Modelling the Acceptance of High Beta-carotene Maize

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Abstract

In the development of high beta carotene (HBC) maize, the focus is on subsistence farms which do not get any (or at least very little) benefit from commercial fortification programs. The technology can be considered to be primarily for the small-scale subsistence farmer. The paper postulates a household decision model that takes into account the production and consumption tradeoffs between traditional and biofortified seed. The objective is to understand the effect of these differing traits on the adoption decision when white maize is preferred by the consumers.

Key words: high beta-carotene maize, biofortified maize, household decision model

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Despite efforts of many international organisations, vitamin A deficiency remains a public health problem in 118 countries: between 100 and 140 million children are vitamin A deficient (WHO, 2005). Dietary supplements and commercial fortification programs – while they are relatively successful – often fail to reach subsistence farmers. Despite the mixed acceptance, commercialisation of golden rice fuelled discussions on fortifying other staples.

The High Beta-Carotene (HBC) Maize Initiative is part of the broader international collaboration on biofortification under the Harvest Plus program and is committed to providing an agricultural solution to the problem of vitamin A deficiency in Sub-Saharan Africa. Studies on the cost-effectiveness of these technologies are being conducted by HarvestPlus and others in the HBC Maize Initiative, and critical factors in evaluating the potential impact of HBC maize are the acceptability of this new technology to producers and acceptability of the new product to consumers. Previous studies (for example, Zimmermann and Qaim 2004; Dawe, Robertson and Unnevehr 2002) have not been specific about the conceptual framework for estimating the adoption rate or have merely made a range of assumptions on it. The focus of this paper will be on developing a theoretical framework that can be later applied for estimating the adoption of the new technology and the new product which primarily would benefit subsistence farmers. The most general case is where the adoption decision is a household joint production and consumption decision, so adoption depends both on production and consumption characteristics.

More significant trade-offs are likely in the consumption traits. In most of Africa, white maize is highly preferred by consumers. More beta-carotene generally increases yellow colour, so this is a problem and again this trait may differ between GMO and non-GMO varieties. Differences in taste and texture could also be factors affecting consumer acceptance. One could counter the "less desirable" appearance, taste or texture with information on the health benefits especially for children. If the woman of the household is the primary decision maker on consumption goods, and if she believes this improves family and especially children’s' health, it may be a factor to offset the less desired appearance or taste. Experience with sweet potatoes in Africa along these lines finds some positive response to health education.

We will postulate a household decision model that takes into account the production and consumption tradeoffs between traditional (meaning unfortified) and biofortified seed in a household that has no access to commercially fortified flour. The effects of the vitamin A will be modelled indirectly via the positive side effect it provides, using a qualitative parameter of “functionality” and health benefits.

After some background on the empirical context, we develop the conceptual model and use it to derive policy and research implications. At a later stage, the exercise will be supplemented by mathematical simulations.

Vitamin A Deficiency

With relatively successful global campaigns against illnesses claiming and devastating human lives in a relatively short period of time (such as tuberculosis, polio, etc.), interests of the research community are encouragingly moving also to the areas of micronutrients[3]. Even though lack of micronutrients is relatively infrequently leading directly to immediate death, it has damaging effects on quality of life, productivity, and overall wellbeing of those affected and can lead to death in severe cases. In many cases, lack of micronutrients weakens the organism and thus facilitates contraction of diseases. People affected by micronutrient deficiency might not appear malnourished, but are unquestionably “misnourished”. Vitamin A deficiency falls into this category. Vitamin A (retinol)[4] is fat soluble and is found mainly in fish liver oils, liver, egg yolks, butter and cream. Green leafy and yellow vegetables contain beta-carotene and other provitamin carotenoids, which are converted to retinal in the mucosal cells of the small intestine. Vitamin A deficiency can be divided into primary and secondary. Primary vitamin A deficiency is usually caused by prolonged dietary deprivation, and is endemic to areas where staple food is devoid of carotene.

