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Demand without Utility: The First Evidence

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Abstract: According to the new attribute theory that is based on but different than Lancaster's attribute theory, the paper builds a linear programming model of minimizing food cost subject to four nutrient requirements and derives a system of food demand functions from this model with a programming method. This derivation is independence of any utility function and at least is an exception of the utility theory. The programming method, which is neither a parametric nor a typically non-parametric method, allows us to thoroughly understand the mechanism of demand's formation. The conclusion implies that the new attribute theory and the programming method might be an alternative approach to utility theory and the related estimation methods to derive the demand system.

Key Words: new attribute theory, programming method, food demand

JEL: C61, D01, D11, D12

1. Introduction and Literature Review

The purpose of this paper is to present a new theory and, especially new method to derive a system of food demand functions. Theoretically, the demand functions are not based on any utility function but on a specific programming model. Empirically, the demand functions are derived not with a parametric method but with a programming method.[1] Strictly speaking, the parametric method is not derivation but estimation. The empirical derivation of a system of demand functions should be anchored in a programming method.

Utility theory might not be a perfect theory. Stigler (1950 I and II) completely criticized this theory and emphasized that it was seldom to be empirically tested. Lancaster (1966) proposed an attribute theory[2] that what the consumer bought was not the goods but the attributes of the goods. The mainstream Economics, however, didn't fully realize Lancaster's potential contribution, probably because this

[1] This programming method for deriving demand functions is neither a parametric nor a typically non-parametric method. Put another way, it is not a method of estimation, but a method of derivation. In general, it can be viewed as a special non-parametric method.

[2] The Lancastrian term was characteristic instead of attribute. But currently attribute is a common term for the nature of goods and characteristic for that of consumers.

theory itself still credited consumers' objective to utility. This paper does not employ the whole Lancaster's theory but only uses its "chief technical novelty" of the attributes of goods.[3] Thus according to part of Lancaster's key findings, we are able to construct a new attribute theory, or for brevity, the attribute theory, that consumers' entire objective is only the attributes of the goods while the utility is totally not necessary. The application of this theory means that the consumer could have multi-objective functions in the optimization model. Therefore, this paper will apply the programming model instead of utility function to directly derive the demand system.

To my knowledge, the existing literature did not provide empirical research to derive a demand function from an optimization model with multi-objective functions or by Duality, subject to a system of related multiple constraints in which the utility did not enter the model. A few researchers explored a theoretical framework where the utility function was not necessary (Dardi, 2008; Dominique, 2007 and 2008). But they had no empirical application. Attema et al. (2010) and Attema et al. (2015) provided new methods to measure intertemporal choice and temporal discounting of money without the information of utility. But these methods cannot be used to derive a demand function. Atkin (2013) and Dubois et al. (2014) conducted two studies that seemed similar to this paper. The two studies, however, were built on utility theory. Especially, the food demand functions in these studies were not directly derived from an optimization system but were estimated with parametric method. Thus they were different than the present paper. Although a general method was proposed for the derivation (Zhu, 2016), no complete dataset was applied to test its effectiveness. This paper will elaborate possibly the first evidence based on the programming method.

The remainder of this paper is as follows. Section 2 builds a linear programming model of food consumption and provides a non-parametric method to derive a system of food demand functions. Section 3 applies the method to the dataset of rural China. Section 4 concludes the paper.

2. From Programming Model to Demand System

2.1 A Linear Programming Model of Food Demand

Food has multiple attributes in daily life. Its primary attribute should be that it provides the nutrition for our body to maintain subsistence and promote growth. For the reason of data unavailability, we focus on such a primary attribute of nutrition that is composed of specific nutrients. All the secondary attributes will not be discussed.[4] The nutrients consist of macronutrients and micronutrients. This paper only

[3] We will review the related theories, e.g., the attribute-based utility model and the hedonic model, in a separated paper.

[4] The secondary attributes of food usually include that it satisfies our taste, diversity, satiety, habit, tradition, and religion.

considers the macronutrients while the micronutrients will be omitted.[5] The three major macronutrients are protein, fat, and carbohydrate.[6] Moreover, because we need food to provide energy for our body, thus this paper builds the programming model with four specific attributes of food, i.e., protein, fat, carbohydrate, and energy,[7] where the unit of energy is calories. For simplicity, we call them as four nutrients.

There are two technical ways to build the programming model of food demand. First, set the nutrient requirements as multi-objective functions and the food budget as the constraint. Second, set the cost minimization of food as a single objective function and the nutrient requirements as a system of constraints. Because it is not easy to quantify the exact food budget, we take the way of cost minimization to build the model. It needs to highlight that Stigler (1945) already constructed and solved a programming model of cost minimization subject to nutrient requirements before the formal solution of programming model had been developed. But this model was built on a basis of production theory and he did not derive a food demand function from that model. McCarl and Spreen (2004, p. 5-31, 5-64) provided an example of how to alter the price of a feedstuff and find a potential demand curve of it in a programming model. But it is not a simulation or verification of the real dataset and there was no demand theory to support it.

