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Abstract: The law of demand might have no exception and the Giffen behavior should be one of the standard forms of the law. According to the new attribute theory and semi-empirical simulation method, Giffen behavior is verified in a general equilibrium framework using the data of food consumption in rural China. The superior food and the wealthy households with high preference for taste have higher possibility than the inferior food and low income households in exhibiting Giffen property. Therefore, to find empirical Giffen behavior, we should focus on the superior food and wealthy households with high preference for taste.

Key Words: Law of demand, New attribute theory, Giffen behavior
JEL: C61, D01, D11, D12, D50

The definition of the law of demand should not be based on the relationship between the price and quantity, but based on whether the demand is derived from a rational optimization model. If we only consider the budget constraint in a maximization model, the law of demand usually exhibits a negative relationship between price and quantity, which is a common demand curve. However, if we consider maximization model in a general equilibrium, for example, a model of two foods and with taste as the second constraint, then the derived food demand curve might not simply be negatively sloping. It could include some positive relationship between the two variables. This paper will show that, in terms of relationship between price and quantity, the law of demand on the ground of a rational optimization model not only can be negative but also could be positive.

Jensen and Miller (2008) provided the first empirical evidence of Giffen behavior, which referred to an upward sloping demand curve, in a real-world experiment of food consumption in China's poor households. The explanation of the behavior, however, was rooted in the traditional utility theory that might not be able to process a model with multi-objective or multi-constraint. Thus the mechanism of the Giffen behavior, especially in a general equilibrium with two foods and two constraints, was not sufficiently clear.

Read (2013) found that during the Irish famine in 1840s, it was not the potato, wheat, or other cereals, but the bacon pigs displayed some Giffen-style behavior among the wealthier classes. This finding made the Giffen good a superior good rather than the standard inferior good like potato, bread, wheat, or rice. For simplicity, we call this finding as "superior Giffen behavior". This paper will reveal that the "superior Giffen behavior" is not a special but a general case of Giffen behavior. Put another way, the Giffen good is more likely to be a superior good than an inferior good.

Other than the two findings above, a widely accepted viewpoint is that Giffen behavior is rarely observed so as to " We shall have to find a new example of the positively sloping demand curve, or push our discussion of it deeper into footnotes" (Stigler,1947). In this paper, we will present a new approach of theory and method to explore the mechanism of the Giffen behaviour. Within one model that generates this mechanism, we will explain all the three facts at same time:

1. The Giffen behavior;
2. The "superior Giffen behavior"; and
3. The new reasons that the Giffen behavior is hardly observed and the new places to find it.

The theory of this paper is new attribute theory that is ascribed to Lancaster (1966) who laid the foundation of attribute theory that consumer's preferences were not exercised on the goods themselves but on their attributes.[1] This attribute theory, however, was still built on the utility theory that had some defects in empirically computing complicated objective functions or constraints. Therefore, we will not use this basic attribute theory but use new attribute theory that is completely independent of utility theory to construct optimization model for deriving demand curve and explaining the Giffen behavior. In the new attribute theory, we only consider the attributes of goods so that consumer's preferences for attributes will directly enter the model as objective functions or constraints, in which there is no any theoretical and empirical space for utility. Lipsey and Rosenbluth (1971) applied Lancasterian method to demonstrate that we should expect to find Giffen behavior "over certain price ranges and in certain defined situations." Davies (1994) introduced a calorie-modified utility function to explain the decision processes of Giffen behavior. These studies, however, were rested on the utility theory and did not provide real data, in particular the price data, to simulate the demand. Moreover, the inclusion of calorie in the modified objective function is also different than the technique of the present paper in that both caloric intake and preference for taste jointly play a key role in the model of this research. There were other studies proposed specific utility functions to generate Giffen behavior (Armendariz, 2016; Biederman, 2015; Haagsma, 2012; Moffatt, 2012; Sørensen, 2007),[2] but none of them contributed an empirical case to verify the existence of the phenomenon. In this

[1] "Attribute" is a more appropriate term with respect to the property of goods, while "characteristic" is appropriate to that of consumers or households.

[2] Wold and Juréen (1953) firstly constructed a utility function of Giffen behavior. But Sproule (2009) found it could not generate Giffen property.

paper, we will not employ any abstract function but operate concrete data to simulate Giffen behavior.

The method of the present paper is to build a multi-constrained programming model to derive the demand curve that exhibits Giffen property. Programming models have been largely applied in economic research, but it seemed that there was no research to formally derive a demand function from the programming model. Without that derivation, we are not able to use the programming model to simulate Giffen behavior. Because the analysis of Giffen behavior is a study of demand or consumption, we need to obtain demand curve and fully understand the demand mechanism first and then do research of specific behaviors. This is the reason that no analysis, to date, is conducted on the empirical mechanism of Giffen behavior. According to the new attribute theory and programming method, Zhu (2016) presented a programming model to derive, not estimate, a demand system of food that could be a theoretical basis for simulating Giffen behavior.[3]

A noticeable feature of this paper is that, with the demand mechanism construed by programming method, we are able to apply this demand mechanism to expound the mechanism of specific behaviors, which is different than the existing research on Giffen behavior that used the regression method. Typically, regression method only reveals a static trend of the data; whereas the programming method elucidates the detailed dynamic changes of the demand if any of the variables is changed. For example, if the data is annual data and if one of the good prices is changed, then the annual demand of this good and other goods should also be changed. Or if we change our preference of taste for some food, then the whole demand system should be changed too. A strong point of the programming method is that it can accurately and fully display the consequences on the dependent variables due to a change of one or more independent variables at the same time, but the regression method usually reports a change on percentage or average. In this paper, different than Gilley and Karels (1991), Nachbar (1998), and Weber (1997) proposed theoretical analyses in a framework of general equilibrium, we might firstly explore the aforementioned empirics of the mechanism of Giffen behavior under general equilibrium.

There are four groups of data used in the programming model of food demand. The first two groups, i.e., nutrition data and price data of two foods, are real data, which will be detailed described in next section. The other two groups of data are budget and taste constraints. Because no exact data on these constraints are available, we have to set parameters to represent the budget and taste. Thus, strictly speaking, the programming model is not constrained by real data but by parameters. For this reason, the programming method is indeed a semi-empirical simulation method (hereinafter empirical simulation method) with the programming model.

[3] Although that demand system was not derived for wheat and pork, which are two representative foods in this paper, but for wheat and edible vegetable oil, it does not affect the results of this paper. Because at least in theory if more detailed information is available, we will be able to derive a larger demand system including wheat and pork.