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[3] This paper is concerned about micronutrients deficiency. However, we do recognise that abundance of certain micronutrients can be toxic and can have immediate health effects.

[4] Adopted from http://www.merck.com/mrkshared/mmanual/section1/chapter3/3b.jsp

Secondary vitamin A deficiency is caused by inadequate conversion of carotene to vitamin A or to interference with absorption, storage or transport. Secondary deficiency is not of interest of this paper.

The severity of the effects of vitamin A deficiency is inversely related to age. Growth retardation is a common sign in children. Inadequate intake or utilization of vitamin A can cause impaired dark adaptation and night blindness; xerosis of the conjunctiva and cornea; xerophthalmia and keratomalacia; keratinisation of the lung, GI tract, and urinary tract epithelia; increased susceptibility to infections; and sometimes death. Follicular hyperkeratosis of the skin is common.

While consumption of foods naturally high on vitamin A or carotene would be the best option, this option might not be feasible in the areas where the historically and culturally consumed staple is low in beta carotene. Regulators are trying to supplement carotene into diets using artificial means, such as providing pharmaceutical supplements and fortifying immediate grocery staples. Nevertheless, supplements are only available to infants and many fortification programs fail to reach out to subsistence rural households which depend mainly on own production and small local mills that do not have fortification capability.

Preliminary Literature Review

The paper extends previous work on this topic (Tothova and Meyers 2006) and aims to model technology adoption where the benefits are not seen as straightforward. In fact, based on the pure consumption characteristics, the consumer prefers the old variety to new because of the colour, consistency, and possibly taste. However, the internal characteristics of HBC maize and its impact on health are expected to jointly influence the decision. The model is tailored to fit subsistence households.

Valuable theoretical models that are potentially applicable can be found in various straits of economic literature, such as development, nutrition, technology adoption, models focused on macro impacts, consumer theory, welfare economics, etc.

When considering the adoption problem, some studies focus on farm characteristics, while some focus on technology characteristics. Technology adoption in the case discussed in this paper relies in fact on nutritional characteristics of the product rather than agronomic or economic benefits.

With the technology still in development, ex-post studies are not feasible. Most of the ex-ante studies of HBC maize and similar technological advancements put a monetary tag on the technology adoption using Disability Adjusted Life Years (DALYs) (Stein et al. 2005 and Zimmerman and Qaim 2004). Overall, there appears to be a lack of theoretical models for this type of application, and this paper attempts to bridge that gap in the literature.

The consumer ultimately prefers the older variety because of its direct consumption characteristics; and when faced with a direct choice without incorporating health benefits, the consumer would choose the "inferior" technology. Possible modelling approaches include but are not limited to incorporating a nutritional element of the new technology to the Solow growth model, adjusting productivity growth, an alternative model of technology adoption, attempting to model demand for micronutrients in a Lancaster fashion, or adjusting Grossman's model of demand for health (Grossman 1972).

Nutritional deficiency seems to be modelled (treated) in the medical literature. Standard modelling approaches related to nutrition are demand for calories and demand for nutrients and micronutrients, which take advantage of Becker and Lancaster's approaches to model attributes assuming a higher level of nutrients leads to a higher utility.

Implications for the Model

The topic at hand is not related to direct technology adoption benefits in terms of productivity growth, lower production costs, etc. The paper discusses technology adoption when nutritional benefits are dominant, and thus differs from a traditional technology adoption approach (Feder et al 1985; Zeller et al 1998). Biofortified maize (or any other biofortified product) does not lead directly to marketable benefits (if anything, it might be less marketable due to less desirable colour) or increases in profit due to savings of inputs or higher yields.

Modelling the biofortified maize adoption decision as a standard technology adoption case when a farmer is deciding between two different varieties possibly requiring a different mix of inputs (e.g. Smale, M. et al, 1994) does not work well in this case. Broader effects originating from (somehow indirect) benefits from the adoption of biofortified maize might get lost in a typical technology adoption framework.

