Optimizing the Global Atmosphere as a Composite of Gaseous Attributes: A Planning and Capability Approach," delivered at the annual meeting of the Society for Environmental Economics and Policy Studies held at Ritsumeikan University, September 25, 1999.

SATO, K.(2005), "The Hedonic MDP Procedures for Quality Attributes: Optimality and Incentives," presented at the autumn meeting of the Japanese Economic Association held at The University of Tokyo, October 17, 1999.

SATO, K.(2008), "Fraudulant Disguise of Latent Attributes of Products," presented at the Autumn Meeting of the Japanese Economic Association held at Kinki University, September 14.

SATO, K.(2009). "Locally Strategy Proof Planning Procedures as Algorithms and Game Forms," *RIMS Kôkyûroku*, 1654, 29–55, Kyoto University.

SEN, A.(1985), *Commodities and Capabilities*, Elsevier Science Publishers B. V., Amsterdam.

SEN, A.(1992), *Inequalities Revisited*, Clarendon Press, Oxford.

SPASH, C.(1993), "Economics, Ethics, and Long-Term Environmental Damages," *Environmental Ethics*, 15, 117–132.

WARGO, J.(1996), *Our Children's Toxic Legacy : How Science and Law Fail to Protect Us from Pesticides*, 2nd ed., Yale University Press.

WESSELER, H.(2005), *Environmental Costs and Benefits of Transgenic Crops*, Springer GW, Berlin.