Although the budget and taste constraints are not real data but parameters, it has an advantage for finding Giffen behavior. Since we are able to target the levels of budget and taste that potentially could generate Giffen behavior by adjusting the two parameters and different combinations of two constraints correspond to different categories of consumers or households, if the results exhibit Giffen property, then we can do a survey on those consumers or households who are at the levels of budget and taste that principally might have the property. A major difficulty in the research of Giffen behavior is how to find the characteristics of consumers or households, especially their income, food budget, and some preferences for food. The empirical simulation method could solve the difficulty. Unlike the nutrition and price data that are exogenous to the model and cannot be controlled, the adjustable parameters of budget and taste make the empirical simulation method a useful and strong instrument to explore the potential places of Giffen behavior in a real world.

The remainder of this paper proceeds as follows. Section 1 sets up the objective function and constraints of budget and taste for the programming model. Section 2 analyzes the mechanism of Giffen behavior not only in a partial but in a general equilibrium. Section 3 highlights that instead of the inferior food, the superior food is usually a Giffen good. The observability of Giffen behavior is discussed in Section 4. Section 5 draws the overall conclusion on the law of demand and specific conclusions of the new findings in this paper.

1. Settings of the Programming Model

In a classical context, there are two foods for a consumer: an inferior (basic) food and a superior (fancy) food. The new attribute theory sheds light on further analyzing the two foods. The inferior food only has an attribute of nutrition or it only offers nutrition to transform into calories. The superior food has two attributes: the primary attribute to offer nutrition as the inferior food and the secondary attributes to satisfy a consumer's preferences of taste, diversity, tradition, etc. For simplicity, the classical assumption usually sets taste as the only one secondary attribute of the superior food.[4]

According to the annual data of rural food consumption in China from 2000 to 2012, wheat and pork are two foods that supply the most calories for rural residents.[5] Thus, we set wheat and pork as the inferior and superior food, respectively. The wheat provides most of the calories that largely come from three major macronutrients of carbohydrate, fat, and protein; while the pork not only provides a certain amount of calories but provides taste to satisfy other preferences.

[4] When the superior food satisfies the consumer's preference for taste, it may satisfy his preference for other attributes at the same time. For example, together with the inferior food, the superior food also satisfies the preference of diversity.

[5] Because it needs too much data and computation to obtain this result, we do not report those processes in this paper. In fact, we may find that other kinds of foods can also be the representatives of inferior and superior foods if their prices have enough fluctuation to allow us conducting analyses.

Most likely, because pork has more than one attributes its unit price is higher than that of wheat. Thus the budget constraint on pork is more strictly than on wheat.

The objective function of the programming model is the total amount of calories consumed from all foods.[6] Regarding the constraints, since we have set two attributes of the foods, thus the model has two constraints, namely budget and taste. Budget is easy to define and set in different scenarios. But how to accurately define taste of pork based on the available data is a problem. In the programming model, the optimal quantities of inferior and superior foods are determined simultaneously, which is different than the classical assumption that the consumer buys the superior food after he already gets enough calories from the inferior food (Jensen and Miller, 2008). Therefore, we need to exactly quantify the taste of pork.

Table 1. Nutrition Content of Wheat and Pork

(Unit: Kilogram/Kilogram Food, Calories)

	Carbohydrate	Fat	Protein	Calories
Wheat	0.752	0.013	0.119	3380
Pork (lean and fat)	0.024	0.370	0.132	3950

Source: China Food Nutrition Network (2016).

A field survey or experiment of the taste may be accurate but currently we do not have that data. In light of the new attribute theory and based on the available data, there is a simple way to objectively quantify the taste. Considering the primary attribute of nutrition, food consists of macronutrients and micronutrients. Due to data issue, we only use three major macronutrients, i.e., carbohydrate, fat, and protein, to define the taste of pork.[7] Our definition of the taste pays special attention to the comparative proportion of nutrition intake.[8]

Table 1 presents the content of macronutrients and calories of wheat and pork, where the pork is regular meat with lean and fat. Table 2 presents the per capita consumption of wheat and pork in

[6] Usually, the objective function of a primal programming model of food consumption based on the new attribute theory with constraints of nutrient requirements should be a vector product of the required nutrients and their shadow prices, which is like the "utility" if applicable. But it barely has any concrete scientific meaning in a real world. Therefore, we use calories instead of the vector product or "utility" as the objective function.

[7] A further research with the data of micronutrients may be better than this research, because more likely the taste may be contained in some of the micronutrients.

[8] Probably the feature of a taste might not be unique and there are a few equivalent ways to define the taste of a food. That is like to identify a person, we can use such ways as a photo identification card, the finger prints, Deoxyribonucleic acid (DNA) test, and iris recognition. On the other hand, some of the ways may have more than one function or effect. For example, the DNA test not only is able to identify a person but can provide more information on the health condition of that person. This is similar to the nutrient fat in that although its main function is to provide calories, it does not mean that it cannot be defined as taste in terms of its proportion in pork and wheat consumption, which will be detailed discussed in the following paragraphs.

rural China from 2000 to 2012, which will be used to calculate the total nutrient intakes for determining the constraint of taste, the unit price of wheat and pork, where the pork is also regular meat with lean and fat but without bones, and the total expenditure of wheat and pork,[9] which will be the maximum value of the budget in all scenarios of the model.[10]

Table 2. The Per Capita Consumption and Unit Price of Wheat and Pork in Rural China

(Unit: Kilogram, Chinese *yuan*)

Year	Per Capita Consumption		Unit Price		Expenditure
	Wheat	Pork	Wheat	Pork	
2000	80.27	13.28	1.02	9.68	210.43
2001	76.81	13.35	1.09	10.18	219.63
2002	76.31	13.70	1.06	9.85	215.83
2003	73.23	13.78	1.14	10.70	230.93
2004	72.39	13.46	1.52	13.97	298.07
2005	68.44	15.62	1.51	13.39	312.50
2006	66.11	15.46	1.47	12.30	287.34
2007	64.41	13.37	1.60	18.93	356.15
2008	62.74	12.65	1.77	23.53	408.70
2009	59.56	13.96	1.92	18.56	373.45
2010	57.52	14.40	2.07	18.93	391.66
2011	54.75	14.42	2.26	26.42	504.71
2012	52.33	14.40	2.34	24.39	473.67
Average	-	-	1.60	16.22	-

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

Table 3 reports the results of the nutrient intakes of carbohydrate, fat, and protein from wheat and pork respectively. Each value is a product of the consumed food in a year (in Table 2) and its nutrient content (in Table 1).[11] To define the taste of pork based on the nutrition data, we notice that the fat intake from pork (5.176 kilograms per year on average) is higher than that from wheat (0.865 kilograms per year on average), whereas the carbohydrate and protein intakes from pork are lower than those from wheat. Considering the proportion of nutrient intakes from pork and wheat in Table 3, it is easy to test that

$$\frac{fat\ intake\ from\ pork}{fat\ intake\ from\ wheat} > \frac{other\ nutrient\ intake\ from\ pork}{other\ nutrient\ intake\ from\ wheat}.$$

[9] For example, the total expenditure of wheat and pork in the year of 2000 is 210.43≈80.27*1.02+13.28*9.68.

