Well-Being and an Optimal Human Diet as a Composition of Characteristics à la Gorman-Lancaster

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ABSTRACT: This paper characterizes *nutritional optimal individual die sts* as a composition of *Gorman-Lancasterian characteristics* embodied in foods. Hazardous attributes must be also considered, since they could be injurious to individuals' proper health. *Amartya Sen's Capability Approach* is taken to define personal health because subjective features such as metabolism and physiology differ from person to person. It is verified that any consumer maximizes his or her *Happiness Function* by ingesting prerequisite micronutrients as characteristics in an optimal composition. This assures the most healthy state in a person's *well-being*: i. e., one of the highest values in the *capability set* in the sense of Sen.

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Key Words: Well-Being, Gorman-Lancasterian Characteristics, Optimal Human Diets, Nutritionally Optimal Individual Diets, Sen's Capability, Functionings, and Happiness Function.

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Better a meal of vegetables
where there is love than
a fattened calf with hatred.
OLD TESTAMENT
PROVERBS 15:17

1. Introduction

1. 1. An individual's well-being may not necessarily require health, but we could say that better health assures better existence. Health in this sense, enlarges the ultimate potential of a person. Individual wellness can be valued by his/her own valuation function which is defined by *capabilities* in terms described by Amartya Sen(1985). This capability approach challenges both utilitarianism and Rawls' theory of justice as fairness[1].

Nutritional Fitness, the idea that health should be supported by nutrition, has become a credo in the nineties in the United States. We focus upon the nutritional aspects of health, putting aside other factors such as getting adequate amounts of sleep, maintaining exercise[2].

Recently, goods or commodities are not necessarily "good" as they were considered for a long time in standard microeconomic theory. For example, foods are in most cases "polluted" by many additives and agricultural chemicals such as pesticides, herbicides, etc. Unfortunately, because consumers cannot observe for themselves the very presence of these compounds in foods, this could entail possible harmful effects upon their health in their lifetime. Health problems may occur due to discrepancies between distinguishing good taste from a good diet[3].

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1) His "capability egalitarianism" is a challenge to both "resource egalitarianism" and "utility egalitarianism." See Sen(1985), (1987) and (1992) for their contrasts and differences. See also Sugden(1993), Fleurbaey(1995) and (1996).

2) See Behrman and Deolaliker(1988) for a detailed discussion about the relationship between health and nutrition in a more generic context than presented here. For an orthodox treatment of the demand for health, see Grossman(1972). See *Earl Mindell's Vitamin Bible*, Warner Books, New York, 1991, for the concept of nutritional fitness.

3) For example, many people in Japan eat foods which are unhealthy such as those with food additives and too much fat. Where do these inconsistencies come from? Economic prosperity, ironically, has driven our diets to a condition which is far from optimal. Let me put a statistic here on illness. Today in the United States, 85% of the most common deaths are due to coronary heart disease, stroke, etc. In Japan, the most common forms of death are cancers which are strongly related to what and how

The classic issue on diet was first treated in the economic literature by Jerome Cornfield in a unpublished note in 1941. It was solved without making use of linear programming in Stigler's(1945) seminal work : "The Cost of Subsistence." Dantzig and Laderman worked out this problem in a linear programming framework in their unpublished peper. A generic model was presented by Dorfman, Samuelson, and Solow (1958, Ch. 2). Gale(1960), Gass(1964), and Intriligator(1971) also used diet as a problem in linear programming. All of them considered its nutritional aspect and gave a definition of the "optimal diet" as *a minimum cost diet*. Importantly, their analysis was not necessarily directed to the *human diet*, but rather to the best mixture of individual agricultural products of mixed feedstuff for domestic animals such as dairy cows [See Mills(1984, Tables 1.5 and 1.6)]. Furthermore, none of them took the individual's different traits such as metabolism and physiology into consideration[4]. What defines us as individuals, as required by molecular biology, is that nobody is the same at the molecular level. Thus, "a nutritionally optimal individual diet" is a more accurate phrase than a nutritionally optimal human diet, or rather, we may say that the latter involves the former.

1. 2. The *New Consumer Theory* initiated by Gorman(1956/1980)[5] and followed by Lancaster(1966) was generically analyzed by Drèze and Hagen(1978). Fundamental theorems of welfare economics state that every competitive equilibrium is Pareto optimal that holds for each quantity of goods, but not for each characteristic or attribute with which goods are composed. This observation was proven by Hagen(1975) in his new consumer theoretical framework. Drèze and Hagen subsequently developed a model

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to eat in everyday life. Many of us, as "passive consumers," are thus faced with hazardous choices in our daily consumption of foods.

4) In a different context, Yaari and Bar-Hillel(1984) considered differences in needs, tastes, and beliefs to evaluate the performance of several distribution mechanisms. When they showed examples in which avocados and grapefruit were to be divided between two people, they took their metabolic capacity into considerations, and made fruitful results on just division.

5) Gorman's 'hidden', but famous classic paper was written in 1956 and finally published in 1980. To my knowledge, he was the first to use the term, "characteristics" to represent ingredients of foods. See Deaton and Muellbauer(1980) for this line of research. Rowcroft(1994) gave a characteristics model with some realistic examples. For other interesting approaches to the new consumer theory, see, for example, Sandmo (1973), Stigler and Becker(1977), Jones(1988), and Stokey(1988). See also Mason(1998) for its recent description.

using the new consumer theory, drove necessary conditions (or conditions for Pareto stationary points) for optimal product quality in a general equilibrium system, and verified a simultaneous establishment of quantitative and qualitative efficiency. They also proved that producers maximizing their profits have an incentive to select the most desirable combination of characteristics which maximizes consumers' utility. That is, Drèze and Hagen demonstrated 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.

This paper seeks to characterize *nutritionally optimal individual diets* as already confirmed by modern dietetics, resulting in an optimal composition of nutritive elements as attributes compounded in foods. More precisely, modern dietetics has already established an optimal fat intake rate for each race, as well as seven prerequisite nutritive elements as follows: vitamin A (beta carotene), vitamin B_6, folic acid, pantothenic acid, calcium, iron, and magnesium. For example, lettuce has all these essential nutrients. Modern dietetics also shows 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[6]. For example, the optimal rate between calcium and phosphorus is 1 : 1 in the blood. In economic terms, all nutritive elements can be considered as *Gorman-Lancasterian attributes* or *characteristics* to be explained below, which can assure healthy living conditions for people. We show that each consumer can maximize his/her 'happiness function' by taking prerequisite nutrients in an optimal composition to establish individual maximum good health or *Individual Super Health* to be defined below. For this purpose, we extend and modify the analyses of Drèze and Hagen whose analysis we will be using as a basis for our discussion.

One may consider two types of consumers: those who are prudent, and those who ignore the possible risks in their everyday consumption of foods. Therefore, it is important to roughly distinguish these two types of consumers in a world without

6) Dr. Roger Williams developed ingenious charts of nutrients contained in each food. See Williams' books: *Nutrition in a Nutshell*, Dolphin Books, 1962, *Nutrition Against Disease*, Pittman, 1971, and *The Wonderful World Within You*, Bantam Books, 1977. For some recent results of modern dietetics, see also D. Steinman's *Diet for a Poisoned Planet: How to Choose Safe Foods for You and Your Family*, Harmony Books, New York, 1990.

food safety precautions. To put it differently, there are those who are unconscious and those who are well-informed about numerous hazards related to foods. If we wrote a paper in the seventies, we could confine ourselves to the characteristics which 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. For example, many food additives may become cancer initiators or promoters inside the body and 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 von Neumann-Morgenstern theoretical framework. That is, foods which have harmful effects on maximization should be attended. This problem was treated in Sato(1998).

The *objective* facets of the food-diet problem also involves *subjective* considerations, since eating and digestion are very personal activities. 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. 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 ingesting prerequisite nutrients as attributes, thus composing an optimal human diet which establishes one of the maximal elements in his/her *capability set* in the sense of Sen, to be defined below.

1. 3. Let us combine good "characteristics" of the above strains of research to achieve efficiency conditions for the products compounded of attributes, some of which may be harmful ones. To accomplish this, we adopt an analytical framework involving firms 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. Also deduced are the necessary conditions for producers to maximize their profits by providing Pareto optimal food quality attributes.

This paper proceeds as follows. Section 2 introduces Sen's capability approach in the Gorman/Lancasterian characteristics model and discusses the valuation of health as related to the well-being. The necessary and sufficient conditions for nutritionally optimal human diets as a composition of attributes embodied in food products are derived in Section 3. Section 4 discusses the model of an economy with foods that have risky attributes such as agricultural chemicals and food additives. Section 5 concludes the paper. Finally, four Appendice follow.

2. Sen's Capability Approach to the Characteristics Theory

2. 1. Goods and Characteristics

As Sen referred to the Gorman-Lancasterian Characteristics Model in his notable book(1985, Ch. 2), we attempt to combine their theories in this section by extending the Drèze and Hagen's(1978) analysis.

Let there be N consumers indexed by $i \in \boldsymbol{N} = \{1,\ldots, N\}$: the set of individuals. We consider goods which are composed of C characteristics indexed by $c \in \boldsymbol{C} = \{1,\ldots, C\}$: the set of attributes. Two terms, "attributes" and "characteristics", are used interchangeably throughout this paper. Denote q_{jc} as an amount of attribute c embodied in one unit of good j, and q as the $\boldsymbol{J} \times \boldsymbol{C}$ (variable) "technology matrix" with typical element, q_{jc}. x_{ij} is person i's consumption of good j, and $x_i = (x_{i1}, \ldots, x_{iJ})$ is his or her consumption vector. Let $\boldsymbol{J} = \{1,\ldots, J\}$ be the set of goods. Each consumer has a convex consumption set M_i in the space of attributes and the numéraire. The initial resources of individual i are defined by a nonnegative vector $\omega_i = (\omega_{i0}, \omega_{i1}, \ldots, \omega_{iC})$, where $\omega_{i0} > 0$ is an amount of the numéraire characteristic and $\omega_{ic} \geqq 0, \forall c \in \boldsymbol{C}$, is the cth attribute's endowment initially given to an individual i. The sale or purchase of 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 j', hence other attributes are measured per unit of characteristic j'. We impose $q_{jj'} = 1$ for size normalization. The index j' differs among goods.