Regarding the daily nutrient requirements, some of them have both minimum and maximum amounts. Others only have a minimum amount and not necessarily have a maximum amount. In this paper, we only set requirements on the minimum amounts of the four nutrients. The main reason is that the objective function is cost minimization that will effectively limit the maximum levels of the nutrients. Besides, we assume the objective function and all constraints are linear for simplicity. Therefore, we set up the linear food programming model based on an annual dataset as: [8]

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[5] We omit the micronutrients not only because many food composition tables did not report the data of micronutrients, but also because micronutrients intake might not be consumers' main objective and consumers can take dietary supplements in case of deficiency for some micronutrients. Therefore, this omission might not affect the final results. Actually, if the detailed data of micronutrients are available and enter the model, we might be able to derive a system of more demand functions.

[6] Indeed, there are five major macronutrients (Wikipedia: List of macronutrients). The other two are water and dietary fiber. But some food composition tables did not report these two nutrients. This is the general reason that the present paper will not discuss them. Strictly speaking, however, the reasons for omitting the two nutrients are different. For the water, we not only take it from food but also directly drink it. But there are no data of water drinking and the price of water is generally unchanged in a long period. For the dietary fiber, we will include the energy intake from all nutrients in the model and that will partly fix the shortcoming that the fiber is omitted. Because the soluble fiber provides energy whereas the insoluble fiber does not (Wikipedia: Dietary fiber).

[7] According to Nutriology, protein, fat, and carbohydrate provide the largest part of the energy. Thus, a concern arises that since the energy mostly comes from these three nutrients, if we include energy as the fourth variable in the programming model, the relationship between the three nutrients and energy might be like multicollinearity in regression. However, the programming method is different than the estimation method. Adding a constraint in a programming model, as the energy in this case that is the fourth constraint added to the model, will shrink the feasible region of the solution and will usually make the solution more accurate.

[8] At the end of this section, I will explain the theoretical relationship between food and nutrients. In the next section, I will provide four ways of how to obtain the exogenous data of the four nutrients.

$$Min \quad Cost = \sum_{i=1}^{n} P_i Q_i \qquad \text{[Model 1]}$$

$$\text{s.t.} \quad \sum_{i=1}^{n} \beta_i^P Q_i \geq P$$

$$\sum_{i=1}^{n} \beta_i^F Q_i \geq F$$

$$\sum_{i=1}^{n} \beta_i^C Q_i \geq C$$

$$\sum_{i=1}^{n} \beta_i^E Q_i \geq E$$

$$P_i > 0, i = 1,2,...n$$

$$Q_i \geq 0, i = 1,2,..., n$$

$$\beta_i^P, \beta_i^F, \beta_i^C, \beta_i^E \geq 0,$$

where *Cost* is the total cost of all food; P_i and Q_i represent the price and demand of food *i* ($i=1,2,...,n$), respectively, in a year; *P*, *F*, *C*, *E* are the required amounts of protein, fat, carbohydrate, and energy, respectively, in that year; β_i^P, β_i^F, β_i^C, and β_i^E are the nutrient coefficients of the average amount of protein, fat, carbohydrate, and energy, respectively, in one unit of food *i* ($i=1,2,...,n$); P_i is positive; Q_i and all the nutrient coefficients are non-negative.[9]

Here arises a concern of "circular reference", i.e., in building a programming model to predict the food demand, almost all the data of nutrition intake are transformed from the food consumption. Thus it seems that the relationship between nutrition and food is circular reference. My explanation, however, is that this relationship is like Duality.[10] On one hand, the nutrition and food are the two sides of a coin and it seems they are similar. On the other hand, they are different. When the price system is changing, usually the combination of food demand will also change. But the nutrition intake could keep at a generally fixed level. The rationality behind this distinction is that the determinants of needs for nutrients and demand for food are different. In this paper we only discuss the determinants of demand for food and do not discuss that of needs for nutrients, which is another topic (Behrman, Deolalikar, and Wolfe, 1988).

[9] This model usually is not a primal model, but a dual model.

[10] Strictly speaking, this relationship is quasi-duality. In the sense of data source, it is easy to transform the data of nutrition intake from that of food consumption with a table of food composition. But it is not easy to calculate the data of food consumption from that of nutrition intake even the food prices are fixed.