Benefits of the technology delivering high beta carotene (or a different nutrition improvement) are not directly market oriented. In addition, the not-so-desired colour of biofortified maize flour (yellow, while general preference is for white) implies lower utility from consuming high beta carotene maize and might make it even more difficult to market. This would result in depressed prices unless there are consumer education schemes. Moreover, preliminary survey results also indicate that many farmers and rural consumers are not fully aware of the benefits of increased intake of Vitamin A delivered via biofortified maize or even commercially fortified maize flour.[5] So consumer education is also a basic necessity for adoption.

Therefore, the effects of the vitamin A are represented indirectly using a qualitative parameter of “functionality” (e.g. in Strauss and Thomas 1998) or healthiness or “improved quality of life”: a function of the amount of beta carotene in the diet (type of maize chosen) and other factors (described in detail momentarily). Thus, the impact of HBC maize is modelled via the positive side effect it provides on the “functionality” and in terms of improved wages.

Conceptual model

We postulate a household decision model that takes into account the production and consumption tradeoffs between traditional[6] and biofortified seed while focusing on the trade-off between consumption preferences and health related characteristics. Given the limited amount of scientific research, any discussion is purely presumptive at this stage.

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[5] This material is drawn from a preliminary research report entitled: Small-scale Maize Milling and Maize Consumption in the Limpopo Province of South Africa: An Overview”, by H. Vermeulen and J. F. Kirsten, University or Pretoria, June 2005

[6] In our formulation, “traditional” seed can also refer to any current variety which does not have HBC fortification, even if it be a modern variety.

The model is tailored to address Vitamin A deficiency in its primary form[7], though it could be adapted to other similar health benefits. The objective of the model is to understand the effects of these differing beta carotene levels (or, adapted to other problems, any other traits) on the adoption decision, keeping in mind that it is a joint decision of production, consumption, and health, although the production side of the model is largely simplified. Future extensions of the model are envisioned to lead to estimating the adoption rate based on known or assumed characteristics of alternative technologies and preferences of households. An extension of the model could also be seen as a way to guide technology by showing the relative importance of different traits. A special case of this model would be applied for rural consumers who do not have home production but rely on village production and local mills for their staple.

At this point the model ignores any preferential treatment within families (such as boys vs. girls, older vs. younger). Despite the empirical evidence that women heads of households might be more willing to adopt crop with health and nutritional benefits, this point is ignored as well in the current version of the model, though one could assume that the woman in the household decides for all.

General comments and assumptions

Consider a representative subsistence household with limited or no access to commercial maize fortification and operating in a perfectly competitive environment with perfect markets. We do not make any assumption on whether the household is a net seller of maize. However, we do assume when purchases of staple food are made, household purchases the same type it cultivates (traditional or biofortified). No shifting to other staple foods is allowed. Households are price takers in either case regardless the type of maize they choose. We do differentiate between the price of maize for seed and price of maize for consumption. However, we do not consider cost of milling or cost of fortification if the grain is milled in a

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[7] As opposed to secondary Vitamin A deficiency, as explained earlier.

mill which routinely fortifies its flour.[8] The paper concentrates on the case when beta carotene is included in the seed.

We consider two “types” of maize: conventional (traditional) and biofortified, without differentiating between biofortified maize developed using traditional breeding techniques or genetically modified maize. One of the justifications for this approach is the relatively limited understanding of genetic modification among lower income and rural populations (Jensen et al, 2006), as revealed by the available surveys. While recognizing the importance of agronomic traits for farmers’ decisions, such as hereditable traits affecting carryover of seed to the next planting season, we refrain from modelling them explicitly except through differing seed cost.

We consider a one period model with perfect foresight and perfect information. Assume all input and output markets are present and functioning. Farmers produce for their own consumption and for sales at a spot market. Mixing both traditional and HBC maize (for example due to crosspollination) is not possible, and conditions for separating equilibrium are satisfied.

