DERIVED DEMAND FOR FOOD NUTRIENTS AS WELFARE INDICATOR OF BIOFORTIFIED CROPS: HIGH-IRON RICE IN THE PHILIPPINES

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Abstract*:* The study estimates potential consumer gains from the introduction of High-Iron Rice in the Philippines. By deriving the demand for dietary iron from a national survey on household food consumption and expenditure, we project consumer welfare implications under both non-market and market analytical frameworks.

Key Words: biofortification, demand analysis, household production, nutrition, Philippines, rice, welfare measurement

JEL Classifications: D13, I12, D12, C13, H43, I31

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Biofortified crops refer to food crops that are bred to load high levels of minerals and vitamins in their seeds and roots (HarvestPlus). These crops are being developed by the Consultative Group on International Agricultural Research (both through conventional and transgenic breeding methods) as a means to complement existing nutrition interventions such as supplementation and postproduction fortification in addressing micronutrient malnutrition. This study is interested in estimating the potential welfare gains from the biofortification effort. We analyze the potential introduction of High-Iron Rice in the Philippines where rice provides about 40% of the calories people consume and where iron deficiency anemia is reported to be the most common form of malnutrition. The aim of the paper is to contribute towards the ex ante economic assessment of product quality-improving research and development initiatives particularly those with potential nutritional benefits. Ex ante agricultural research evaluation is an established practice in aid of decision-making, research design and/or resource allocation, however, there seems to be no consensus on the appropriate method for measuring benefits provided by improved nutrition and health.

Caswell notes that economists use different approaches in measuring the benefits of safer or more nutritious foods especially at the consumer end because the food attribute to be analyzed and the benefit to be measured are rarely directly valued in markets. There are inherent

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information problems associated with attributes where the consumer cannot judge their quality level even after consumption of the product. Among the various methods used for the measurement of nutritional benefits are: 1) the cost of illness approach, to estimate the value of avoided illnesses, deaths, losses in income and leisure, pain and suffering due to consumption of a product or service; 2) contingent valuation and experimental auction markets, to elicit consumer's willingness to pay for the new and more nutritious/safer good; 3) conjoint analysis, while also contingent is said to mimic more closely the actual choice process in markets, to examine trade-offs that determine the combination of attributes that will be most satisfying to the consumer; 4) prices paid in markets and hedonic pricing techniques, to measure the value consumers place on products with different nutritional profiles; 5) liability costs, to estimate potentially avoidable costs for parties in product liability cases; and 6) trade analysis, to measure the benefits of improved access to foreign markets or alternatively, the cost of reduced access because of failure to meet quality standards.

In the health economics literature, willingness-to-pay (WTP) measures and quality-adjusted life years (QALYs), which are indices of health outcomes, are often used to measure health gains from a product or service. Olsen and Smith reviews that there has been increasing interest in the use of WTP [5] as a measure of health benefits based on three primary arguments advanced for the superiority of WTP over QALYs: 1) WTP is the "theoretically correct" approach because of its foundation in welfare economics; 2) WTP imposes no restriction on which attributes of a program people are allowed to express a value for, compared with QALYs which are based on preferences for health outcomes only; and 3) WTP involves the valuation of benefits in the same unit as costs, which is required for advising decision-

[5] The 71 WTP surveys reviewed by Olsen and Smith all used contingent valuation. One of these surveys, however, used willingness to accept rather than willingness to pay as the benefit measure.

makers on improvements in allocative efficiency.[6]

In the ex ante economic evaluation of biofortified crops, Bouis roughly estimates a $1 per capita benefit from zinc-dense wheat consumption in Turkey based on World Bank estimates of productivity losses due to micronutrient deficiency. Zimmermann and Qaim, Stein et al, and Javelosa have used Disability-Adjusted Life Years (DALYs)[7], a variant of QALYs, in measuring respectively the potential health benefits of Golden Rice (Vitamin A biofortified rice) in the Philippines, High-Iron Rice in India and Iron and Zinc-Dense Rice in the Philippines. The DALY approach to measuring health benefits aims to account for additional life years that could be gained if those who are nutrient-deficient consumed the biofortified crop. The difference between DALYs lost without the biofortified crop and DALYs lost with the biofortified crop is calculated to represent the impact of the innovation.