[10] Indeed, besides wheat and pork, many other foods are consumed in the real world. But in this paper, we assume that only wheat and pork are the available foods.

[11] For example, the intake of carbohydrate from wheat in the year of 2000 is 60.363≈80.27*0.752.

This is a distinctive feature of the consumption of pork comparing with wheat, even though the total consumption of pork is less than that of wheat. Therefore, to identify the most typical attribute of pork based on the available data, fat intake could be a good proxy.[12] This fact implies that we can use nutrient fat that has comparative advantage in the nutrient proportion to quantify the taste of pork as a constraint in a programming model.[13] Thus we define

f_0 = the taste of pork in the form of fat intake.

But the consumer's fat intake is not only from pork but also from wheat, which means that f_0 cannot enter the model as taste constraint exclusively. Therefore we have to consider the total fat intake f from pork and wheat jointly and set is as the taste constraint, i.e.,

$$f=1.044+f_0,$$

where 1.044 is the maximum fat intake from wheat which is in the year of 2000; f_0 is the taste of pork that can induce Giffen behavior. For simplicity, we will not consider the value of f_0 but only consider the value of f in the following model and scenarios because f_0 can be simply calculated from f. To set the value of the taste constraint f, it is easy to know that if $f \leq 1.044$ (that is equivalent to the consumption of wheat at 80.27 kilograms in 2000), then the entire fat intake may be provided by wheat[14] and the consumer does not have to buy pork. Thus we specifically define the taste constraint as

$$f>1.044 \text{ or}$$

$$f_0>0.$$

Because only under this condition has the consumer to buy pork to maintain a higher level of nutrient fat. Put another way, the definition of taste of pork works only if $f_0>0$ to satisfy consumer's preference for the attribute of taste from pork.

[12] This is analogous to the Heckscher–Ohlin theory using factor-proportions to identify the most typical characteristic of a country and explain the pattern of international trade (Krugman, Obstfeld, and Melitz, 2012, p. 80). The Heckscher–Ohlin theory can be viewed that the foreign consumers buy a factor abundant, say, capital abundant country's capital intensive goods because these goods provide some primary and secondary attributes and the reason of the advantage of these goods is that they have a distinctive attribute of comparatively high proportion of capital intensity. In the language of the present paper, the pork is so abundant of fat relative to wheat that its main attribute could be that it has a comparatively or even absolutely high fat intensity. Therefore, based on the available data, this attribute is the main reason that the consumer buys pork, or equivalently, we could say that this is the taste of pork for which the consumer has preference.

[13] Anecdotally, in explaining why the birds consumed more conventional than organic wheat, McKenzie and Whittingham (2010) applied the higher levels of protein in conventional than organic wheat among sixteen potential causal factors to conclude their finding.

[14] Because the per capita consumption of wheat after 2000 keeps decreasing and the fat intake from wheat is also decreasing, thus the value of 1.044 is not the exact maximum value in each year. But in this paper we focus on deriving the Giffen behavior and do not discuss the range of any parameter. Therefore we set 1.044 as a fixed value of maximum fat intake from wheat.

Table 3. The Constraint of Taste of Pork

(Unit: Kilogram)

Year	Wheat			Pork		
	Carbohydrate	**Fat**	**Protein**	**Carbohydrate**	**Fat**	**Protein**
2000	60.363	1.044	9.552	0.319	4.914	1.753
2001	57.761	0.999	9.140	0.320	4.940	1.762
2002	57.385	0.992	9.081	0.329	5.069	1.808
2003	55.069	0.952	8.714	0.331	5.099	1.819
2004	54.437	0.941	8.614	0.323	4.980	1.777
2005	51.467	0.890	8.144	0.375	5.779	2.062
2006	49.715	0.859	7.867	0.371	5.720	2.041
2007	48.436	0.837	7.665	0.321	4.947	1.765
2008	47.180	0.816	7.466	0.304	4.681	1.670
2009	44.789	0.774	7.088	0.335	5.165	1.843
2010	43.255	0.748	6.845	0.346	5.328	1.901
2011	41.172	0.712	6.515	0.346	5.335	1.903
2012	39.352	0.680	6.227	0.346	5.328	1.901
Maximum	60.363	1.044	9.552	0.375	5.779	2.062
Average	50.029	0.865	7.917	0.336	5.176	1.846
Taste Constraint(*f*)	-	**1.044**	-	-	f_0	-

Then the programming model is set as

$$\text{Max} \quad Calories=3380w+3950p \qquad \text{[model 1]}$$

$$\text{s.t.} \quad w*P_w+p*P_p \le b$$

$$0.013\text{w}+0.370\text{p} \ge f$$

w,p are non-negative

P_w, P_p are positive,

where w and p are the demand quantities of wheat and pork, respectively; P_w and P_p are the prices of wheat and pork, respectively; b is the parameter of budget constraint; f is the parameter of taste constraint in the amount of fat. All prices are positive, while the demand of wheat and pork can be zero. The two coefficients in objective function (3380 and 3950) are the caloric

contents of wheat and pork per kilogram. The two coefficients in the taste constraint (0.013 and 0.370) are the fat contents of wheat and pork per kilogram.[15] These data are in Table 1.

There is a "purchase concern" in the study of Giffen behavior that needs to be explained. The rural residents in China are also the peasants who grow the grain and feed the hogs for both consumption for themselves and for selling to the urban market. But the Giffen behavior is a response to price change that at first should be a purchase behavior. If the peasants do not have to buy all the foods or just buy part of the foods in a market, their response to the price change may be not sensitive enough as that of the consumers who buy all foods from market. We have two explanations for this concern. First, the peasants' food consumption can be linked to the market price of the same and substitute foods by adjusting the trade-off among consumption, selling, and rational storage of all the foods they have. Thus the peasants' food consumption is also affected by the market price[16]. We do not address this topic because it is beyond the scope of the present paper. Second, the truth that the peasants produce foods does not guarantee that they are able to always control and consume their own products. Lin and Yang (2000) tested Sen's entitlement approach (Sen, 1981) using the data of China's Great Famine during 1959-1961 and found that the peasants were suffered more by the famine than the urban residents. Further, no evidence can ensure that this inequality or discrimination will not occur again if there is another food crisis. Therefore, food shortage might be a more important problem in rural China than in urban areas and the research of Giffen behavior in rural China is also full of theoretical and policy implications.