While the yellow colour of the seed and its flour[9] is considered a disadvantage by the consumers, from the modelling perspective a different colour of the meal would avoid the principal agent problem, even if perfect foresight and full information were not imposed. Ultimately, the driving force behind the model presented in the paper is to set the framework for estimating or simulating adoption rates using survey data[10] or mathematical simulation software.

The model captures a single period, for example a growing season. It can be interpreted in a broader model as a first stage in a multiple period model where a subsistence farmer decides what variety to grow next planting season. The original decision in the model at hand is exogenous: at the beginning,

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[8] While adding this aspect would be straightforward, following iceberg delivery cost, it is ignored at this stage. In any case, most local mills are not equipped to provide fortification of maize products.

[9] When vitamin A is added in commercial mills, there is no yellowing of the flour which is not different in appearance than other flour. It is when it is biofortified so it is in the pulp or the germ of the kernel that it becomes yellow even when it is milled.

[10] Recognizing the project is still in the experimental stage and in reality farmers were not faced with this decision yet, we might consider data for alternative staple crops – such as sweet potato to derive implications for biofortified maize.

each household makes a decision whether to grow traditional or HBC maize, and consequently purchases the inputs. For the sake of simplicity, we assume seed is purchased every year rather than used as a carryover from the last planting season. The seed purchase is considered to be some sort of a capital investment, irreversible during the season.

Model

We start with a basic household model (for example, Singh et al, 1986) where a representative household is deriving utility from consuming the agricultural staple (X_a), a market purchased food (X_m) and leisure (X_l) subject to full income, time and production constraints, assuming only one staple crop, family and hired labour being perfect substitutes, risk-less production, and household being a price taker in all markets. Although the negative consequences of vitamin A deficiency affect children the most, the paper models the household as a unit relying on an assumption of equal distribution within a household.

We consider maize to be the agricultural staple. While the model only considers one market purchased good, it can possibly be a vector. We introduce two new parameters: M and f. The parameter M is defined as a “type of maize”, or in the context of the paper, traditional or conventional ($M = C$) and biofortified maize ($M = B$). M is irreversibly chosen at the beginning of the planting season. To ease the notation, unless otherwise indicated, superscripts clarify whether a variable is a function of other variables and parameters. Subscripts represent types of goods: $_a$ stands for agricultural staple (maize), $_m$ for market good, and $_l$ for leisure.

For reasons which will be made clear momentarily, the model measures the consumption of the staple (maize) in units of beta carotene. Following the development literature, f stands for “functionality”. It is defined as a function of the endogenously determined consumption of staple measured in terms of beta carotene units (X_a), endogenously determined demand for the market purchased product (X_m) and a parameter h:

$$f = f\left(X_a^M, X_m, h\right) \tag{1}$$

Functionality f (defined in Equation 1) can be interpreted as "healthiness" or "quality of life". f is increasing in all parameters (X_a^M , X_m, h), implying a higher utility of a well nourished and health agent. The hypothesis is that healthier labour is more productive both on-farm and off-farm, resulting in higher income, and more market-purchased goods that otherwise would not have been available. The state of "functionality" is directly observable. Assume the consumption of the market good is measured in physical units, and increased consumption of the market good improves functionality (for example in terms of calories). h embodies other factors contributing to functionality and thus reinforcing the impact of beta carotene. The amount of beta carotene consumed is a function of the variety chosen (conventional or biofortified), and this is represented by a superscript ^{M} on the consumption of agricultural staple measured in units of beta carotene. To simplify modelling, the model does not consider the case of possible overdose of Vitamin A or overdose of market good, although the problem could be easily fixed by adopting a constraint setting a cap on the consumption. This paper does not consider direct productivity gains, but assumes the market wage reflects the healthiness of the labour. That is, market wage is a function of functionality. Furthermore, possibly higher income is reflected in increased intrinsic value of consuming market purchased goods and leisure.