Due to the reason stated above, the duality relationship is not the same as the circular reference in which its both sides should change at the same time. Therefore, the circular reference is not a problem in this paper. But when we conduct prediction, the Duality of nutrition and food could lead to an endogeneity concern, which is an incorrect modeling technique that the data of nutrition in a programming or regression model are transformed from food consumption in the same model. We will further explain this concern in Section 3.2 and provide four ways to remove the difficulty in Section 3.3.

However, it must be emphasized that the reason we have to tackle with the concerns of circular reference and endogeneity is the data unavailability. In principle, our demand for food is rooted in our primary preferences for nutrients and secondary preferences for other attributes. That means our preferences for nutrients and other attributes are exogenous to the demand for food;[11] in other words, the demand for food is a derived demand that is mainly originated from the demand for nutrients and other attributes.[12] Therefore the attributes of food are also rooted in, or map to, the above preferences and are exogenous to the demand for food. However, even it is widely accepted that the average energy needs for an adult female and male is approximately 2000 and 2600 calories per day (USDA, 2016), we still cannot apply these data to exactly compute a prediction model.[13] If we have the detailed data of our preferences for nutrients and other satisfactions, then we would be able to build accurate models to simulate the food demand functions without considering the endogeneity concern.

2.2 **Derivation of Demand Functions**

Based on the annual datasets and an assumption that the nutrient coefficients are fixed for each food over all the years, there are three steps to derive a system of food demand functions.[14]

First, calibrate the linear programming model (hereinafter the programming model) in one year and run the model to obtain the solutions of a system of food demand[15] if every constraint is available.

[11] A good explanation is that if some nutriment, for example, the glucose, can provide enough energy to maintain life in a period of time, then we do not have to dependent on food in those days. Thus, the preferences for nutrients are not endogenous from, but exogenous to the demand for food.

[12] Indeed, the real relationship between the nutrition and food is not duality or quasi-duality, but basic needs or basic demand (for nutrients) and derived demand (for food). But when we build a programming model, we have to take advantage of the duality relationship to transform the nutrition data from food consumption with some exogenous ways. The only reason we do this is the data of our preferences for nutrients are unavailable. Further, if we have to account for the endogeneity or exdogeneity between the basic needs and derived demand, we would like to say that it is the derived demand that is endogenous to the basic needs rather than the reverse.

[13] An evident application of the fact that the demand for nutrients are exogenously to the demand for food is that as long as we have the data of the population in a city or country, then we are able to approximately calculate the total food demand for the city or country based on our regular demand for nutrients . We do not have to transform the nutrients from the consumed food. But for making detailed forecast, we need more information.

[14] Zhu (2016) had proposed a similar procedure of the derivation. For convenience, this paper briefly repeats that method.

[15] Usually we do not need the solutions of minimum expenditures on the foods.

Sometimes we have to build a trend line and adjust it to forecast a constraint.[16] If this is the case, we solve the constraint in the calibration year before running the model.

Second, change the data of food price and the amount of nutrient requirements to another year, and run the programming model again to find the results of food demand system in that year. If some constraint is unavailable, compute it before running the model. Enumerate the data in each year and run the model repeatedly, then we get all the results of the food demand system. Within this demand system, the price of a food and related demand of that food over all the years can be drawn as a demand curve. Although the demand curve is not in a form of function, this procedure may be completed because all the basic information of food price and demand[17] has been obtained.

Third, if it is necessary to express the results from the programming model in the form of functions, we can estimate the obtained demand of all foods simultaneously with an econometric method and then we obtain a system of demand functions. Indeed, this step is not essential for the pure theory of Economics.

3. A System of Food Demand Functions in Rural China

3.1 Data

We consider the vegetarian foods (not including the vegetables) in rural China from 2000 to 2012. The kinds of foods in consumption database include wheat, rice, soybeans, and edible vegetable oil. For the price database, however, there is no classification exactly corresponding to rice and edible vegetable oil. We need to take a simple average value of the prices of long-grained nonglutinous rice, high quality long-grained nonglutinous rice, and round-grained rice as that of rice, and simple average value of the prices of peanut oil, rape oil, and soybean oil as that of edible vegetable oil (hereinafter the oil). Appendix Table 1 reports the results of how to compute the two average prices. The prices of wheat and soybeans are directly from the same food in the price database, respectively. Table 1 describes the consumption and price of the four foods.

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[16] See the first way to find the exogenous nutrient requirements of prime foods in Section 3.3.