Moreover, the Food and Agriculture Organization of the United Nations (FAO, 1996) points out that it is the poverty that primarily determines the food security. The rural residents usually have a lower income level than the urban residents. In particular, the "hungry farmer paradox" (Apata, Apata, and Kehinde, 2015) indicates that lots of farmers in the world who are specialized in growing crops like banana and coffee sometimes encounter food shortage. Thus, the farmers may also have quite a few chances to display the Giffen behavior and it is necessary to focus on the food demand in the rural areas.

2. Giffen Behavior: Partial and General Equilibrium

This paper concentrates not on the values of the parameters b and f but on the explanation of the three stated facts within one modeling method at the same time. Thus we will not report the range of values for the parameters when some behavior occur, but merely adjust them to display the occurrence of the behavior since the parameters are flexible in the model.

[15] Jensen and Miller (2008, Online Appendix) proposed a model that taste might be the maximizing objective subject to budget and a minimum caloric requirement, which is the dual form of Model 1.
[16] See, for example, the analyses in Fackler and Livingston (2002) and Peterson and Tomek (2005).

For verifying the Giffen behavior, we first set values for the parameters b and f. From Table 2 we know that the minimum expenditure on wheat and pork is 210.43 *yuan* in the year of 2000. Considering this is a normal expenditure[17] but we need to simulate the purchase behavior of a poor consumer, then setting b=200 *yuan* should be a suitable starting point. The minimum fat intake from pork is 4.681 kilograms per capita per year in Table 3, for the same reason and for simplicity, we set f=2 kilograms per capita per year, which means even in the normal condition, the consumer still needs to intake some fat from pork. The reason is he can at most get 1.044 kilograms fat from wheat[18] and have to get more fat from pork to meet the requirement of 2 kilograms of fat. Indeed, f=2 kilograms per capita per year indicates that the daily fat intake is 5.48 grams.[19] Comparing with 61 grams of fat intake[20] as the 2010 American food pattern at the level of 1800 calories per day (USDA, 2016 I), in which the reference person is a sedentary 18 years old female (USDA, 2016 II), the setting of fat intake in this model is much less than that standard. Therefore, the starting point of the model is a good simulation of a poor consumer.

Table 4. Inferior and Superior Giffen Behaviors

(Unit: Kilogram, Calories)

Year	Scenario A: b=200, f=2			Scenario B: b=250, f=2			Scenario C: b=250, f=3		
	Wheat (1)	Pork (2)	Calories (3)	Wheat (4)	Pork (5)	Calories (6)	Wheat (7)	Pork (8)	Calories (9)
2000	196.08	0	662745	245.10	0	828431	245.10	0	828431
2001	183.49	0	620183	229.36	0	775229	228.67	0.07	773191
2002	188.68	0	637736	235.85	0	797170	235.85	0	797170
2003	175.44	0	592982	219.30	0	741228	213.65	0.60	724526
2004	120.96	1.16	413406	164.47	0	555921	132.86	3.44	462640
2005	122.77	1.09	419267	165.56	0	559603	136.05	3.33	473004
2006	128.65	0.89	438320	170.07	0	574830	144.79	3.02	501328
2007	104.48	1.74	359987	156.25	0	528125	103.24	4.48	366634
2008	77.19	2.69	271540	130.20	0.83	443347	62.78	5.90	235503
2009	78.62	2.64	276160	118.05	1.26	403980	78.49	5.35	286422
2010	69.53	2.96	246698	105.12	1.71	362053	68.70	5.69	254693
2011	42.94	3.90	160541	80.49	2.58	282233	26.87	7.16	119119
2012	45.96	3.79	170320	79.68	2.61	279595	35.23	6.87	146205

(To be continued)

[17] This expenditure is only the summation of wheat and pork. The real total food expenditure is larger than this amount.

[18] The amount of fat from wheat has been decreasing after 2000.

[19] Suppose a year has 365.25 days, then f/365.25=2000/365.25≈5.48 grams.

[20] Not as in this model that the fat comes only from wheat and pork, in real life most fat is from edible oil and meat.

2.1 Giffen Behavior in Partial Equilibrium

We run Model 1 using the General Algebra Modeling System (GAMS) to obtain results. Because in the dataset of Table 2, all prices are equilibrium prices and the consumers considered in this model are assumed being a very small part of all consumers, Thus the price system is exogenous to them and they cannot affect any price. Thus the demand quantities solved by the programming model will also be equilibrium quantities. Table 4 reports the results at different levels of parameters or scenarios. The first part of this table is the results of scenario A when b=200 *yuan* and f=2 kilograms. To verify the Giffen behavior, we consider the demand curve of wheat first. Figure 1 plots the demand curve of wheat from 2006 to 2012.[21] Its X-axis and Y-axis are the quantity and price of wheat, respectively. The legend of the figure is the yearly quantity of wheat. It is easy to find that two segments of this curve have upward slope. During 2008-2009, the wheat price increases from 1.77 to 1.92 *yuan*. At the same period, its demand also increases from 77.19 to 78.62 kilograms. Therefore, this is the evidence that the Giffen behavior exists. Further, in Table 4 we know that the total calories increase from 271540 in 2008 to 276160 in 2009. Together with the three groups of changes above, the mechanism of Giffen behavior is: as a response to the increase of wheat price that it actually decreases the consumer's real income, his rational choice is to cut down the budget on pork and buy more wheat in order to reach an higher calories than before and at the same time to satisfy a minimum level of taste constraint. Indeed, his caloric intake is increased by this mechanism.[22] Another upward slope takes place during 2011 to 2012, which is not repeatedly discussed, and its final result of caloric intake also increases, though at an extremely low level.

To test if a high budget makes the Giffen phenomenon disappear, we increase b=250 *yuan* but keep f=2 kilograms as the Scenario B and run Model 1 again. The results are in the second part of Table 4 that indicate the demand curve of wheat has a downward slope. Thus, other things being equal, the Giffen behavior is dependent on the budget level. A low budget leads to a Giffen behavior while a high budget does not.

But it is not clear whether there is Giffen phenomenon at a higher budget level along with a higher taste level. Then the two parameters are both raised to Scenario C at b=250 *yuan* and f=3 kilograms to run Model 1. The last part of Table 4 reports the similar results as the first part. The new demand curve of wheat is like that in Figure 1, which is not repeated. This finding partly

[21] The curve starts from 2006 because the two segments of 2004 to 2005 and 2005 to 2006 are downward sloping and illegible due to almost overlapping that of 2006 to 2007.

