Sensitivity of welfare effects estimated by equilibrium displacement model: a biological productivity growth for semi-subsistence crop in Sub-Saharan African market with high transactions costs

Hiroyuki Takeshima

*International Food Policy Research Institute, Abuja, Nigeria*

H.takeshima@cgiar.org


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Abstract

This paper discusses the application of the equilibrium displacement model (EDM) to estimate ex-ante the welfare effects of biological productivity growth for semi-subsistence crop and its impact on poverty reduction. The conventionally used EDM is compared with an alternative model (alternative EDM) that reflects arguably more realistic assumptions for African semi-subsistence crops, such as the shape and shift of supply curve, significant margins due to high transportation costs between farmgate and consumption market, as well as between different consumption markets, and the degree of precisions of estimated structural parameters. The application to the dataset for Benin cassava farmers provides an example that the conventional EDM may significantly overestimate the total welfare gains, and may also lead to very different interpretation of how pro-poor the technology is.

Key words: equilibrium displacement model, pivotal shift, cassava, semi-subsistence, market margins, double buffering

JEL classifications: C65, D13, D31, D60, Q11, Q12

1. Introduction and research questions

Biotechnology including genetic modification (GM) has a potential to significantly increase the yield of many orphan crops such as cassava in Sub-Saharan Africa. Public research on semi-subsistence crops like cassava can greatly influence the development of pro-poor technologies since semi-subsistence cassava producers are often the most impoverished citizens of even the low-income countries.

The fact that cassava is generally non-traded and a semi-subsistence crop help us roughly identify that a productivity growth for non-traded agricultural crops often benefits consumers rather than producers, particularly when the demand for those crops is inelastic leading to a sharper decline in the crop price. The scale-neutral productivity growth for semi-subsistence crops may, however, benefit producers because producers also benefit as consumers (Hayami and Herdt, 1977; Norton et al., 1987; Qaim, 2001; Andreu et al. 2006). The equilibrium displacement model (EDM) is often used to estimate ex-ante welfare effects for producers as well as consumers.

The literature often employs the EDM with several restrictive assumptions (called conventional EDM hereafter) about semi-subsistence producers. Among the key assumptions for conventional EDM, this study focuses on 1) linear supply curve; 2) productivity growth as expressed by a parallel shift in supply curve; and 3) zero market margins (producers and consumers face a single price). Due to its simplicity, conventional EDM is also subject to other restrictive assumptions as discussed in section 2.

Literature raises questions to these restrictive assumptions, although they are often employed to facilitate the estimation of welfare gains. Market margins can be significantly large and have complicated structures in the market for semi-subsistence crops (Barrett, 2008). Several lines of theoretical reasoning can also invalidate assumptions of a linear supply curve and a

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1 Another implicit assumption in conventional EDM is perfectly inelastic home consumption. The relaxation of the perfectly inelastic home consumption assumption, however, has relatively small impacts on the estimated welfare effects, and thus excluded from the subsequent discussion, although it is included in the actual estimation of alternative EDM.
parallel shift in the supply curve used as opposed to other forms such as pivotal shifts, particularly for biological productivity growth (Lindner and Jarrett, 1978; Rose, 1980).

The consequence of restrictive assumptions in conventional EDM has been less studied on either aggregated welfare effects or more disaggregated welfare effects, which reflect distributional effects, of certain types of productivity growth. Some of the consequences can be seen rather straightforwardly. For example, as is discussed later, assumptions 1) through 3) if combined, tend to underestimate (overestimate) the benefit of virus-resistant biological productivity growth for producers who belong to the higher (lower) farmgate price zones. In the case of cassava producers in Benin, lower-income cassava producers tend to sell cassava at higher farmgate price possibly because of their proximity to major consumption market. Using conventional EDM therefore can potentially underestimate the pro-poorness of virus-resistant cassava in Benin.

It is, however, rather complicated to assess the degree of aforementioned underestimation since it involves simultaneously relaxing aforementioned assumptions and they must be estimated using the parameters such as supply and demand elasticities that are also empirically estimated and thus contain errors. This study therefore uses a simulation approach to assess the quantitative aspects of how conventional EDM may bias the pro-poorness of potential impacts of virus-resistant GM cassava in Benin. More specifically, this study therefore examines how the conventional EDM underestimates the pro-poorness of GM cassava by reformulating the conventional EDM, a model with alternative assumptions (called alternative EDM hereafter), namely 1’) supply curve in constant elasticity form; 2’) productivity growth as expressed by a pivotal shift in supply curve; 3’) non-zero market margins with structures indicated by Barrett (2008). This study then empirically compares conventional and alternative EDM using the Benin data set.

This study contributes to the literature by improving our understanding of how the conventional EDM with restrictive assumptions on transactions costs and biological productivity growth may provide a significantly different picture of the total size and pro-poorness of the welfare effects of biological productivity growth in Sub-Saharan African countries.

2. Conceptual framework

2.1 Conventional EDM and its restrictive assumptions

The equilibrium displacement model, originally developed by Muth (1964), is one method used to evaluate ex-ante the economic effects of scale-neutral productivity growth (Alston et al., 1998) and has been applied to semi-subsistence agriculture (Hayami and Herdt, 1977; Norton et al., 1987; Qaim, 1999, 2001; Andreu et al., 2006). Despite some limitations, EDM is still a powerful tool to measure the aggregate welfare effects of certain population groups when conducting an ex-ante welfare-effects analysis for GM subsistence cassava.

The market clearing conditions for the equilibrium displacement model can be expressed as,

\[ q_{s,i} = q_{s,i}(p, \delta_i) \]  

(1)

Although they sell cassava at higher farmgate price, they are still with low-income because their production costs are high, and production is small.

3 The alternative EDM itself is proposed by neither Barrett (2008), Alston et al. (1998) nor other studies, but is a model this dissertation proposes by replacing four assumptions in conventional EDM with those of alternative EDM, listed in Table 1.
\[ q_d (p) = q_{d, \text{market}} (p) + \sum_{i} q_{d,i}^{\text{home}} \]  
\[ \sum_{i} q_{s,i} (p, \delta_i) = q_d (p) \]

in which \( q_{s,i} \) is cassava supply by household \( i \), \( q_d \) is the cassava demand which is further broken down into demand by producer themselves \( q_{d,i}^{\text{home}} \) and demand by the rest of the consumer \( q_{d,i}^{\text{market}} \), \( \delta_i \) is the production technology level that affects the marginal cost curve. Conventional EDM assumes \( p = \) farmgate sales price = consumption price.