[17] It is true that other variables can also affect the food demand. The best example is income. But probably income does not directly affect the food demand. Instead, it could directly affect consumer's preferences, e.g., a higher income may change one of the preferences to higher energy intake. Then the consumer attempts to map the new preferences into the attributes of foods in the market. If this procedure is successful, then the demand for the foods is thus satisfied. Thus income might only indirectly enter the food demand. Further, if we accept the opinion that an increasing income does not change the preferences but just relaxes some constraints, like that in Stigler and Becker (1977), then we can rewrite the programming model by Duality so as to move the relaxed constraints being part of the objective function or functions. Hence we are able to have the equivalent result that the income directly changes the preferences or objective and indirectly changes the demand. Therefore, this paper does not explicitly include income in the programming model and the demand functions. This conjecture will be further expounded in footnote 31 after we obtain the final results. For simplicity, we do not discuss other variables in the present paper.

Table 1. The Per Capita Consumption and Price of Vegetarian Foods in Rural China

(Unit: Kilogram, Chinese *yuan*)

Year	Wheat		Rice		Soybeans		Oil	
	Consumption (1)	Price (2)	Consumption (3)	Price (4)	Consumption (5)	Price (6)	Consumption (7)	Price (8)
2000	80.27	1.02	126.82	1.15	2.53[a]	2.53[a]	5.45	7.20
2001	76.81	1.09	122.89	1.20	2.46	2.43	5.51	6.51
2002	76.31	1.06	123.11	1.12	2.20	2.38	5.77	6.39
2003	73.23	1.14	119.31	1.18	2.05	2.96	5.31	7.67
2004	72.39	1.52	117.40	1.65	1.91	3.88	4.31	8.95
2005	68.44	1.51	113.36	1.67	1.91	3.59	4.90	8.39
2006	66.11	1.47	111.93	1.70	2.09	3.48	4.72	8.27
2007	64.41	1.60	109.35	1.85	1.74	4.09	5.06	10.71
2008	62.74	1.77	110.98	2.02	1.75	5.51	5.36	14.70
2009	59.56	1.92	105.67	2.08	1.69	4.84	5.42	11.51
2010	57.52	2.07	101.91	2.36	1.61	5.19	5.52	12.60
2011	54.75	2.26	97.09	2.78	1.38	5.59	6.60	14.97
2012	52.33	2.34	92.59	2.90	1.14	5.85	6.93	16.23

Note: [a] These two values of soybeans consumption and price are same in the year of 2000.

Source: Department of Rural Survey, National Bureau of Statistics of China (2001-2013).

The nutrient coefficients or nutrient composition of the foods are from the database of China Food Nutrition Network. For the oil, the nutrient coefficients are a simple average of that of peanut oil, rape oil, and soybean oil. Indeed, the macronutrients of the three kinds of oils are all the same. The nutrient coefficients of wheat, rice, and soybeans are measured at an average quality of these foods. Table 2 presents the nutrient coefficients of the foods. The unit of nutrients is kilogram per kilogram of the food. The unit of energy is calories.

Table 2. Nutrient Coefficients

(Unit: Kilogram/Kilogram Food, Calories)

Foods	Protein	Fat	Carbohydrate	Energy
Wheat	0.119	0.013	0.752	3380
Rice	0.074	0.008	0.779	3470
Soybeans	0.350	0.160	0.342	3900
Oil	0	0.999	0	8990

Source: China Food Nutrition Network (2016).

3.2 The Prime Foods

The prime foods refer to a subcategory of foods that the nutrients contained by these foods can satisfy all the nutrient requirements of its supercategory of foods at the minimum cost in a changing price context during a time period. Put another way, all the nutrients of a supercategory of foods can be represented by that of the prime foods. According to this definition, the difference between the prime foods and the supercategory of foods is that the supercategory of foods has multiple attributes, while the prime foods have only one attribute of nutrition. Since this paper focuses on the attribute of nutrition, we will only discuss the prime foods and derive the demand functions of them based on the attribute theory.

The method for finding the prime foods is to run a programming model of the supercategory of foods by minimizing the cost while satisfying all the nutrient requirements for the supercategory of foods. The kinds of prime foods can vary in different years and sometimes only one kind of food is the prime food. The computer software of General Algebra Modeling System (GAMS) is used to run the programming model.[18] As for the results, we only need to know which kinds of foods are the prime foods. We do not need all other information. In the case of the supercategory of wheat, rice, soybeans, and oil, the prime foods are wheat and oil.