Leisure (X_l) not included in the "functionality", although a case can be made that leisure also contributes to the wellbeing and functionality. However, in the model presented, leisure enters into the utility function directly and is modelled as a function of wellbeing, represented by superscript ^{f} but it is not one of the household's choice variables. Nevertheless, the direction of causality is naturally open to discussion.

A representative household maximises the following utility function:

$$\max_{\left\{X_a^M, X_m, X_l^f\right\}} \mathrm{U} = \mathrm{U}\left(X_a^M, X_m, X_l^f, f\right) \tag{2}$$

subject to a full income constraint (Equation 3), time constraint (Equation 4) and production constraint (Equation 5).

(3) $$p_m X_m = p_a^M \left(Q_a - X_a^M\right) - p_l^f \left(L - F\right) - p_V^M V + E$$

(4) $$X_l^f + F = T$$

(5) $$Q_a = Q_a\left(L, V, A, K, M\right)$$

While the choice of variety (*M*) appears in the production function, we assume the yields are the same regardless the variety chosen. This assumption assures that adoption of any variety is not driven by the output market, and instead we can fully focus on the impact on improved nutrition on "functionality" and its impact on increased wages and income. Moreover, breeders are assumed to make no sacrifice of agronomic traits when enhancing beta carotene.

The partial derivative of the utility function with respect to consumption of the staple (X_a) is negative. This indicates that if the choice was made on the consumption characteristics (colour, consistency, possibly taste, etc.) alone, households prefer white maize to yellow maize, which transposed to beta carotene units means less beta carotene to more. The total derivative of the utility function with respect to X_a taking into account effects on "functionality" is positive.

As already mentioned, consumption of the agricultural staple is measured in terms of beta carotene units. From the consumer's point of view, maize white in colour (that is, containing less beta carotene) is preferred to maize yellow in colour. However, in terms of health benefits contributing to the functionality, more beta carotene is preferred to less, and yellow maize is considered to be better in terms of health quality.

Conventional and biofortified varieties are assumed to not differ in terms of yields, making it easier to focus on the adoption based on consumption and nutrition characteristics. However, we assume that the price of the biofortified seed is higher than the price of conventional seed:

(6) $$p_V^C < p_V^B$$

Assume the price of the market purchased good (p_m) is invariant with respect to choice of the staple variety. The price of the agricultural staple differs between conventional (white) and biofortified ("yellowish") maize. Since consumers prefer white maize to yellow, we will assume that the market price of a unit of conventional maize exceeds the market prize of a unit of biofortified maize:

(7) $$p_a^C > p_a^B$$

However, since market wage is an increasing function of functionality defined in Equation (1):

(8) $$p_l^f = p_l(f)$$

Healthier and better nourished labour receives higher wages. Since functionality is in large part influenced by intake of beta carotene, it is clear that:

(9) $$p_l^C < p_l^B$$

where the superscript indicates the choice of variety. Descriptions of variables are summarised in Table 1.

Table 1: Description of variables

Variable	Description
f	Functionality as defined in equation (1)
X_a^M	Consumption of agricultural staple (maize), measured in units of beta carotene. If $M = C$, conventional maize is consumed. If $M = B$, biofortified maize is consumed.
X_m	Consumption of market purchased good
X_l^f	Consumption of leisure. Superscript ^{f} indicates that it is a function of functionality
H	Other factors contributing to functionality
p_a	price of the agricultural staple (maize)
p_m	price of the market purchased good
Q_a	household's production of staple. If $(Q_a - X_a) > 0$, household markets its surplus. If $(Q_a - X_a) < 0$, household is a net buyer. However, household only purchases the type of maize grown.
p_l	market wage

L	total labour input
F	family labour input. If *(L - F)>0*, household hires labour. If *(L - F)<0*, household earns market wage off-farm.
V	variable input, likely a vector. Includes purchased seed.
p_v	price of the variable input
E	any non-labour, non-farm income
T	total stock of household time
A	household's fixed quantity of land
K	household's fixed quantity of capital
M	choice of variety

While we do not ignore the production decision, in the case of perfect markets the solution to the producer problem – the profit maximising decision – is independent of utility maximisation (see Singh et al, 1986), so we focus the discussion on the consumption side of a joint household decision.

