Distribution of welfare gains from GM cassava in Uganda across different population groups and market margins

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The conventionally used equilibrium displacement model (EDM) provides a convenient way to estimate the distribution of welfare gains from crop productivity growth across different population groups. However, it ignores the high market margin. Little research has been done on the potential bias in estimated welfare gains when the market margin is omitted. This study assesses ex ante how the welfare effects of genetically modified (GM) cassava in Uganda will be distributed across large-scale producers, small-scale producers and non-producers, and how much bias is embedded in the conventional EDM that ignores the market margin. The results indicate that welfare gains from GM cassava will be enjoyed by all three groups but most by large-scale cassava producers, and that the bias that results from ignoring the market margin is relatively small when looking at the benefits for the entire country, but more serious for the population groups regarded separately.

Keywords: equilibrium displacement model; subsistence producer; cassava; market margin; sensitivity analysis

JEL classification: D13; D31; D81; O33; Q11; Q16

Le modèle de déplacement d'équilibre (MDE), utilisé de manière conventionnelle, est un moyen pratique d'évaluer la distribution des bénéfices sociaux obtenus grâce à la croissance de la productivité des récoltes, à travers différents groupes de population. Cependant, celui-ci ignore la forte marge du marché. Peu d'études se sont penchées sur la distorsion systématique potentielle dans l'estimation des bénéfices sociaux lorsque l'on exclut la marge du marché. Cette étude évalue, ex ante, la manière dont les répercussions sociales du manioc génétiquement modifié (GM) en Ouganda seraient distribuées auprès des grands producteurs, des petits producteurs et des non producteurs, et l'importance de la distorsion systématique dans le modèle conventionnel MDE qui ignore la marge du marché. Les résultats indiquent que les bénéfices sociaux issus du manioc GM profiteront aux trois groupes, mais principalement aux grands producteurs de manioc, et que la distorsion systématique que cause l'omission de la marge du marché demeure relativement négligeable au regard des bénéfices de tout le pays, mais plus sérieuse pour les groupes de population lorsque pris séparément.

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Mots-clés : *modèle de déplacement d'équilibre ; producteur de subsistance; manioc ; marge du marché ; analyse de sensibilité*

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1. Introduction

1.1 Background

Cassava is an important source of income and nutrition across sub-Saharan Africa, and efforts have been put into breeding high-yielding varieties in several of these countries, including Uganda (Woodward et al., 1999; Nweke et al., 2002; Gabre-Madhin & Haggblade, 2004). Throughout the 1980s the crop was threatened by the cassava mosaic disease (CMD), one of the most serious cassava diseases. To mitigate the problem in Uganda several new varieties, including the CMD-resistant varieties, were released by the National Program (Mahungu et al., 1994), starting in 1993 with the conventional breeding methods.

Modern breeding technologies, especially genetic modification (GM), improve the possibility of increasing the cassava yield. It generally takes about six years to develop genetically modified (GM) cassava, which is a quicker way to create an improved strain than using the conventional breeding method. The GM method can also develop the desired quality of cassava more precisely and accurately than the conventional breeding method, since the desired genes can be directly introduced into popular varieties to produce the desired attributes (Fregene & Puonti-Kaerlas, 2001), and the GM method makes it easier to develop high-yielding varieties without losing the preferred attributes, such as taste, texture, appearance and resistance to disease.

1.2 Research question

With an increasing prospect of commercialization of GM cassava in Uganda, it is important to assess its potential benefits to the country as a whole and across the different population groups, because the public effort that goes into increasing the productivity of subsistence crops like cassava can often be justified by the pro-poor nature of the crop and the way it can help reduce poverty. While GM cassava is likely to benefit Uganda as a whole, it is less clear how the benefits will be distributed across cassava producers and the rest of the population and between large-scale commercial producers and small-scale producers. There is a significant chance that, depending on the market characteristics, the main beneficiaries of the productivity growth, and thus drop in the price of cassava, will be non-producers rather than producers, since cassava is rarely traded internationally. Whether cassava producers, particularly small-scale producers who tend to be the poorest, will benefit substantially from GM cassava will determine how pro-poor the technology will be, and whether it should be promoted by public sector involvement.

Assessing how the welfare gains are distributed across these different population groups can be complicated for several reasons, including their semi-subsistence nature and the significantly high market margins that separate farmgate price and retail price. In Uganda, a typical cassava producing household consumes almost half of its harvest (Larson & Deininger, 2001). The price margin is relatively large in the Ugandan cassava market; the retail price being on average about 50% higher than the farmgate price (Larson & Deininger, 2001), with a potentially large variation across regions inside Uganda, as suggested by Collinson et al. (2002). The level of price margin is one factor that will determine the quantity of production and home consumption, and will thus influence some producers' decisions whether to participate in the market after the productivity growth brought about by GM cassava.

If the interest is in estimating welfare gains from GM cassava without reference to the market margin, we can use the equilibrium displacement model (EDM) to measure the welfare impacts of research-induced supply shifts formulated by Alston et al. (1995) and follow the extensions suggested by Hayami and Herdt (1977) and Qaim (2001) to incorporate the effect of the semi-subsistence consumption. (We refer to this method as 'the conventional EDM' hereafter.) As we show later, the conventional EDM is in one way attractive for its parsimony and thus quite useful for obtaining a good approximation of welfare effects in many cases. It is, however, still questionable when the welfare effects estimation needs to consider the existence of significantly high market margins. Few studies using the conventional EDM have incorporated the market margins into the welfare effects estimation, even when high margins were likely. As we show later, one key consequence of market margin is that some producers become autarkic when the prices of a commodity drop to certain ranges after the productivity growth. The impacts of productivity growth are therefore generally biased when estimated using only the information of elasticity and productivity growth as in the conventional EDM. The use of the conventional EDM can be justified only if the bias from ignoring the market margin is negligible.