Table 3. Stable Ratios of Nutrients of Prime Foods (To be continued)

(Unit: Kilogram, Calories)

Year	Nutrients of Prime Foods (Wheat and Oil)				Nutrients of Supercategory of Foods (Wheat, Rice, Soybeans, and Oil)			
	Protein (1)	Fat (2)	Carbohydrate (3)	Energy (4)	Protein (5)	Fat (6)	Carbohydrate (7)	Energy (8)
2000	9.552	6.488	60.363	320308.1	19.822	7.907	160.021	770240.5
2001	9.140	6.503	57.761	309152.7	19.095	7.880	154.334	745175.0
2002	9.081	6.756	57.385	309800.1	18.961	8.093	154.040	745571.8
2003	8.714	6.257	55.069	295254.3	18.261	7.539	148.713	717255.0
2004	8.614	5.247	54.437	283425.1	17.971	6.492	146.545	698252.1
2005	8.144	5.785	51.467	275378.2	17.202	6.997	140.428	676186.4
2006	7.867	5.575	49.715	265884.6	16.881	6.805	137.623	662432.7
2007	7.665	5.892	48.436	263195.2	16.366	7.045	134.215	649425.7
2008	7.466	6.170	47.180	260247.6	16.291	7.338	134.232	652173.2
2009	7.088	6.189	44.789	250038.6	15.499	7.305	127.684	623304.5
2010	6.845	6.262	43.255	244042.4	14.950	7.335	123.194	603949.1
2011	6.515	7.305	41.172	244389.0	14.183	8.303	117.277	586673.3
2012	6.227	7.603	39.352	239176.1	13.478	8.526	111.870	564909.4

Source: Calculated from Table 1 and Table 2.

There is an endogeneity concern of the nutrients for the supercategory of foods. In finding the prime foods, we run the programming model subject to the constraints of nutrient requirements that are exactly

[18] The GAMS' codes are based on Stigler's nutrition model in GAMS model library with the name of DIET.

transformed from the consumption of supercategory of foods. The goal of this procedure, however, is totally not to make any prediction or forecast of the foods, but to find prime foods. Therefore, the endogeneity concern does not affect the derivation of demand functions of the prime foods.

Columns 1 to 8 of Table 3 report the nutrient intake from the prime foods, i.e., wheat and oil, and from the supercategory of foods. Each value is a product of a food consumed in Table 1 and the related nutrient coefficient in Table 2.[19]

3.3 Exogenous Nutrient Requirements of Prime Foods

We will derive, not estimate, a system of demand functions for the prime foods. However, the nutrient requirements of the prime foods in the columns 1 to 4 of Table 3 cannot be used in the programming model, because they are exactly computed from the food consumption. Otherwise, there is an endogeneity problem.[20] But in this case we have four ways to solve such a problem:

First, since the prime foods within a supercategory can provide all the nutrient requirements for the supercategory, then their trend of the nutrient requirements should be correlated to that of the supercategory.[21] With this assumption, we can estimate a trend line[22] of a nutrient intake for the supercategory of foods and set one year as the calibration year, then embed the trend line in a datum of same nutrient requirement of prime foods at that year. Thus we obtain a trend line of that nutrient of prime foods. This trend line is exogenous to the intake of that nutrient of prime foods, because it is not transformed from the consumption of prime foods, but shifted from the trend of same nutrient of the supercategory of foods and then is embedded into the requirement of that of the prime foods. Repeat this procedure to the other three nutrients, we are able to find four trend lines of the nutrient requirements for the prime foods, thus the food demand system of the prime foods can be derived. However, despite the fact that this way is theoretically elegant, it has a disadvantage. If the goodness of fit of a nutrient's trend line for the supercategory of foods is not high enough, then usually the goodness of fit of that nutrient's embedded trend line for prime foods will also be not high enough.[23] As a result, the derived food demand will not be accurate. In the dataset of this paper, the goodness of fit of a linear trend line is not sufficiently high for deriving the demand functions. Therefore, we do not use this method for the dataset.

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[19] For example, in 2000, the protein intake of prime foods 9.552≈0.119*80.27+0*5.45; the energy intake of wheat, rice, soybeans, and oil 770240.5≈3380*80.27+3470*126.82+3900*2.53 +8990*5.45. For the reason of rounding to 3 decimal places in GAMS, the equations are approximately held.

[20] If some of the nutrient intake is from a doctor or nutritionist's advice or a detailed national dietary guideline, then this part of nutrient intake is for certain exogenous.

[21] The supercategory of foods may not be an arbitrary combination of foods. It should be some regular group of foods, for example, the staple grain foods, the vegetables, or the meat and fish.

[22] The trend line can be any form, linear or non-linear.

[23] The reason could be that the assumption outlined above does not hold or our econometric techniques are not good enough to find a trend line of high goodness of fit for the nutrient intake of the supercategory of foods. If the latter is the case, we need to improve the modeling techniques, for example, to develop better functional forms or to estimate the trend line with some non-parametric methods.