### 2.1.1 Conventional EDM

With a productivity growth, in conventional EDM, supply curve \( q_{s,i} \) shifts in parallel vertically down by \( \delta_i \) where \( \delta_i / p = K_i \) with \( K_i \) defined as % reduction in MC relative to the equilibrium price \( p = p_0 \). The welfare effects for producers (\( \Delta PW \)) and consumers (\( \Delta CS \)) are expressed as

\[ \Delta PW = p \sum_{i=1}^{n} q_{s,i} \left( \frac{dp}{p} + K_i \right) \left( 1 + 0.5 \varepsilon_{s,i} \left( \frac{dp}{p} + K_i \right) \right) - \frac{dp}{p} q_{s,i} h_i \]  
\[ \Delta CS = -pq_d \frac{dp}{p} \left( 1 + 0.5 \varepsilon_d \right) - \left( -dpq_d \sum_{i=1}^{n} (h_i s_{si}) \right) \]

in which \( \varepsilon_{s,i} \) is price elasticity of production by producer (or producer groups) \( i \), \( \varepsilon_d \) is price elasticity of demand (including home consumption), \( K_i \) is % reduction in production costs, \( h_i \) is proportion of home consumption to production by \( i \), and \( s_{si} \) is the proportion of production by \( i \) to total production. Total welfare effect (\( \Delta \text{Total} \)) is simply

\[ \Delta \text{Total} = \Delta PW + \Delta CS \]  

### 2.1.2 Restrictive assumptions behind conventional EDM and alternative assumptions in alternative EDM

The advantage of conventional EDM is that, given the basic information of productivity growth, welfare gains can be easily calculated using formulas (4) through (7). The conventional EDM is, however, subject to assumptions that are questionable in the context of semi-subsistence crops. Among those, three assumptions (listed in Table 1) are discussed in this section while Figure 1 through Figure 4 illustrate how those assumptions may be relaxed in alternative EDM using the example of two cassava producing households with different characteristics.

| Table 1. Underlying assumptions for conventional EDM and alternative EDM |
|-----------------------------|-----------------------------|
|                            | Conventional EDM | Alternative EDM |
| Supply curve                | Linear            | Constant elasticity |
| Shift in supply curve       | Parallel          | Pivotal           |
| Market margin               | Zero              | Positive          |
2.1.2.1 Linearity of the supply curve and shifts in the supply curve (parallel or pivotal)

Formula (4) assumes linear supply curves with productivity growth expressed as a parallel shift in the supply curve. Using (4) when the supply elasticity is less than one is controversial. Any linear supply curve with elasticity less than one measured at the initial equilibrium has zero MC for up to some positive production quantity. Voon and Edwards (1991) also prefer the use of constant elasticity form with pivotal shifts since it provides more conservative estimates of benefits than does the linear form when the supply elasticity is less than one, which is the case of this study. The alternative EDM assumes a supply curve in constant elasticity form, which avoids the problem of zero MC for positive production quantity.

The alternative EDM uses a pivotal shift to express productivity growth. First, a pivotal shift in a constant elasticity supply curve assumes a proportional reduction in MC at each production quantity. For biological or yield-increasing productivity growth that does not require additional input, such as GM cassava, a proportional reduction in marginal cost may be realistic since for each unit of output a farmer reduces the input by the same proportion. Therefore a pivotal shift in the supply curve is more reasonable (Lindner and Jarrett, 1978; Rose, 1980).

Second, for computation purposes, when we assume different farmgate price levels, assuming the same reduction in MC for all producers is questionable. Moreover, it is not feasible in simulation since the reduction in MC can be greater than the initial level of MC for some producers with relatively low MC at the initial equilibrium production level.

2.1.2.2 Zero market margins in conventional EDM

High transactions costs in Africa have been widely reported in literature and significant margins exist both between farmgate price and the local consumption market price, and between consumption markets (Barrett, 2008). Alternative EDM incorporates positive market margins between farmgate sales price and consumption market price in a very specific way. Although later sections describe this issue in more depth, I define consumption market here as the end-market of cassava, as opposed to intermediate markets like collection points. One way to incorporate market margins to reflect either the difference in farmgate price and end-market price or the difference in end-market prices in different regions is to keep those market margins constant and exogenous to productivity growth (Alston et al., 1998, p. 317), which will be employed in the alternative EDM as is described in later sections.

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4 The terms “consumption market” and “collection point” are both used in the Benin data set. Although the Benin data set does not provide the definitions of these terms, “collection point” is often used to refer to a place where cassava sellers bring their cassava to traders who then transport cassava to the consumption market. I distinguish consumption market from collection point in that in the consumption market, cassava reaches consumers, and from the consumer welfare perspective, the price of cassava in the consumption market is more important than the price in collection points. Therefore in the EDM, I focus on the estimated price at the consumption market, not at the collection point, to calibrate the demand curve that represents the aggregate marginal utility of cassava consumption in Benin.

Collection point is still important when I estimate the farmgate sales price of some cassava producers who report only the price at the collection points. Prices received at this collection point should include some margin in addition to the farmgate price, and this margin is similar to the margin between the farmgate price and the price at the consumption market.
2.1.3 Other important properties in conventional EDM

Estimates from conventional EDM are proportional to the initial equilibrium price $p_0$ in (4) through (6). Since plant breeding research is often justified based on the total benefit, the level of $p_0$ is critical in the estimation of welfare effects using EDM. Literature using conventional EDM generally uses farmgate price reported by secondary sources like the FAO or local government as $p_0$ (Qaim 1999, 2001) or the average of reported farmgate and wholesale prices (Andreu et al., 2006). The information of $p_0$ is, however, less accurate or simply unavailable for some developing countries and commodities. The estimation of $p_0$ for cassava is particularly difficult since cassava is rarely traded outside the country and no border price exists as it does for crops like maize. The definition of $p_0$ is also vague when there are different price levels. Later sections describe how this study defines and estimates a price equivalent to $p_0$.

Another important property of conventional EDM, particular embedded in (4) through (6), is that when $K_i$ is the same for all $i$, $\varepsilon_d < 0$ and $\varepsilon_{si} > 0$, then conventional EDM tends to estimate more positive $\Delta PW_i$ for producers with larger production $q_{si}$. As shown in the simulation, the alternative EDM may be less affected by the restrictions mentioned here, although it may be rather difficult to generalize the results.

2.2 The representation of cassava market with double-buffer concept in Barrett (2008)

Market margin, primarily composed of transportation costs, are relatively high in Sub-Saharan African countries, and individual as well as aggregate supply and demand can be significantly different from those under no market margin. Section 2.2.1 describes the supply and demand schedules for semi-subsistence farmers facing high market margins between farmgate and consumption market following Minot (1999) and how welfare effects are measured. The section 2.2.2 describes how the market for non-traded crops like cassava is cleared when there are multiple consumption markets whose difference in equilibrium price is largely determined by the inter-market margins.

2.2.1 The effect of market margin between farmgate and consumption market

2.2.1.1 Household supply and home consumption curve\(^7\)

There is one cassava producing-household $i$ and a large market where a large quantity of cassava is traded at price $p_i^{CM}$ (Figure 5). For household $i$, the total cost (including opportunity cost of input factors) of producing $q_p$ unit of cassava $C(q_p)$ includes the opportunity cost of time required for planting seeds and weeding and the opportunity cost of land required. Since land is scarce and labor is often limited (especially if there is a failure in the labor market) for many cassava-producing households, we assume $\partial C(q_p)/\partial q_p$ is strictly increasing in $q_p$.

Household $i$ derives utility $U(q_C)$ from consuming $q_C$ unit of cassava. The household consumes cassava as food, gifts for the family or in-kind payment for labor, and we assume that the marginal utility of cassava consumption is strictly decreasing in $q_C$.