Taking into account that the output price of the staple and input price of the seed are functions of the varieties selected, and that wages are functions of "functionality", after algebraic manipulation the first order conditions of the consumer's utility maximisation problem become:

$$\frac{\partial U}{\partial X_a^M} + \left[\frac{\partial f}{\partial X_a^M}\left(\frac{\partial U}{\partial X_l}\frac{\partial X_l}{\partial f}+1\right)\right] = \lambda\left[p_a^M - \frac{\partial p_l}{\partial f}\frac{\partial f}{\partial X_a^M}\left(F-L\right)\right] \tag{10}$$

$$\frac{\partial U}{\partial X_m} + \left[\frac{\partial f}{\partial X_m}\left(\frac{\partial U}{\partial X_l}\frac{\partial X_l}{\partial f}+1\right)\right] = \lambda\left[p_m - \frac{\partial p_l}{\partial f}\frac{\partial f}{\partial X_m}\left(F-L\right)\right] \tag{11}$$

$$\frac{\partial U}{\partial X_l} = \lambda p_l \tag{12}$$

$$p_a^M X_a^M + p_m X_m + p_l^f X_l = Y^M \tag{13}$$

Where λ is a Lagrange multiplier. Notice extra terms in Equations 10 and 11: These terms capture marginal utility plus the marginal impact of variety choice on "functionality" and of functionality on wage and leisure. The current version of the paper refrains from analysing the first order conditions in their general form, and opts for a deeper analysis of specific functional form and later a numerical example.

Solving the system of Equations (10 – 13), uncompensated demand functions for agricultural staple, market purchased good, and leisure are obtained:

(14) $$X_a^M = X_a^M\left(p_a^M, p_m, p_l^f, Y^M\right)$$

(15) $$X_m = X_m\left(p_a^M, p_m, p_l^f, Y^M\right)$$

(16) $$X_l^f = X_l^f\left(p_a^M, p_m, p_l^f, Y^M\right)$$

where income Y^M is defined as:

(17) $$Y^M = p_l^f T + \pi^M + E$$

and profit π^M is defined as:

(18) $$\pi^M = p_a^M Q_a - p_l^f L - p_v^M V$$

Insert the demand functions into the utility function (Equation 2) to obtain a welfare function:

(19)

$$W^M = W^M\left[X_a^M\left(p_a^M, p_m, p_l^f, Y^M\right), X_m\left(p_a^M, p_m, p_l^f, Y^M\right), X_l^f\left(p_a^M, p_m, p_l^f, Y^M\right)\right]$$

Adoption decision

To derive an adoption decision – for example, for the next planting season – the household compares indirect utility that would be achieved producing and consuming traditional maize (Equation 19 for conventional variety) with an indirect utility that would be achieved if HBC maize is cultivated (Equation 19 for the HBC variety). Define ΔW to be the difference in the subsistence farmer's welfare (captured by the indirect utility function) from two different actions: adopting biofortified maize or adopting (or staying with) a conventional variety:

(20) $$\Delta W = W^{B} - W^{C}$$

Thus, if the indirect utility in the scenario in which biofortified maize was grown and consumed exceeds the indirect utility from the scenario in which traditional maize was cultivated, the household prefers the HBC maize and adopts it for the next planting season. If the relationship is opposite and the indirect utility achieved in the scenario when traditional variety was grown exceeds the biofortified variety, household adopts the traditional variety. If the relationship is indeterminate, a household is indifferent.[11]

Specific functional form - example

To analyse the adoption based on the difference between welfares achieved under adopting different varieties, we derive a case with specific functional forms and numerical values for exogenous parameters. We use variable descriptions summarised in Table 1.