[22] Suppose a year has 365.25 days, the daily caloric intake of the consumer in 2009 is 276160/365.25≈756 calories. According to USDA's data, a sedentary 18 years old female needs 1800 calories to maintain daily calorie balance (USDA, 2016 II). Thus that consumer usually cannot maintain regular daily activities. On one hand, we can reduce the fat constraint in the model to increase the caloric intake and at the same time keep wheat having the Giffenity. On the other hand, food aid is needed to provide as soon as possible for this low income consumer. Thus that situation might not take a year but perhaps several weeks. However, either the parameter adjustment or the food aid is not the central topic of the present paper.

agrees to the conclusion of Doi, Iwasa, and Shimomura (2009) that the income level has no effect on Giffen behavior but is still different than it because their paper was built on the utility theory and the only constraint was the share of income spent on the Giffen good, while in the present study utility plays no role in the model and there are two constraints of budget and taste.

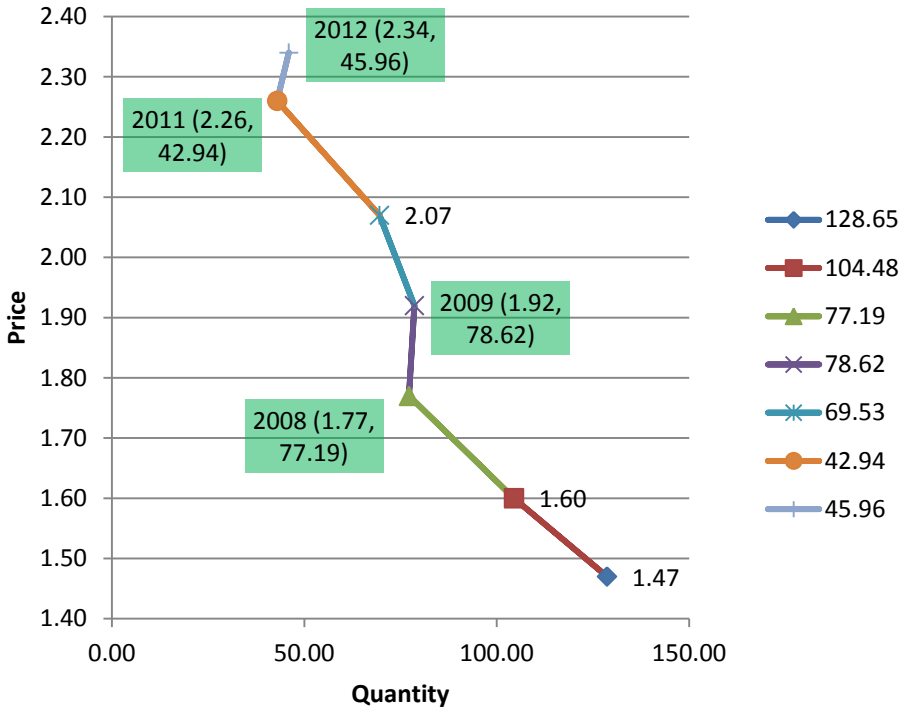

Figure 1. The Demand Curve of Wheat (*b*=200, *f*=2; 2006-2012)

Therefore, in a partial equilibrium with the inferior food, neither the budget nor the taste separately generates the Giffen mechanism. It is the combination of budget and taste determines the occurrence of the phenomena. Low levels of budget and taste as well as relatively high levels of budget and taste activate the Giffenity of the inferior food. When the budget is at a high level but taste at a low level, the demand curve of the inferior food is a common downward sloping curve.

2.2 Giffen Behavior in General Equilibrium

Most of the existing literature only discussed the Giffen behavior in a partial equilibrium, i.e., only discussed the inferior food. This paper, however, will extend the study to a general equilibrium with both inferior and superior foods. Figure 2 plots the demand curve of pork for

Scenario A with the parameters at b=200 *yuan* and f=2 kilograms. The definitions of two axes and the legend are the same as those in Figure 1.[23]

It is evidently to conclude that this demand curve has an upward slope. Thus the demand of pork is a universal Giffen demand, at least in this model. Other than the demand of wheat that it only exhibits Giffenity in two segments, this demand of pork reveals a wide-ranging occurrence of that property from 2006 through 2012. In particular, such a result also verifies the theoretical prediction that meat is more likely than the inferior food, i.e., potato or wheat, to be the Giffen good (Kohli, 1986) in that the time period of pork with Giffenity is longer than that of wheat with the property. Put in another way, regarding the possibility of being a Giffen good, pork is much higher than wheat.

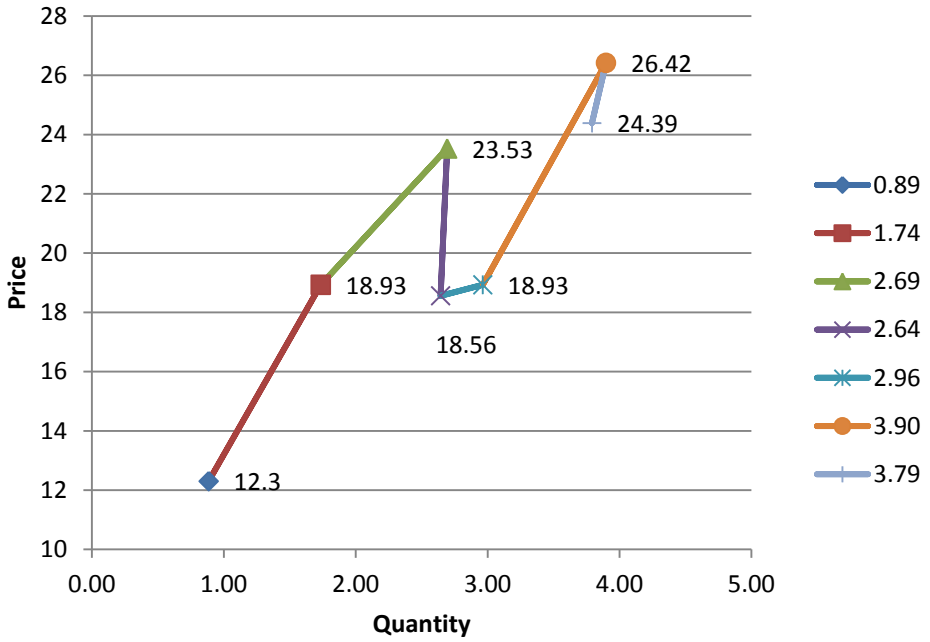

Figure 2. The Demand Curve of Pork (b=200, f=2; 2006-2012)

In Scenario B of b=250 *yuan* and f=2 kilograms, not all parts but only half parts of the pork demand curve have Giffenity. In Scenario C of b=250 *yuan* and f=3 kilograms, the demand curve is like that in Figure 2 that it displays a universal Giffenity from 2006 through 2012. These two scenarios, which are not repeatedly plotted, further confirm the previous finding that the combination of budget and taste jointly generate the Giffen phenomena.