In the agricultural research evaluation literature, the common approach in evaluating the impact of product quality-enhancing technology is by modeling the impact of the quality improvement through an outward shift in the demand curve of the improved good (e.g. Unnevehr, Lemieux and Wohlgenant, Voon and Edwards). An outward demand shift for the improved crop assumes that the quantity consumed of the good will increase due to its improved quality or consumers will be willing to pay a premium for the quality-improved good. However, in analyzing the impact of biofortified crops, such a representation, while an

[6] QALYs are oftentimes used in cost-effectiveness studies rather than cost-benefit analysis, due to the controversial issue of placing a value to a person's life.

[7] DALYs were first used in a joint World Bank, World Health Organization and Harvard School of Public Health study to quantify the burden of disease and injury of human populations and as a measure for cost-effectiveness studies of health projects (WH0). In the Zimmermann and Qaim, Stein et.al. and Javelosa studies, the DALY index is used to account for the life years lost both through deaths and health conditions due to micronutrient deficiency. Among the key information needed to estimate DALYs lost are incidence rates of the deficiency, duration of the health condition caused by the deficiency, severity weights of these health conditions, and nutrient intakes. A monetary value is placed on a DALY for cost-benefit analysis.

empirical question, can be argued to be inappropriate since target consumers of biofortified crops (i.e. those who are micronutrient deficient in developing countries) may have limited purchasing power to translate nutritional needs to effective demand. For this reason, DALYs have been adopted as an alternative economic measurement approach to capture the potential gains of the innovation by placing a value on projected health improvements for the consuming population (Zimmermann and Qaim).

In this paper, we explore the use of household production theory to estimate consumers' "WTP" for the product trait being enhanced through biofortification to serve as basis for estimating the technology's potential gains. Most studies employ contingent valuation to measure consumer WTP for a new product or a particular product characteristic (e.g. Dalton, Ara on WTP for rice traits, Hurley and Kliebenstein for environmental attributes of pork products). A large number of studies also use the hedonic approach (usually justified in terms of household production theory) to derive the marginal willingness to pay for agricultural or food product characteristics (e.g. Stanley and Tschirhart, Harris, Dalton, Hurley and Kliebenstein). Here, we use a household production model to derive the implicit value and demand for the micronutrient being enhanced i.e. iron, based on households' past food consumption choices. Estimating potential implicit price changes along the demand curve for the non-market nutritional trait is initially shown to represent consumer gains from the potential introduction of biofortified crops. In addition, when we relax the assumption that there may be no changes in the price of the nutritionally-improved market good as a result of biofortification, the paper shows how the derived demand for iron can project potential changes in the demand for the nutritionally-enhanced rice, in both cases where biofortification of rice would lead to either an outward or inward demand shift.

The Household Production Model

Household production theory suggests that a household obtains utility from some underlying commodities that cannot be bought in the market but are instead produced in the household from inputs of market goods and leisure time. The classic early references to the theory are Becker and Lancaster (1966, 1971). In benefit measurement, a common problem encountered in using a market analytical framework is the case where some change other than the price of a good in an observable market affects the economic well-being of a consumer (or factor owner). In such a case, the analyst is motivated to measure welfare changes indirectly on the basis of behavior in observable markets, which household production theory can provide a framework for (Just, Hueth and Schmitz).

To illustrate the use of household production theory in our assessment of potential welfare benefits from High-Iron Rice, consider a household that produces utility-yielding, non-market consumable meals that contain nutrients, particularly iron, using market goods: food items, time and human capital as factor inputs. Let vector z = [z_1, z_2] represent the non-market utility-yielding outputs: iron amounts consumed from household food production, z_1 where $z_1 = \sum_{j=1}^{n} X_{j1}$ where X_{j1} is nutrient 1 i.e. iron embodied in food item j; $z_2 =$ total food amount produced and consumed by the household. In order to produce non-market vector z, the household purchases a vector of food inputs (q_i, i=1,..., n;n types of food) and labor inputs (l_j,j=1,..,r; r types of labor inputs) at given market prices (p_i, i=1,..,n), wage rates (s_j, j=1,..,r) and capital stock, k. In the following discussion, $q=[q_1, .., q_n, l_1, \ldots, l_r]$ and $p=[p_1, .., p_n; s_1, .., s_r]$ are the column vectors of inputs and prices, respectively.

