PREDICTING THE ACCEPTANCE FOR HIGH BETA-CAROTENE MAIZE: AN EX-ANTE ESTIMATION METHOD

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Predicting the Acceptance for High Beta-carotene Maize: An Ex-ante Estimation Method

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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 focus of this paper is on the adoption decision, which is a household joint production/consumption decision. Adoption depends both on production and consumption characteristics. In the case of HBC maize, the production characteristics may be less problematic than the consumption characteristics, but that remains to be seen. Research is under way in the High Beta Carotene Maize Initiative to develop high pro-vitamin A beta carotene seed technologies by both conventional and transgenic means. Studies on the cost-effectiveness of these technologies are being conducted, and this paper seeks to refine the theoretical foundations for estimating the adoption rate for such studies.

Influencing the production decision are traits and tradeoffs on both the seed and production sides. There may be an issue of whether or not the seed stock is a genetically modified organism (GMO), since they would have different characteristics and the non-GMO varieties would likely have lower beta carotene content. There may be a trade-off on other traits but, in principal, the breeders plan no sacrifice of other desirable production traits when beta carotene is enhanced. More significant trade-offs are likely in the consumption traits. In most of Africa, white maize is highly preferred by consumers. More beta carotene increases yellow colour, so this preference 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.

We postulate 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, keeping in mind that it is a joint decision about production and consumption. The model is designed to estimate the adoption rate based on known or assumed characteristics of alternative technologies and preferences of households. It could also be seen as a way to guide policy makers and scientists pursuing maize fortification through technology for subsistence farmers.

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

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Introduction

The High Beta-Carotene 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. An interdisciplinary team of plant scientists and human nutritionists is developing biofortified varieties of maize, a widely consumed food in much of Sub-Saharan Africa. Maize is being bred through conventional and transgenic means to provide increased amounts of beta-carotene, a vitamin A precursor, in the kernels. The expected result will be a low-cost, self-sustaining food intervention that can be grown and consumed by vulnerable populations with limited access to formal food distribution or health care systems.

In the quest for high beta-carotene (HBC)[1] maize, the focus is on subsistence farms, which do not get any (or at least very little) benefit from commercial fortification programs. Thus the technology can be considered to be primarily for small-scale subsistence farmers. Another group of potential beneficiaries are other poor rural residents such as landless workers who obtain their maize and maize products from local production and village maize mills that cannot feasibly implement commercial fortification. The latter group of beneficiaries is a special case where only the consumption decision matters.

Studies on the cost-effectiveness of these technologies are being conducted (Jensen et al.), 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 of this nature (Zimmermann and Qaim, 2004; Dawe, Robertson and Unnevehr, 2002) have not been specific about the conceptual framework for estimating the adoption rate. The focus of this paper is on developing a theoretical framework that can be applied to estimate the adoption of the new technology and the new product. The most general case is where the adoption decision is a household joint production/consumption decision, so adoption depends both on production and consumption characteristics. Following some background on the empirical context, this paper develops a conceptual model and uses it to derive policy and research implications.

Maize Production and Consumption Characteristics

White maize is one of South Africa's most important staple foods. Yellow maize is also an important agricultural crop, but is rarely used for human consumption except in cases of severe shortage of white maize. Commercial production of maize is located in the Free State, North West, and Mpumalanga provinces; however, maize is produced in most parts of the country. Based on the agricultural production section of the Household Questionnaire (World Bank, 1994), approximately nine percent of households reported

[1] Although not necessarily technically precise because of zinc and iron biofortification programs, this paper uses biofortified maize, and HBC maize interchangeably.

that they grew crops or kept livestock for sale, exchange or home consumption; 95 percent of those households practiced subsistence/small scale agriculture.

Unlike the data on consumption that show maize is widely consumed in both urban and rural areas, the distribution of subsistence production varies more among the provinces. Most of the subsistence producer households surveyed were located in the (former) provinces of Natal, Eastern Cape and Northern Transvaal. Approximately 56 percent of those farming at the subsistence level produced maize grain and 78 percent produced either maize grain or fresh maize. Participation ranged from nearly 90 percent in Eastern Cape and Natal to levels below 50 percent of subsistence farmer households in Western Cape and Eastern Transvaal. Producers were predominantly African (80.6 percent).

Genetically modified (GM) insect resistant (Bt) white maize was planted in South Africa for the first time during the 2001/02 season. Approximately three percent (2.8 percent) of the total area planted to white maize and 17.3 percent of the total area planted to yellow maize were expected to be genetically modified in the 2002/2003 season. In 2004/2005 Bt white maize covered close to 8 percent of the total area under white maize and Bt yellow maize covered close to 250,000 hectares or 23 percent of the yellow maize area (Van Der Walt, 2005). The primary purpose of genetic modification was to improve insect resistance to the maize stalk borer.