Therefore, comparing with the partial equilibrium, a general equilibrium framework provides more evidence of the Giffen phenomena. This indicates a complete mechanism of Giffen behavior can only be demonstrated in a general equilibrium. The existing literature on the Giffen

[23] This curve starts from 2006 because the two upward sloping segments of 2004 to 2005 and 2005 to 2006 almost overlap that of 2006 to 2007.

behavior in a partial equilibrium did not entirely clarify the mechanism. The detailed relation between the inferior and superior foods will be addressed in the next section.

It is worth emphasizing that if we put all the results of partial and general equilibriums together we can convincingly conclude that it is the same rational optimization model that derives the totally different behaviors for different consumers due to different parameters. Put another way, since a fundamental assumption of Economics is that the consumers are rational, then all the different behaviors are consistent with the law of demand because these behaviors are based on a same rational model. Thus a logical corollary of this conclusion is that a demand curve can be either downward sloping or upward sloping. Namely, Giffen behavior is not an exception but is also one of the standard forms of the law of demand.[24] The reason of its low possibility of occurrence may be that the two parameters of budget and taste do not always cooperate very well in the real world.[25]

3. The "Superior Giffen Behavior"

The "superior Giffen behavior" refers to a type of Giffen behavior in which it is not the inferior good (wheat) but the superior good (pork) that has the Giffenity. Kohli (1986) first proposed that the Giffen good would most probably be found as meat rather than the inferior food.[26] Based on the available data, Read (2013) presented empirical evidence that bacon pigs may be the only Giffen good during the Irish Great Famine.

Applying the method of empirical simulation to China's food consumption data, the results of this paper concur with the preceding studies, i.e., pork exhibits stronger Giffenity than wheat. According to the results in Figure 1 and Figure 2, we find that pork can be the Giffen good in two situations. First, from 2008 to 2009 and from 2011 to 2012, both pork and wheat are Giffen goods. Second, in other years, only pork is Giffen good. In a general equilibrium, when we

[24] Not considering the specific functional forms of a demand function, the law of demand has four standard forms with respect to its slope: downward, upward, infinite, and zero slopes. The reason that the law of demand can take an upward slope is not because our rationality is changed but because the constraints in the optimization model are changed.

[25] Because sometimes the consumer could reduce the taste constraint to maximize his caloric intake, e.g., the consumption is switched from the scenario C to scenario B, thus the Giffen behavior is not found in the wheat consumption and has much less occurrence in the pork consumption. Generally speaking, there is a trade-off between the objective and some constraint. If the constraint of the preference for taste, which is the case in this paper, has the priority to the objective of caloric intake, then the Giffen behavior holds. Otherwise, it does not hold. Indeed, here we partly explain the reasons that why the Giffen behavior was not easily observed, which is the topic in Section 4. But in that Section, we will emphasize the reasons that the existing theory misguided the empirical research to focus on the inferior food and poor households.

[26] Baruch and Kannai (2001) found that the lowest-grade rice-based Japanese spirit (shochu) might be a Giffen good. Generally speaking, the spirit is not an inferior but a superior food or beverage because it is not necessary for providing calories to maintain subsistence.

explain the mechanism of "superior Giffen behavior" with pork, we actually also explain the mechanism of Giffen behavior with wheat. Indeed, the mechanism of two goods is in a same framework. We start from the first situation.

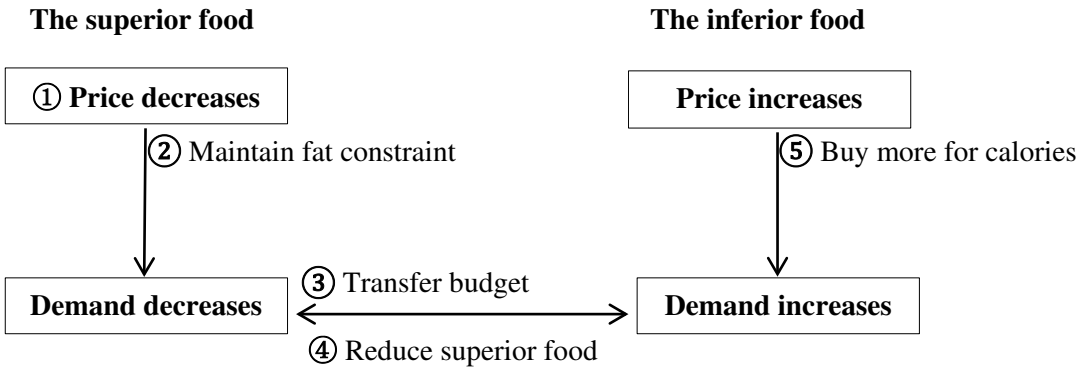

Figure 3. The Mechanism of Giffen Behavior in General Equilibrium

Figure 3 depicts the mechanism under a general equilibrium with the superior food (pork) at left side and inferior food (wheat) at right side in five steps. First, the decreasing price of superior food, i.e., the pork price in 2009 and 2012, triggers the mechanism. It is equivalent to an external intervention as subsidy for the consumer to increase his real income. Although the trend of pork price is increasing, it cannot exclude an occasional price fluctuation in a normal market.[27] Second, because the main reason or even single reason that the consumer buys pork is to satisfy the fat constraint, thus now he does not have to buy more pork due only to its lowering price, which is still relatively higher than wheat price, but maintain the same demand quantity of pork to meet the same fat constraint. As a result, he is able to save some budget from pork because the total expenditure on it decreases like there is a food subsidy. Third, since his objective is to maximize the caloric intake, he transfers the released budget from pork to buy more wheat. The logic behind this transferring is that the unit price of wheat is lower than that of pork in terms of the caloric content. Consequently, the more wheat provides the consumer not only more calories but more fat because wheat also has fat content even it is relatively low. Together with the fat from the same quantity of pork and more quantity of wheat, its total amount is higher than the constraint. Fourth, a rational consumer will decrease the demand of pork because its relatively high price does not favour the objective of calories while part of the fat constraint is already compensated by wheat. Therefore, the pork exhibits Giffen property, i.e., the "superior Giffen behavior" holds.

[27] We will try to explain why the price of superior food could decrease during a famine period in the end of this section.