With given $C(q_p)$ and $U(q_C)$, household $i$ can decide either to sell or buy some cassava at the market or not to trade cassava at all, depending on $p_i^{CM}$ and the per unit transport cost. If the per unit transport cost is $\tau_i$, then the farmgate sales price $p_i^f$ for $i$ is $p_i^f = p_i^{CM} - \tau_i$. Similarly, the

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5 For example, the FAO does not provide producer prices for cassava for Benin but does for Côte d’Ivoire, Ghana, Nigeria and Togo.
6 See Appendix A. 1.
7 For simplicity, price and quantity in this section are measured as fresh-tuber equivalent.
farmgate purchase price \( p_i^f \) for \( i \) is \( p_i^f = p_i^{CM} + \hat{\tau}_i \). The relationship between \( p_i^f \) and \( p_i^p \) is thus
\[
p_i^f = p_i^p - 2\hat{\tau}_i.
\]

The household supply and demand curves for cassava are similar to market supply and demand curves except, as in Minot (1999), the supply and demand of cassava become perfectly inelastic when the market price is in a band with width \( 2\hat{\tau}_i \) (Figure 6).

Productivity growth for semi-subsistence farmers first shifts the marginal cost curve and the production and home consumption curves under new production technologies are derived as was in Figure 6. Figure 7 illustrates the productivity growth as the shifts in supply and consequent home consumption curves.

### 2.2.1.2 Welfare measurement for subsistence farmers (Marshallian surplus)

We measure the welfare of a cassava-producing household in a form similar to the concept of the Marshallian surplus\(^8\). Let us define \( Q^* \) as \( Q^* = \max\{Q^P, Q^C\} \). More specifically, \( Q^* = Q^P \) for a cassava-selling household, \( Q^* = Q^C \) for a cassava-purchasing household, and \( Q^* = Q^P = Q^C \) for an autarkic household. With \( Q^* \), the welfare for a cassava-producing household \( i \) (\( W_i \)) can be expressed as
\[
W_i = \int_0^{Q^*} \left[ \max\{MU(q), p_i^{CM} - \hat{\tau}_i\} - \min\{MC(q), p_i^{CM} + \hat{\tau}_i\} \right] dq
\]
where \( MU \) and \( MC \) are marginal utility curve and marginal cost curve, respectively.

The expression \( \max\{MU(q), p_i^{CM} - \hat{\tau}_i\} - \min\{MC(q), p_i^{CM} + \hat{\tau}_i\} \) measures the maximum possible net benefit a cassava producer can derive from the \( q \)-th unit of cassava at hand. Since a cassava producer has \( Q^* \) of cassava to derive net benefit from, his total welfare can be measured by integrating \( \max\{MU(q), p_i^{CM} - \hat{\tau}_i\} - \min\{MC(q), p_i^{CM} + \hat{\tau}_i\} \) up to \( Q^* \).

### 2.2.2 The effect of market margins between consumption markets

This section describes how cassava prices vary across different consumption markets inside Benin, and how the price difference can be treated exogenous to cassava productivity growth. The assumptions presented in this section are not necessarily the most accepted assumptions in the literature and are sometimes made in order to facilitate the simulation while maintaining consistency with the Benin data set. This paper, however, still employs additional assumptions since the assumption of zero market margins employed in EDM for subsistence crops in past literature is very restrictive and that it is important to examine how zero market margin assumptions may bias the estimated welfare effects for certain population groups.

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\(^8\) The benefit of using the Marshallian demand curve instead of the Hicksian demand curve is that the Marshallian demand curve can be estimated with less information, like income elasticity, than can the Hicksian demand curve (Alston et al., 1995). Although the welfare effects using the Marshallian demand curve are biased since it ignores the income effect caused by cassava productivity growth, Alston and Larson (1993) argue that the bias included in the Marshallian demand curve may be smaller relative to the additional errors brought into the estimation of welfare effects in the process of recovering the Hicksian demand curve from the Marshallian demand curves using the empirically estimated elasticities. That is the reason this study continues using the Marshallian demand curve to conduct EDM, even though the estimation of demand curves in the previous chapter includes the income effects as well.
2.2.2.1 Double-buffering

Figure 8 illustrates the concept similar to double-buffering in Barrett (2008). There are two layers of channels through which cassava is traded, one between each cassava producer and local consumption market and the other between different consumption markets. Barrett (2008) distinguishes the relationship between semi-subsistence farmers and the local markets from the relationship between semi-subsistence local markets and other markets.

Applying the argument by Barrett (2008), the price of the commodity in each non-autarkic market \( j \) differs from prices in other markets by the difference in the margin between each market \( j \) and border price, or the international price. The “geographic specificity” of price (Barrett, 2008) has been frequently observed for many commodities in Africa, and also appears consistent with the Benin dataset. It therefore seems appropriate to employ (9) in the EDM:

**Assumption:** Price differences across different consumption markets are exogenously fixed to the GM cassava introduction in ex-ante welfare effects estimation using EDM

\[ (9) \]

The (9) relates to the theory of market integration widely studied in the literature regarding the efficiency of inter-market price transmissions, and generally supported for West African countries including Benin (Kuiper et al, 1999; Badiane and Shively, 1998).

Several questions, however, remain regarding how restrictive (9) is. First, it is unclear whether the argument by Barrett (2008) holds for cassava since it is generally not traded internationally and no “border price” exists for cassava. Second, it remains to be seen how (9) facilitates the inclusion of market margins to EDM with certain limitations associated with the Benin data set, even though (9) requires that no local market \( j \) is autarkic.

2.2.2.2 Price determination schemes

For commodities traded internationally, their prices in each market (either consumption market or collection point) **inside the country** can be expressed as

\[ p_{j}^{CM} = p_{j}^{cb} + \hat{\tau}_{j}^{M} (G, Q) \quad \text{if } j \text{ is an importing market} \]

\[ p_{j}^{CM} = p_{j}^{cb} - \hat{\tau}_{j}^{M} (G, Q) \quad \text{if } j \text{ is an exporting market} \]

\[ p_{j}^{CM} = p_{j}^{CM,a} \quad \text{if } j \text{ is autarkic} \]

in which \( p_{j}^{cb} \) is the border price or price at the international market, \( \hat{\tau}_{j}^{M} \) is market-specific transactions costs, \( G \) is “the state of public goods and services (e.g., communication and transport infrastructure, property rights, etc.)”, \( Q \) is “the aggregate throughput in the local market”, and \( p_{j}^{CM,a} \) is “the local market price that equates local market demand […] with local market supply” (Barrett, 2008). \(^9\)

(9) requires that relationships similar to (10) hold for cassava which is not traded internationally, has no border price and that no consumption market is autarkic. First we define weighted average consumption price of cassava (fresh-tuber equivalent), \( \hat{P} \), equivalent to \( p_{j}^{cb} \) for cassava as

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\(^9\) Notations are modified from those in Barrett (2008) to fit this paper.
\[ \hat{\bar{P}} = \sum_j \left( \hat{p}_j^{CM} \cdot \frac{\hat{D}_j}{\sum_j \hat{D}_j} \right) \]  