It is therefore important to assess the extent to which the conventional EDM can approximate the true welfare effects in the presence of high market margins, and under what conditions it is more advisable to use the model that explicitly incorporates the market margin. We need to do this because it has become increasingly important to examine not only the aggregate welfare effects of certain GM crops but also how the gains are distributed between consumers and producers and among different types of producers. This is particularly important when we need to assess the extent to which such productivity growth can be pro-poor, i.e. of benefit to the small-scale producers, who tend to be the poorest, and in cases where the bias may be more serious when the welfare effects of each population group are taken into account.

1.3 Approach and contribution of the paper

This paper extends the model used by Hayami and Herdt (1977) and Qaim (2001) to estimate ex ante the welfare impacts of introducing GM CMD-resistant cassava in Uganda by incorporating market margin. To make the results as robust as possible, we estimate the welfare effects for only two producer groups, large-scale and small-scale, and non-producers. In the absence of detailed data for the quantity of production and home consumption, this study defines the two types of producers in terms of the quantity of production and home consumption, using the aggregate data. To reflect the high uncertainty in market information in sub-Saharan Africa, we use the estimation method proposed by Davis and Espinoza (1998) and Zhao et al. (2000), which provides better sensitivity analyses to account for the changes in many structural parameters for the EDM.

This study contributes to the literature in the following way. First, it adds more empirical information on the potential impacts of GM subsistence crops in sub-Saharan African countries. Second, it provides key insights into how well the conventional EDM that ignores the market margins can approximate the welfare effects in a market with significantly high margins, as well as when the conventional EDM should be replaced with more complicated models. Third, it applies the recently developed sensitivity analysis methods to the case of welfare effects estimation in the sub-Saharan African market with relatively large uncertainty in structural parameters due to the scarcity of information. The results of the study mainly show that, while the conventional EDM gives a good approximation of the welfare effects for the whole population in Uganda, it may underestimate the welfare gains for producer groups and overestimate the gains for non-producers when the market margins are significantly high.

The paper is structured as follows. Section 2 briefly explains the GM cassava development market in Uganda, Section 3 describes the theoretical framework and the model structure and estimation methods, Section 4 interprets the results, and Section 5 concludes.

2. GM cassava development in Uganda

While the application of GM technology to cassava has been slow in most of sub-Saharan Africa, Uganda has been one of the exceptions. The commercialization of the GM CMD-resistant cassava is expected to start in Uganda in a few years. After feedback from the cassava growers, the CMD-resistant cassava will be distributed to six local stations around Uganda. Local cassava producers who participate in the extension training program will then be able to obtain a small quantity of the root of the CMD-resistant cassava free of charge. Producers will be able to purchase in bulk quantity at negotiated prices. In some cases the local government or NGO groups will discount the CMD-resistant cassava stocks and distribute them among producers. Monetary expenses that farmers incur for obtaining GM cassava will therefore be minimized and so have been ignored in the analysis in this paper.

The current status of cassava in Uganda indicates that the productivity growth for cassava through GM will bring major improvements in welfare for the poor. Cassava is, on the national average, the second largest source of calorie intake in Uganda. From 1999 through 2003, it provided 300 cal/day per person (see Figure 1), slightly less than plantains (440) and more than maize (260). Cassava is particularly important for an impoverished population. Appleton (2001) estimates that cassava provides 23% of calorie intake for the impoverished population of Uganda compared with 13% for the country as a whole (FAOSTAT, 2006). Larson and Deininger (2001) estimate that 76% of cassava produced is marketed,[1] while on average farm households market 44%. This means that a small number of larger producers market a large portion of their production, while a large number of small farmers produce cassava primarily for subsistence consumption, and the distribution of gains from GM cassava is likely to be heterogeneous across different producer groups. Other sources of demand for cassava in Uganda are for livestock feed and for starch (Graffham et al., 2003) but if they are to grow, these sectors need not only an

[1] The share of marketed amount is higher than that of other crops, for example maize grain (35%).

increase in cassava yields but also an improvement in infrastructure such as roads and large-scale post-harvest processing facilities. Major benefits from GM cassava, for the foreseeable future, may be therefore rest on its potential for the poor who consume it as food and trade it as a source of income.