Deaton and Muellbauer presents two optimization problems in a household production model. In application to our particular case, first, the household is assumed to minimize expenditures necessary to achieve given levels of nutrients and food consumption. The household is characterized by cost-minimizing behavior with food inputs assumed to be weakly separable from all other commodity groups. This allows the expenditure allocation among food groups to be isolated from other commodities. The household's consumption choices may be written as:

$$\text{Min } C = p'q$$

$$\text{s.t. } H(q,z:k) \geq 0, \tag{1}$$

where H (q,z;k) denotes the corresponding transformation function that converts food inputs (q_i), labor inputs (l_j), and fixed capital stock (k, capital stock is considered fixed in the short run) into the non-market output vector z. The solution to equation 1 is the household cost or expenditure function, $C^o = x(p,z;k)$ indicating the minimal short-run cost of obtaining given levels of non-market outputs, i.e. iron nutrients and the amount of meals/food consumed at prevailing prices and wages. In line with traditional consumer theory, this cost function is positively linear homogeneous, non-decreasing and concave in p, increasing in z and non-increasing in k. Differentiating the expenditure or cost function then allows the calculation of shadow/implicit prices of nutrients in food intake. The shadow values of z_h, h=1,2 are defined as:

$$\tau_h = \partial C/\partial z_h, \; h=1, 2 \tag{2}$$

Deaton and Muellbauer represents the second optimization stage as a household output maximization problem, which depends implicitly on the calculated shadow prices. The implicit solution to this problem is then the demand level for nutrients. This approach has been applied for example by Shonkwiler, Lee and Taylor, and Chung. In this study, we initially estimate the implicit price of dietary iron from the first optimization problem and then derive the demand for iron by iterating the cost minimization problem given new levels of iron that can be potentially contained by iron biofortified rice, while other factors remain the same. The resulting implicit prices as the iron output levels change trace the household demand curve for iron.

The derived household demand for iron can now serve as the basis for estimating household gains from the introduction of iron biofortified rice. The standard economic surplus model (e.g. Currie, Murphy and Schmitz) suggests that consumer gains can be estimated from a given demand curve. From the derived demand curve for iron, a decrease in the implicit price of iron due to an increased iron supply in the diet through the introduction of biofortified rice will provide consumer gains that can be measured through the area that is bounded by the initial and subsequent price line of iron and its demand curve.

Data and Estimation Procedure

The study uses household food expenditure data and intake levels of food and nutrients from the 1993 National Food Consumption Survey of the Philippines (FNRI)[8]. The one-day food weighing technique was used in data collection. We aggregate the intake and expenditure data per food item into food groups: 1) cereals and cereal products; 2) meat, fish, fruits and vegetables; and 3) all other food items. Both wage rates of meal preparers and labor inputs are not reported in the survey, so the wage and labor variables are deleted from the p and q vectors discussed in the previous section. We analyze only 4,035 households out of the total survey sample size of 4,050. Fifteen households with zero consumption entries in the major food groups were omitted. Descriptive statistics of key variables in the data set are shown in Table 1.

Given no a priori knowledge about the household cost function C^o, a translog cost formulation is used. With input prices of the three food groupings, p_i, i=1,2,3 and two outputs, z_h, h=1, 2 where z_1=iron amount in total food produced and consumed and z_2= amount of total

[8] The 1993 national food consumption data set is the most current data available. While the most recent national food consumption survey was conducted in 2003, the data collected from the survey can not yet be publicly accessed.