Let labor, z_{i0}, be individual j's *numéraire characteristic* that he/she possesses, by which every attribute is utilized. This choice may be justified by the fact that labor is generated by the human body which in turn is composed of many characteristics — macronutrients and micronutrients — contained in the foods and metabolized in the human bodies.

Amounts of each characteristic embodied in goods consumed by person i is given by

$$z_i = (z_{i0}, z_{i1}, \ldots, z_{iC}) = \omega_i + (x_{i0}, x_i' q')' \tag{1}$$

where

$$z_{ic} = \sum_{j=1}^{J} x_{ij} q_{jc}. \tag{2}$$

Equation (2) may be interpreted as *nominal objective characteristics availability function*, which converts commodities into attributes, q_{ic}, $\forall j \in \boldsymbol{J}$, $\forall c \in \boldsymbol{C}$, can be regarded as parameters which are objective and common to all consumers, i.e., they have a public-good property. Only producers can vary q_{ic} by their production technologies, but consumers cannot. They can change their consumption of attributes by varing the amount of x_{ij}, $\forall j \in \boldsymbol{J}$.

Let there be J producers, indexed also by $j \in \boldsymbol{J} = \{1, \ldots, J\}$: the set of producers. Each firm j produces a good j by using an input x_{j0} with

$$\sum_{j=1}^{J} x_{j0} + \sum_{i=1}^{N} z_{i0} \leqq \sum_{i=1}^{N} \omega_{i0}. \tag{3}$$

The production function is represented by $\phi_j(y_j) \leqq 0$, $y_j \geqq 0$, where

$$y_j = (x_{j0}, x_j, q_{j1}, \ldots, q_{jC}) \tag{4}$$

in its convex production set Y_j, with $x_j \geqq 0$, and $q_{jc} \geqq 0$, $\forall j = 1, \ldots, \boldsymbol{J}$, $\forall c = 1, \ldots, \boldsymbol{C}$. The producers sell their product x_j at the price p_j, and a price of x_{j0} is normalized to be unity.

Here we need to make an assumption.

ASSUMPTION 1: For any $j \in \boldsymbol{J}$, ϕ_j is convex and twice continuously differentiable, with $\partial \phi_j / \partial x_{j0} < 0$, $\partial \phi_j / \partial x_j > 0$, and $\partial \phi_j / \partial q_{jc} > 0$, $\forall c \in \boldsymbol{C}$, $c \neq j'$. Furthermore, $x_j > 0$ implies $x_{j0} > 0$, and $\forall \Lambda \in \mathbf{R}_+$, $\{y_j \mid \phi_j(y_j) \leqq 0, \ x_{j0} \leqq \Lambda\}$ is compact.

2. 2. Beings and Functionings

Diverse beings are attained by individual functionings with which consumers use commodities available to them. A person does not necessarily possess all of the goods he or she uses. The individual must have access only to the commodities which are necessary. Hence, referring to x_{ij}, this does not imply that the goods x_{ij} are possessed by person i, but rather just available to i. A person's state of being is understood as a vector of functionings. The set of feasible vectors of functionings for any person is the person's *capability set*, i.e., opportunities to achieve beings that he or she wishes to have.

Needless to say, functionings of the digestive organs such as stomach and intestines are very important to keep proper health. As it is clearly exemplified below, many functionings can be considered as a consequence of a person's health. It seems therefore that there is an order among functionings. This is because health as one of the functionings *à la* Sen, must result from other functionings such as knowing methods or recipes of cooking, maintaining regular exercise, getting adequate amounts of sleep, and establishing healthy relationships with others, which all contribute to a person's well-being[7].

An individual can experience happiness even if he or she is not in perfect health. For example, some of his/her functionings may not function well due to a medical illness or a physical disability. The sets of health and happiness do not always coincide, but they may intersect. Consequently, a person may not necessarily be happy even if he or she is in a perfect condition, and vice versa. Before rushing into our diet-consumer theory results, let us introduce some basic concepts originally due to Sen(1985).

A person i's beings generated by utilizing a K_i-tuple of his/her functionings, f_{ik}, $k = 1, \ldots, K_i$, may be represented by a vector

$$b_i = (f_{i1}(z_i), \ldots, f_{iK_i}(z_i)),\ \forall f_i \in \boldsymbol{F}_i \tag{5}$$

where f_i is person i's vector of functionings and $\boldsymbol{F}_i$ is his/her set of functionings vectors. To paraphrase Eq.(5), let me give an example. When a person is eating, he or she utilizes simultaneously several functionings such as hands, fingers, mouth, tongue, nose, eyes, teeth, etc. The maximum number of functionings, K_i, varies according to an individual. Let $\boldsymbol{K}_i$ be person i's set of functionings.

ASSUMPTION 2 : For any $i \in \boldsymbol{N}$, f_{ik} is strictly quasi-concave and twice continuously differentiable, with $\partial f_{ik} / \partial z_{i0} \neq 0, \forall f_{ik} \in \boldsymbol{K}_i$.

Remark 1 : We consider that an infinitesimal change in the numéraire attribute z_{i0} can vary person i's functionings. For example, maintaining regular exercise could strengthen

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7) Sen(1992, p. 38) wrote that "living may be seen as consisting of a set of interrelated functionings, consisting of beings and doings." Examples of functionings as aspects of living are as follows: being adequately nourished; acting freely; having friends; having self-respect; avoiding premature mortality; having choices; being happy(or experiencing pleasure); appearing in public without shame; having adequate shelter; participating in a community; being in good health; avoiding escapable morbidity, etc.

physical functionings such as the system of circulation. The sign of $\partial f_{ik} / \partial z_{ic}$ depends upon what characteristic c is, i.e., it can take a sign $\{+, 0, -\}$ according to c which is good (irrelevant, bad, respectively) for person i's health. If c is some food additive or some agricultural chemical, then the sign is minus. An introduction of risky attributes is postponed to Section 4 [See also Sato(1998)].

Limiting our analysis to an individual's aspect of living, supported only by nutrition utilized by functionings, we have a person i's *health* as a functioning which includes digestive power and dental quality as functionings. If a person can eat foods with healthy teeth, then his or her health may be increased. Good mastication is another important functioning, which could prevent cancers[8, 9].

Equation (5) assumes that person i's beings depend only upon his/her capability of utilizing goods. We consider in this paper that the set of functionings includes cooking techniques and consumption technologies, since being a good cook may also be an important functioning.

Next, in order to prepare healthy dishes, a person must have time. Archibald and Eaton(1989) explained two sorts of costs: *transaction costs and costs due to the combining technologies*. In our context, the former means that buying more various types of foods rather than a greater quantity of one type of food costs more. The latter is related to the costs of time and effort, i. e., you have to spend more time

8) Moreover, nutritional intake can differ according to how foods are cooked. For example, DHA and EPA intakes from tuna can vary. If it is eaten raw, 100% of DHA of the corresponding amount of the tuna is achieved, whereas if the tuna is boiled or baked, 20% of DHA is lost, and subsequently, 50% is depleted when fried. Hence, the method of cooking is very important, since the amount of nutrients absorbable will vary with each cooking method [See, for example, Table 5 in Rand et al.(1987), which shows "selected nutrient composition of cruciferous vegetables by different cooking methods (amount per 100g)"].

9) The use of oils is also important to prepare foods, since the composition of the fats differs among olives, flaxseeds, safflowers, corns, colzas, canolas and sesame. The fats such as ω-3, ω-6, and ω-9 are embodied in different proportions in these oils, and these differences influence the human health. Dietitians have verified that the rate between ω-3 and ω-6 is 1 in the brain of healthy babies, so that it is considered to be an optimal rate. In reality, however, the rate is far from the optimal rate. ω-6 has been overrunning ω-3 in the meals of many people in Japan, which may be one of the causes of about 271,000 deaths of cancer in 1996. Daily intakes recently recommended in *Food, Nutrition and the Prevention of Cancer: a Global Perspective*(1997), are no more than 6g/day for salt and 80g/day for lean meat to prevent cancers. It is recommended to eat 400g~800g/day of fruits and vegetables whose nutrients play very important roles to combat cancers. The report insists that 30~40% of cancers are avoidable by eating foods that it recommends.

in the kitchen to cook more foods and combine more ingredients into dishes. It would be more reasonable to make the q_{jc} functions of both the physical nutrition content of the various foods and of time taken in preparing foods to be cooked. In order to complete our theory, we have to involve an analysis as in the theory of time allocation. [See Becker(1965), and Stigler and Becker(1977). See also Deaton and Muellbauer(1980).]

Labor which we may identify with time has been already included in our theory. As ω_{i0} is a labor or time initially endowed to person i, and it may be free time that individual i can dispose, e. g., to shop, prepare meals, eat foods, sleep, and maintain regular exercise. These activities are also closely related to person i's happiness through his/her functionings by employing z_{i0}. Note that z_{i0} is used as a numéraire characteristic to utilize other characteristics.

2. 3. 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. Thus, we have

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

In order to deepen his analysis to obtain our desired results, we need the differentiability assumption. It is natural to consider that an infinitesimal change in any functioning of a person can vary his/her happiness, so that we impose the following:

ASSUMPTION 3: *For any $i \in \boldsymbol{N}$, H_i is strictly quasi-concave and twice continuously differentiable, with $\partial H_i / \partial f_{ik} \neq 0$, $\forall f_{ik} \in \boldsymbol{K}_i$.*

Here we introduce a new concept. Denote a characteristic c's marginal contribution to a person's marginal happiness through his/her functionings in terms of the numéraire characteristic z_{i0} as:

$$\pi_{ic} = \frac{\sum_k (\partial H_i/\partial f_{ik})(\partial f_{ik}/\partial z_{ic})}{\sum_k (\partial H_i/\partial f_{ik})(\partial f_{ik}/\partial z_{i0})}, \ \ \forall i \in \boldsymbol{N}, \ \ \forall c \in \boldsymbol{C}. \tag{7}$$

π_{ic} is individual *i's hedonic price* of an attribute c in terms of his/her functionings. It can be interpreted also as a '*hedonic marginal willingness to pay*(HMW),' which corresponds to a "marginal rate of substitution(MRS) between an attribute c and the numéraire characteristic z_{i0}" 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 Drēze and Hagen(1978), because our concept involves the functionings *ã la* Sen. Hence, we have had to replace a happiness function for a utility function to emphasize on the differences. π_{ic} also represents any nutritive element as an attribute.