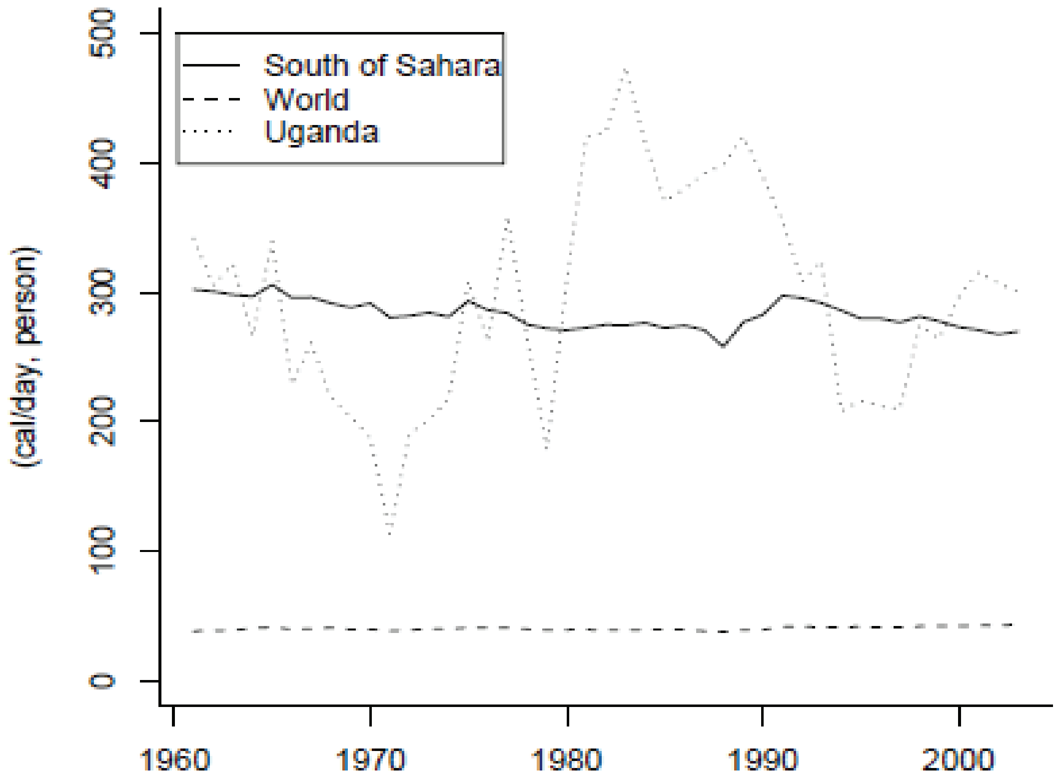


Figure 1. Calorie intake from cassava
Source: Author's calculation based on FAOSTAT (2006).

Most of the information about current regulations on GM products in Uganda is unavailable. The National Environmental Statute issued in 1995 contains no regulation on biotechnology. Although the Ugandan Government has been in favor of importing GM foods since August 2004,[2] additional regulatory policies may be implemented in the future. This poses an uncertainty with regards to possible welfare outcomes from GM cassava production, as several studies suggest that GM crops, if sold as foodstuff, may face significantly higher consumer resistance (Johnson et al., 2005; Lence & Hayes, 2005). Several studies, however, suggest that consumers in sub-Saharan Africa generally have favorable opinions of GM foods (Vermeulen et al., 2005; Adeoti & Adekunle, 2007; Kimenju & De Groote, 2008). This paper therefore assumes that

[2] Information available at www.biosafetyafrica.net/east.htm#ref28

consumers, including subsistence producers, are indifferent as to whether they consume GM or non-GM cassava, and the estimation results are based on this assumption.

3. Conceptual framework

The EDM has been widely used to analyze ex ante the economic impacts of GM crops in developed countries and to a lesser extent in developing countries (Smale et al., 2006). A few studies incorporate the subsistence consumption into the EDM. Hayami and Herdt (1977) present a framework to estimate welfare impacts for producers and consumers resulting from the technology advance in the Philippines rice sector, describing how the change in welfare is affected by the level of subsistence. A study by Qaim (2001), which measures ex ante the welfare effects of adopting transgenic virus- and weevil-resistant sweet potatoes in Kenya, provides a framework that can also be used to analyze the welfare impacts of the distribution of GM cassava. Not many studies using EDM for ex ante analysis of GM subsistence crops, however, consider the effect of market margins that are exogenous to the productivity growth, although Alston et al. (1995) suggest that market margins can be incorporated into the EDM with the assumption that they remain constant during the productivity growth. The welfare effects estimated from EDM are found to be sensitive to the underlying assumptions about elasticities, yield and productivity growth effects of GM crops (Price et al., 2003; Scatasta et al. 2006), and may be sensitive to the market margins.

This section first describes the conventional EDM and its underlying assumptions. It then provides a simple illustration of the system that cassava producers use to make production decisions, showing how the conventional EDM may fail to capture such systems. Lastly, this section provides the alternative model which accounts explicitly for the market margin and explains how the estimation is done.

3.1 The conventional EDM and its limitations

Following Qaim (1999, 2001), the welfare effects for different producer groups and non-producer groups can be expressed as the following formula in the conventional EDM. The market clearing conditions are described as

$$q_{s,i} = q_{s,i}(p,\delta_i) \quad (1)$$

$$q_d = q_d^{\text{market}}(p) + \sum_i q_{d,i}^{\text{home}} \quad (2)$$

$$\sum_i q_{s,i}(p,\delta_i) = q_d(p) \quad (3)$$

in which production by producer group $i, q_{s,i}$ is a function of price p and technology parameter δ_i, and total quantity demanded in the country is the sum of quantity demand at the market by non-producers, q_d^{market} at price p, and subsistence demand by cassava producer group i, $q_{d,i}^{\text{home}}$. Price p is the market clearing price, which equates production with total demand.