food produced and consumed , the cost function can be written formally as:

$$\ln C = \alpha_o + \sum_{i=1}^{3} \alpha_i \ln p_i + \sum_{h=1}^{2} \beta_h \ln z_h + \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3} \delta_i \ \ln p_i \ln p_j + \frac{1}{2}\sum_{h=1}^{2}\sum_{k=1}^{2} \beta_{hk} \ln z_h \ln z_k + \sum_{i=1}^{3}\sum_{h=1}^{2} \theta_{ih} \ln p_i \ln z_h \tag{3}$$

Differentiating equation 3 with respect to each of the input prices and applying Shephard's Lemma, we obtain the cost share equations:

$$s_i = \frac{p_i q_i}{C} = \frac{\partial \ln C}{\partial \ln p_i} = \alpha_i + \sum_{j}^{n} \alpha_{ij} \ln p_j + \sum_{h}^{g+1} \theta_{ih} \ln z_h \tag{4}$$

We then estimate the parameters of the cost function and two (n-1) cost share equations using the iterated seemingly unrelated regressions (SUR) technique to obtain maximum likelihood estimates which are invariant to the share equation dropped.[9]

Differentiating the translog cost function with respect to z_h, we get the shadow price of iron (z_1) and total food consumed (z_2):

$$\tau_h = \frac{\partial \ln C}{\partial \ln z_h}(\frac{C}{z_h}) = (\beta_h + \sum_{h=1}^{2} \beta_h \ln z_h + \sum_{i=1}^{2} \theta_{ih} \ln p_i)(\frac{C}{z_h}) \tag{5}$$

Iterating the cost minimization procedure discussed above using new potential levels of iron from biofortified rice consumption while all other factors remain the same provides new levels of implicit prices at various output levels of iron in the household. These implicit prices trace the household demand for iron, which we use as our welfare indicator of consumer gains from iron biofortified rice.

[9] One of the share equations is dropped to solve the problem of singularity of the disturbance covariance matrix of the system of equations. Christensen and Greene points out that jointly estimating the cost function and the cost share equations as a multivariate regression system has the effect of adding degrees of freedom without adding any unrestricted regression coefficients and will thus result in more efficient parameter estimates than would be obtained by applying ordinary least squares to the cost function alone.

Empirical Results

After imposing symmetry and homogeneity restrictions and given prices of three food groups and two levels of output produced by the household in terms of iron and total food consumed, the translog cost function has 21 parameters. The results of the iterated SUR of the translog cost function and two cost share equations are reported in Table 2. The translog cost specification appears to fit the data successfully. Out of the 21parameter estimates, nineteen are significant, exceeding twice their associated standard errors. At the means of the data, the estimated cost function also satisfies the theoretical properties of a cost function. The estimated cost function is increasing and concave in prices and non-decreasing in output. The own-price elasticities of demand for the three food groups also have the correct sign (Table 3).

At 1993 consumption levels, our calculations show that the implicit price at which a household on average values each mg of iron consumed is 4 centavos. If households consumed the same amounts of all food items and the iron content in rice increased, the implicit price for iron effectively decreases, thus the household gains as a result of the implicit price decline. We trace out the calculated shadow prices of iron given various total iron intakes to derive the household demand curve for iron. Plotting the respective shadow prices approximate a linear relationship between implicit iron prices and iron intakes as shown in Figure 1. If the current iron content in rice increases by 40%[10] due to biofortification, the implicit price of iron can decline up to 0.1 centavos/mg.

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[10] Based on the conversion factor used by the FNRI to calculate the amount of iron in rice, it appears that every gram of rice contains 0.01 mg of iron (10 mg of iron per kilogram of rice or 10 parts per million (ppm). The rice biofortification effort may develop rice varieties containing even higher iron amounts.

Consumer Welfare Measurement Based on the Demand for Iron

Estimating the consumer welfare change based on a linear demand curve for iron following standard economic surplus theory (i.e. areas A+B in Figure 1), we approximate that the household can gain P2.40/day ($0.04/day)[11] as a result of iron biofortification of rice due to a decline in the price of the utility-yielding trait in the food consumed. These gains could translate to P874.50/household/year ($15.62/household/year) and assuming that at least 30% of Filipino households will avail of the high-iron rice, total gains for consumers in the Philippines will be about P3.5 billion/year or $63.3 million. This amount is 2.3 times higher than the estimate calculated by Javelosa when the potential gains from iron biofortified rice in the Philippines is analyzed using the DALY index.