The Gorman-Lancasterian characteristics theory is most suitable to analyze foods which are perfectly divisible and decomposable into nutritive elements as characteristics. We explicitly consider foods whose micronutrients are regarded as attributes, $c=1, \ldots, C-3 \in \boldsymbol{C}$. Let calorie, cholesterol, and dietary fiber be indexed respectively by $C-2$, $C-1$, C. These are not micronutrients, but contained in foods. Let $\boldsymbol{I}=\{C-2, C-1, C\}$ be the set of ingredients other than micronutrients.

Equation(2) 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. Eq.(2) can be interpreted as a *nominal objective nutrient availability* in our food context. Each person's metabolism and physiology differ, so we must introduce *substantial personal nutrient availability* function represented by Eq.(5).

Note that any individual cannot necessarily choose his/her highest value of H_i, "since maximizing one's own well-being may not be the only motive for choice," as was written in Sen(1985, p. 14). However, one of our issues is that if the maximal element value H_i^* is chosen, then what is the composition of nutritions as characteristics embodied in foods, which corresponds to the value with the highest ranking, and assures the nutritionally optimal individual diet, z_i^*? We can say that our issue is to find an *individually optimal nutrients mix*, z_i^* such that $z_i^* = \underset{x_i}{argmax}\ H_i(f_{i1}(Z_i^*), \ldots, f_{ik}(Z_i^*))$.

One may interpret z_i as a '*Health Level Index*,' since z_i, *ceteris paribus*, corresponds to some health level. f_{ik} is a continuous function of nutritional 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 a means that permits a person to have 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."

Whether a person considers a commodity as good, irrelevant, or bad to his/her functionings is verified by the sign of $\sum_c \pi_{ij}$ for each food j. Whether a food is socially accepted or not may also be examined by summing the value as $\sum_i \sum_c \pi_{ic} x_{ij}$ for each food j. Thus, we can show below the necessary conditions for nutritionally optimal individual diets in terms of nutrients as characteristics. Apart from the Drēze and Hagen's analysis, we must add 'dietetic constraints' to confirm balanced nutritional intakes and to maximize a person's happiness function, which depends upon his/her functionings as required by modern dietetics. The next section will show the results.

3. Optimal Human Diet As a Composition of Characteristics

3. 1. What is an 'Optimal Human Diet'?

Earl Mindell, a dietitian, tells us that there are six important nutrients such as macronutrients(carbohydrates, proteins made up of amino acids, fats), micronutrients (minerals and vitamins), and water[10]. These absorbable components of foods, i.e., attributes or characteristics in our terminology, are necessary to achieve optimal health. The macronutrients provide energy only when there are sufficient micronutrients to release them. Both nutritive elements are necessary for proper health, although each amount needed is vastly different. This section focuses upon micronutrients as good attributes.

Moreover, there is a very interesting description in Mindell's book(op. cit. pp.100-101) : "In order for the body to effectively use and synthesize protein, all the essential amino acids must be present and *in the proper proportions*. Even the temporary absence of a single essential amino acid can adversely affect protein synthesis. In fact, whatever essential amino acid is low or missing will *proportionately* reduce the effectiveness of all others." The expressions that I made in italics are reminiscent of a concept of economics, namely, *complements* in the consumer demand theory. As an application of an economic term, Huang(1996) presented some numerical simulations based on real data on foods, and drove nutrient elasticities by using a complete food demand system.

An *excess demand* of protein of more than 100g/day deprives the human body of some calcium: an average intake by Americans is 102g/day. There is a negative relationship among minerals, as an excess of one mineral entails a deficiency of the other. For example, an excess intake of phosphorus results in a lack of calcium, and too much calcium entails in a lack of magnesium and zinc. Almost all nutrients work as

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10) See footnote 2.

team players. Thus, no nutrient is *dominated* by any other nutrient, according to Lancaster(1991). There is also a strict relationship among the essential eighteen minerals.

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 vector from the origin. Calcium(*Ca*) : Phosphorus(*P*)=1:1 must be kept in the blood, so you should take these prerequisite nutrients by eating foods in this optimal proportion, hence, $tan\,\delta_{cc'}=1$ for *Ca*(*c*) and *P*(*c*′). 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 introduce its formal representation as:

CONDITION **ICOL** (*Individual Chain of Life*): $R_{ic}=R_{ic'}\,tan\,\delta_{cc'}\,,\ \forall c,\ c' \in \boldsymbol{C}.$ (8)

Remark 2: Both R_{ic} and $R_{ic'}$ are values that are given, for example, by the Recommended Dietary Allowances(RDA) in the U. S., where one can easily choose foods by checking the "Nutrition Facts" that are attached on the food products[11, 12].

Here we must modify a concept of "distance" introduced by Archibald and Eaton(1989) to distinguish any two bundles of goods having different characteristics. In our context, it reads as follows:

DEFINITION 1. *Individual Nutritional Distance*(*IND*) is given by

$$d_i = d_i(z_i^*,\ z_i) \tag{9}$$

11) For example, 15mg/day is a recommended intake for *Zn*, 15mg/day for *Fe*, 5000IU/day for Vitamin *A*, 60mg/day for Vitamin *C*, etc. Hence, the Condition *ICOL* applies to all pairs of nutrients and fats named ω-3, ω-6, and ω-9. 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. Recommended nutritional intake can differ according to personal features: age, sex, race, fitness level, etc. [See, for example, Guthrie(1996) for this point.] Recommended daily calcium and phosphorus intake is 1000mg/day for adults and 1200mg/day for children/adolescents aged from eleven to eighteen as well as for pregnant and nursing women. Moreover, 800~1000mg of calcium is needed daily for the elderly on account of weakened digestive and absorption powers. See Appendix 2 for the daily value of other ingredients.

12) Archibald(1980), and Archibald and Eaton(1989) introduced this tangent representation in the characteristics theory. They used it by showing figures in their two applications to location and monopolistic competition theories.

where $z_i{}^*$ and z_i are *consumer i's optimal individual nutrients mix, and his/her currently prefered nutrients mix without any knowledge of modern dietetics,* respectively. Different from Archibald and Eaton(1989), d_i is a norm and a metric which measure the distance between $z_i{}^*$ and z_i.

Thus, we have another definitions as follows:

DEFINITION 2. *Individual Super Health(ISH)* is not only just a healthy state, but also combats diseases, and even slows the process of aging. More precisely, ISH is attained if IND is zero, i. e.,

$$z_i{}^* = z_i \iff d_i(z_i{}^*, z_i) = 0. \tag{10}$$

DEFINITION 3. *A Nutritionally Optimal Individual Diet(NOID)* is a diet which satisfies *CONDITION* **ICOL.** The optimal rates among micronutritions composing the individual chain of life, assuring the highest health level for each person, viz., his/her *Individual Super Health,* which is needed for successful aging.

Remark 3: Notice that these three definitions are of course 'constrained' because anyone has to maximize his/her happiness function under the constraints of personal features such as metabolism and physiology, as well as time and money. Of course, NOID is one of the necessary conditions for attaining ISH, putting aside other factors contributing to proper health. "Super Health" is also a term advocated by Roger Williams.

3. 2. Optimizations by Dietetically Well-Informed Consumers Aiming at Individual Super Health and Profit Maximizing Producers

Let us assume hereafter that consumers are dietetically well-informed and that they have an incentive to consume an optimal human diet in order to aim at Individual Super Health, defined above. Each consumer has to solve his/her optimization problem as follows. The maximand we have chosen is the *'daily* happiness function', since some nutrients such as Vitamin B complex are water soluble and thus cannot be reserved for the next day, one must take them everyday, preferably by eating natural foods themselves.

$$Max \quad H_i = H_i(b_i) \tag{11}$$

$$s.\ t.\quad b_i = (f_{i1}(z_i),\ldots, f_{iK_i}(z_i)) \in \boldsymbol{B}_i(\boldsymbol{X}_i), \forall f_i \in \boldsymbol{F}_i \tag{12}$$

$$z_{ic} = \sum_{j=1}^{J} x_{ij} q_{jc'},\ \forall c \in \boldsymbol{C} \tag{13}$$

$$z_{ic} = R_{ic'}\ tan\ \delta_{cc'},\ \forall c' \in \boldsymbol{C} \tag{14}$$

$$z_{ic} = R_{ic'},\ \forall c \in \boldsymbol{I} \tag{15}$$

$$\sum_{j=1}^{J} p_j x_{ij} = z_{i0} \tag{16}$$

$$x_{ij} \geqq 0,\ \forall j \in \boldsymbol{J}. \tag{17}$$

where $B_i(X_i)$ is an individual i's capability set. See APPENDIX 1 for its explanation.

Thus, we can assuredly state the characterization result.