Thus, assume *f* (functionality, described in Equation 1) takes form of:

(21) $$f = \left(X_a^M\right)^h X_m$$

Taking logs of both sides and manipulating the terms, the functionality function becomes:

(22) $$\ln f = h \ln X_a^M + \ln X_m$$

The parameter *h* is exogenous, and can capture effects such as health education. Define the utility function (Equation 2) as:

(23) $$U = \left(X_a^M\right)^{-\alpha} \left(X_m\right)^{\gamma} \left(X_l^f\right)^{\delta} f$$

Notice that the partial derivative with respect to consumption of the agricultural staple (maize) measured in units of beta carotene and not taking into account is effect on functionality is negative, indicating decreasing (direct) utility from consuming yellow maize. Recall that consumption of leisure (X_l) is a

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[11] If HBC maize was produced using both conventional and transgenic methods, a household would compare three alternatives by ranking traditional, biofortified conventional and biofortified genetically modified.

function of functionality in qualitative terms: a healthier individual is more capable of enjoying and actively pursuing his or her leisure time. Thus:

(24) $$X_l^F = fX_l$$

Combining Equations 22 and 24 with the utility function (Equation 23), and taking log of both sides of the utility, we obtain:

(25) $$\ln U = (h+\delta h-\alpha)\ln X_a^M + (\gamma+\delta+1)\ln X_m + \delta \ln X_l$$

Maximising the utility function (Equation 25) subject to the full budget constraint is a trivial task. The individual demand functions are:

(26) $$X_a^M = \frac{h+\delta h-\alpha}{h+\delta h-\alpha+\gamma+2\delta+1}\frac{Y^{f,M}}{p_a^M}$$

(27) $$X_m = \frac{\gamma+\delta+1}{h+\delta h-\alpha+\gamma+2\delta+1}\frac{Y^{f,M}}{p_m}$$

(28) $$X_l = \frac{\delta}{h+\delta h-\alpha+\gamma+2\delta+1}\frac{Y^{f,M}}{p_l^M}$$

To simplify notation define:

(29) $$A = h+\delta h-\alpha+\gamma+2\delta+1$$

Substitute demand functions back to the utility function (Equation 25) to obtain welfare function:

(30) $$W^M = A\ln Y^{f,M} - (h+\delta h-\alpha)\ln p_a^M - (\gamma+\delta+1)\ln p_m - \delta \ln p_l^M + D$$

where *D* is a constant defined as:

(31) $$D = (h+\delta h-\alpha)\ln(h+\delta h-\alpha) + (\gamma+\delta+1)\ln(\gamma+\delta+1) + \delta\ln\delta - A\ln A$$

Before comparing the welfare function in the adoption decision, recall that prices under different scenarios were compared in Equations 6 – 9. Total income ($Y^{f,M}$) is defined as:

(32) $$Y^{f,M} = p_l^F T + \pi^M + E$$

where the profit is defined as:

(33) $$\pi^{M} = p_{a}^{M} Q_{a} - p_{l}^{f} L - p_{V}^{M} V$$

Recall that by construction a household is facing higher input and lower output prices if it decides to grow the biofortified variety. Therefore, it will not adopt biofortified variety should this decision be based solely on higher profits. However, the household is earning higher wages if it consumes the biofortified variety. Therefore, it is not straightforward whether total income increases or decreases with the adoption of new variety.