One motivation for using a non-market approach in our estimation of potential consumer benefits from technology that nutritionally-enhances a staple as shown above is the assumption that the impact of the innovation may not show up in the price of the good in an observable market (i.e. rice) but could affect consumer well-being. Relaxing this assumption, we show in the next section how our non-market welfare estimates can be used to project potential consumer welfare changes in the rice market.

Projecting Welfare Changes in the Rice Market

Introducing biofortified rice in the market provides at least two possibilities for the household demand for rice. The first possibility is an outward shift in the demand for rice, implying that households will consume more rice at a given price level or would be willing to pay a premium for the same quantity of rice consumed when iron density in rice increases while all other factors remain the same. The second possibility is an inward shift in the demand for

[11] Currency conversion rate used is P56: $1.

rice, implying that less rice will be consumed to meet the same level of nutrition the household attains when the rice consumed was not biofortified, ceteris paribus.

If an average household improves its welfare by an amount of P2.40per day as a result of consuming High-Iron Rice (as calculated in the previous section using the derived demand for iron), this amount should equivalently be the household welfare gain when analyzed using the demand for rice as the framework.[12] Under the first possibility and assuming a linear rice demand curve, in order for the household to gain P2.40 per day, it should be increasing its consumption by 40% or 629 grams of rice (from about 1.6 kg/day to 2.2 kg/day for an average household of 6 members). This is illustrated in Figure 2, where D_o is the initial rice demand curve, D_1 is the new demand curve when the rice is biofortified with iron, the initial and subsequent supply curves, S_o and S_1, are assumed to be perfectly elastic and Area *abcd*, the area bounded by the 2 demand curves and the price line approximates the magnitude of consumer gains as a result of the demand shift.

Under the second possibility, despite less rice consumption at a given price level, consumer gains are still obtained due to cost savings from being able to consume less rice to have the same amount of nutrients as before the biofortified rice was introduced. In figure 3, we illustrate that for the household to gain P2.40/day, the household could potentially decrease its rice consumption by 12% or 190 grams. Area *abcd* in Figure 3 represents food cost savings --- the consumer benefits obtained from the nutritionally enriched rice variety as a result of the inward shift in the demand for rice.

[12] There is only one value for the true welfare change provided by an intervention and this should be the same whether the welfare change is estimated in input (iron) or output (rice) space. See Just, Hueth and Schmitz for a proof of this stylized fact.

Concluding Notes

The paper presents an economic theory-based approach to measure potential consumer gains from an intervention aimed at nutritional improvement. The concern that the welfare impact of nutritional enhancements in staples may not be captured through the price of the market good is addressed by our implicit valuation of the utility-yielding nutrient trait in food. Meanwhile, if we allow the possibility for changes in the market good in view of new nutrient-dense varieties, we have shown how our derivation of the implicit demand curve for the iron nutrient can be used to project rice demand changes.

In a few ways, our approach addresses some criticisms of existing measurement approaches such as the DALY methodology and contingent valuation. The biofortification program currently uses the DALY index to assess the potential economic impact of biofortified crops to make the biofortification initiative comparable with other health projects, which similarly uses the DALY for evaluation purposes (apart from the premise that a market model is not appropriate to analyze welfare gains of biofortified crops). However, the DALY measure has been criticized by some to be an ad-hoc measure that is not upheld by economic theory and which imposes valuations of health outcomes that do not emanate from the concerned consumers themselves. In contrast, our approach is rooted on consumer theory by using a household production model to derive potential consumer valuations of improved nutrition that can be brought about by nutrient-dense crops through an implicit valuation of the nutritional trait being enhanced.

Contingent valuation is viewed by some as the only alternative for approximating consumer WTP for new products or product traits. Critics however question the reliability of this approach to determine the WTP for a good or product trait for several reasons e.g. respondents' stated preferences might be biased and ignore income constraints. Our approach uses instead revealed preferences through past consumption choices which take into account given prices and household budget constraints to infer implicit prices paid for a nutritional trait to simulate potential benefits from improved product attributes. Our household production approach might then be similarly applied to the measurement of consumer benefits resulting from the introduction of new products infused with already known attributes.