Indeed, these steps are based on the condition that the wheat price is not changed. In reality, however, the wheat price keeps increasing from 2006 to 2012. As long as this price does not change dramatically,[28] the fifth step of the consumer is to increase his demand of wheat. The rationality is straightforward: since the fat constraint is already satisfied and the wheat price is lower than pork price in terms of the caloric content, the consumer maximizes his calorie objective by taking more wheat. Thus, the wheat also has the Giffen property. In sum, the results of decreasing pork price in 2008 to 2009 and 2011 to 2012 are that both pork and wheat are turned into Giffen goods.

The second situation is simple: in other years, the pork price keeps rising but its demand also keeps rising, whereas the wheat price rises and its demand declines. Namely, in this situation, the pork is a Giffen good but the wheat is a normal good.

According to the facts of the above situations, two findings can be confirmed that under a low budget and low fat constraint (Scenario A), if the price of superior food is increasing, then only this food is Giffen good; if its price is decreasing, then both the superior and inferior foods are Giffen goods. That is to say, the superior food can always be the Giffen good or the "superior Giffen behavior" holds all the time. These findings can also be true when the two constraints move to high budget and high fat (Scenario C). Therefore, it is empirically reasonable to accept the fact that the superior food has a higher possibility to be Giffen good than the inferior food. Namely, when Giffen behavior exists, most probably it should not be an "inferior Giffen behavior", i.e., the inferior food is Giffen good, but a superior Giffen behavior. Moreover, it is clear that both the superior and inferior Giffen behaviors can be generated within a same rational optimization model.

Consequently, we need to answer three questions. First, is it the main reason that the fat constraints are so high that make pork be a Giffen good? It is quite true that if these constraints lower down to a certain level, pork will not have Giffenity. But FAO (2010, p. 14) and the World Health Organization (WHO, 2003, p. 18) has a minimum recommendation that the percentage of the calories from fat divided by the total calories from all nutrients is 15% for adults. The second part of Table 4 reports the results of the percentages. In Scenario A, the highest percentage in the year of 2011is 11.21%. This value is below the recommendation. In Scenario B, all the percentages are far below the recommendation. In Scenario C, the two highest percentages are 22.67% and 18.47% in 2011 and 2012, respectively. In these two years, the calories are too low to maintain subsistence for a long time. The consumer should change his preference of taste to a lower level as soon as possible or he needs external food aid.[29] Therefore, only in two years

[28] As stated before, this paper does not discuss the range of any variable. We analyse the mechanism only on the ground of real price system.

[29] The preference of taste is only one of several reasons that leads to a low caloric intake for the consumer. Probably the main reason is the increasing prices of wheat and pork, given the food budget is fixed in the model. Therefore, a better policy suggestion might be to improve the consumer's income to such a level that his food budget will be also improved.

of the extreme conditions among all scenarios and all years are the percentages higher than the minimum recommendation. Even we do not consider adjusting the parameter of fat constraint in Scenario C, the results in general are not seriously beyond the recommendation of the minimum fat intake. That is to say, the fat constraints in Model 1 are not too high.[30]

Table 4. Inferior and Superior Giffen Behaviors (Continued)

(Unit: Kilogram, Calories)

Year	Scenario A: b=200, f=2			Scenario B: b=250, f=2			Scenario C: b=250, f=3		
	Total Fat (10)=(1) *0.013 +(2) *0.370	Calories from Fat (11)=(10) *1000*9	Percentage (12)= (11)/(3)	Total Fat (13)=(4) *0.013 +(5) *0.370	Calories from Fat (14)=(13) *1000*9	Percentage (15)= (14)/(6)	Total Fat (16)=(7) *0.013 +(8) *0.370	Calories from Fat (17)=(16) *1000*9	Percentage (18)= (17)/(9)
2000	2.55	22941	3.46	3.19	28676	3.46	3.19	28676	3.46
2001	2.39	21468	3.46	2.98	26835	3.46	3.00	27001	3.49
2002	2.45	22075	3.46	3.07	27594	3.46	3.07	27594	3.46
2003	2.28	20526	3.46	2.85	25658	3.46	3.00	26999	3.73
2004	2.00	17998	4.35	2.14	19243	3.46	3.00	26999	5.84
2005	2.00	18000	4.29	2.15	19371	3.46	3.00	27000	5.71
2006	2.00	17999	4.11	2.21	19898	3.46	3.00	27001	5.39
2007	2.00	18001	5.00	2.03	18281	3.46	3.00	27000	7.36
2008	2.00	17999	6.63	2.00	18000	4.06	3.00	26999	11.46
2009	2.00	17999	6.52	2.00	18001	4.46	3.00	26998	9.43
2010	2.00	18001	7.30	2.00	17999	4.97	3.00	26999	10.60
2011	2.00	18001	11.21	2.00	17999	6.38	3.00	27000	22.67
2012	2.00	18001	10.57	2.00	18000	6.44	3.00	26999	18.47

Notes: 1. The total fat is a summation of fat intake from both wheat and pork. For example at b=200 and f=2 in 2000, 2.55 ≈196.08*0.013+0*0.370, in which the nutrition contents of fat in wheat and pork, i.e., 0.013 and 0.370, are in Table 1.

2. The value of calories from fat is a product of fat in the unit of gram multiplying the fat's energy density of 9 (Wikipedia: Food energy). For example at b=200 and f=2 in 2000, 2.55 kilograms =2550 grams, then 22941≈2550*9.

3. The percentage is a quotient of the calories from fat dividing by the total calories. For example at b=200 and f=2 in 2000, 3.46%≈22941/662745.

Second, does an inferior Giffen good have to accompany with a superior Giffen good? The data in Table 4 support the answer to be "yes". The logic is if there is no such a superior good (pork) and when the price of inferior good (wheat) is increasing, then there is no budget for the consumer to buy more inferior good since his real income is worsen by the increasing price of

[30] Considering the taste attribute may also satisfy some other secondary attributes, e.g., the diversity, a relatively high fat constraint might be acceptable in the real world.

inferior good, given the condition of no any external financial or other forms of intervention. This is one of the reasons that a general equilibrium analysis is better than a partial equilibrium one. Further, it strongly indicates that the finding of "superior Giffen behavior" is a reasonable consequence of the application of general equilibrium analysis.

Third, during a famine period, is it possible for the price of superior food to decrease? The background is the famine should increase the prices of all foods. The key point to answer this question might lie in the price of feedstuff. The surging prices of foods in a famine may raise the price of feedstuff to such a level that the peasants cannot afford the cost to keep feeding the animals, e.g., the hogs, even some of the feedstuff is kitchen leftovers. Then a good choice for peasants might be to sell the hogs, in which some other reasons may strengthen or weaken this choice. When lots of the hogs are selling in the market during a short time, the price of hog should drop more or less. This is a normal process of vertical price transmission.[31] At least in principle it should hold. However, it was not supported by the historical price data of bacon pigs during the Irish famine in 1840s (Read, 2013). On one hand, we need to search evidence to validate this process.[32] On the other hand, just because the bacon pig price did not decrease, thus there was no opportunity for wheat to display Giffenity during the Irish famine. Nevertheless, it is a piece of solid evidence that during a famine we should focus not on the inferior food but on the superior food to explore Giffen behavior. Otherwise, it is not easy to observe a Giffen good. But if it is not a famine period but a normal period and if the price of superior food is decreasing as a common price fluctuation, then we can observe that both the inferior and superior foods are Giffen goods like the case of this paper.