The data from 1994 show that nearly 90 percent of households consumed either maize grain or mealie meal/maize flour during the survey month (World Bank). Over 41 percent of households consumed maize as grain and 87 percent of households consumed maize as mealie meal/maize flour. Most of the surveyed households procured these foods by purchasing them. The rural population depends to a greater extent on their own production, and in many rural areas small scale and subsistence farmers depend almost entirely on their own production. Maize was a staple crop consumed by nearly all households in all provinces except Western Cape. Consumption of maize varied by race. Almost all black African households consumed maize, in contrast to lower percentages for others (60-70 percent).

Knowledge of production systems for households that consume mostly their own production is very relevant to potential adoption of a biofortified variety. In South Africa, subsistence and semi-subsistence farmers normally grow traditional varieties for their home consumption, and for these they select the best seed from the previous year's harvest. If they buy improved/high yielding varieties of seed, it is usually from local seed producers. In part of Kwa Zulu Natal Province, one of the largest potential markets for HBC maize, a very high percentage of small-scale farmers have adopted hybrid seed that they purchase every year (Gouse), including *Bt* and *Roundup Ready* maize varieties. But this use of hybrids is not as prevalent in other areas or other provinces. Seed cost will play a very big role, since the study indicates the adoption rate for Bt maize would have been much higher if it had not been for the additional technology fee.

The available production inputs are rather low, so the added cost of inputs for any newly introduced technology needs to be weighed in the adoption decision. However, a survey of small-scale farmers in Mpumalanga, KwaZulu Natal, and Eastern Cape found that 55 percent to 100 percent indicated that they used some commercial fertilizer (Gouse). It is assumed that the varieties used as carriers for the HBC trait will have as good or better agronomic traits as what small-scale farmers are currently growing.

The critical importance of subsistence and semi-subsistence production is seen in Figure 1. Though these production statistics are not readily available, small growers are a significant part of national production; but maize grown by subsistence and semi-subsistence farmers is an even larger share of what is consumed by the low income, rural population. The survey of small-scale farmers in Mpumalanga, KwaZulu Natal, and Eastern Cape found that 10 percent to 22 percent of harvested maize was sold to local community households (Gouse),who are likely landless or produce less than they consume.