Table 1. Descriptive Statistics of Selected Household Variables in the 1993 National Food Consumption Survey of the Philippines [a]

Variable (units)	Mean	Standard Deviation	Minimum	Maximum
Total Food Expenditure (pesos)	91.88	63.50	4.67	859.27
Value of Food Group 1 (pesos) [b]	27.44	16.53	1.49	373.06
Value of Food Group 2 (pesos) [c]	45.17	42.50	0.16	646.67
Value of Food Group 3 (pesos) [d]	19.27	19.78	0.02	443.51
Intake of Food Group 1 (grams)	1985.71	953.17	162.71	8347.67
Intake of Food Group 2 (grams)	1894.33	1395.76	25.00	15702.93
Intake of Food Group 3 (grams)	665.12	684.77	4.00	9725.22
Total Food Intake (grams)	4545.16	2290.48	414.34	23523.19
Unit Price of Food Group 1 (pesos/gram)	0.01	0.01	0.004	0.16
Unit Price of Food Group 2 (pesos/gram)	0.03	0.02	0.002	0.54
Unit Price of Food Group 3 (pesos/gram)	0.03	0.02	0.001	0.34
Iron Intake from All Food (milligrams)	59.60	35.52	3.87	359.20
Iron Intake from Rice (milligrams)	17.22	9.43	0.19	137.92
Household size (number)	5.94	2.44	1.00	20.00

[a] Number of households analyzed = 4,035; Method used by the Food and Nutrition Research Institute in collecting data is the one-day food weighing technique.
[b] Food group 1 = cereals and cereal products
[c] Food group 2 = meat, fish, fruits and vegetables
[d] Food group 3 = all other food items

Table 2. Translog Cost Function Parameter Estimates*

Parameter	Value	Standard Error	t-statistic	P-Value
α_0	- 1.75891	0.366497	-4.79925	[.000]
α_1	1.32401	0.032546	40.6817	[.000]
α_2	- 0.348167	0.031641	-11.0038	[.000]
α_3	0.024155	0.028107	0.859405	[.390]
α_{11}	0.163291	0.318149E-02	51.3252	[.000]
α_{12}	- 0.120858	0.246819E-02	-48.9662	[.000]
α_{13}	- 0.042433	0.218986E-02	-19.3770	[.000]
α_{22}	0.133802	0.289921E-02	46.1513	[.000]
α_{23}	- 0.012944	0.209538E-02	-6.17754	[.000]
α_{33}	0.055377	0.240315E-02	23.0435	[.000]
β_1	- 0.554798	0.079577	-6.97179	[.000]
β_2	1.71418	0.114676	14.9480	[.000]
β_{11}	- 0.116043	0.015407	-7.53187	[.000]
β_{12}	0.126598	0.014828	8.53790	[.000]
β_{22}	- 0.152114	0.019030	-7.99354	[.000]
θ_{11}	0.045479	0.474113E-02	9.59240	[.000]
θ_{12}	- 0.128452	0.535320E-02	-23.9953	[.000]
θ_{21}	- 0.045007	0.468031E-02	-9.61620	[.000]
θ_{22}	0.111408	0.527070E-02	21.1372	[.000]
θ_{31}	- 0.472054E-03	0.407250E-02	-0.115913	[.908]
θ_{32}	0.017044	0.461456E-02	3.69350	[.000]

*Estimates were obtained using TSP 4.4 .

Table 3. Hicksian own-price and cross price elasticities at the means [a]

Food Group [b]	1	2	3
1	-0.182218 (0.92E-02)[c]	0.102105 (0 .71E-02)	0.080114 (0.63E-02)
2	0.078437 (0.55E-02)	- 0.252332 (0.64E-02)	0.173895 (0.46E-02)
3	0.136992 (0.01)	0.387076 (0.01)	- 0.524067 (.01)

[a] Own price elasticity = $-1+ s_i + \alpha_{ii} / s_i$; Cross price elasticity = $s_j + \alpha_{ij} / s_j$

[b] Food group 1 = cereals and cereal products; Food group 2 = meat, fish, fruits and vegetables; Food group 3 = all other food items.