PROPOSITION 1 : *Nutritionally Optimal Individual Diets as a composition of Gorman-Lancasterian attributes are characterized by the conditions:*

$$\sum_{c=1}^{C} \pi_{ic} q_{jc} \leqq p_j,\ \Big(\sum_{c=1}^{C} \pi_{ic} q_{jc} - p_j\Big) x_{ij} = 0,\ \ \forall j \in \boldsymbol{J},\ c \neq j' \tag{18}$$

$$b_i = (f_{i1}(z_i),\ldots, f_{iK_i}(z_i)) \in \boldsymbol{B}_i(\boldsymbol{X}_i),\ \forall f_i \in \boldsymbol{F}_i \tag{19}$$

$$z_{ic} = \sum_{j=1}^{J} x_{ij} q_{jc},\ \ \forall c \in \boldsymbol{C} \tag{20}$$

$$z_{ic} = R_{ic'}\ tan\,\delta_{cc'},\ \ \forall c,\ c' \in \boldsymbol{C} \tag{21}$$

$$z_{ic} = R_{ic,}\ \forall c \in \boldsymbol{I} \tag{22}$$

$$\sum_{j=1}^{J} p_j x_{ij} = z_{i0} \tag{23}$$

$$x_{ij} \geqq 0,\ \ \forall j \in \boldsymbol{J}. \tag{24}$$

Remark 4: (i) p_j is the price of food j. Eq. (23) is person i's budget constraint, since a wage rate or the price of numéraire is normalized to be unity. Proofs follow from the Kuhn-Tucker Conditions for the above optimization problems with special constraints (21) and (22) required by modern dietetics. In **PROPOSITION 1**, these are not only necessary but also sufficient conditions from the assumptions on the functions. In the above equations, π_{ic} signifies a *shadow price* of an ingredient as an attribute acquired by i's labor through his/her functionings. The left-hand side of the first equation in (18) is the sum of individual i's evaluations of components embodied in x_{ij} units of food j. Eq. (18) means that the unit price of the food j is equal to the aggregate marginal contributions of nutrients generated by person i's labor to his/her happiness. The conditions in Eq. (18) assure a Pareto optimality for a quantity of each food and give a basis upon whether consumers choose to buy foods.

(ii) In the maximization problem, z_{ic} is an amount of nutrient c that an individual i should consume. Eq. (21) is a *dietetical constraint* which defines strict proportionality between any pair of micronutrients required by *Condition* **ICOL**. x_{ij} is a person i's consumption of food j, and q_{jc} is an amount of nutritive element c embodied in one unit of food j. Values of essential micronutrients as indicators for adults each day are given in APPENDIX 2. These are data for the dietetical constraints, and the values are daily needed for proper health. In the above equation, $R_{ic'}$ denotes an amount of nutrient c' daily recommended for person i to ingest. If we normalize that 100g≡1 unit, then the value $R_{ic'}$ is 7.3mg for a carrot, 0.62mg for a pumpkin, 0.72 mg for a broccoli, and 5.2mg for a spinach. Thus, you can take a sufficient amount of beta carotene(6mg) if you eat more than 83g of carrot, i. e., 0.83 units. An optimal metabolic rate between two prerequisite nutrients is fixed as required by modern dietetics. Hence, a specific value is once given to some nutrient c, the values of other nutritive elements to be taken are immediately determined. For example, if calcium is chosen as a *numéraire nutrient*, any other values of nutritive elements are all determined owing to the dietetical constraint(21), which is very important in our diet-consumer theory.

(iii) Calorie intake is subject to the "closed satiation" of Lancaster(1991) in which calorie as a characteristic changes from being desirable to being undesirable at some level. Fat intake should not exceed 25% of total calorie to keep health. Cholesterol level is also subject to the closed satiation. Whereas, he termed "open satiation," where the consumer has zero interest in further quantities beyond some critical level. Dietary fiber subject to open satiation is needed more than 30g a day. Eq. (22) is required for these ingredients of foods. For simplicity, we impose(22) as equality constraints.

(iv) There are of course many combinations of nutritious foods as solutions, $x_i^* = (x_{i1}^*, ..., x_{iJ}^*)$, which satisfy the above optimization problems. By selecting foods with the highest *N/K* (nutrient value/kilocalorie) *rate* could achieve *Individual Super Health* as an *optimum optimorum*. By modern dietetics we can say that the higher the *N/K rate*, the healthier an individual can be. For example. boiled spinach contains 1.1mg/100kcal of vitamin B_6, 634mg/100kcal of folic acid, and 15.5mg/100*kcal* of iron.

A raw oyster has 113.2mg/100kcal of zinc. All you have to do every day is to cook and eat tasty dishes with foods having higher *N/K rate*. This can be done by utilizing functionings of a person.

We must present here the optimization by profit maximizing producers, because they are to supply goods having Pareto optimal product quality to dietetically well-informed consumers. In the profit-maximization problem. P_j is a profit of producer j: the first term is its revenue and the second term is its cost.

$$Max\ P_j = \sum_{i=1}^{N} p_j x_{ij} - x_{j0}, \tag{25}$$

where $x_{j0} = \phi_j(x_j,\ q_{j1},\ldots,\ q_{jC})$. x_j is a food (i. e., a private good), thus, its price, p_j, is exogenously determined in its market.

Proposition 2: *Necessary conditions for Pareto optimal product quality in terms of attributes are*: $\forall c \in \boldsymbol{C},\ \forall j \in \boldsymbol{J},\ c \neq j'$

$$\sum_{i=1}^{N} p_j \partial x_{ij} / \partial q_{jc} \leqq \partial x_{j0} / \partial q_{jc}, \tag{26}$$

$$\left(\sum_{i=1}^{N} p_j \partial x_{ij} / \partial q_{jc} - \partial x_{j0} / \partial q_{jc}\right) q_{jc} = 0 \tag{27}$$

The left hand-side of Eq.(26) is the marginal revenue and the right hand-side is the marginal cost of an infinitesimal change of an amount of nutrient embodied in one unit of good j.

4. Optimaization With Foods Having Hazardous Characteristics

4. 1. Profit Maximization by Producers Using Deleterious Characteristics

We have assumed so far that every food is composed of nutrients as *good* attributes. However, we have to generalize our model by introducing harmful characteristics such as food additives, agricultural chemicals, e. g., pesticides, weedicides, fertilizers, preservatives, antibiotics, hormones, etc.[13] Our analysis below can be applied

13) These issues are analyzed by Sato (1998). There are more than 1,200 food additives, including 466 natural additives which are produced, sold, or imported in Japan : the number of natural additives is five times larger than the United States and ten times larger than EU. The Ministry of Health and Welfare of Japan authorized that these

to other cases where farmers are replaced by food makers using additives as risky characteristics[See Sato(1998)].

There are two types of farmers($j=1,\ldots, J$), i. e., those who do($j \in \boldsymbol{J}^-$) and do not use($j \in \boldsymbol{J}^+$) agricultural chemicals, where $\boldsymbol{J}^+$ and $\boldsymbol{J}^-$ are the sets of each type of farmers, respectively. We employ a similar framework of Drèze and Hagen(1978), with some modifications to involve the phenomenon of persistant pollution caused by hurtful agricultural chemicals, in which we assume that each farmer maximizes his/her profit by choosing a $(C+4)$-dimensional input-output vector

$$y_j = (x_{jc+1}, x_{j0}, x_j, q_{j1},\ldots, q_{jc}, q_{jc+1}) \tag{28}$$

in its production set Y_j, where x_{jc+1} denotes an amount of pesticide that farmer j uses as one of the inputs, and q_{jc+1} is an amount of the residual pesticide in x_j. It is assumed that $q_{jc+1} = p_{jc+1}x_{jc+1}$, where $0 < p_{jc+1} \leqq 1$ is a remaining proportion of the pesticide as a hazardous attribute, i. e., a part or all of x_{jc+1} may stay behind in the food as a hazardous attribute, q_{jc+1}.

An index c represents both any nutrient and other attribute hereafter. Let p_{c+1} be a unit price of pesticide, x_{jc+1}. Then, we have pesticide-using farmer j's profit maximization problem:

$$Max\ P_j^- = \sum_{i=1}^{N} p_j x_{ij} - (x_{j0} + p_{c+1} x_{jc+1}), \ \ \forall j \in \boldsymbol{J}^- \tag{29}$$

over the set

$$\{y_j \mid \phi_j^-(x_{jc+1}, x_{j0}, x_j, q_{j1},\ldots, q_{jc}, q_{jc+1}) \leqq 0,\ q_{jc} \geqq 0,\ \forall c = 1,\ldots, C+1\} \tag{30}$$

where P_j^- is a farmer j's profit when he/she uses the pesticide.

Denote X_{ij}^+ as a product of an organic farmer $j \in \boldsymbol{J}$, consumed by $i \in \boldsymbol{N}$. Then,

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additives can be used. Antibiotic substances and hormone drugs are used abundantly in the livestock farming and fish breeding to prevent diseases and to promote growth. Japan enacted the Product Liability Law in 1994, and put it in force in July 1995. This law allows consumers to legally and more easily make claims against product defects. Many new products appear daily and some may not have been checked thoroughly beforehand in commodity tests for safety. After discovering lots of flaws in consumer products, the administration unwillingly put the product liability law into effect, but its effectiveness is doubtful. Food industries use so many additives which remain as bad characteristics in foods. Consequently, these ingredients could harm the body in the long run. Thus, we have to fight against prevailing food contamination by giving incentives to farmers and food industries to prevent to use agrochemicals.

we have an organic farmer j's profit maximization problem:

$$Max\ P_j^+ = \sum_{i=1}^{N} p_j^+ x_{ij}^+ - x_{j0}^+,\ \ \forall j \in \boldsymbol{J}^+ \tag{31}$$

over the set

$$\{y_j^+ \mid \phi_j^+(x_{j0}^+, x_j^+, q_{j1}^+, \ldots, q_{jC}^+) \leqq 0,\ q_{jc}^+ \geqq 0,\ \forall c = 1, \ldots, C\} \tag{32}$$

where P_j^+ is an organic farmer j's profit when he/she does not use the pesticide and p_j^+ is the price of its product. It is assumed that ϕ_j^+ and ϕ_j^- are convex and twice continuously differentiable with other conditions satisfied such as in Assumption 1. It is also supposed that $p_j^+ > p_j$, since organic farmers' products do not contain pesticides as harmful attributes and their productions cost more. The production functions may not be convex, but the problems arising from nonconvexities are not treated here.