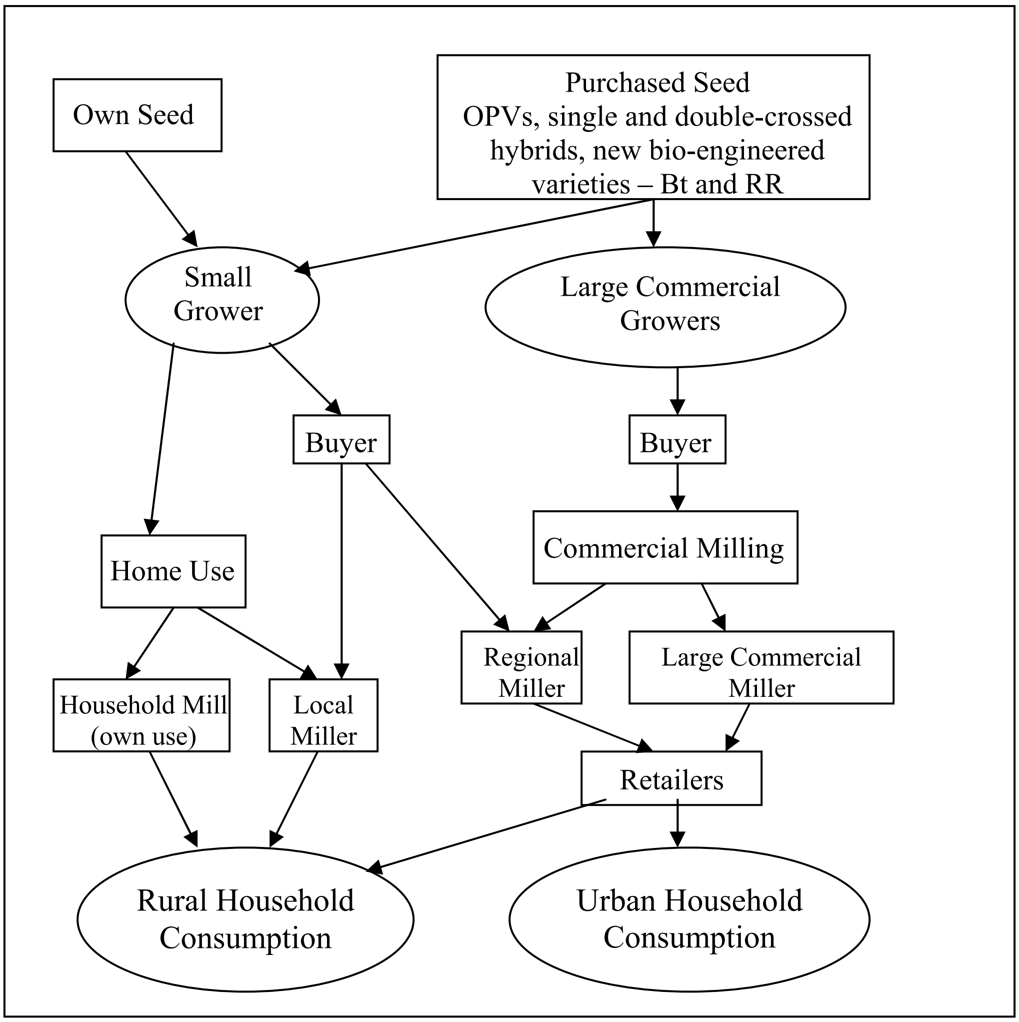

Figure 1. Marketing chain for white maize in South Africa

Despite the recent law requiring fortification of maize meal, a significant share of maize consumed in rural areas does not pass through commercial mills and is consumed without the benefit of fortification. In theory, the law applies also to local mills, but in practice it is not economically feasible and possibly not even safe to enforce fortification at local mills. The safety factor relates to the toxicity of the supplements if they are not fully and evenly blended with the flour in the correct proportions. A recent survey of small and medium scale millers in Limpopo province indicates that most small scale millers do not know about fortification and none of those interviewed had implemented it. Among medium scale millers, all were aware of it and most had implemented it (Vermeulen and Kirsten, 2005). It is estimated that nationwide up to 30 percent of maize meal is not biofortified, but a much larger percentage of maize consumed by low income, rural populations is not biofortified.

Influencing the production decision are differing traits and tradeoffs in the seed characteristics and the cost of seed. Since HBC maize is being developed both by traditional breeding and transgenic means, there may be a GMO vs non-GMO issue. There may be a trade-off on other traits but, in principal, the breeders plan no sacrifice of desirable production traits when the beta carotene is enhanced. However, another possible trade-off on the production side is whether or not the seed has heritable traits, especially if the higher cost of HBC varieties is not mitigated by government assistance. Between traditional and HBC varieties there may be differences in input requirements, yield, storage characteristics, drought and disease resistance and market price that could influence adoption. Information campaigns or policy incentives to encourage adoption of a new variety could have influences on adoption.

In the case of HBC maize, more significant trade-offs may occur 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 this trait may differ between GMO and non-GMO varieties. They may also have different beta carotene content. Between the GMO and non-GMO varieties there may be differing acceptance rates. Differences in taste and texture could also be factors affecting consumer acceptance. The "less desirable" appearance, taste or texture may be offset with information on the health benefits especially for children. If the woman of the household is the primary decision maker on consumption and/or production acceptance, and if she believes this improves family health and especially the health of children, 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, so information campaigns could be a factor. Acceptability may be influenced by cooking properties. For the simplified case of households without home production, the market price would also be a factor in the consumption decision.

A study by Vermeulen (2005) in Limpopo and KwaZulu Natal Provinces indicated that nutrition education can have a significant effect on consumer choice. When asked to choose between a bowl of white maize meal and a bowl of yellow maize meal, most chose white meal. The group of respondents were then exposed to an information session with the following components:

- The advantages of Vitamin A,
- The natural food sources of Vitamin A and the link to the yellow or orange color of the food types,
- The presence and relative quantity of vitamin A in normal yellow maize, and
- The presence and relative quantity of vitamin A in "Golden" maize.

Following this information session, respondents in one province increased preference for yellow maize from 23 to 90 percent, and in another province preference for yellow maize increased from 0 to 85 percent. Though it was a limited test of the information effects, it strongly suggests that without information there would be very little adoption, and with information there would be a high adoption rate.

Conceptual Model

We postulate a household decision model that takes into account the production and consumption tradeoffs between traditional[2] vs biofortified seed. While we outline trade-offs among alternative biofortified technologies, given the limited amount of scientific research, any discussion would be purely presumptive at this stage

The objective of the model is to understand the effect of these differing traits on the adoption decision, keeping in mind that it is a joint decision of production and consumption. The model is designed 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 formulation of this model would be applied for rural consumers who do not have home production.

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, the 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 of 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 and cost of fortification if the grain is milled in a mill which routinely fortifies its flour.[3]

[2] In our formulation, "traditional" seed can also refer to any current variety which does not have HBC fortification, even if it is a modern variety.
[3] While adding this aspect would be straightforward, following iceberg delivery cost, it is ignored at this stage.

We consider two types of maize: traditional and biofortified, without differentiating between biofortified maize developed using traditional breeding techniques or genetic modification. One of the justifications for this approach is relatively little understanding of genetic modification among lower income and rural populations (Jensen et al., 2005), as revealed by the available surveys. While recognizing the importance of agronomic traits for farmers' decisions, such as heredity affecting carryover of seed to the next planting season, we refrain from modelling them explicitly except through differing seed cost.

Modelling approach chosen and expected outcomes

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 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 usual 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 resulting in depressed prices unless there are consumer education schemes. Preliminary survey results also indicate 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 (Vermeulen and Kirsten, 2005). Therefore, Becker's idea of searching for product attributes, in this case Vitamin A, and deriving direct utility from them, cannot be employed in this case.