(11)
in which \( \hat{D}_j \) is fresh-tuber equivalent quantity of cassava consumed in consumption market \( j \). As is clear from (11), \( \hat{\bar{P}} \) is the weighted average consumption price of cassava with share of \( \hat{D}_j \) to the total consumption (\( \sum_j \hat{D}_j \)) used as weights. I then define the relationship between \( \hat{p}_j^{CM} \) and \( \hat{\bar{P}} \) as

\[ \hat{p}_j^{CM} = \hat{\bar{P}} + \hat{\tau}_j^{CM} \]  

(12)
in which \( \hat{\tau}_j^{CM} \) measures the difference between \( \hat{p}_j^{CM} \) and \( \hat{\bar{P}} \). \( \hat{p}_j^{CM} \) is the counterpart of \( \hat{\tau}_j^{M} \) in (10), except \( \hat{\tau}_j^{CM} \) can be both positive and negative since it is unclear whether consumption market \( j \) is an exporting or importing market. \( \hat{D}_j \) is defined as

\[ \hat{D}_j = \sum_i (\hat{S}_{ji} - \hat{H}_{ji}) + \sum_{k \neq j} \hat{X}_{kj} \]  

(13)
in which \( \hat{S}_{ji}, \hat{H}_{ji} \) are production and home consumption by producer \( i \) and \( \hat{X}_{kj} \) is the net trade between consumption market \( j \) and \( k \) for all \( k \neq j \). \( \hat{X}_{kj} \) must satisfy the following conditions:

\[ \hat{X}_{kj} \geq 0 \text{ (cassava is traded from } k \text{ to } j \text{ if trade exists)} \text{ if } \hat{p}_j^{CM} > \hat{p}_k^{CM} \]

\[ \hat{X}_{kj} \leq 0 \text{ (cassava is traded from } j \text{ to } k \text{ if trade exists)} \text{ if } \hat{p}_j^{CM} < \hat{p}_k^{CM} \]  

(14)
\[ \hat{X}_{kj} = 0 \text{ (cassava is not traded between } j \text{ and } k) \text{ if } \hat{p}_j^{CM} = \hat{p}_k^{CM} \]

In other words, cassava is traded only from a lower-price consumption market to a higher-price consumption market.

**2.2.2.3 Assumptions of no autarkic consumption market(s)**

The second requirement in (9) is that no consumption market or group of consumption markets is autarkic. In other words, every consumption market \( j \) must trade cassava with at least one other consumption market, and every subgroup of consumption markets must trade cassava with at least one other subgroup of consumption markets. Figure 9 presents some of the examples that satisfy or violate the requirement.

**2.2.3 Disaggregation of the EDM to the individual cassava producer’s level**

The simulation in later section calibrates the model for individual observations in the Benin dataset and is thus more disaggregated than some other studies that apply EDM. This study argues the benefit of disaggregating EDM on the following counts, although aggregated EDM in previous literature has required less information and may be more robust to the violation of assumptions employed in disaggregated EDM.

Aggregated supply and demand curves may be illustrated as in Figure 6, although Figure 6 is used for individual cassava producers, with a good approximation of market margin \( \tau \) for the entire market. This paper, however, argues that Figure 6 is not a very good representation of aggregated supply and demand. For example Figure 6, if used for aggregate market, implies
perfectly inelastic aggregate supply and demand when price is in a certain range, which is not only too restrictive but also requires the assumption that all producers face the same per-unit transactions costs. In addition, the Benin data suggests significant variations in price received by each cassava producer or heterogeneity in the characteristics of producers.

Supply and demand curves for a semi-subistence cassava producer in Figure 6 can thus be linked to the average consumption price $\hat{p}$, as in Figure 10.

### 2.3 Summary of alternative EDM

In summary, alternative EDM can be defined as the counterpart of (1) through (3). The above discussion of different consumption market prices can be extended to the case in which each observation in Benin dataset trades cassava at its corresponding consumption market\(^{10}\). We therefore, from this point on, replace notation $j$ used to indicate consumption market in the previous sections, with $i$ that indicates each household observation.

With the price $\hat{p}$ and $\hat{\tau}_i^{CM}$ as defined in (22) and (23), $\hat{p}$ satisfies the following market clearing condition:

$$\sum_{i} \left[ S_i(\hat{p} + \hat{\tau}_i^{CM}, \hat{\tau}_i) - H_i(\hat{p} + \hat{\tau}_i^{CM}, \hat{\tau}_i) \right] - \sum_{i} D_i(\hat{p} + \hat{\tau}_i^{CM}) = 0$$

where $S_i(\cdot)$ and $H_i(\cdot)$ are cassava production and home consumption curves with cassava price at the nearest consumption market and per-unit transactions costs to transport cassava from the farm to the consumption market, as defined above. More explicitly,

$$S_i(p_i^{CM}, \hat{\tau}_i) = \begin{cases} \hat{\alpha}_i(h) (p_i^{CM} - \hat{\tau}_i) \hat{h}_si (1 + A_i \Delta Y_i), & \text{if } p_i^{CM} - \hat{\tau}_i \geq p_i^* \\ \hat{\alpha}_i(h) (p_i^{CM} + \hat{\tau}_i) \hat{h}_si (1 + A_i \Delta Y_i), & \text{if } 0 < p_i^{CM} - \hat{\tau}_i < p_i^* \\ \hat{\alpha}_i(h) (p_i^{CM} + \hat{\tau}_i) \hat{h}_si (1 + A_i \Delta Y_i), & \text{if } 0 < p_i^{CM} - \hat{\tau}_i \end{cases}$$

$$H_i(p_i^{CM}, \hat{\tau}_i) = \begin{cases} \hat{\alpha}_i(h) (p_i^{CM} - \hat{\tau}_i) \hat{h}_si (1 + \hat{\tau}_i), & \text{if } p_i^{CM} - \hat{\tau}_i \geq p_i^* \\ \hat{\alpha}_i(h) (p_i^{CM} + \hat{\tau}_i) \hat{h}_si (1 + \hat{\tau}_i), & \text{if } 0 < p_i^{CM} - \hat{\tau}_i \end{cases}$$

in which $A_i$ is the adoption rate of a new GM variety among producer group $i$, $\Delta Y_i$ is the yield growth expressed as the horizontal shift in supply curve. In the context of structure as in (10), $\hat{p}_i^{CM}$ should in theory be determined through condition (17) although in this study (17) is simplified as (17'),

$$\hat{p}_i^{CM} = \hat{p} + \hat{\tau}_i^M,$$

$\hat{p}_i^{CM}$ satisfies $S_i(\hat{p}_i^{CM}, \hat{\tau}_i) - H_i(\hat{p}_i^{CM}, \hat{\tau}_i) = D_i(\hat{p}_i^{CM})$ if $p_i^{CM*} \geq \hat{p} + \hat{\tau}_i^M$

$$\hat{p}_i^{CM} = \hat{p} - \hat{\tau}_i^M,$$

$\hat{p}_i^{CM}$ satisfies $S_i(\hat{p}_i^{CM}, \hat{\tau}_i) - H_i(\hat{p}_i^{CM}, \hat{\tau}_i) = D_i(\hat{p}_i^{CM})$ if $p_i^{CM*} < \hat{p} + \hat{\tau}_i^M$$

(17')

First, condition (17) is similar to the supply and demand curves for individual producers. Condition (17'), on the other hand, states that the initial difference between $\hat{p}_i^{CM}$ and $\hat{p}$ for each $i$

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\(^{10}\) This is reasonable since the data is collected in a way such that each observation represents a group of farmers in the same village.
is set constant in the simulation since the consumption volume in each market $i$ is unavailable. In other words, we assume that if consumption market $i$ is a net exporter of cassava, then it remains a net exporter throughout the entire period, and vice versa. This assumption is required so that the simulation reflects the regional differences in cassava price in a way consistent with the data set, which is why this study employs (17') instead of (17).