We already know that organic products contain more amounts of good nutritives such as chromium, iodine, potassium, sodium, etc. They have, however, less quantities of deleterious nutrients like alminium, lead, mercury, and so on. Thus, we can impose $q_{jc}^+ > q_{jc}$ for almost all nutrients except rubidium.

Let us compare the profits of two types of behaviors that are optional to farmer j. Use of pesticides in agricultural productions may result in the less consumption by environment-friendly consumers, so we can easily assume that $x_{ij}^+ - x_{ij}$ is positive.

We observe therefore,

$$P_j^- - P_j^+ = \sum_{i=1}^{N} p_j x_{ij} - (x_{j0} + p_{c+1} x_{jc+1}) - \Big(\sum_{i=1}^{N} p_j^+ x_{ij}^+ - x_{j0}^+\Big) < 0 \tag{33}$$

Hence, an incentive not to use pesticides is given to farmers, provided that the above situation is realized[See Henry(1989) for a tax-subsidy system to give farmers the proper incentive not to use pesticides].

4. 2. The Generalized Model with Many Risky Attributes

Let $G = \{C+1, \ldots, C+G\}$ be the set of injurious characteristics used in foods. Let x_{jc} be an amount of an agricultural chemical that farmer j uses as an input. Then, we can easily generalize the model to many deleterious attributes as

$$\{y_j \mid \phi_j^-(x_{jc+1}, \ldots, x_{jc+G}, x_{j0}, q_{j1}, \ldots, q_{jC}, \\ q_{jC+1}, \ldots, q_{jC+G}) \leqq 0,\ q_{jc} \geqq 0,\ \forall c \in \boldsymbol{C} \cup \boldsymbol{G}\}. \tag{34}$$

As above, it is assumed that $q_{jc} = p_{jc} x_{jc}$, where $0 < p_{jc} \leqq 1$, $\forall c \in \boldsymbol{G}$, is a percentage of a residual agricultural chemical, i. e., a part or all of x_{jc+1} may persist in the food as a hazardous attribute, q_{jc+1}. Let p_c be a unit price of risky input x_{jc} in the producers' optimization problem. Then, Eq.(29) is replaced by

$$Max\ P_j^- = \sum_{i=1}^{N} p_j x_{ij} - (x_{j0} + \sum_{c=C+1}^{C+G} p_c x_{jc}),\ \ \forall j \in \boldsymbol{J}^- \tag{35}$$

subject to Eq.(34). Finally, the same inequality as in Eq.(33) is easily verified.

Proposition 3: Necessary conditions for Pareto optimal product quality in terms of characteristics including hazardous attributes are:

$$\sum_{i=1}^{N} p_j \partial x_{ij}/\partial q_{jc} \leqq \partial x_{j0}/\partial q_{jc} \tag{36}$$

$$\Big(\sum_{i=1}^{N} p_j \partial x_{ij}/\partial q_{jc} - \partial x_{j0}/\partial q_{jc}\Big) q_{jc} = 0$$
$$\forall c \in \boldsymbol{C},\ \forall j \in \boldsymbol{J},\ c \neq j' \tag{37}$$

$$\sum_{i=1}^{N} p_j \partial x_{ij}/\partial q_{jc} \leqq \partial x_{j0}/\partial q_{jc} + p_c/p_{jc} \tag{38}$$

$$\Big(\sum_{i=1}^{N} p_j \partial x_{ij}/\partial q_{jc} - \partial x_{j0}/\partial q_{jc} - p_c/p_{jc}\Big) q_{jc} = 0$$
$$\forall c \in \boldsymbol{G},\ \forall j \in \boldsymbol{J},\ c \neq j'. \tag{39}$$

Remark 5: Equations (36) and (37) are the necessary conditions for Pareto optimal product quality in terms of characteristics (or Pareto stationary condition) which are not hazardous to health. In Eq. (38), the left-hand side is the marginal revenue and the second term is a marginal cost by using an infinitesimal change of an agrochemical or food additive as a persistent harmful characteristic. The second term in the R. H. S. of Eq.(38) means that the more costly, the less amount of any pesticide persisted in a food. The reason why producers use deleterious inputs is to try to increase the amount of their product and to reduce their costs.

We can easily generalize our model to incorporate many food additives and agrochemicals, so we extend Eq.(1) as

$$z_i = (z_{i0}, z_{i1}, \dots, z_{iC}, z_{iC+1}, \dots, z_{iC+G}) \tag{40}$$

where z_{ic} is a consumption of a characteristic c which may be hazardous if $c \in \boldsymbol{G}$.

In the presence of risky attributes, we can state the following proposition.

Proposition 4: *Nutritionally Optimal Individual Diets with hazardous foods as a composition of characteristics, including deleterious attributes, are characterized by the conditions:*

$$\sum_{C=1}^{C+G} \pi_{ic} q_{jc} \leqq p_j, \ \Big(\sum_{C=1}^{C+G} \pi_{ic} q_{jc} - p_j\Big) x_{ij} = 0, \ \ \forall j \in \boldsymbol{J}, \ c \neq j' \tag{41}$$

$$b_i = (f_{i1}(z_i), \ldots, f_{iK_i}(z_i)) \in \boldsymbol{B}_i(\boldsymbol{X}_i), \ \ \forall f_i \in \boldsymbol{F}_i \tag{42}$$

$$z_{ic} = \sum_{j=1}^{J} x_{ij} q_{jc}, \ \ \forall c \in \boldsymbol{C} \cup \boldsymbol{G} \tag{43}$$

$$z_{ic} = R_{ic'} \tan\delta_{cc'}, \ \ \forall c, c' \in \boldsymbol{C} \tag{44}$$

$$z_{ic} = R_{ic}, \ \ \forall c \in \boldsymbol{C} \tag{45}$$

$$z_{ic} = \xi_{ic}, \ \ \forall c \in \boldsymbol{G} \tag{46}$$

$$\sum_{j=1}^{J} p_j x_{ij} = z_{i0} \tag{47}$$

$$x_{ij} \geqq 0, \ \ \forall j \in \boldsymbol{J}. \tag{48}$$

Remark 6: The solution procedure follows Propositions by adding the arguments regarding food additives and agricultural chemicals as hazardous charactersitics. The L. H. S. of the first equation in (41) is the sum of values of attributes including ingredients as well as agrochemicals and food additives embedded in x_{ij} units of food j. Eq.(41) means that the unit price of the food j is equal to the aggregate marginal contributions of characteristics generated by individual i's labor to his/her happiness. The above equations are similar to Propositions except for Eq.(46), where ξ_{ic}, $\forall c \in \boldsymbol{G}$, is regarded as a tolerable daily intake(TDI) of an additive or an agricultural chemical that person i may consume.

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 some persons put negative valuations $\pi_{ic} < 0$ on some characteristic c, the aggregate value of MRSs over consumers can still be positive. It is this social acceptance that gives rise to public discussion. Even if consumers know that some additives are contained in food j, they do not necessarily refuse that food because of its good taste, irrespective of uncertain food-related risks in the future. Moreover, if $\sum_i \pi_{ic} x_{ij} < 0$ holds for some c, food j may not be socially admitted especially by prudent, risk-averse and dietetically well-informed consumers, since it is a hazardous attribute that may cause risks. Additives such as preservatives and food flavorings used in the manufacturing processes could not be digestible and thus persist in human bodies by the same quantities until they will he excreted.

5. CONCLUSION

5. 1. In this paper, we have presented our discussion based on the premise that the optimal human diet supported by the idea of nutritional fitness, as suggested by modern dietetics, can be represented as a combination of ingredients (i. e., vitamins, minerals, amino acids) as attributes *à la* Gorman-Lancaster embodied in various foods. We believe that the characteristics model is the most suitable one to analyze the choice of hazardous foods especially in recent years. What we have proposed is a new framework to analyze the classical issue of diet in a modern way to incorporate both the objective and subjective features : i. e., nutritive elements compounded in the foods and functionings of individuals such as metabolism and physiology.

Our analysis differs from Drèze and Hagen (1978) in two ways. We have introduced the nutritive elements as attributes embodied in foods. As suggested by modern dietetics, we now know that there is no priority among nutritives and that there are optimal rates among them. Thus, we have required efficient conditions presented above.

Secondly, in contrast to the Drèze and Hagen's notion of characteristics, we have taken harmful attributes into consideration to define an optimal human diet in an enlarged sense. Their approach is not adequately applicable to our diet-consumer issue, since converting goods to characteristics is just an objective fact which is common to all consumers. Nonetheless, how to use these attributes depends on each consumer's capability set because all of the functionings with which he or she utilizes them differ. Thus, we have introduced Sen's concept of capability to distinguish personal features from objective attributes in goods. We have assumed differentiable happiness function to obtain our desired results.

Let me address some issues for further research. First of all, as in Drèze and Hagen (1978), we have assumed complete information in that a shadow price of each attribute is correctly obtained from consumers. Gorman (1956/1980), Deaton and Muellbauer (1980), and Drèze and Hagen (1978), developed the methods showing how shadow prices are computed themselves. Without corner solutions, consumers buy as attributes and given that the q_{jc} are observable, one can always compute the π_{ic}'s by solving such a system of simultaneous equations (18). The revelation problem is not explicitly discussed here. Dietetically well-educated consumers cannot choose but to select an optimal human diet if they are risk-averters in health related decision-making.

Secondly, our necessary conditions for optimal human diets are static concepts, so we cannot deal with the dynamics of food consumption behavior. Goods with optimal qualities in a dynamic setting should be one of the main concerns of the next paper which will show that a composition of characteristics in the lifetime of each consumer can be intertemporally optimized by adjusting each of its components, namely by reshuffling the combination of foods. Thus, we have to design a learning process for people to become dietetically well-informed to behave rationally by choosing foods that are better for the health. Also, designing a possible procedure to elicit consumers' hedonic marginal willingness to pay for safe foods is an open question.[14]

Thirdly, our analysis in this paper can be applied to genetically modified(GM) crops, for which the necessary conditions for efficient quality characteristics are derived in Sato(1998). The genetic attributes of their seeds are engineered by agrochemical makers that simultaneously provide pesticides complementary to the seeds they supply. Some farmers use GM seeds and insecticides, and some food manufacturers utilize GM crops. Consumers are not given any choice, but to eat foods which may be made from GM plants, and they are faced with an optimization problem under uncertainty. Non-traceable genetic engineering-biohazards may continue to spread, since the bacteria embedded in GM plants create an endotoxin which confers a resistence to insects and pesticides. Hence, we may have to construct a tax-subsidy scheme to implement our efficient conditions by giving producers incentives to provide benign foods in markets. The next issue will therefore be to analyze in detail the behaviors of firms producing food products and those of the government.