4. Observability of Giffen Behavior: Superior Food and Wealthy Households

Jensen and Miller (2008) summarized almost all conceptual viewpoints on the reasons that why the Giffen behavior was not easily observed, including theoretical criticism on the understanding of the demand and market as well as the empirical difficulties in data collecting. This paper will extend the list of the reasons in a framework of general equilibrium. It needs to emphasize that here we do not fully repeat the reason of the adjustment or combination of parameters but focus on that due to lack of the general equilibrium, the traditional theory might misguide the research into the inferior food and poor households for targeting the Giffen behavior and in light of the general equilibrium, we may find more evidence of Giffenity with superior food in wealthy households.

[31] It seemed that few academic studies discussed the long price transmission from feedstuff through hog to pork. Most of the studies only focused on the short price transmission from the hog to pork (Emmanoulides and Fousekis, 2014).

[32] Anderson and Anderson (2009) found there were several factors, e.g., biology and market structures, affecting the transmission process.

According to Model 1 and the results in Table 4, Giffen behavior occurs at low levels of budget and taste (Scenario A) as well as high levels of the two constraints (Scenario C). It is likely that lots of the households meet these conditions. But as stated above, first, the taste constraint needs to well cooperate with the budget constraint that some households will not be qualified; second, when a famine is impending, many households may cut down their preferences for taste to maximize the caloric intake. Thus the number of households that could exhibit Giffen behavior might not be the majority but the minority of the whole households. Further, although we do not have exact data on the scale of these minor households, the fact that little evidence was documented in more than one century, which is under the expectation that finding evidence of Giffen behavior would bring great rewards to the scientists of economics,[33] can be a proof that the Giffen behavior of these minor households is masked by other major households at least at the level of aggregate data. However, if the fundamental demand theory and its optimization model have no flaw, then the observability of Giffen behavior cannot be rejected. Therefore, most probably the reason that Giffen behavior is usually not observed might be that we are guided to the wrong directions. Namely, the Giffen behavior is not necessary related to the inferior food and low income households, it can occur in a superior food and wealthy households. We discuss the type of food and characteristics of the households respectively.

First, regarding which one of the inferior and superior foods is more likely to be Giffen good, we know from the general equilibrium analysis that the cause of the inferior food exhibiting Giffenity when its price is increasing is that the price of superior food is decreasing. But during a famine no evidence, to date, shows that the price of superior food could decrease. The price of bacon pigs kept increasing during the Irish famine was the case (Read, 2013). Thus if no external price intervention like food subsidy, it is not easy to observe the inferior food to be a Giffen good even during a normal period.[34] Indeed, if the taste constraint is maintained at a relatively high level, the superior food will be a Giffen good regardless its price is decreasing or increasing as depicted in Figure 2. Therefore, this paper highlights that the superior food is most probably the Giffen good, while the inferior food being a Giffen good is only by chance. For empirical research, it is clear that to improve the probability of finding Giffen behavior, we should not focus on the inferior food but on the superior food.

Second, regarding the characteristics of the households of having potential Giffen behavior, since we focus on the superior food it is more likely to find Giffen phenomena in those households that they have high levels of both income and preferences for taste. For example, comparing to households with kids, especially with teenagers, those households with only senior individuals

[33] Stigler (1966, p. 24) proposed that "if an economist were to demonstrate its failure [the failure of downward sloping law of demand] in a particular market at a particular time, he would be assured of immortality, professionally speaking, and rapid promotion while still alive. Since most economists would not dislike either reward, we may assume that the total absence of exceptions is not from lack of trying to find them."

[34] This might be the reason that the first empirical evidence of Giffen behavior documented by Jensen and Miller (2008) was a field experiment using food vouchers as subsidy.

might change their food baskets in response to a food price surging, e.g., reduce more consumption of meat than staple foods as wheat and rice. Other things being equal, the households with kids might have higher preference for meat than senior households. Therefore, the empirical implication of this hypothesis is that in order to find Giffen behavior, we should switch our focus from the poor households to relatively wealthy households with high preference for taste attribute or superior food.

In sum, other than the traditional explanations that Giffen behavior is rarely observed, this paper emphasizes that the hardly observed Giffen behavior and its observability can be comprised within one programming model. In particular, if we only concentrate on the inferior food and poor households, the probability of finding Giffen behavior is very low. As a result in empirics, the relatively easily observed superior Giffen food in wealthy households, the scarcely observed inferior food in poor households, and perhaps in most cases the fact that Giffen behavior does not exhibit due to parameter reason can coexist within a general equilibrium framework.

5. Conclusions

The overall conclusion of this paper is that based on a same rational optimization model, the law of demand can either have a negative or positive relationship between the quantity and price. Giffen behavior is not an exception of the law but one of the standard forms of it, though the conditions to generate the behavior are not commonly met. However, we cannot reject that Giffen behavior is one of the rational human behaviors merely because of its uncommon conditions.

According to the new attribute theory and semi-empirical simulation method, this paper builds a programming model with an objective of maximum caloric intake and two constraints of budget and taste to explain three facts: inferior Giffen behavior, superior Giffen behavior, and the reasons of why these behaviors cannot be easily observed. In a general equilibrium and under constraints of low budget and low taste as well as high budget and high taste, the superior food has a higher possibility than the inferior food to exhibit Giffen property. This indicates that not only does Giffen behavior exist but also the households and foods satisfying the combination of two constraints have more opportunities in displaying Giffenity. In particular, the “superior Giffen behavior” is not a special but a general case of the phenomenon. Further, the reason that the observability of Giffen behavior becomes a problem is that we are misguided to search the behavior in low income households with inferior food.

The theoretical disadvantage of the semi-empirical simulation method might also be a kind of pragmatic advantage. Because the two constraints of budget and taste are not the real data but parameters, then the results of the model are not the real phenomena, which is its disadvantage. But at the same time, the parameters clearly suggest that for efficiently targeting Giffen behavior, the field survey should be conducted on wealthy households with high preference for the

secondary attribute, e.g., the taste. Finally, if more data are available, we can try other measurable definitions of one or more secondary attributes to specifically target the potential households of Giffenity.

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