This paper follows Qaim (2001) in expressing the productivity growth for producer group i (K_i) as the percentage reduction in per-unit production cost relative to the price p times the adoption rate for producer group i. With productivity growth expressed as K_i, the percentage change in the clearing price $p, \frac{dp}{p}$, is determined as

$$\frac{dp}{p} = \frac{\sum_{i=1}^{n} \varepsilon_{si} ss_i K_i}{\varepsilon_d - \sum_{i=1}^{n} \varepsilon_{si} ss_i} \tag{4}$$

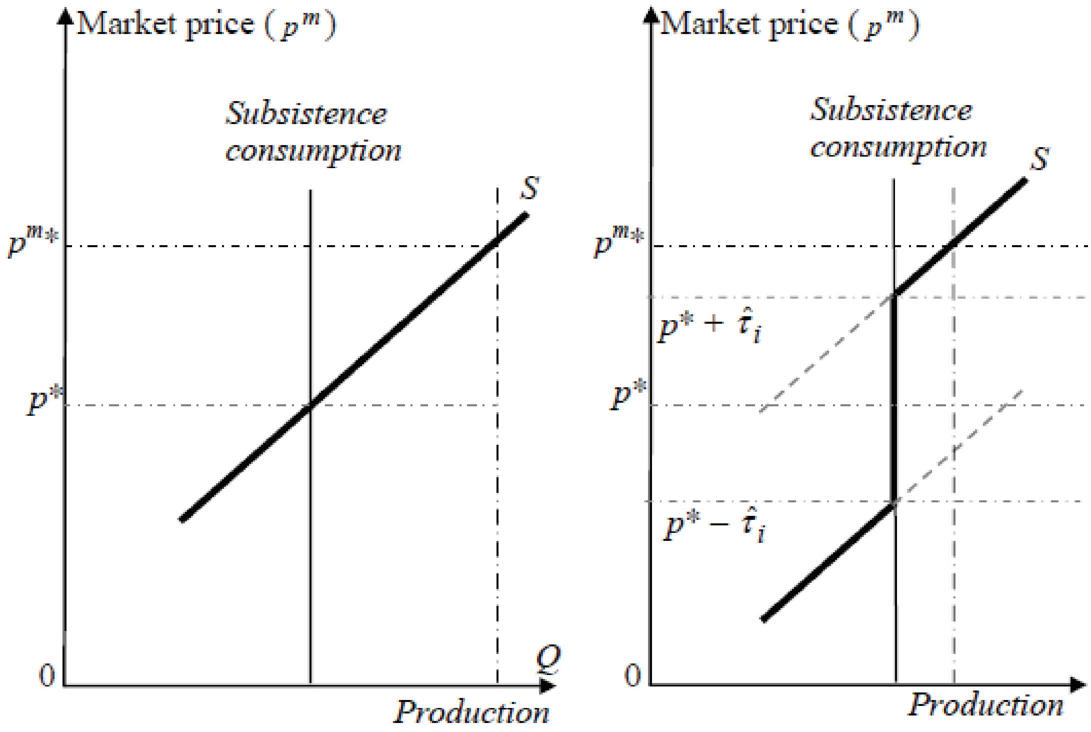
in which $\varepsilon_{s,i}$ is the price elasticity of production by producer group i, ss_i is the share of production by producer group i, and ε_d is the price elasticity of total demand. With $\frac{dp}{p}$ as (4), the welfare effects for producer group i (ΔPW_i) and non-producers (ΔCS) can be expressed concisely as

$$\Delta PW_i = p\left[q_{s,i}\left(\frac{dp}{p} + K_i\right)\left(1 + 0.5\varepsilon_{s,i}\left(\frac{dp}{p} + K_i\right)\right) - \frac{dp}{p} q_{s,i} h_i \right] \tag{5}$$

$$\Delta CS = -pq_d \frac{dp}{p}\left(1 + 0.5\varepsilon_d \frac{dp}{p}\right) - \left(-dpq_d \sum_{i=1}^{n} (h_i ss_i)\right) \tag{6}$$

in which h_i is the share of subsistence consumption in production by producer group i. The expressions (4) through (6) are quite attractive, as the welfare effects can be calculated using only the information of initial equilibrium and the nature of productivity growth, without actually solving for the new market clearing conditions after the productivity growth occurs.

The calculation of welfare effects, however, becomes more complicated when there is a certain level of market margin τ_i. Part of the reason for this is that, in the presence of market margin, the production curve becomes perfectly inelastic to price for certain ranges of prices regardless of the elasticity at the initial equilibrium (Figure 2). Important deviations of the production and home consumption curves in the presence of market margin from those without the market margin, as indicated by the Figure 2, are as follows (Key et al., 2000; Takeshima, 2009). Under the assumption that market margin is constant across all levels of supply, and there is no fixed transaction for entering the cassava market, the production and home consumption by producers become perfectly inelastic to price when the price is in the band with $2\tau_i$. At the higher price, where the producer is selling the surplus to the market, the production curve in the presence of market margin is shifted backward compared to the case with no market margin. Similarly, at the lower price, where the producer is buying the deficit from the market, the production curve in the presence of market margin is shifted outward compared to the case with no market margin.



(a) No market margin (b) With market margin $_i$

Figure 2. Supply curve for cassava producing households

Source: Author.

When the market margin is in place, the expressions (4) through (6) from the conventional EDM are biased. For example, the formula (6), which relies on the slopes of supply curves at the initial equilibria, will not hold when the supply curves can be perfectly inelastic when the price drops to a certain level.