Second, if there is another area, e.g., another country or province, that it has the similar income level,[24] taste, habit, and other determinants to those in our case in the same time period, then we can assume that the trend of nutrient intake for prime foods in that area is similar to that in our case in the same time period and use this area's nutrient intakes as the nutrient requirements in our case. These nutrient requirements are exogenous.[25]

Third, if there is no such an area in the same time period, but there is still another area that its past income level in a historical time period is similar to the current income level of our case, and if all other things are equal, then we can apply its nutrient intakes in that time period as current nutrient requirements in our case. These nutrient requirements are also exogenous.

Fourth, the stable ratios of nutrients provide a simple way to find exogenous nutrient requirements.[26] Such a way is based on a stylized fact that the ratios of four nutrients of prime foods divided by the same four nutrients of the supercategory of foods, respectively, are stable,[27] at least during the time period of the dataset. The continued part of Table 3 demonstrates this fact.

The columns of 9 to 12 of Table 3 are the ratios of four nutrients of the prime foods divided by that of the supercategory of foods, respectively. For example, column 9 is a ratio of the protein of prime foods in column 1 divided by the protein of the supercategory of foods in column 5. Then we calculate their simple average values in the last row of the table. Although it is not easy to define a criterion of stability, probably the best evaluation principle is to test that whether the obtained demand functions have high goodness of fit. If it is true, then we can conclude that the ratio is stable. The rationality behind this principle is that if the ratio is not stable, the obtained demand functions cannot have high goodness of fit.

It should be noted that the nutrient requirements calculated from the ratios of nutrients are not endogenous. The last four columns of Table 3 are the results of those nutrient requirements. They are products of the average ratios and the nutrient intake of the supercategory of foods. For instance, column 13, the protein requirement of prime foods, is a product of the average ratio of protein, 0.469, and all the protein intake of the supercategory of foods in column 5. Because column 13 is a fixed ratio of column 5, it is endogenous from column 5. But we have no evidence to claim that the total protein intake of the supercategory of foods in column 5 can determine the protein intake of prime foods in column 1, because other things being equal, the protein intake of prime foods depends not only on the price system of wheat and oil but also on that of rice and soybeans. If the price of any food in the supercategory

[24] That indicates the consumers may have similar preferences.

[25] Dubois et al. (2014) used a similar way to solve the endogeneity problem in regression.

[26] Other things being equal, a simple way is better than other ways. Another reason that we take this way for setting the exogenous nutrient requirements is to attempt revealing a potential law from the stylized fact, which will be further explained in footnote 30, and test its effectiveness.

[27] If these ratios are not stable but we still want to use a method only based on the data of prime foods, then we can estimate the trend line of each nutrient of the prime foods to make prediction and then put these predictive values into the programming model. Strictly speaking, the estimated trend lines cannot change the overall feature of the programming model, i.e., the derivation of food demand functions from the programming model is still a special non-parametric method.

changes, not only will the consumption of the supercategory change but also that of prime foods will change and nothing guarantees that the proportions of the changes within two categories are same. That means column 1 is not endogenous from column 5. Thus column 13 is also not endogenous from column 1. For the same reason, the other nutrient requirements of prime foods in columns 14, 15, and 16 are all not endogenous from the related nutrient intake in columns 2, 3, and 4, respectively. Therefore, the endogeneity concern is removed.

Table 3. Stable Ratios of Nutrients of Prime Foods (Continued)

(Unit: Kilogram, Calories)

Year	Stable Ratios of Nutrients of Prime Foods				Exogenous Nutrient Requirements of Prime Foods			
	Ratio of Protein (9)=(1)/(5)	Ratio of Fat (10)=(2)/(6)	Ratio of Carbohydrate (11)=(3)/(7)	Ratio of Energy (12)=(4)/(8)	Protein (13)= 0.469*(5)	Fat (14)= 0.840*(6)	Carbohydrate (15)= 0.362*(7)	Energy (16)= 0.409*(8)
2000	0.482	0.821	0.377	0.416	9.299	6.639	57.985	315320.5
2001	0.479	0.825	0.374	0.415	8.958	6.616	55.924	305059.2
2002	0.479	0.835	0.373	0.416	8.895	6.795	55.817	305221.7
2003	0.477	0.830	0.370	0.412	8.567	6.330	53.887	293629.3
2004	0.479	0.808	0.371	0.406	8.431	5.450	53.102	285850.0
2005	0.473	0.827	0.367	0.407	8.070	5.875	50.885	276816.7
2006	0.466	0.819	0.361	0.401	7.920	5.713	49.869	271186.2
2007	0.468	0.836	0.361	0.405	7.678	5.915	48.634	265861.4
2008	0.458	0.841	0.351	0.399	7.643	6.161	48.640	266986.2
2009	0.457	0.847	0.351	0.401	7.271	6.133	46.267	255168.0
2010	0.458	0.854	0.351	0.404	7.013	6.158	44.640	247244.3
2011	0.459	0.880	0.351	0.417	6.654	6.971	42.496	240171.9
2012	0.462	0.892	0.352	0.423	6.323	7.159	40.537	231262.2
Average	**0.469**	**0.840**	**0.362**	**0.409**	-	-	-	-