Finally, a person's health is not necessarily of individualistic character, rather it depends on members in his/her family. That is to say, a person's health relies upon

14) In a different dynamic context, planning procedures for quality adjustments are presented with an application to global warming due to the buildup of greenhouse gases as *gaseous attributes*. See Sato (1999) and (2000 a, b). See also Gilboa and Schmeidler(1997) who advocated an interesting dynamic theory of consumer choices based on a cumulative utility related to the relative frequency and developed a concept of a cumulative satisfaction index. See Gul and Pesendorpher(2001) for the most recent and interesting dynamic choice theory of consumers with temptation and self-control.

the functionings of other person. For example, children's health heavily depends upon their caregiver. If these interrelated relationships are involved, then the model must be modified to derive efficient conditions in the larger sense of an optimal human diet. PROPOSITIONS 1～4 are efficiency conditions for nutritionally optimal *individual* diets. If someone else prepares dishes for you, then your health partially depends on that person's ability of cookery.

5.2. Here we must add an important fact that a 'dietetically right' diet does not have to necessarily taste bad as shown by Stigler(1945). It can rather assure both good flavor and good health by elaborately preparing meals. The methods and recipe have already been found which permit compatibility between relish and nutrition. For example, minestrone involves many vegetables: kidney beans, onions, carrots, tomatoes, potatoes, garlic, celery, laurier, etc. This meal provides sufficient nutrients which can satisfy your physical needs. Foods can be assumed to have free combinability property, but some types of foods are not congenial when you want to cook dishes that have good flavor. For example, a recipe involving wheat flour, evaporated milk, cabbage, spinach, and dried navy beans, as materials composing a *minimum cost diet* was defined by Stigler. He said, "[n]o one recommends these diets for anyone, let alone everyone; it would be the height of absurdity to practice extreme economy at the dinner table in order to have an access of housing or recreation or leisure." (1945, pp. 312-313). Therefore, the Stigler's minimum cost diet approach and a simple use of linear programming do not suffice to have an optimal health diet with great tasting dishes.

From the above discussion, we distinguish between the aspects of taste and a healthy diet. In so doing, we partition off taste and health as two separate functionings. Thus, we have the set $\boldsymbol{F}_i$ which also includes relishing as a functioning. A diet which tempts the appetite should belong to the optimal human diet. Gustation is one of the most important functionings. We want to stress the importance to eat delicious meals everyday and to take necessary nutrients to live in proper health, rather than to recommend 'dietetically-bounded' dishes which may be stressful. Eating is an intellectual activity that should occur three times a day. What is essential from the dietetical viewpoint is not only what to eat but also who eats what and how. Of course, the time of the day and which foods to eat in each season are also important facets. Finally, the most significant condition that is good for both physical and mental health is the company of sharing and enjoying the meals. Sen(1985) provided a detailed explanation of numerous attributes of breads, other than nutritional ones.[15)]

Another important thing to be added is the following. It is now known that diets good for the health are simultaneously good for the 'health' of this Planet. An optimal human diet must consist of unpolluted and unrefined grains, beans, vegetables, fruits, fish, etc. This composition is reasonable from the dietetical viewpoint. One does not necessarily need meat to obtain a healthy diet.[16)] For example, vegans or vegetarians who do not eat dairy products, fish, poultry, and/or eggs can easily survive without being a burden to the soil and the resources of our common Earth. The sense of vegetarianism supported by modern dietetics could guide us to the world where the tastes are in harmony with the globe without depleting its precious resources.

Paradoxically, now is the time when our economic prosperity has drastically changed our composition of foods in the wrong direction, especially in Japan. This will result in a negative effect on human health and the situation we face today is very different from that of the 1960's. As human beings, we have a propensity of self-subversion and we are now given the misfortunes of prosperity. What we have shown are just the conditions for a nutritionally optimal individual diets, however, they are derived not only for economic efficiency, but also for the "dietetical optimality," represented in the propositions supra. We do not contend insolently that we can artificially control the nutritional combination of characteristics that producers supply. What we have done is not only to verify the theoretical model of nutritionally optimal conditions, but also to show the possibility of protecting ourselves with our own common sense, which simultaneously results in the protection of our holistic existence and our irreplaceable Earth.

Since there has not been a theory in the systematic analyses of microeconomics which involves nutrition as a prerequisite for humans to have proper health, further research is needed. This is especially true with respect to the study of modern consumer

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15) See Lupton(1996) for the detailed descriptions and very interesting analyses of eating.

16) It was in England in 1986 that one discovered the *bovine spongiform encephalopathy* (*BSE*), commonly called *mad cow disease*. It has just been discovered in Japan as well, and the Japanese people is now seized with fear of knowing the gloomy fact that *BSE* is an infection disease which infects human beings as the *Creutzfelt-Jacob Disease*. The contagion source has been specified to cows' prion as one of proteins, but the route of infection is not yet elucidated. Now is the chance of a lifetime to abstrain from eating beef as well as pork and poultry. See Cox(1986) and Rifkin (1992) for numerous gloomy hazards related to the human health and to the health of the Planet.

theory in microeconomics through a literally 'microscopic viewpoint': i. e., inside the human body as a microcosmos. This research area surely restructures and strengthens economics as a policy science to improve the quality of human life. We remember Sen's response when interviewed: i. e., he replied that "the subject has much to gain from remaining innovative and progressive, rather than inward-looking and obsessive." [See Gaertner and Pattanaik (1988), p. 79].

What will be the combination of food characteristics we may eat in the 21st century? What will be 'future diets'? Only God knows.

APPENDIX 1

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

Person i's *valuation function* for his/her beings is given by

$$v_i = v_i(b_i). \tag{A 1}$$

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 provides a person an incentive to achieve optimal health by changing his/her consumption life. For example, deciding to start to eat nutritionally-balanced foods as required by modern dietetics is a role of the valuation function to value many aspects of person i's life[17].

Let $\boldsymbol{X}_i$ denote the set of vectors of goods available to an individual i. Given $\boldsymbol{X}_i$, we can represent the set of feasible functionings vector, or the *capability set* of a person i as :

$$\boldsymbol{B}_i(\boldsymbol{X}_i) = \{b_i \mid b_i = (f_{i1}(z_i) \ldots, f_{iK_i}(z_i)), \textit{ for some } f_i \textit{ in } \boldsymbol{F}_i \textit{ and for some } x_i \textit{ in } \boldsymbol{X}_i\} \tag{A 2}$$

The crucial problem is that functionings would decline and this set could shrink by continuing to prefer to eat unhealthy foods with too much fats and/or additives.

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

$$\boldsymbol{V}_i = \{v_i \mid v_i(b_i), \textit{ for some } b_i \textit{ in } \boldsymbol{B}_i(\boldsymbol{X}_i)\}. \tag{A 3}$$

One can choose whatever v_i from $\boldsymbol{V}_i$ by changing the way of the use of functionings.

---

17) *An example* of a valuation function is given by

$$v_i(b_i) = H_i(b_i)^{\rho(i)}$$

where $\rho(i) = 1/(d_i+1)$. If $d_i(z_i^*, z_i) = 0$, then the values of the functions, v_i and H_i coincide. Unless, the larger the value of d_i, the further from ISH. We can say that a person can be healthier, as his/her nutritional distance, $d_i(z_i^*, z_i)$, approaches zero.

APPENDIX 2

Nutritional Daily Value for Americans

Nutrient	Daily Value
Vitamin A (as Beta-Carotene)	5000 IU[1]
Vitamin C (as Calcium Ascorbate)	60 mg
Vitamin D (as Cholecalciferol)	400 IU
Vitamin E (as Natural d-Alpha Tocophenyl Succinate)	30 IU
Vitamin K (as Phytonadione)	80 μg[2]
Vitamin B-1 (as Thiamine Mononitrate)	1.4 mg
Vitamin B-2 (as Riboflavin)	0.02 mg
Vitamin B-3 (as Niacinamide, and as Inositol Niacinate)	20 mg
Vitamin B-6 (as Pyridoxal 5 phosphate HCL, and	2 mg
as Pyridoxine HCI)	
Folate (as Folic Acid)	400 μg
Vitamin B-12 (as Natural Cyanocobalamin)	6 μg
Biotin	290 μg
Pantothenic Acid (as Calcium Pantothenate)	10 mg
Calcium (as Calcium Ascorbate, and as Calcium Citrate)	1000 mg
Iron (as Iron Glycinate)	
Magnesium (as Magnesium Oxide, and	15 mg
as Magnesium Lysinate)	400 mg
Zinc (as Zinc Glycinate)	15 mg[3]
Selenium (as Selenium Methionate)	70 μg
Copper (as Copper Glycinate)	2000 μg
Manganese (as Manganese Citrate)	2 mg
Chromium (as Chromium Arginate and	120 μg
as Chromium Nicotinate)	
Molybdenum (as Molybdenum Citrate)	75 μg