3.2 The alternative EDM that incorporates market margin

The important question in this paper is, as was explained in the introduction, whether the welfare effects in the presence of market margin can still be approximated well using formulas (4) through (6). Such information would be useful because the expressions of welfare effects in the presence of market margin may not be obtainable in analytical forms such as (4) through (6), and if (4) through (6) can provide a good approximation even in the presence of a certain market margin, much effort can be saved by incorporating the market margin into the estimation procedure. We therefore test the ability of formulas (4) through (6) to approximate the welfare effects by building a model which explicitly accounts for the market margin τ_i (called 'the alternative EDM'), estimating the unbiased welfare effects using the alternative EDM, and comparing the estimates obtained from (4) through (6) (the conventional EDM).

The analytical expression of the alternative EDM, which corresponds to the illustration in Figure 2, is the following. For simplicity, following Qaim (2001), we consider only two producer groups, with i = 1 for the small-scale producer group, i = 2 for the large-scale producer group, and one consumer group, and assume that both producer groups face the same τi (we therefore drop i from notations for production elasticity ε_s and market margin τ hereafter). For producer groups i, and the non-producers, the supply function S_i and the demand function D are assumed to take a linear shape, with their slope determined by the elasticity of production and demand at the initial equilibria. More specifically, S_i and D are algebraically expressed as in (7) and (8):

$$S_i(p^m,\tau_i,K_i)=\begin{cases} a_i(p^m-\tau)+a_iK_ip^{m0}+b_i & \text{if} \quad p^m-\tau\geq p_i^* \\ q_{s,i}h_i & \text{if} \quad p^m-\tau<p_i^*<p^m+\tau \\ a_i(p^m+\tau)+a_iK_ip^{m0}+b_i & \text{if} \quad p^m+\tau\leq p_i^* \end{cases} \tag{7}$$

$$\text{where } a_i=\varepsilon_s\frac{q_{s,i}}{p^{m0}}, b_i=q_{s,i}-a_i(p^{m0}-\tau)$$

$$D(p^m)=cp^m+d$$
$$\text{where } c=\varepsilon_d\frac{q_d}{p^{m0}}, d=q_d-cp^{m0} \tag{8}$$

in which p^{m0} is the initial market price of cassava, p_i^* is the marginal cost of production at which the production is equal to the subsistence consumption by producer group i ($q_{s,i}h_i$), as illustrated in Figure 2, and a_i, b_i, c and d are parameters that determine the slopes and intercepts of S_i and D. Apart from the market margin τ and perfectly inelastic section of supply curve, the model is the same as Qaim's (2001) model. With the productivity growth K_i, the new equilibrium price $pm*$ satisfies the market clearing condition (9).

$$\sum_{i=1}^{2} S_i(p^{m*}, \hat{\tau}_i, K_i) = D(p^{m*}) + \sum_{i=1}^{2} q_{s,i} h_i \qquad (9)$$

This paper assumes that cassava producers in Uganda fall into one of two types, and that all producers in the same category are identical. With this assumption, it becomes more feasible to compute the supply function, and the household demand function for a given farmgate price for each type of producer, satisfying the information at the aggregate level as set out by Larson and Deininger (2001).

By modifying the concept of Marshallian aggregate surplus, the welfare of a cassava producing household (W_i) in this study is measured by

$$W_i = \int_0^{q_i^*} \max\left[MU_i(q), p^{m*} - \tau_i\right] dq - \int_0^{q_i^*} \min\left[MC_i(q, K_i), p^{m*} + \tau_i\right] dq \qquad (10)$$

in which $q_i^* = \max[S_i(p^{m*}, \tau_i), q_{s,i} h_i]$. The functions MU_i(q) and MC_i(q) denote the marginal utility curve of cassava consumption and the marginal cost curve of cassava production. More explicitly, $MU_i(q) = \infty$ for $q < q_{s,i}h_i$, $MU_i(q) = 0$ for $q > q_{s,i}h_i$ and $MC_i(q) = S_i^{-1}(p^m, \tau_i)$. Then the welfare effects $\Delta PW_i = W_i\big|_{K_i = \hat{K}_i} - W_i\big|_{K_i = 0}$ and, although the expression (10) is infinite under the perfectly inelastic home consumption H, the welfare effects ΔW_i will be finite. The welfare effects for the non-producers are expressed as

$$\Delta CS_i = \int_{p^{m*}}^{p^{m0}} \left[D(p^m) - \sum_{i=1}^{2} q_{s,i} h_i \right] dp \qquad (11)$$

which is the benefit enjoyed by all cassava consumers (including semi-subsistence producers) minus the benefit enjoyed by the producers.

It is important to note that the welfare effects (10) and (11) reduce to those from the conventional EDM (5) and (6) if $\tau_i = 0$, so the difference between the results obtained from the conventional EDM and the alternative EDM in Section 4 is solely attributable to the inclusion of $\tau_i = 0$ in the alternative EDM.

3.3 Market conditions assumed in the model

The initial market conditions are summarized in Table 1. The total supply of cassava in Uganda is around 5,000,000 tonnes (FAOSTAT, 2006). Using the information supplied by Larson and Deininger (2001), it is expected that non-producers consume approximately 3,750,000 tonnes (75% of total supply), while the remainder is consumed by the producers themselves, and that small-scale producers consume 50% of their production. Since the exact quantities produced by large-scale and small-scale producers are unavailable, we assume that the large-scale and small-scale producers provide 70% and 30% of total supply respectively. The population of cassava producers is estimated to be about 7.83 million (UBOS, 2004). Since data is unavailable, we assume that 2 million are large-scale cassava producers, leaving 5.83 million as small-scale producers. The population of each type of producer will not affect the estimated welfare effects, and is used only to help interpret the welfare effects at approximate per capita levels.