3.4 The Demand System of Prime Foods

Run Model 1 with the data of price in Table 1, nutrient coefficients in Table 2, and the nutrient requirements of prime foods in the last four columns in Table 3, we obtain the annual results of the demand of wheat and oil simultaneously.[28] Table 4 reports the results. We do not estimate the demand of wheat and oil in a form of function. Because the evaluation criteria of a demand function depend on the techniques of estimation and that is beyond the scope of this paper. For simplicity, however, we still call the two series of demand data in Table 4 as demand functions.

The facts that the correlation coefficient of wheat demand and its consumption, the column 1 of Table 1, is 0.9971 and that of oil, with the consumption in column 7 of Table 1, is 0.9814, evidently show that

[28] The GAMS' codes are based on Stigler's nutrition model in GAMS model library with the name of DIET.

the two demand functions are highly related to their real consumption. Further, the two R^2s, which can be viewed as the goodness of fit in our case, of the demand functions and the real consumption of wheat and oil calculated by Microsoft Office Excel are 0.9942 and 0.9633, respectively.[29] That indicates the variation in the consumption of wheat and oil can be explained significantly by the demand functions at 99.42% and 96.33%, respectively. [30]

From the procedure of computing the demand functions, it turns out that one of the salient features of this paper is that we are able to well understand the mechanism of how the food demand forms through the programming method. Other than the parametric and typically non-parametric estimation methods, the programming method is an instrument of empirical derivation that allows us to simulate and realize the most probably true mechanism of demand's formation, in particular when the annual data of price and the nutrient requirements repeatedly enter the model and then we get the results of food demand. The demand mechanism can be simulated with a programming model that a rational consumer minimizing the cost when the price and other constraints change jointly or separately. Then the results of quantities from the model are the demand function or a system of demand functions.

Good results are typically not obtained by chance but by the theoretical insight. Comparing with the mainstream utility theory and regression methods, the results in Table 4 might be solid evidence that this system of food demand functions is also a good simulation of the real consumption.[31] At least, this

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[29] The condition that the R^2 equals the square of correlation coefficient is that the sample covariance between the fitted values and the residuals is zero in a linear least square regress with a constant. We suppose this condition is satisfied here.

[30] For the highly significant results, there might be an argument that the sample size of only 13 annual data is not large enough to robustly validate the results. However, the results are significant not only because of the sample size or the stability of one nutrient intake in this case, but because of the joint stability of three nutrient intakes, i.e., protein, fat, and carbohydrate, in 13 years. The probability to keep these three intakes stable at the same time should be very low. The stability of energy intake is a consequence of that of the three nutrients. Therefore, the reason that the stability of nutrient intakes holds is at least partly independent of the sample size. Indeed, from the three main determinants of this stability, i.e., the possibly variable nutrient coefficients of the prime foods (but they are assumed to be fixed in this paper), the changing demand for nutrients due to the increasing per capita income, and the changing price system, we can find that every determinant can be changeable. Thus the fact that nutrient intake is stable is not a coincidence, but could be a law, i.e., a law of stable nutrients. Moreover, the way that we use to solve the endogeneity concern affects the significance of demand functions. If we apply other ways to derive the demand functions, the results should be different. It is true that the law of stable nutrients may contribute heavily to the significance. But it might also be one of the best ways to reveal a stylized fact in the real world for deriving the demand functions in this case. Finally, the sample time period of 13 years may be not long enough for verifying the law of stable nutrients, but it might be long enough for proposing a conjecture that income should not directly enter the demand function, which is discussed in footnotes 17 and 31.

[31] Because the two R^2s are so high, especially the one of wheat demand function at 99.42%, that we could confirm the conjecture in footnote 17 that there is almost no space for income to enter the food demand functions. For this case, however, an argument could be that just because the wheat and oil are prime foods, so they are the necessities for maintaining subsistence. Thus the income has no effect on them. But the facts that the consumption of wheat is decreasing and that of oil is increasing in Table 1 suggest that at least one of the two foods should be positively or negatively affected, though indirectly, by income while the per capita income in rural China has been increasing during the same period. Therefore, the implication of the two significant R^2s is that the income might not directly affect the food demand, but directly affect the consumer's preferences or constraints, which then

demand system is the first exception[32] of the mainstream doctrine and we might have no reason to refuse thinking about that the approach of attribute theory and programming method could be an alternative approach to the mainstream counterparts.