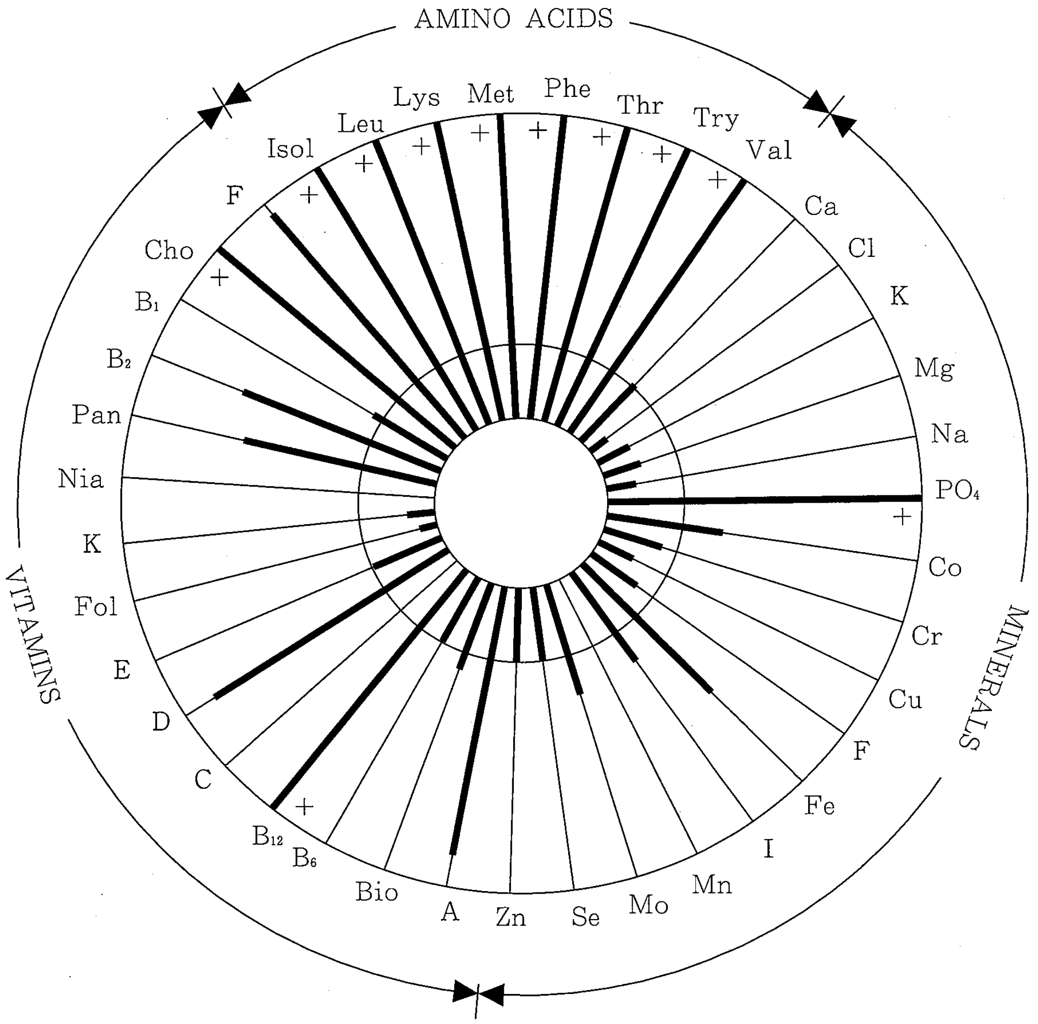
1) IU is an abbreviation of "international unit."

2) μg is microgram.

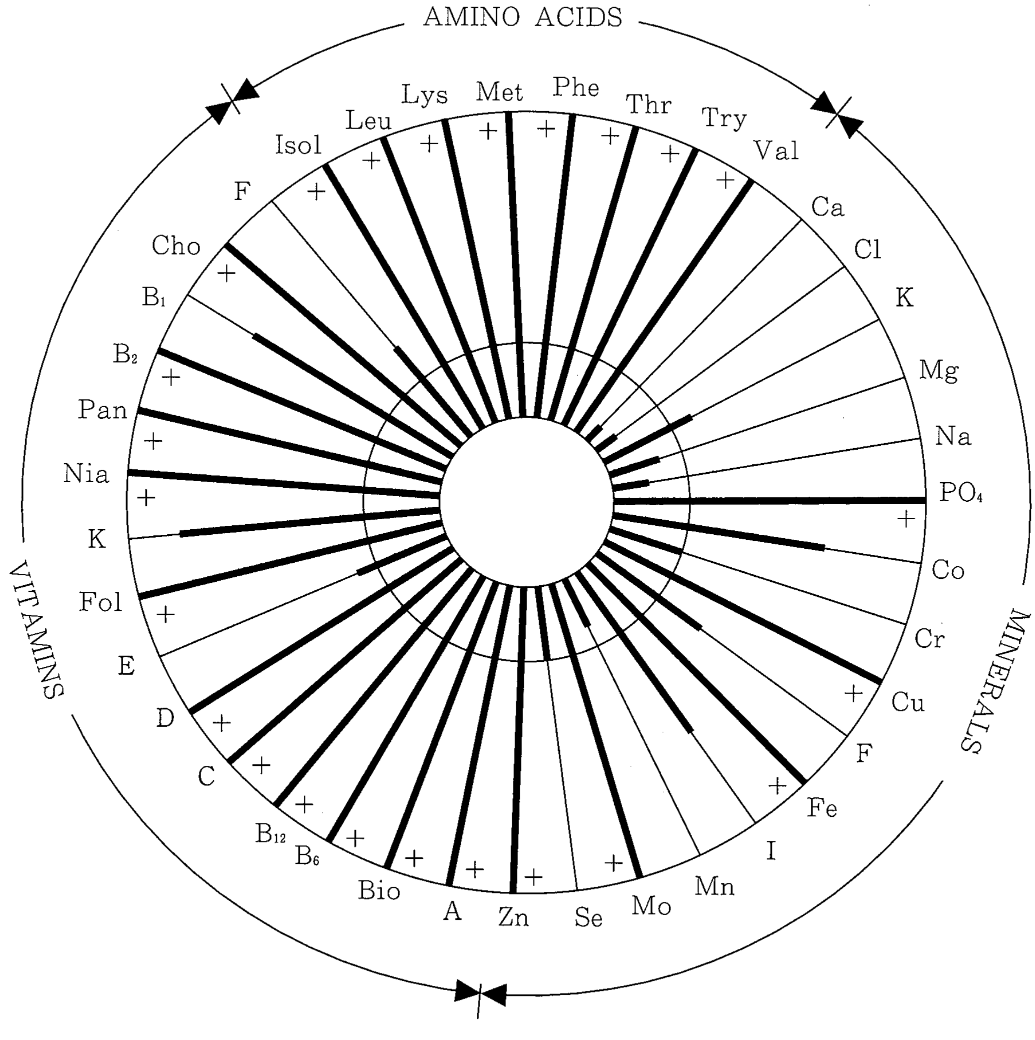
3) For the American women, 12mg is recommended. The same value is recommended for the Japanese men, whereas, 9mg is for the Japanese women.

APPENDIX 3

Here we present the charts of ingredient analysis of representative four foods composed of nutrients as characteristics, as were shown by the Clayton Biochemical Institute in Texas University. Each chart shows what amounts of prerequisite nutrients can he taken by each food only. An inner smaller circle measures the 2500 calorific intake necessary for a day. The solid lines signify contents of micronutrients, some of which are short of the daily calorific intake, such as Vitamin K. Vitamin C and Molybdenum are not contained. The sign "+" means the excess of content of each nutrient. For these charts, see WILLIAMS, R. (1977) *The Wonderful World Within You*, Bantam Books.



EGG


AMINO ACIDS
Lys
Met
Phe
Leu
Thr
Try
Isol
Val
F
Ca
Cho
Cl
K
B1
Mg
B2
Pan
Na
Nia
PO4
K
Co
Fol
Cr
E
Cu
D
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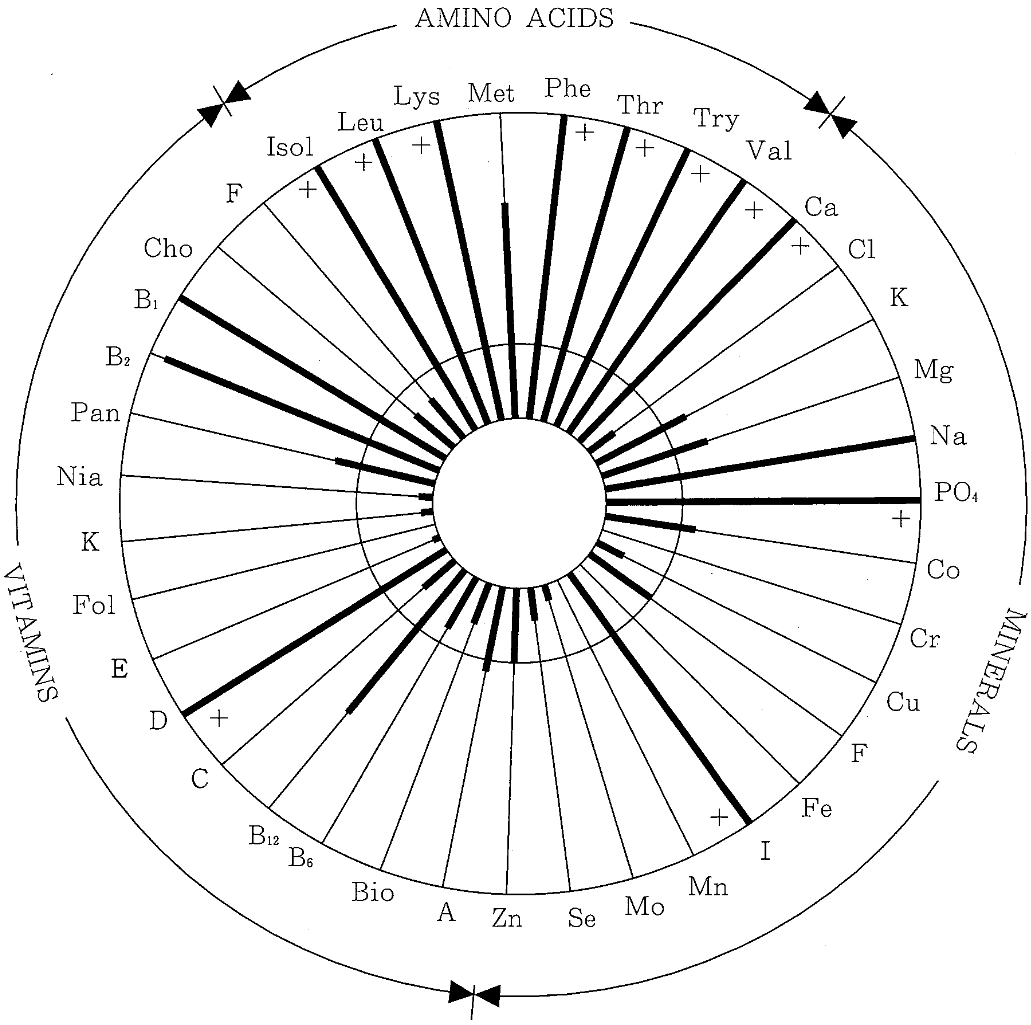
C
Fe
B12
I
B6
Mn
Bio
Mo
A
Zn
Se
VITAMINS
MINERALS