Alternatively, the effects of the vitamin A are represented indirectly using a qualitative parameter of "improved quality of life": a function of the type of maize chosen and leisure (described in detail below). Thus, the impact of HBC maize is modelled via the positive externality it imposes. The externality effect is not modelled as an externality per se, such as when the utility of one consumer is directly affected by the actions of another consumer.[4]

We consider a one period model with perfect foresight and perfect information. We also assume mixing both traditional and HBC maize is not possible (for example due to crosspollination). The yellow colour of the flour[5] is considered a disadvantage by the consumers. From the modelling perspective, a different color 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 this paper is to set the

[4] This case will be considered in the analysis of non-producing households when a producing household's choice of biofortified maize imposes a positive externality on the consuming household.

[5] 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 endosperm or the germ of the kernel that it becomes yellow even when it is milled.

framework for estimating or simulating adoption rates using survey data[6] or mathematical simulation software.

Model

The model captures a single period, for example a planting 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 on hand is exogenous: at the beginning, 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 purchase of seed is considered to be some sort of a capital investment, irreversible during the season.

We start with a basic household model (for example, Singh et al, 1986) where a representative household is deriving utility from consuming agricultural staple (X_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 labor being perfect substitutes, riskless production, and household being a price taker in all markets.

We consider maize to be the agricultural staple. While the model only considers one market purchased good, it can possibly be a vector. Following the discussion on the modelling approach, we introduce two new parameters: M and β. M is defined as a "type of maize" – or in the context of the paper, traditional ($M = TR$) and biofortified maize ($M=HB$). M is irreversibly chosen at the beginning of the planting season. β is defined as a function of the variety chosen exogenously (M) and endogenously determined demand for market purchased product (X_m) and leisure (X_l):

(1) $$\beta = \beta\left(M, X_m, X_l\right).$$

β (defined in Equation 1) can be interpreted as "improved quality of life" – a difference between "quality of life in the traditional scenario" and "quality of life in the biofortified scenario," taking "traditional scenario" as a baseline. The hypothesis is that healthier labor 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. This paper does not yet consider productivity gains. Rather, it simplifies the matter by considering increased intrinsic value of consuming market purchased goods and leisure. When traditional maize is chosen, the "quality of life" parameter disappears. Thus:

(2) $$\text{if } M = TR \Rightarrow \beta\left(\mathrm{TR}, \mathrm{X_m}, \mathrm{X_l}\right) = 1 \text{ and}$$

(3) $$\text{if } M = HB \Rightarrow \beta\left(\mathrm{HB}, \mathrm{X_m}, \mathrm{X_l}\right) > 1.$$

[6] 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.

A representative household maximises the following utility function:

$$\max_{\{X_a, X_m, X_l\}} \mathrm{U} = \mathrm{U}(X_a, X_m, X_l, \beta) \quad (4)$$

subject to a full income constraint (Equation 5), time constraint (Equation 6) and production constraint (Equation 7).

$$p_m X_m = p_a(Q_a - X_a) - p_l(L - F) - p_v V + E \,. \quad (5)$$

$$X_l + F = T \,. \quad (6)$$

$$Q_a = Q_a(L, V, A, K, M) \,. \quad (7)$$

Table 1: Description of variables

Variable	Description
X_a	consumption of agricultural staple (maize)
X_m	consumption of market purchased good
X_l	consumption of leisure
B	improvement in "quality of life" if HBC maize is adopted, defined in Equations 1 – 3
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 labor input
F	family labor input. If $(L - F)>0$, household hires labor. If $(L - F)<0$, household earns off-farm market wage.
V	variable input, likely a vector. Includes purchased seed.
p_v	price of the variable input
E	any non-labor, 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

Notice the "quality of life" parameter does not enter the utility function directly – that is, a household does not optimise the choice of β term.

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 (Singh et al, 1986), so we focus the discussion on the consumption side of a joint household decision.

If the household chooses traditional variety, there is no difference in the "quality of life", and the β term disappears from the utility function. Similarly, M has no impact on the production function. The solution to the household problem is trivial, and the demand functions for staple, market purchased good and leisure are:

(8) $$X_a = X_a(p_a, p_m, p_l, Y),$$

(9) $$X_m = X_m(p_a, p_m, p_l, Y),$$

(10) $$X_l = X_l(p_a, p_m, p_l, Y),$$

where income Y is defined as:

(11) $$Y = p_l T + \pi + E$$

and profit π is defined as:

(12) $$\pi = p_a Q_a - p_l L - p_v V \, .$$

Plugging the demand functions (Equations 8 – 10) into the utility function (Equation 4) we obtain an indirect utility function:

(13) $$W^{TR} = W^{TR}\left[X_a(\bar{p}, Y), X_m(\bar{p}, Y), X_l(\bar{p}, Y)\right],$$

where Y is defined in Equation 11, $\bar{p}$ is a vector of prices $\left(p_a^{TR}, p_m, p_l\right)$ - with superscript TR on the price of agricultural staple standing for traditional, non-biofortified variety.