In addition, condition (15) needs slight modification in the simulation. We modify (15) to

$$\sum_i \left[ S_i \left( \hat{P} - \hat{\tau}_i^{CM}, \hat{\tau}_i \right) - H_i \left( \hat{P} - \hat{\tau}_i^{CM}, \hat{\tau}_i \right) \right] - D(P) = 0 \quad (18)$$

in which we use the aggregate demand function $D(P)$ instead of $\sum D_i \left( \hat{P} - \hat{\tau}_i^{CM} \right)$ since the information is only available for aggregate cassava consumption by non-producers\(^{11}\).

Welfare for a cassava-producing household $i$ ($W_i$) that is expressed as (8) can be measured for both with and without GM cassava. To express the measurement of welfare gains, we first define $W_i$ for with GM cassava ($W_i^{GM}$) and without GM cassava ($W_i^{No\ GM}$). For convenience, we expand the notation for $Q_i^*, p_i^{CM}, MC(q)$ that change between with GM cassava and without GM cassava to $Q_i^{*, GM}, p_i^{CM, GM}$ and $MC^{GM}(q)$ for with GM cassava, and $Q_i^{*, No\ GM}, p_i^{CM, No\ GM}$ and $MC^{No\ GM}(q)$ for with GM cassava. $W_i^{GM}$ and $W_i^{No\ GM}$ are then

$$W_i^{GM} = \int_0 \left[ \max[MU(q), p_i^{CM, GM} - \hat{\tau}_i] - \min[MC^{GM}(q), p_i^{CM, GM} + \hat{\tau}_i] \right] dq \quad (8')$$

$$W_i^{No\ GM} = \int_0 \left[ \max[MU(q), p_i^{CM, No\ GM} - \hat{\tau}_i] - \min[MC^{No\ GM}(q), p_i^{CM, No\ GM} + \hat{\tau}_i] \right] dq \quad (8'')$$

The welfare effects for producer group $i$ ($\Delta P\ W_i$) for alternative EDM is therefore

$$\Delta P\ S_i = W_i^{GM} - W_i^{No\ GM} \quad (19)$$

Welfare effects for consumers (non-cassava producers) $\Delta C\ S$ in alternative EDM is

$$\Delta C\ S = \int_{\hat{P}^{No\ GM}}^{\hat{P}^{GM}} D(P)dp \quad (20)$$

in which the notation for price $P$ as defined in (11) is expanded to $\hat{P}^{No\ GM}$ and $\hat{P}^{GM}$.

\(^{11}\) This requires certain assumptions on the shape of $\sum D_i \left( \hat{P} - \hat{\tau}_i^{CM} \right)$, which is the demand curve for each consumption market. For example, if we assume the aggregate demand curve $D(P)$ to have constant elasticity of demand such that $D(P) = AP^\eta$ with $\eta$ as demand elasticity, $D_i$ may not be exactly in constant elasticity form. More precisely, we may have,

$$D(P) = AP^\eta = \sum D_i(P - \tau_i^{CM}) = \sum A_i(P - \tau_i^{CM})^\eta$$

Therefore the assumption of $D(P) = AP^\eta$ requires that not all $D_i\ S$ have constant elasticity form. The literature, however, uses constant elasticity forms as well as linear forms for aggregate demand curve often with little theoretical reasoning. This study therefore regards (18) to be appropriate.
As summarized in Table 3, the alternative EDM consists of individual supply and home consumption schedules (equations (16), (17')) and market clearing conditions (18). Welfare measurements $\Delta PW$ and $\Delta CS$ in the alternative EDM are generally expressed as (19) and (20).

3. **Empirical comparison of conventional EDM and alternative EDM**

We now conduct a welfare effects estimation using both conventional EDM and alternative EDM for hypothetical introduction of GM cassava in Benin and examine how the two EDMs provide different estimates of welfare effects, whether the two EDMs indicate differently how the welfare gains are distributed across cassava producers with different income levels.

3.1 **Estimation methods**

This section describes how this study uses the dataset from Benin to calibrate the parameters introduced in the conceptual framework above. The description here is for the alternative EDM in Table 2 and this section also briefly summarizes an additional model that is included due to reasons explained in 3.1.2.

3.1.1 **Structure and calibration of the model**

The structural parameters used in alternative EDM are listed in Table 4, some of which are estimated from the data set, and the others are calculated as described below using specific assumptions in manners consistent with the discussions in section 2.

3.1.1.1 **Condition (11) in the Benin data set**

In calculating $\hat{P}$ in (11) using the Benin data set, this study assumes that $\hat{D}_i$ can be approximated as

$$\hat{D}_i \approx \left( \hat{S}_i - \hat{H}_i \right) \cdot \hat{w}_i \quad (21)$$

in which $\hat{S}_i$ and $\hat{H}_i$ are production and home consumption quantities reported by producer $i$ and $\hat{w}_i$ is the sample weight for observation $i$ in the Benin data set. In other words, $(\hat{S}_i - \hat{H}_i) \cdot \hat{w}_i$ is the total net sales of cassava supplied to local consumption market $i$ sold by producers represented by observation $i$.

Equation (21) assumes that almost all cassava consumed in consumption market $i$ is provided by the local cassava farmers who sell cassava to market $i$ and that a relatively small quantity of cassava is transported between different consumption markets. As was mentioned above, each observation $i$ represents the group of $\hat{w}_i$ similar producers who all sell cassava to the same consumption market $i$. $\hat{P}$ is therefore approximated to $\hat{P}^*$ in the simulation as:

$$\hat{P} = \sum_i \left( \hat{p}_i^{CM} \cdot \hat{D}_i \right) \approx \hat{P}^* \quad (22)$$

in which $\hat{p}_i^{CM}$ is estimated from the data set (discussed in equation (29)). With (12) and (22),

$$\hat{\varepsilon}_i^{CM} = \hat{p}_i^{CM} - \hat{P}^* \quad (23)$$

The assumption behind (22) is that interregional trade is small relative to the consumption quantity in each local consumption market, while (23) still reflects (9). Although
there is no direct evidence, some studies indicate that the quantity of cassava traded inter-regionally is small relative to total production (Gabre-Madhin et al., 2001).