Table 1: Cassava production, consumption and demographics at the initial equilibrium

	Large-scale producers	Small-scale producers	Non-producer	Total
Production (tonnes)	3,500,000	1,500,000		5,000,000
Consumption (tonnes)	500,000	750,000	3,750,000	5,000,000
Population (million)	2.00	5.83	19.37	27.2

Source: Author's calculation based on FAOSTAT (2006); Larson & Deininger (2001); UBOS (2004)

The welfare effects estimation in this study follows the approach taken by Davis and Espinoza (1998) and Zhao et al. (2000), which allows for stochastic sensitivity analyses that are more appropriate than conventional sensitivity analyses to account for the uncertainty in various structural parameters. More specifically, this study assigns distributional assumptions to structural parameters that reflect the most likely values and uncertainty embedded in them. Following Zhao et al. (2000), this study uses the estimates of each structural parameter from other studies as the mean for the assumed distribution for the parameter, and specifies the standard deviation of the distribution assigned to each parameter, so the coefficient of variation is 0.2 for all parameters (Table 2).

Table 2: Distributional assumptions

Parameter	Definitions	Distribution
ε_s	Price elasticity of production	$N^+(0.85, 0.17)$
ε_d	Demand elasticity of cassava by non-producers	$N^-(-0.91, 0.182)$
τ	Price margin (US cent/kg)	$N^+(90, 18)$

K_{small}	Per-unit cost reduction (% in proportion to the initial cassava price) times the adoption rate for small-scale producers	$N^{+}(0.1, 0.02)$
K_{large}	Per-unit cost reduction (% in proportion to the initial cassava price) times the adoption rate for large-scale producers	$N^{+}(0.2, 0.04)$

The elasticity of production and demand are assigned the normal distribution, with their mean values inferred from similar estimates from other studies done in sub-Saharan African countries, which are shown in Table 3. As is commonly suggested in the literature (Qaim, 2001), the elasticity of production is assumed to be the same for both large-scale and small-scale producers. Similarly, the elasticity of total demand for cassava is assumed to be -0.91, which was inferred from Tsegai & Kormawa (2002)[3] and Deaton (1988).

Table 3: Parameter estimates and source

Parameters	Description	Country	Income group		Source
			Low	High	
ε_{d}	Price elasticity of demand	Nigeria	-0.91	-0.13	Tsegai &Kormawa (2002)
		Ivory Coast	-0.91		Deaton (1988)
$\varepsilon_{\text{s,i}}$	Price elasticity of supply	Thailand	0.85		Inferred from Sathirathai & Siamwalla (1987)

Transport costs in the Uganda cassava market are high, so the retail price of cassava is around US$270/tonne (UBOS, 2004),[4] which is almost 50% higher than the farmgate price (Larson & Deininger, 2001). This study therefore sets the initial retail price as US$270/tonne, and assumes that the market margin (τ) for both types of producer will have the normal distribution with a mean of $90/tonne and a standard deviation of $18/tonne. We consider only the per-unit transactions cost, so the market margin is the same across all production levels, and remains unchanged after the productivity growth.

The GM CMD resistant cassava is expected to reduce the cost of production per unit by 30%. The impact of GM cassava, however, is expected to vary between the two types of producer groups on the basis of the different adoption rates. Farmers' adoption rates are assumed to be determined exogenously by a set of factors such as the initial socioeconomic characteristics, farmers' preferences, and information about the expected yield growth of new varieties that are going to be introduced. Several studies find a positive relationship between the farm size or the

[3] Although Tsegai and Kormawa (2002) report the elasticity of demand for both high income and low income consumers, this study uses only the estimates for low income consumers, assuming that the higher income consumers observed in Nigeria are relatively rare in Uganda.
[4] It is assumed that US$1 = 1850 Uganda shilling.

income level and farmers' adoption rates of new varieties of cassava (Kebebe et al., 1990; Polson & Spencer, 1991). Since impoverished farmers generally own small farms, the adoption rates for new technology may be lower for those impoverished farmers if the new technology requires capital or is risky. The adoption rates for the new technology may, however, be higher for them if the new technology is scale-neutral, as is often the case for productivity growth through biotechnology (Tollens et al., 2004). Large-scale cassava producers are therefore more likely to adopt new varieties than small-scale cassava producers. This study therefore assumes that the mean adoption rate (%) by large-scale cassava producers is 67%, while that for small-scale producers is 33%. Therefore the variable K_i, which is defined as the product of the expected per-unit cost reduction and adoption rates, has a mean of 0.2 for large-scale producers (K_2) and 0.1 for small-scale producers (K_1).

Qaim (2001) also considers the welfare gains realized over the span of 16 years, taking into account the increase in adoption of new varieties and the increase in demand driven by population growth during the period, with an arbitrary discount factor. Although the increases in adoption and demand are important, this study excludes such aspects and focuses the analysis on only two time periods, namely before and after the introduction of GM cassava. This simplification is made because the exact paths of the adoption increase and the demand increase remain very uncertain, as does the appropriate discount factor, so the estimation of bias due to market margins may be more robust if these uncertain factors are not included in the model.

In the simulation, 10,000 combinations of parameters are drawn independently from the assigned distributions. Welfare effects are then calculated for each combination of parameters. The combinations of parameters and the corresponding estimates of welfare effects are then used to conduct the sensitivity analysis, as described in the next section. The simulation was programmed using statistical software R version 2.7.0, an open-source software developed by the R Development Core Team.