Assume now that the household would exogenously choose the biofortified variety. In the utility maximisation problem (Equation 4) the term β is present, and is taken into account in the first order conditions. Since in the production part M is treated as an endogenous variable, the profit maximising solution does not change. Note that a household is likely to face a different set of prices, namely p_a and p_v, as differently coloured flour allows product differentiation.

We use superscript ^{HB} to identify variables and parameters that differ from the earlier case when the traditional variety was adopted. Denote Y^{HB} to be available income when high beta carotene maize is chosen. Taking into account a different set of prices, Y^{HB} is defined as in Equations 11 and 12. The first order conditions for the utility maximisation problem are:

(14) $$\frac{\partial U}{\partial X_a} = \lambda p_a^{HB},$$

(15) $$\frac{\partial U}{\partial X_m} + \frac{\partial U}{\partial \beta}\frac{\partial \beta}{\partial X_m} = \lambda p_m,$$

(16) $$\frac{\partial U}{\partial X_l} + \frac{\partial U}{\partial \beta}\frac{\partial \beta}{\partial X_l} = \lambda p_l, \text{ and}$$

(17) $$p_a^{HB} X_a + p_m X_m + p_l X_l = Y^{HB},$$

where λ is a Lagrange multiplier. Note the extra term in Equations 15 and16: while the right hand side of the equation does not depend on the type of maize chosen for cultivation, the left hand side captures marginal utility plus the marginal impact on the "quality of life" – and as such is higher than in the previous scenario. The demand functions are:

(18) $$X_a^{HB} = X_a^{HB}\left(p_a^{HB}, p_m, p_l, Y^{HB}\right),$$

(19) $$X_m^{HB} = X_m^{HB}\left(p_a^{HB}, p_m, p_l, Y^{HB}\right), \text{ and}$$

(20) $$X_l^{HB} = X_l^{HB}\left(p_a^{HB}, p_m, p_l, Y^{HB}\right).$$

As before, Y^{HB} is defined as:

(21) $$Y^{HB} = p_l T + \pi^{HB} + E$$

and profit π^{HB} is defined as:

(22) $$\pi^{HB} = p_a^{HB} Q_a^{HB} - p_l L^{HB} - p_v^{HB} V^{HB}.$$

Plugging the demand functions (Equations 18 – 20) into the utility function (Equation 4) we obtain an indirect utility function:

(23) $$W^{HB} = W^{HB}\left[X_a^{HB}(\chi), X_m^{HB}(\chi), X_l^{HB}(\chi), \beta\left(M, X_m^{HB}(\chi), X_l^{HB}(\chi)\right)\right]$$

where

(24) $$\chi = \left(\bar{p}^{HB}, Y^{HB}\right).$$

Y^{HB} is defined in Equation 21, $\bar{p}^{HB}$ is a vector of prices $\left(p_a^{HB}, p_m, p_l\right)$ - with superscript *HB* on the price of agricultural staple standing for biofortified variety.

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 with an indirect utility that would be achieved if HBC maize is cultivated (Equations 13 and 23). Define ΔW to be the difference in the subsistence farmer's welfare (captured by the indirect utility function) from two different actions: adopting HBC maize or adopting (or staying with) a traditional variety:

(24) $$\Delta W = W^{HB} - W^{T}.$$

Thus, if the indirect utility in the scenario in which biofortified maize was grown and consumed (recall in this case household experienced an improvement in the "quality of life") 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 the traditional variety was grown exceeds the biofortified variety, the household adopts the traditional variety. If the relationship is indeterminate, a household is indifferent.[7]

Numerical examples

To visualise the adoption based on the difference between levels of welfare achieved by adopting different varieties, we simulate a case with specific functional forms and numerical values for exogenous parameters. We use the variable descriptions summarised in Table 1.

Thus, define β ("quality of life", described in Equations 1 – 3) as:

(25) $$if\ M = TR \Rightarrow \beta(\mathrm{TR}, \mathrm{X_m}, \mathrm{X_l}) = 1 \text{ and}$$

(26) $$if\ M = HB \Rightarrow \beta(\mathrm{HB}, \mathrm{X_m}, \mathrm{X_l}) = X_m * X_l > 1.$$

[7] 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.

Taking natural logarithms of both sides of the Equation 26 and rearranging terms for later use we obtain:

(27) $$\ln \beta = \ln X_m + \ln X_l .$$

Define the utility function (Equation 4) as:

(28) $$U = \beta X_a^{\gamma} X_m^{\delta} X_l^{\omega} .$$

By definition (Equation 25), when traditional variety is chosen, $\beta = 1$. For the sake of simplicity assume that:

(29) $$\gamma + \delta + \omega = 1$$

Thus, after taking logs of both sides and re-arranging the terms, the utility function for the traditional variety becomes:

(30) $$\ln U^{T} = \gamma \ln X_a + \delta \ln X_m + \omega \ln X_l ,$$

where the superscript *T* denotes traditional variety. Similarly, when an HBC maize is chosen, the utility function becomes:

(31) $$\ln U^{HB} = \ln \beta + \gamma \ln X_a + \delta \ln X_m + \omega \ln X_l ,$$

where the superscript *HB* denotes an HBC variety. Substituting for the natural logarithm of β from Equation 27 and re-arranging the terms we obtain:

(32) $$\ln U^{HB} = \gamma \ln X_a + \delta^{HB} \ln X_m + \omega^{HB} \ln X_l ,$$

where

(33) $$\delta^{HB} = 1 + \delta \text{ and}$$

(34) $$\omega^{HB} = 1 + \omega .$$

By construction:

(35) $$\delta^{HB} > \delta \text{ and}$$

(36) $$\omega^{HB} > \omega .$$

Thus, differently sized parameters in case of traditional and HBC varieties conveniently capture the "externality" effects in terms of quality of life discussed earlier in the paper.