Section 2.1.3 discussed how the choice of $p$ is important in conventional EDM and that Qaim (1999, 2001) uses farmgate price. In this simulation, since the representative farmgate price is unavailable, $p$ is defined as the weighted average of farmgate price $\hat{P}^f$ estimated for each $i$ with weights as fresh-tuber equivalent production by $i$. More explicitly,

$$\hat{P}^f = \sum_i \left( \hat{p}^f_i \cdot \frac{\hat{S}_i}{\sum_i \hat{S}_i} \right)$$  \hspace{1cm} (24)

The Benin data set contains the $p_i^f$ of cassava for only on-farm sellers, and $\tau_i$ for only off-farm sellers. This study follows Vakis et al. (2003) to predict $\hat{p}_i^f$ and $\hat{\tau}_i$ for all cassava producers, including autarkic producers, in the data set. More specifically, we first run regressions

$$\ln(p_i^f) = x_i^{pf} \beta^{pf} + u_i^{pf}, \quad \forall i = \text{on farmersellers} \hspace{1cm} (25)$$

$$\ln(\tau_i) = x_i^{\tau} + u_i^{\tau}, \quad \forall i = \text{off farmersellers} \hspace{1cm} (26)$$

in which $x_i^{pf}$ and $x_i^{\tau}$ are exogenous factors assumed to affect $p_i^f$ and $\tau_i$, respectively. We then obtain the predicted values of $p_i^f$, $\tau_i$ and $p_i^{CM}$ as,

$$\hat{p}_i^f = \exp(x_i^{pf} \hat{\beta}^{pf}), \quad \forall i \neq \text{on farmersellers} \hspace{1cm} (27)$$

$$\hat{\tau}_i = \exp(x_i^{\tau} \hat{\beta}^{\tau}), \quad \forall i \neq \text{off farmersellers} \hspace{1cm} (28)$$

$$\hat{p}_i^{CM} = \hat{p}_i^f + \hat{\tau}_i \hspace{1cm} (29)$$

in which (29) indicates the assumption that for every producer group $i$, there is a consumption market $i$ which is an end-market for cassava, and the price at consumption market $i$ ($\hat{p}_i^{CM}$) also satisfies condition (12). Although very strict, the assumption (30) allows market clearing condition (15)) (shown below) to be valid without the actual data for price in each consumption market and enables the simulation using Benin data.

Using (29) and formula (22), we calculate $\hat{P}$, which is the price that satisfies the market clearing conditions in the alternative EDM in (18). Although $\hat{S}_i - \hat{H}_i = Sales_i = 0$ for $i = \text{autarkic producers}$, $\hat{p}_i^{CM}$ is still defined for such markets in (29)$^{12}$. $\hat{\tau}_i^{CM}$ is then obtained as the difference between $\hat{p}_i^{CM}$ and $\hat{P}$ for each $i$ and kept constant before and after productivity growth.

Conventional EDM generally uses the reported farmgate price as $p$ in the model. In this study, by using formula (24) and $\hat{p}_i^f$ estimated above, weighted average farmgate price $\hat{P}^f$ is calculated and inserted into $p$ in formulas (4) through (7).

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$^{12}$ Extending the assumption in section 2.2.2.2, for $i = \text{autarkic producers}$, $D_i \neq 0$ so that $\hat{p}_i^{CM}$ is set by the transportation costs between other consumption markets, but $D_i$ is small enough so that price $\hat{p}_i^{CM}$ does not affect the average consumption price $\hat{P}$.
Supply and consumption curves ($S_i$ and $H_i$ in (16)) can be calibrated using $\hat{p}_i^f$, estimated production and consumption elasticities ($\hat{e}_{si}, \hat{e}_{hi}$), reported production ($\hat{S}_i$) and home consumption quantity ($\hat{H}_i$). Calibration for autarkic producers is more complicated. As illustrated in Figure 15, given $\hat{p}_i^f$, $\hat{\tau}_i$, $\hat{S}_i$ and $\hat{H}_i$, $S_i$ and $H_i$ can be any of (a) ~ (c). Whether each autarkic producer has supply and home consumption curves like (a), (b) or (c) affects how productivity growth through GM cassava leads to a change in aggregate supply throughout the entire market and $P$, and thus the welfare effects estimation.

Due to the lack of information, this study assumes

$$\alpha_i^s = \frac{\hat{S}_i}{\left(\hat{p}_i^f + \delta\hat{\tau}_i\right)^{\alpha_{si}}} \quad \alpha_i^h = \frac{\hat{S}_i}{\left(\hat{p}_i^f + \delta\hat{\tau}_i\right)^{\alpha_{hi}}} \quad \text{for } i = \text{autarkic}$$

(31)

in which $\delta \sim U [0, 2]$ which is one of the stochastic parameters included in the simulation as listed in Table 8. To be more precise, $\delta = 1$ in Figure 15(b) and $\delta = 0.5$ in Figure 15(a), $\delta = 1.5$ in (c). With $\delta \sim U [0, 2]$, we assume $MC$ and $MU$ for autarkic producers so that $C$ is uniformly distributed in A and B. Alternative methods are available but have little practicality

3.1.2 Other models

In addition to conventional and alternative EDM, one additional model is estimated. Three models are therefore compared as characterized in Table 2. The differences between each model are the shape of the supply curve, how the supply curve shifts and whether the model includes non-zero market margin.

Models 1 is included so that the quantitative difference between estimates from conventional and alternative EDM can be more easily understood. For example, the total gains from alternative EDM are expected to be much smaller than those from conventional EDM not only because of market margins but largely because alternative EDM uses pivotal shift while conventional EDM uses parallel shifts in the supply curve, and switching from parallel shift to pivotal shift often reduces the estimated total welfare gains (Alston et al., 1998). Therefore if the focus is on the inclusion of market margins, then the comparison of model 1 and alternative EDM may be more informative than the comparison of conventional and alternative EDM.

This study, however, does not examine in detail the difference between alternative EDM and model 1. This is because model 1 is rarely used in the literature, nor is it preferred over alternative EDM because of their restrictive assumptions about zero-market margins or home consumption curves. In addition, findings from comparing alternative EDM and model 1 is only empirical and cannot be easily generalized because the differences depend on many other structural parameters used in the model, even though comparison of alternative EDM and model 1 may provide some picture of how relaxing assumptions on market margin and home consumption curves alter the estimation results.

Model 1 is similar to conventional EDM and begin with conditions (1) through (3) with $p = \bar{p}^f$ (weighted average of farmgate sales price) obtained in (24). The only difference between

\[ 13 \text{ For example, it is possible to predict } \hat{\alpha}_i^s \text{ and } \hat{\alpha}_i^h \text{ using regression results in previous chapter. With } \hat{\alpha}_i^s \text{ and } \hat{\alpha}_i^h \text{ estimated this way and } \hat{p}_i^f \text{ and } \hat{\tau}_i, \text{ however, many producers falls outside autarky. It is because the estimation of } MC \text{ and } MU \text{ using regression results from previous chapter is unreliable due to the data limitation.} \]
models 1 and conventional EDM is the fact that now both \( q_{s,i} \) and \( q_d \) are in constant elasticity form and for model 2,
\[
q_d(p) = q_d^{\text{market}}(p) + \sum_i I_{d,i} q_d^{\text{home}}(p)
\]

(2')

3.1.3 Expected findings on pro-poorness of GM cassava from a comparison of conventional and alternative EDM

The differences between conventional EDM and alternative EDM may lead to different implications on the pro-poorness of GM cassava, and how they differ can be partly inferred from the characteristics of cassava producers. Some insights are gained from analyzing formulas (4) through (7) for \( \Delta PW \) combined with how relevant characteristics of cassava producers vary across different income levels.