[c] Calculated standard errors

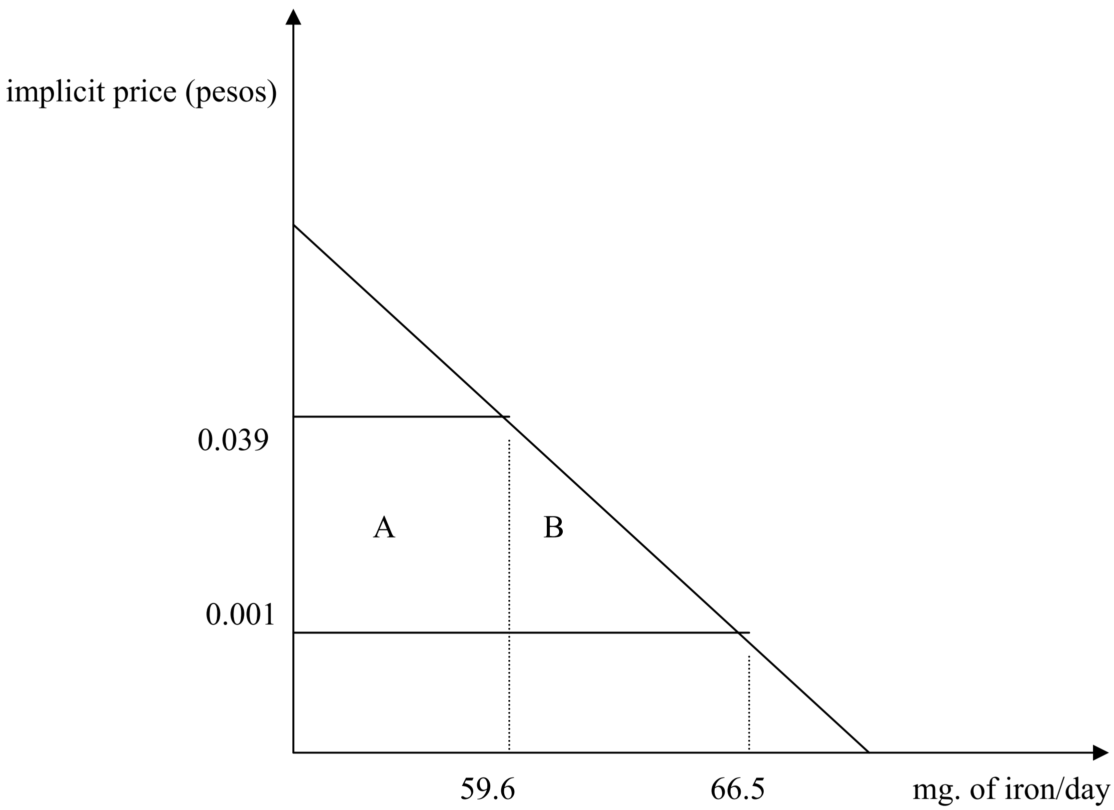

Figure 1. Household Demand for Iron

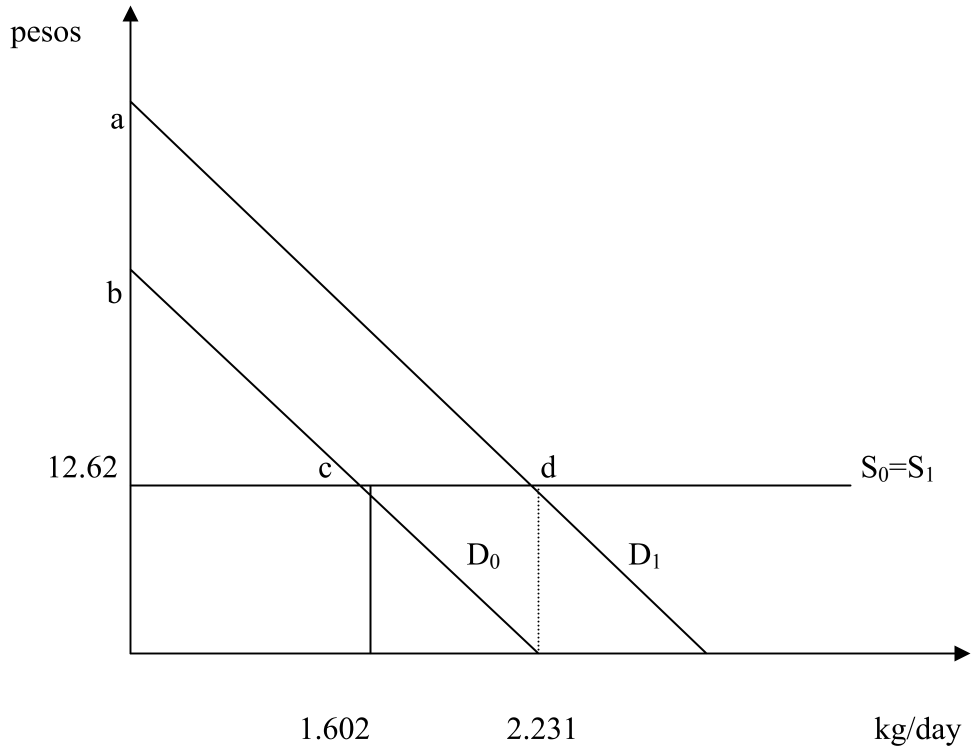

Figure 2: An Outward Shift in Household Demand for Rice due to the Nutritional Enhancement of Rice