A household prefers (and adopts) biofortified variety over conventional variety if welfare obtained when biofortified variety is adopted if greater than welfare obtained of traditional variety is adopted:

(34) $$\Delta W = W^{B} - W^{C}$$

Substituting Equation 30 into 34 and rearranging terms we obtain:

(35) $$\Delta W = A \ln\left(\frac{Y^{B}}{Y^{C}}\right) + \left(h + \delta h - \alpha\right) \ln\left(\frac{p_{a}^{C}}{p_{a}^{B}}\right) + \delta \ln\left(\frac{p_{l}^{C}}{p_{l}^{B}}\right)$$

The sign of Equation 35 depends on the ratio of incomes, ratio of output prices of agricultural staple, and ratio of wages. Recall that by equations 7 and 8, the price ratio for the staple p_a is less than 1 and the price ratio for labor p_l is greater than 1, so natural logs of these ratios are negative and positive, respectively. To simplify the analysis, assume three different cases can occur in theory:

Case I: $Y^{B} = Y^{C}$

Case II: $Y^{B} > Y^{C}$

Case III: $Y^{B} < Y^{C}$

If the ratio of incomes is equal to one (Case I), a household will adopt HBC maize if:

$$\frac{\left|\ln\left(\frac{p_a^C}{p_a^B}\right)\right|}{\left|\ln\left(\frac{p_l^C}{p_l^B}\right)\right|} > \frac{\delta}{h+\delta h-\alpha} \tag{36}$$

If $Y^B > Y^C$ (Case II), a household will adopt HBC maize if:

$$A\left|\ln\left(\frac{Y^B}{Y^C}\right)\right| + \left(h+\delta h-\alpha\right)\left|\ln\left(\frac{p_a^C}{p_a^B}\right)\right| > \delta\left|\ln\left(\frac{p_l^C}{p_l^B}\right)\right| \tag{37}$$

Finally, if $Y^B < Y^C$ (Case III), a household will adopt HBC maize if:

$$\left(h+\delta h-\alpha\right)\left|\ln\left(\frac{p_a^C}{p_a^B}\right)\right| > A\left|\ln\left(\frac{Y^B}{Y^C}\right)\right| + \delta\left|\ln\left(\frac{p_l^C}{p_l^B}\right)\right| \tag{38}$$

Conclusions and Policy Implications

For a subsistence farmer to make a link between what this paper calls “functionality” and increased intake of Vitamin A, an extension and education program would have to be put into place (which in terms of the model would operate through the parameter *h*). Recognizing the cost of extension, and societal benefits from improved health status of the population – in the case discussed in this paper, the most vulnerable population – a proper venue to address the issue would be using a social welfare function accounting for such costs.

Consumer education, extension, properly designed policies encouraging adoption, mitigating the higher seed cost, and lessons learned from sweet potato are all part of the desired policy mix to enhance adoption. Such an education campaign could be linked with the introduction of HBC maize but should also incorporate a basic promotion on the value of increased vitamin A intake and what other foods (not yet considered in the model) could contribute. Experience with sweet potatoes in Africa along these lines finds some positive response to health education.

Because white maize is strongly preferred by most consumers in South Africa, it is reasonable to assume that without an education campaign there would be little understanding of HBC benefits and, therefore, little or no adoption. However, the Vermeulen (2005) study indicates a strong potential impact if such an education program is undertaken.

An implication for technology development and transfer is that improved production characteristics in the HBC maize, could add some incentive on the cost reduction or yield enhancing side, but without consumer acceptance, it is not likely to be sufficient incentive to induce significant adoption.

The adoption decision described above lends itself nicely to a probit model estimating response probabilities. This type of empirical evidence would be very important in trying to quantify the parameters and thereby the relative importance of prices and factors affecting incomes in the adoption decision. In order to test the model with empirical data, the HBC sweet potato case may be a good one. It has already been introduced in some areas, and it has some of the same colour related issues that maize has.

The highly stylized exercise based on assumed functional forms indicate that mitigating higher seed costs would be important to adoption, since adoption is so sensitive to the income ratio. Also, and perhaps more importantly, it suggests that extending this analysis to a time frame that could include increased productivity and other health benefits would likely increase the income differentials between HBC and traditional choices.

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