Figure 11 through Figure 14 show the most salient characteristics of cassava producers across different income levels. Figure 11 shows the proportion of the population who belong to a cassava-producing household with a particular income range. Figure 12 through Figure 14 plot the median of farmgate prices (estimated for some groups of producers using regressions (25) and (27)), per capita annual cassava production and per capita daily cassava consumption against per capita income levels. Ignoring all the intra-household income allocation, Figure 11 indicates that almost half of cassava-producing households earned less than US$100 per capita; 75% earned less than US$200 in 1997. Figure 12 through Figure 14 suggest the following: lower-income cassava producers tend to produce and consume less and face higher farmgate prices. Section 2.1.3 indicates that the \( \Delta PW \) in conventional EDM tends to be more positive for cassava producers with larger production and home consumption quantity. In addition, since conventional EDM assumes only one price and \( \Delta PW \) in conventional EDM uses the relative change in equilibrium price \( dp/p \) for all types of producers, it may overstate \( dp/p \) for cassava producers with a relatively higher farmgate price when \( dp \) is the same for all producers and thus may underestimate the welfare gains for producers with higher farmgate prices.

The fact that lower-income cassava producers tend to produce and consume less and face higher farmgate prices does not necessarily indicate how alternative and conventional EDM may differ since the alternative EDM includes additional structural parameters not present in conventional EDM. The characteristics of lower-income cassava producers, however, do indicate that although welfare gains obtained through alternative EDM is likely to be lower than through conventional EDM, it may not be so for lower-income cassava producers.

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14 Per capita GDP for Benin in 1997 was around US $300 (World Bank).

15 As mentioned in section 2.1.2.2, alternative EDM follows Alston et al. (1998) and treats market margins between consumption markets and farmgate price as exogenous and constant ((9)). (9) therefore assumes that the change in farmgate sales price is the same for the entire cassava producer group \( i \). In the alternative EDM, the similar value for \( dp/p \) is smaller for producers with a higher farmgate price (\( dp \) is negative since the productivity growth lowers the price). On the contrary, the alternative EDM also follows the suggestions by Lindner and Jarrett (1978) and assumes that GM cassava lowers the marginal cost for all cassava producers by the same proportion, which means that cassava producers with a higher farmgate price experience a larger reduction in marginal cost so that \( K_i \) is the same for all producers. Then \( dp/p + K_i \) when alternative EDM is more positive for producers with a higher farmgate price, and assuming the same \( dp/p \) as in conventional EDM will underestimate \( dp/p + K_i \).

From conventional EDM formulas (4), we can see that the larger \( dp/p + K_i \) leads to more positive \( \Delta PW \) (see Appendix A. 2).
3.2 Description of cassava market structure in Benin inferred from the Benin data set and other sources of information

Table 4 and Table 5 summarize the Benin cassava market structure inferred from the Benin data set, and annual population growth rate in 1997\(^{16}\). To be consistent with the findings in Takeshima (2008), cassava farmers are grouped into 2 categories, namely on-farm seller type who are likely to sell cassava at farmgate and off-farm seller type who are likely to sell cassava at the distant markets. Autarkic farmers are categorized into one of aforementioned seller types by using the regression results for probit in Takeshima (2008), so that an autarkic producer \(i\) is assumed an on-farm seller if

\[
\text{Prob}(i = \text{on farm seller} | x_i^{pr}) > 0.5, \text{ or } x_i^{pr} \gamma_{pr} < 0.5
\]  \hfill (32)

and \(i\) is an off-farm seller otherwise.

3.3 Estimation of welfare effects

3.3.1 Simulation method

Many recent studies using EDM deal with the uncertainty in market structures such as the supply and demand elasticities by adding idiosyncratic errors to some of the structural parameters and analyzing the sensitivity of estimates with respect to the change in structural parameters (Davis and Espinoza, 1998; Zhao et al., 2000). Although the choice of error terms can be arbitrary, a common approach is to use the standard deviation associated with parameters estimated in previous studies. This study, using the regression results from Takeshima (2008) and regressions (25), (26), assigns the distributions for some parameters in Table 8. 1000 simulations are run, each of which uses different combinations of parameters drawn from the distributions specified in Table 8. The simulation results are then presented as the range rather than the point estimates.

3.3.2 Potential rates of adoption and expected yield growth of virus-resistant cassava in simulation

This study does not explicitly model the adoption rates over time as has been done in the literature. This study instead assumes that all cassava producers will adopt a new GM variety after a certain period of time due to the following reasons. First, the purpose of this study is to compare the estimates from conventional and alternative EDM, and including an adoption trend may add more uncertainty to each model and thus make it more difficult to interpret the difference between conventional and alternative EDM. Second, GM cassava is expected to be distributed to producers at a significantly low price. Adoption rates for GM cassava can therefore eventually reach 100%.

Expected percentage growth of yield (\(y\)) depends on many factors. The development of GM cassava for Benin seems to be lagging behind some other African countries whose data are not available; furthermore, how the cassava yield will be affected depends on the particular varieties introduced in the future.

Studies of cassava in other African countries provide some insights into the expected yield growth of several varieties of cassava (30% for virus-resistant cassava in Uganda\(^{17}\), loss due to virus is up to 60% in Ghana (Horna et al., 2007)). Assuming that the average loss in

\(^{16}\) More detailed description of the dataset is available in Takeshima (2008).

\(^{17}\) Based on conversations at the Donald Danforth Center in Saint Louis, which spearheads the research in the development of GM cassava.
Cassava yield in Ghana is 30% (mid-point of 0% and 60%), a similar yield growth for a virus-resistant variety of cassava in Benin should be around 30%.

Complications arise when information about a new GM variety is given in terms of cost reduction instead of yield growth, since a 30% cost reduction is not necessarily 30% yield growth unless the supply elasticity is one. The alternative EDM therefore uses two scenarios: 1) 30% yield growth for all producers; 2) 30% reduction in MC relative to the initial farmgate sales price. For 1), the supply curve is shifted out by 30% horizontally, while for 2) the supply curve is shifted down by 30% vertically. Since the elasticity of supply is less than one, the supply curve shifts down by more than 30% in case 1) and shifts out less than 30% in case 2).\textsuperscript{18}

This study therefore considers two scenarios. Scenario 1 assumes $y_i = 0.3$ (30% increase in yield); scenario 2 assumes $k_i = 0.3$, as shown in Table 8, in which $k_i$ is the percentage reduction in marginal cost at the initial equilibrium production quantity. The underlying assumptions for both scenarios are the following: in scenario 1, producers with a less elastic supply curve experience a larger proportional reduction in MC. In scenario 2, producers with a less elastic supply curve experience a smaller yield growth.