Table 4. The Demand System of Wheat and Oil

(Unit: Kilogram)

Year	**Wheat**	**Oil**
2000	78.325	5.626
2001	75.277	5.643
2002	74.800	5.828
2003	72.530	5.393
2004	72.573	4.511
2005	68.632	4.988
2006	67.353	4.842
2007	65.162	5.074
2008	64.831	5.324
2009	61.525	5.339
2010	59.362	5.392
2011	56.511	6.243
2012	53.906	6.465
Correlation Coefficient of the Demand and Consumption	0.9971	0.9814
R^2 of the Demand and Consumption	0.9942	0.9633

Note: The *p*-value of correlation coefficient is 0.6835 at the significant level of 1% (n-2=11).

It is worth reporting, as stated, that the effectiveness of the stable ratios of nutrients depends on the prediction of demand functions. According to the fact that the two R^2s of food demand functions are significant, we are able to validate that the ratios of nutrients of prime foods are stable, at least in this dataset. Indeed, the method of stable nutrients is not the only way to solve the endogeneity problem. If it does not hold, three other ways that we already outlined above can be applied to find the exogenous nutrient requirements of prime foods.

attempt to map into the attributes of foods, and finally indirectly affect the food demand. Probably the common estimated demand function with income, which is in essence a proxy of constraints based on some attributes, might not be a true demand function but a demand response function.

[32] Indeed, we obtain similar results from the suppercategory of meat, eggs, and aquatic products in the same dataset. But because the theory and method are the same and the results are no more significant than those in Table 4, we do not report the results.

4. Conclusions

Consumers are the scientists of themselves. Probably they do not need some strict assumptions in making decision. Based on the new attribute theory and data of consumption and price of vegetarian foods in rural China, this paper builds a linear programming model subject to four nutrient requirements and simultaneously derives a system of food demand functions from the solutions of the model. The method to obtain the demand functions is derivation, which is different than the mainstream methods of parametric or typically non-parametric estimation, and sheds new light on the mechanism of demand's formation. Moreover, this paper is independent of any utility function. Especially, it does not depend on the assumption of the continuously differentiable objective function that is crucial in the classical utility theory.

Some major weak points are also obvious. First, the stable ratios of nutrients of prime foods need more evidence to test its robust effectiveness. Second, the data of the secondary attributes of foods, not just the primary attribute of nutrition, are unavailable. If all the data are available, then we will be able to run a complete programming model of multiple attributes and simultaneously derive a system of more demand functions. Finally, it is necessary to develop some programming methods to incorporate more empirical information, for example, the error terms, to simulate the real world with fewer assumptions.

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Appendix:

The price of rice in column 4 of Table A1 is a simple average of the prices of long-grained nonglutinous rice, high quality long-grained nonglutinous rice, and round-grained rice in columns 1 to 3. The price of oil in column 8 of Table A1 is a simple average of the prices of peanut oil, rape oil, and soybean oil in columns 5 to 7. The results are reported in Table A1.

Table A1. The Simple Average Prices of Rice and Oil

Year	Long-grained Nonglutinous Rice (1)	High Quality Long-grained Nonglutinous Rice (2)	Round-grained Rice (3)	Average Price of Rice (4)=((1)+(2)+(3))/3	Peanut Oil (5)	Rape Oil (6)	Soybean Oil (7)	Average Price of Oil (8)=((5)+(6)+(7))/3
2000	1.01	1.18	1.27	1.15	8.49	6.73	6.37	7.20
2001	1.05	1.24	1.31	1.20	8.04	5.98	5.50	6.51
2002	1.04	1.16	1.15	1.12	7.88	5.79	5.50	6.39
2003	1.08	1.25	1.20	1.18	9.43	6.85	6.74	7.67
2004	1.51	1.72	1.72	1.65	11.15	7.99	7.71	8.95
2005	1.50	1.72	1.78	1.67	10.80	7.43	6.93	8.39
2006	1.51	1.75	1.83	1.70	10.81	7.20	6.79	8.27
2007	1.69	1.92	1.94	1.85	13.56	9.77	8.81	10.71
2008	1.90	2.13	2.02	2.02	18.36	13.89	11.86	14.70
2009	1.93	2.16	2.15	2.08	14.77	11.02	8.73	11.51
2010	2.13	2.37	2.57	2.36	16.62	11.73	9.46	12.60
2011	2.51	2.83	2.99	2.78	20.14	13.55	11.22	14.97
2012	2.73	--	3.07	2.90[a]	22.80	14.40	11.48	16.23

Notes: -- The datum is not available.

[a] This price is an average of 2.73 and 3.07.

Source: Department of Rural Survey, National Bureau of Statistics of China (2001-2013).