4. Results and interpretation

4.1 Welfare effects

The welfare gains for different population groups estimated using both the conventional and the alternative EDM are presented in Table 4. At the median level, the estimated welfare gain is $3.7 per person (US$22.17 million / 5.83 million) for small-scale cassava producers, $58.7 per person for large-scale cassava producers ($17.8 per cassava producer), $5.1 per person for non-producers and $8.8 per person for the whole of Uganda. The total welfare gain accounts for approximately 1% of the aggregate GDP (PPP adjusted) in Uganda, which may be significant as the gain is realized from the productivity growth for a single crop.

Table 4: Median welfare effects (US$1 million)

	Population (million)	Welfare effects			
		Conventional EDM	Model with market margin	Bias	Bias in %
Welfare gains for small-scale producers (ΔPW_1)	5.83	21.52	22.17	-0.65	-2.9%
Welfare gains for large-scale producers (ΔPW_2)	2.00	114.45	117.30	-2.85	-2.4%
Welfare gains for non-producers (ΔCS)	19.37	102.45	98.95	3.50	3.5%
Welfare gains for the whole population ($\Delta Total$)	27.20	238.67	238.66	0.01	0.0%

The significant portion of the gain is enjoyed by the cassava producers rather than the non-producers because, although the productivity growth also leads to a drop in the cassava market price, the producers themselves benefit from lower costs for their home consumption of cassava. The share of the welfare gains for producers is smaller than in the case of Qaim (2001), primarily because cassava production in Uganda is assumed to be more elastic (with a mean elasticity of 0.85) than sweet potato production in Kenya (with an elasticity of 0.3 – Qaim, 2001), which means there is a larger drop in the cassava price, and the proportion of home consumption by producers themselves to the total consumption is smaller than in the case described by Qaim (2001) (0.25 compared to around 0.4). With the assumption of a relatively higher adoption rate of GM cassava among large-scale producers, the large-scale producers are expected to be the major beneficiaries. The benefit for small-scale producers may be small and GM cassava in Uganda may therefore not be pro-poor.

Tables 4 also provides important insights into the question of how the conventional EDM can approximate the less biased welfare effects from the alternative EDM. The estimated results show that the conventional EDM generally provides a good approximation of the total welfare gains and also shows how the gains are distributed across the different population groups. Thus the conventional EDM can still be a fairly useful tool for obtaining good approximations of total welfare gains and a rough idea of how the gains are distributed across population groups, if the market margins are in the region of 30% of the end-market price. The conventional EDM, however, still overestimates the welfare effects for non-producers and underestimates those for both small-scale and large-scale producers by approximately 3% (Table 4). The possible reason for such results is that the conventional EDM tends to overestimate the decline in price brought about by the productivity growth, while the actual decline in price is smaller than what the conventional EDM estimates as some of the effect of productivity growth is absorbed by the market margin, even when producers experience the same level of reduction in production costs.

4.2 Sensitivity analysis

The ex ante welfare effects estimation in this study is subject to a large degree of uncertainty because of parameter uncertainties. Zhao et al. (2000) develop a methodology for analyzing sensitivity when the estimated welfare effects are simultaneously affected by a large number of parameters. They then estimate the elasticity of sensitivity, which is the percentage change of estimated welfare effects with respect to a 1% change in the value of the parameters of interest, and they propose its use for assessing the relative importance of each parameter in obtaining robust estimates of welfare effects. The present study follows Zhao et al. (2000) in presenting the elasticity of sensitivity, which is obtained as the following. Let us define Θ_k as the welfare effects of the *k*-th population group. Θ_k is the joint probability density function for all *k* welfare effects, which is called the 'response surface' in the simulation literature (Zhao et al., 2000). With the second-order Taylor approximation, the estimated Θ_k ($\hat{\Theta}_k$) can be approximated as

$$\hat{\Theta}_k \approx \hat{\alpha}_0 + \sum_{m=1}^{M} \hat{\alpha}_m \hat{\theta}_m + \sum_{m=1}^{M} \hat{\beta}_m \hat{\theta}_m^2 + \sum_{\substack{m,n=1 \\ m<n}}^{M,N} \hat{\gamma}_{mn} (\hat{\theta}_m \hat{\theta}_n) \qquad (12)$$

where $\hat{\theta}_m$ is the value of *m*-th parameter θ_m listed in Table 2 (the hat symbol is attached to all notations to indicate that they are either estimated or assumed values, rather than the true values). In the simulation, 10,000 of $\hat{\Theta}_k$ are obtained from 10,000 combinations of $\hat{\theta}_m$ in the same way as above. Equation (15) is then estimated by an OLS regression to obtain $\hat{\alpha}_m$, $\hat{\beta}_m$ and $\hat{\gamma}_{mn}$ which are used to calculate the sensitivity of $\hat{\Theta}_k$ with respect to a change in parameter values $\hat{\theta}_m$. Then the estimated elasticity of sensitivity with respect to parameter *m* is

$$\frac{\partial \hat{\Theta}_k}{\partial \hat{\theta}_m} \cdot \frac{\hat{\theta}_m}{\hat{\Theta}_k} \approx \left(\hat{\alpha}_m + 2\hat{\beta}_m \hat{\theta}_m + \sum_{\substack{n=1 \\ m<n}}^{N} \hat{\gamma}_{mn} \hat{\theta}_n \right) \cdot \frac{\hat{\theta}_m}{\hat{\Theta}_k} \qquad (13)$$

in which the elasticity is calculated using the median of each parameter and $\hat{\Theta}_k$.