We now turn to the discussion of the production function (Equation 7). Since the household's quantity of land and capital remain fixed in the model, we fixed them at one. The simplified production function becomes:

$$(37) \qquad Q_a = Q_a(L, V, M)\,.$$

Simplifying further, we assume the agronomic attributes of the seed remain the same (that is, the yield does not change depending on the variety chosen) only the seed as a variable input (*V*) is a function of the variety chosen (*M*). Thus, Equation 37 can be rewritten as:

$$(38) \qquad Q_a = Q_a(L, V\{M\})\,.$$

The profit function (Equation 12) for the traditional variety (superscript *T*) then becomes:

$$(39) \qquad \pi^T = p_a^T Q_a - p_l L - p_v^T V$$

and for the HBC variety:

$$(40) \qquad \pi^{HB} = p_a^{HB} Q_a - p_l L - p_v^{HB} V\,.$$

Recall that *V* includes seeds, and thus is a function of *M* (choice of variety, traditional or HBC). Thus, depending on the variety chosen, subsistence farmers face a different set of input and output prices for their staple. Since the profit maximising decision is independent of the utility maximisation problem, we do not elaborate the production part further by speculating on possible differences between prices of traditional and HBC maize, but the simulations will show the impacts of hypothetical price differences. For the purposes of analysing the welfare changes associated with adopting different varieties, assume that π^T and π^{HB} are levels of profits achieved with the profit maximising bundle of inputs. These levels of profits enter the full income constraint (touched upon in Equations 5 and 11):

$$(41) \qquad p_a^O X_a + p_m X_m + p_l X_l = Y^O\,,$$

where *O* (output) stands for *T* (in case of the traditional variety) or *HB* (in case of HBC maize), and Y^O – the full income – ignoring any non-labor, non-farm income, is:

$$(42) \qquad Y^O = p_l T + \pi^O\,.$$

Since the total stock of labor (*T*) and the market wage rate (p_l) do not change depending on the variety chosen, the full income becomes a function of profit. Maximizing the utility functions in the traditional variety case (Equation 30, subject to the relevant full income constraint, Equation 41) is a trivial case of a Cobb-Douglass utility maximisation problem. Substituting the Marshallian demand functions into the objective function in case of the traditional variety, we obtain an indirect utility function (identical with the welfare function):

$$(43) \qquad W^T = \ln Y^T - \gamma \ln p_a^T - \delta \ln p_m - \omega \ln p_l + C,$$

where C is a constant defined as:

$$(44) \qquad C = \gamma \ln \gamma + \delta \ln \delta + \omega \ln \omega .$$

The welfare function of the traditional case takes advantage of the assumption that the sum of parameters in the Cobb-Douglass utility function as specified in this paper is unity (Equation 29). However, due to the "externality" imposed in the HBC model (Equations 27 and 32), the structure of the Marshallian demand functions and consequently the indirect utility function is different. The Marshallian demand functions in the HBC case are:

$$(45) \qquad X_a^{HB} = \frac{\gamma}{\gamma + \delta^{HB} + \omega^{HB}} \frac{Y^{HB}}{p_a^{HB}},$$

$$(46) \qquad X_m = \frac{\delta^{HB}}{\gamma + \delta^{HB} + \omega^{HB}} \frac{Y^{HB}}{p_m}, \text{ and}$$

$$(47) \qquad X_l = \frac{\omega^{HB}}{\gamma + \delta^{HB} + \omega^{HB}} \frac{Y^{HB}}{p_l}.$$

From Equations 33 – 34, which define δ^{HB} and ω^{HB}, we derive that:

$$(48) \qquad \gamma + \delta^{HB} + \omega^{HB} = 3.$$

By substituting the demand functions (Equations 45 – 47) into the HBC objective function (Equation 32) we obtain the welfare function for the HBC case:

$$(49) \qquad W^{HB} = 3 \ln Y^{HB} - \gamma \ln p_a^{HB} - (1+\delta) \ln p_m - (1+\omega) \ln p_l + D,$$

where D is a constant defined as:

$$(50) \qquad D = \gamma \ln \gamma + (1+\delta) \ln (1+\delta) + (1+\omega) \ln (1+\omega) - 3 \ln 3 .$$