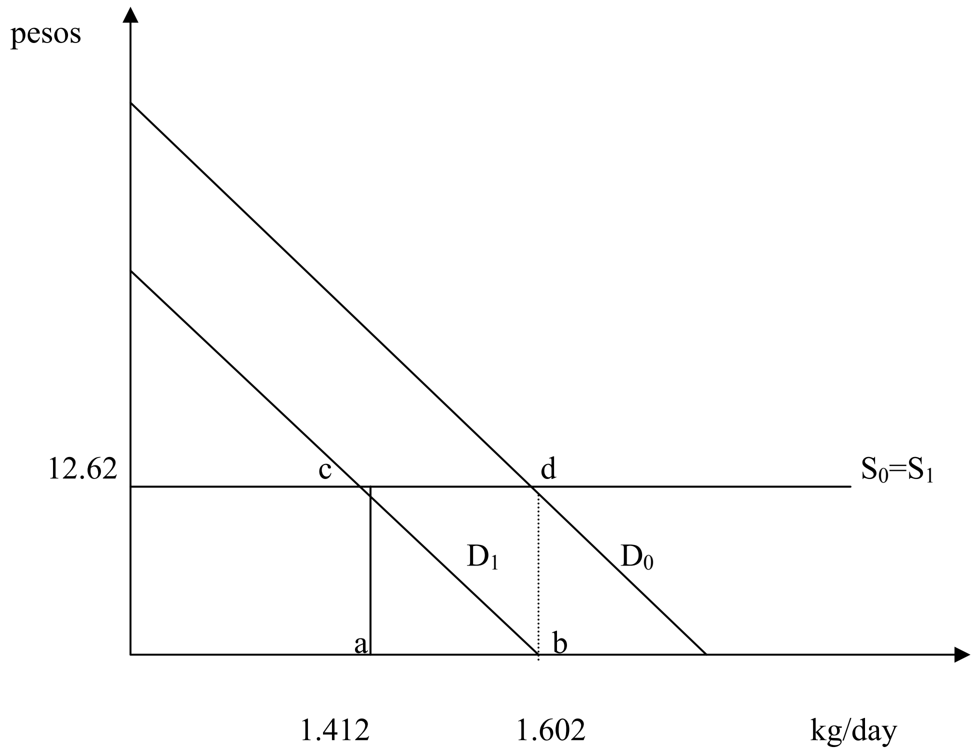

Figure 3: An Inward Shift in Household Demand for Rice due to the Nutritional Enhancement of Rice

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