Table 5 presents the estimated elasticities of sensitivity of the welfare effects of each group with respect to each of τ, ε_s, ε_d, K_1 and K_2. Around the median values of each parameter shown in Table 5, the estimated welfare effects are relatively less sensitive to the marginal change in τ (.0003 for large-scale producers is the maximum), and the total welfare effects are relatively insensitive to all the parameters except K_2. The estimated welfare effects for each population group are relatively more sensitive to parameters ε_s, ε_d, K_i and the signs of elasticity of sensitivity are intuitive. More elastic production curves lead to less positive welfare gains for producers and more positive welfare gains for non-producers because the same productivity growth leads to a larger drop in prices. Similarly, a more elastic demand curve leads to more (less) welfare gains for producers (non-producers) because the same productivity growth leads to a smaller decline in prices. The more adoption of particular productivity growth technologies (larger K_i) by the small-scale producer groups and the less adoption by the large-scale producer groups leads to more welfare gains for the small producer groups. Because of the larger production scale, higher adoption among the large-scale producers of GM cassava will bring larger welfare gains to non-producers and the whole population.

Table 5: Estimated elasticity of sensitivity

	Median	**Market margin (τ)**	**Production elasticity (ε_s)**	**Demand elasticity (ε_d)**	**Cost reduction times the adoption rate (K_1)**	**Cost reduction times the adoption rate (K_2)**
Median		*90.00*	*.85*	*-.91*	*13.59*	*27.27*
Welfare gains for small-scale producers (ΔPW_1)	*22.17*	.0000	-.39	.40	1.73	-.72
Welfare gains for large-scale producers (ΔPW_2)	*117.30*	.0003	-.29	.33	-.13	1.17
Welfare gains for non-producers (ΔCS)	*98.95*	.0000	.48	-.43	.19	.86
Welfare gains for the whole population ($\Delta Total$)	*238.66*	.0001	.02	.02	.000	.86

It must be noted that the sensitivity is valid only in the neighborhood of the median values of each parameter, as shown in Table 5. The results in Table 5 therefore should be interpreted as meaning that the estimated welfare effects are insensitive to a marginal change in τ around $\tau = 90$, but that the estimated welfare effects when $\tau = 0$ still differ from those when $\tau = 90$, with the difference measured as the bias in Table 4.

The estimated distribution and sensitivity of welfare gains from GM cassava shown in Tables 4 and 5 will allow policy makers to make more educated decisions on whether to use GM cassava to reduce poverty or maximize the benefit for the entire country. For example, if the goal is to bring the maximum possible benefit to the whole country, the effort should be put into encouraging the adoption of GM cassava by large-scale cassava producers. If the goal is to reduce poverty effectively, the effort should be put into the fast adoption of GM cassava by small-scale cassava producers. Lastly, the aggregate benefit of GM cassava is found to be relatively robust to the level of market margin if the margin is around one third of the end-market price, and thus it is advisable to obtain the rough approximation of welfare effects using the conventional EDM.

The results, however, also suggest that the conventional EDM should be applied with caution, particularly when the interest is in how producers in particular benefit from the productivity growth. Although the estimated bias of 3% may be small relative to the omitted market margin, which is one third of the end-market price, the results in this study are based on the rather restrictive assumption that there are only two types of cassava producers, and that all producers are facing the same level of market margins. The bias from the conventional EDM that ignores the market margin may be bigger when the welfare effects are estimated for more disaggregated producer groups facing different levels of market margins, although such analysis must be done in future studies. It is thus advisable to incorporate the market margins into the model when conducting ex ante estimation of distributions of welfare effects of GM crops like cassava across population groups that are more heterogeneous than in this study in terms of their characteristics, including market margins.

5. Conclusion

This paper estimates ex ante the welfare effects of introducing GM CMD-resistant cassava in Uganda. The distribution of gains between producers and consumers and between large-scale and small-scale producers is particularly important as the literature often suggests that cassava productivity growth has a role to play in reducing poverty and is thus pro-poor. The conventional EDM has been used in the literature to obtain the distributional welfare effects of semi-subsistence crops across different producer groups and consumers. One potential drawback of the conventional EDM has been its omission of market margins, which are considered significantly high for the cassava market in sub-Saharan African countries like Uganda. The focus of this paper was to extend the conventional EDM to incorporate the market margins (the alternative EDM) and examine how the conventional EDM can approximate the welfare gains for different producer groups and consumers of cassava in Uganda estimated from the alternative EDM.

The results indicate the following main points. GM cassava in Uganda can provide significant gains to the country as a whole, and to both producers and non-producers, as producers can potentially benefit from both larger sales and lower cost for their own home consumption. The conventional EDM, in spite of its omission of market margins, can still provide a good approximation of the total welfare gains for the country where high market margins exist. The conventional EDM can still be useful for policy makers as a tool to assess the relative size of benefits for highly aggregated population groups from productivity growth similar to that of GM cassava in developing countries. The results, however, also point to the need for further investigation into the issues of welfare effects estimation in the presence of market margins. The results indicate the possibility of significantly greater bias from ignoring the market margin, particularly when estimating the distribution of welfare effects distributions across more heterogeneous population groups with different levels of market margin.

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