In the adoption decision (Equation 24), levels of welfare achieved under the traditional and HBC scenarios are compared. In the case of the specific functional forms we have assumed, Equations 43 and 49 are compared:

$$\Delta W = 3\ln Y^{HB} - \ln Y^{T} - \gamma\left(\ln p_a^{HB} - \ln p_a^{T}\right) + E, \tag{51}$$

where E is a constant defined as:

$$E = D - C - \ln p_m - \ln p_l. \tag{52}$$

Equation 51 can be further simplified as:

$$\Delta W = \ln\left(\frac{Y^{HB}\wedge 3}{Y^{T}}\right) - \gamma\ln\left(\frac{p_a^{HB}}{p_a^{T}}\right) + E. \tag{53}$$

Equation 53 depicts the adoption decision based on the change in welfare between the HBC and traditional variety. If $\Delta W > 0$, the indirect utility from HBC maize exceeds the indirect utility from the traditional maize. After eliminating the constant, Equation 53 can be graphed as a function of ratios of full incomes and prices:

$$\Delta W = \ln A - \gamma \ln B, \tag{54}$$

where

$$A = \frac{Y^{HB}\wedge 3}{Y^{T}} \text{ and} \tag{55}$$

$$B = \frac{p_a^{HB}}{p_a^{T}}. \tag{56}$$

Equation 54 is graphed on Figures 2 and 3 for low and high values of γ. The difference in welfare between HBC and traditional cases is shown to vary with the price ratio of HBC and traditional maize, and a ratio including an arithmetic function of full incomes under different scenarios.

Recall that a higher level of γ implies a relatively lower effect of market goods and leisure on household utility and a relatively stronger impact of the stable good (Equations 29 and 48). Since the benefit of the externality represented by β has a greater impact when the parameters on market goods and leisure are higher, this impact is moderated when γ is higher (Figure 3), so adoption requires larger income differences. Adoption clearly increases in all cases as the ratio of HBC to T incomes increases. In the case of lower γ, adoption is reduced slightly as the ratio of HBC to T prices increases

(Figure 2). This rate of decline in adoption increases as γ increases (Figure 3) The sensitivity of ΔW and this adoption to the price ratio is intriguing, but it is highly unlikely that the HBC price would be much higher than traditional varieties and quite possible that it would be lower.