LIVER


AMINO ACIDS
Lys
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Cho
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B2
Pan
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E
D
C
B12
B6
Bio
A
Zn
Se
Mo
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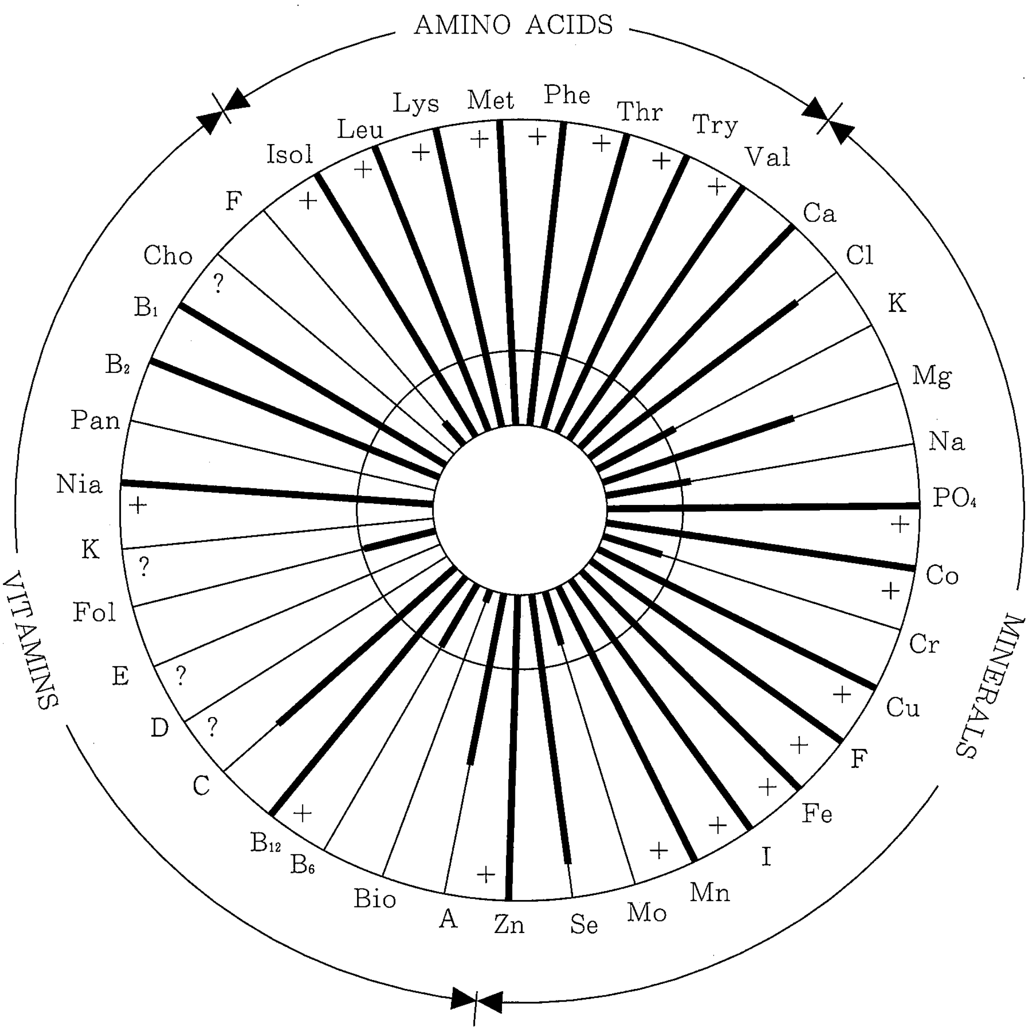
Cu
Cr
Co
PO4
Na
Mg
K
Cl
Ca
VITAMINS
MINERALS

MILK


AMINO ACIDS
Isol
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MINERALS
Ca
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Cr
Cu
F
Fe
I
Mn
Mo
Se
Zn
VITAMINS
A
Bio
B6
B12
C
D
E
Fol
K
Nia
Pan
B2
B1
Cho
F

OYSTER

APPENDIX 4

FIGURE 1 RATES BETWEEN NUTRIENTS AS CHARACTERISTICS

	PHOSPHORUS	CALCIUM
Chicken	70	1
Pork	32	1
Beef	30	1
Salmon	20	1
Potato Chips	5.9	1
Optimal Rate	1	1

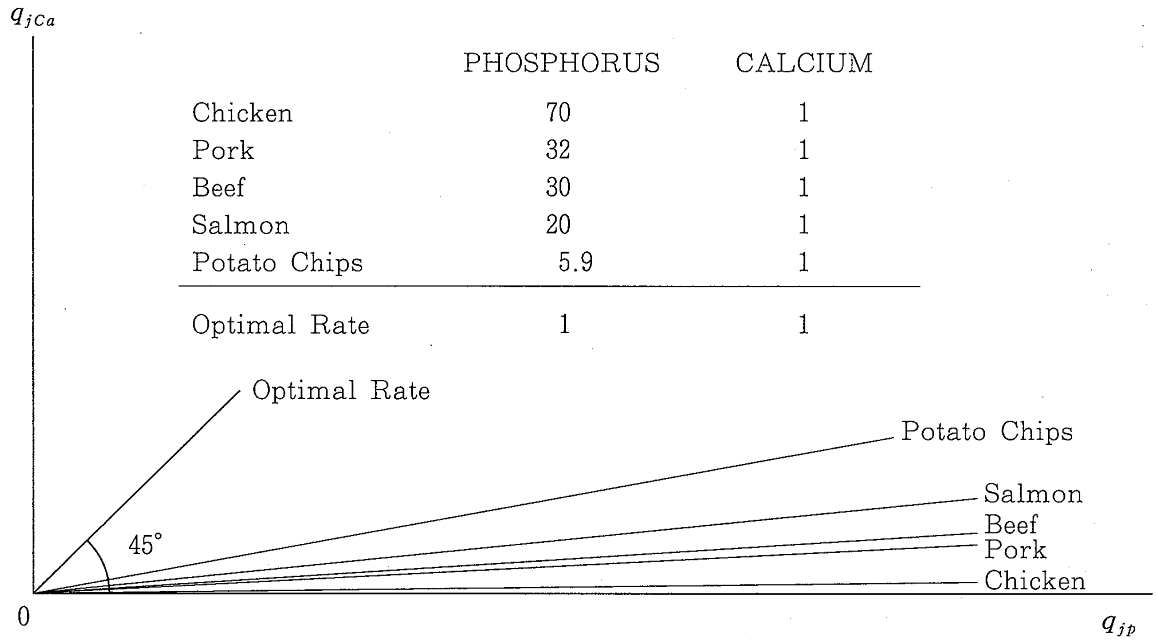
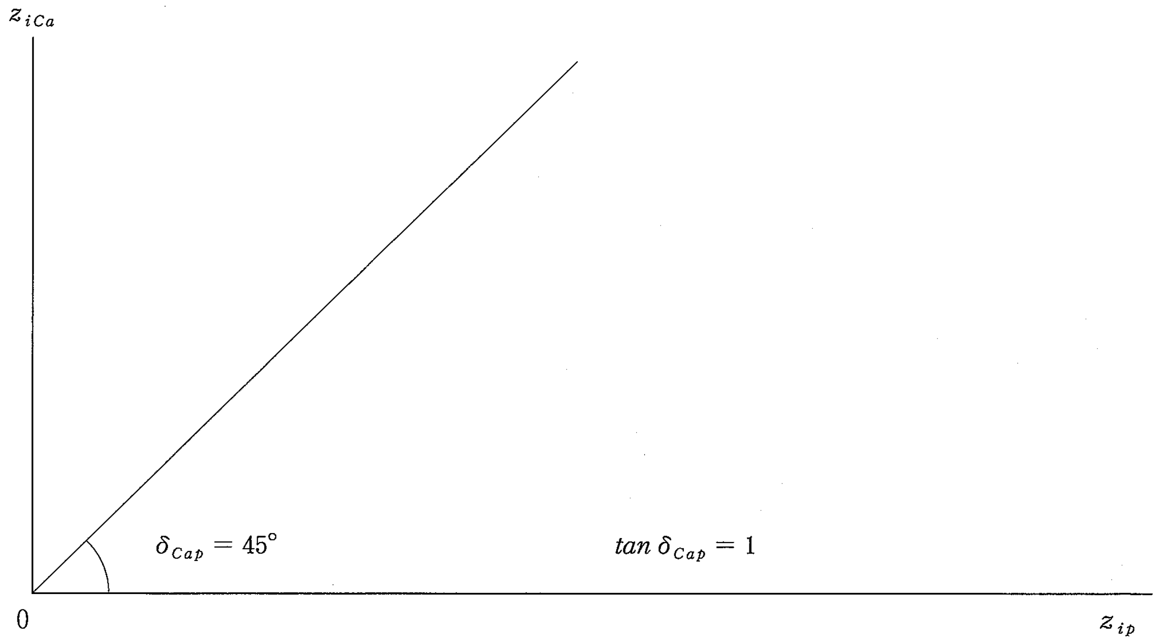


FIGURE 2 The Individual Chain of Life



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