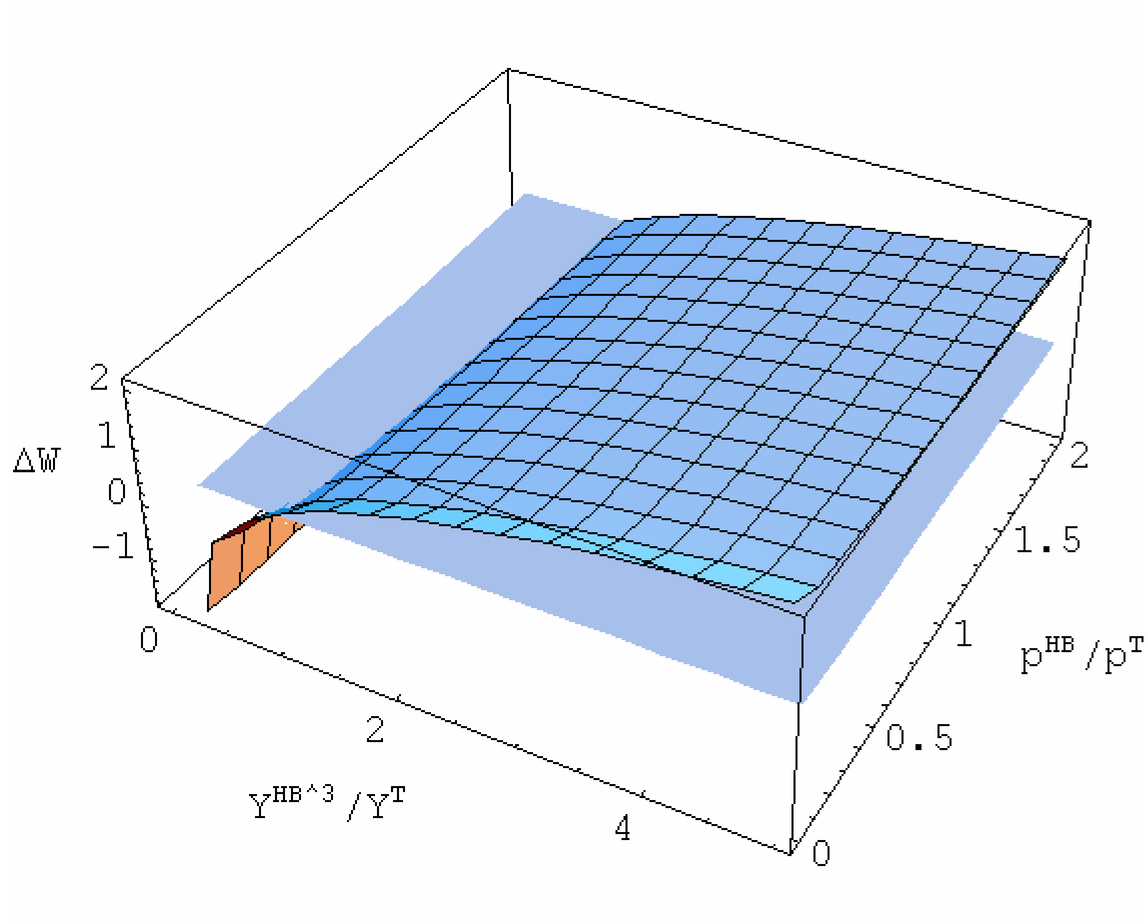

Figure 2. Impacts of price and income ratios on adoption when $\gamma = 0.1$

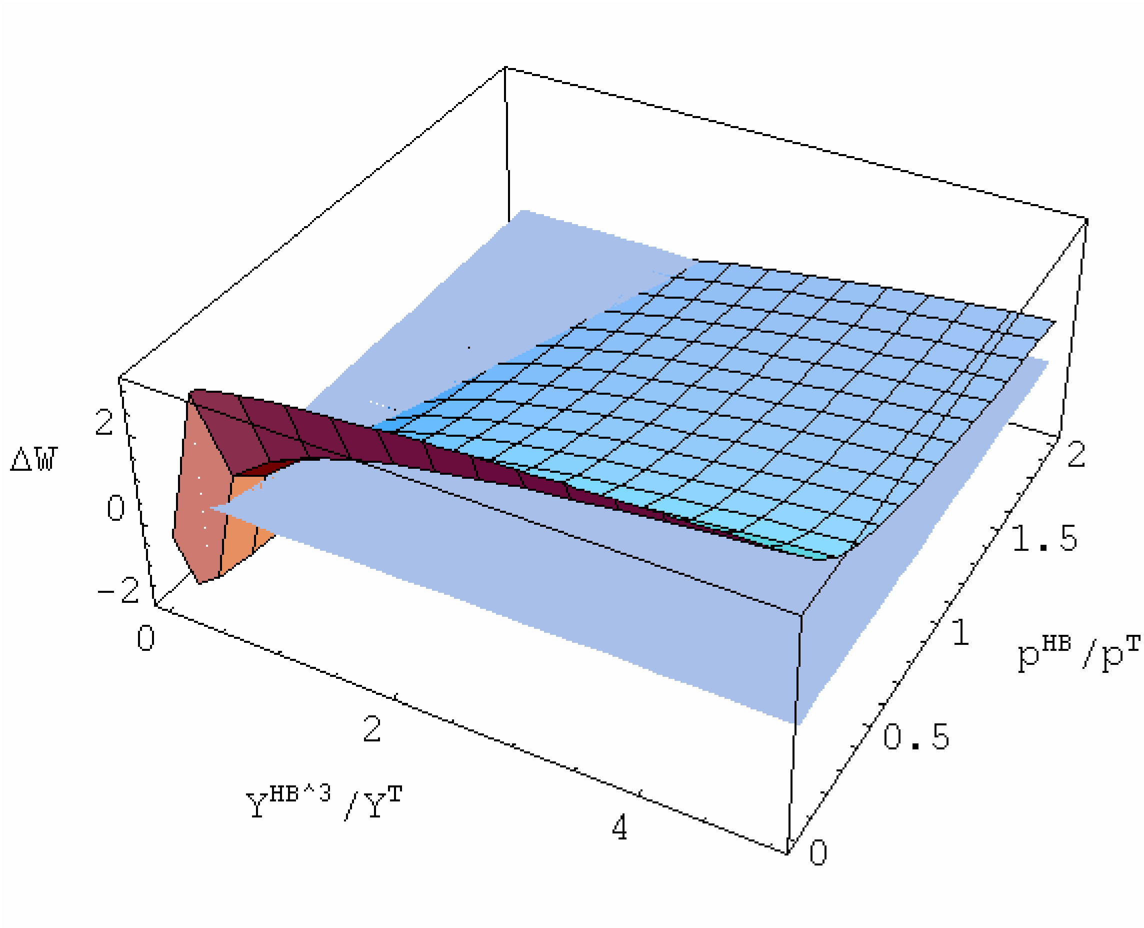

Figure 3: Impacts of price and income ratios on adoption when $\gamma = 0.9$

Extending this model to non-producing (landless) rural households is straightforward, since the consumption side would be the same, except for the income formulation. It would be a special case of the more general model laid out in this paper. The full income ratio is one, so all that matters to the decision is the ratio of prices. It is like taking the two-dimensional graphic from Figures 2 and 3 on the plane where the income ratio is one.

Policy and Research Implications

For a subsistence farmer to make a link between what this paper calls "improved quality of life" and increased intake of Vitamin A, an extension and education program would have to be put into place. 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, recall the Vermeulen (2005) study referenced earlier indicating 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 numerical simulations 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.

Opportunities for further research include but are not limited to extending the model on the household level beyond one period and considering future benefits from improved health. This would include impacts on household productivity, increased off-farm wage, etc.

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