Benin’s population growth rate is around 2.5%, so this study shifts out the demand curve horizontally by 2.5% from the initial demand curve as is suggested by Norton et al. (1987). Using a 100% adoption rate and shifting the demand curve by 2.5% mean that the estimated welfare gains assume that all cassava producers will adopt GM cassava after one year. This may be unrealistic, so it might be wise to use the population level in 10 years since it is possible to reach 100% adoption by then. However, assuming explicitly when the 100% is reached does not make the model more realistic for several reasons. First, it is unclear how population growth can lead to the shift in demand curve. Second, many studies apply rather arbitrary discount factors for welfare gains in the future. From these perspectives, assuming a 100% adoption rate in one year may not be so problematic, particularly where the comparison of alternative and conventional EDM is concerned.

The simulation is programmed using statistical software $R$ version 2.7.0, an open-source software developed by $R$ Development Core Team.

4. Results and interpretations
4.1 Total welfare gains

The results of interest are summarized in Table 9 through Table 11 and Figure 16. Table 9 and Table 10 show the percentile of estimated welfare effects from alternative and conventional EDM for scenarios 1 and 2. For example, Table 9 says that the total welfare effects ($\Delta\text{Total}$) estimated by alternative EDM are above US$13.9 million 50% of the time; 95% of the time it is between US$9.5 million and US$27.3 million. Table 9 and Table 10 indicate the following: 1) Consumers’ welfare effects estimated using conventional EDM ($\Delta\text{CS}_C$) is more positive than those estimated using alternative EDM ($\Delta\text{CS}_A$); 2) Total welfare effects estimated using conventional EDM ($\Delta\text{Total}_C$) is generally more positive than those estimated using alternative EDM ($\Delta\text{Total}_A$); 3) whether producers’ welfare effects estimated using conventional EDM ($\Delta\text{PW}_C$) is more positive or negative than those estimated using alternative EDM ($\Delta\text{PW}_A$).

\textsuperscript{18} At the median, the supply curve shifts down by 50% in scenario 1) and shifts out by around 15% in scenario 2).
is less obvious, and the intervals for both \( \Delta \hat{PW}_C \) and \( \Delta \hat{PW}_A \) are large relative to the median of \( \Delta \hat{PW}_C \) and \( \Delta \hat{PW}_A \) (high coefficient of variations).

At the median (50%) of the estimates, the bias for \( \Delta \text{Total}_C \) is roughly

\[
\text{Bias for } \Delta \text{Total}_C = \frac{\Delta \text{Total}_C - \Delta \text{Total}_A}{\Delta \text{Total}_A} = \frac{31.5 - 13.9}{13.9} \\
\approx 127\% \ (\text{scenario 1}), \ 109\% \ (\text{scenario 2})
\]

Since Benin’s GDP in 1998 was approximately US$ 2 billion (World Bank), the difference in \( \Delta \text{Total}_C \) and \( \Delta \text{Total}_A \) is roughly 1.6% or 0.7% of GDP for scenario 1 and 0.8% or 0.4% of GDP for scenario 2, which can be substantial. The results indicate that, at the median level, the difference between conventional and alternative EDM can be significantly large and lead to serious policy implications.

The results in Table 9 and Table 10 indicate how the estimated welfare effects can drop from conventional EDM to model 1. The reason for the much lower estimate from model 1 compared to conventional EDM is mainly that model 1 assumes pivotal shift while conventional EDM assumes parallel shift in the linear supply curve. Although the estimates from models 1 and 2 are not directly comparable with alternative EDM, they indicate that the important result for alternative EDM is relatively high \( \Delta PW \) compared to \( \Delta \text{Total} \) and \( \Delta CS \). One reason for the relatively high \( \Delta PW \) is that given the same level of yield growth or proportional reduction in marginal cost at the initial equilibrium, the drop in price is relatively smaller in the alternative EDM.

### 4.2 Implication of results using the information of intervals

The inference made at the median is, however, based on only one of the many possible estimates. In connection to the empirical estimation methods, the inference based on the intervals is more informative, particularly for \( \Delta \hat{PW}_C \) and \( \Delta \hat{PW}_A \), whose coefficient of variation seems high. The focus thus shifts to how the estimates from conventional EDM differ from those from alternative EDM “given each combination of structural parameters.” We first define a variable,

\[
\hat{w}_D(\hat{\theta}_C, \hat{\theta}_A) = \hat{w}_\text{conventional EDM}(\hat{\theta}_C) - \hat{w}_\text{alternative EDM}(\hat{\theta}_C, \hat{\theta}_A) = \hat{w}_C(\hat{\theta}_C) - \hat{w}_A(\hat{\theta}_C, \hat{\theta}_A),
\]

in which \( \hat{\theta}_C = (\hat{\epsilon}_s, \hat{\epsilon}_d, \hat{A}, \hat{y}) \) and \( \hat{\theta}_A = (\hat{\tau}_i, \hat{\tau}_i^{CM}(\hat{p}_i), \hat{\epsilon}_h, \hat{\delta}) \) in Table 8, \( \hat{w}_C(\hat{\theta}_C) \) and \( \hat{w}_A(\hat{\theta}_C, \hat{\theta}_A) \) are general notation for the welfare effects (total, producer, consumers) estimated using conventional EDM (which is a function of \( \hat{\theta}_C \) alone) and alternative EDM (function of \( \hat{\theta}_C \) and \( \hat{\theta}_A \)).

Table 11 shows the probability that \( \hat{w}_D(\hat{\theta}_C, \hat{\theta}_A) > 0 \) or probability that \( \hat{w}_C(\hat{\theta}_C) > \hat{w}_A(\hat{\theta}_C, \hat{\theta}_A) \) from the simulation. \( \Delta \text{Total}_C > \Delta \text{Total}_A \) over 99% of the time in both scenarios 1 and 2. The fact that \( \Delta \text{Total}_C \) is larger than \( \Delta \text{Total}_A \) with such a high probability

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19Models 1 is not comparable with alternative EDM for several reasons including the issues discussed in footnote 32. Alternative EDM assumes individual demand curves at each consumption market calibrated from respective market price \( p_i^{CM} \) in which not all demand curves have constant elasticity form, as explained in footnote 32, while models 1 implicitly assumes the same price for all consumption markets as well as farmgate sales price.
provides one ground for why policy implications based only on conventional EDM may not be reliable and a model such as alternative EDM should also be considered.

4.3 Detailed analysis of $\Delta PW_C$ and $\Delta PW_A$

As in Table 11, whether $\Delta PW_C$ is more positive than $\Delta PW_A$ is unclear. The importance of comparison between $\Delta PW_C$ and $\Delta PW_A$ rather relates to their estimated intervals which reflect their accuracy given the precisions of estimated structural parameters. Figure 16 shows how each combination of structural parameters $\hat{\theta}_C$ and $\hat{\theta}_A$ results in different $\Delta \hat{PW}_A(\hat{\theta}_C, \hat{\theta}_A)$ and $\Delta \hat{PW}_C(\hat{\theta}_C)$. Figure 16 indicates two important points. First, as is indicated by the correlation coefficient, $\Delta \hat{PW}_A$ and $\Delta \hat{PW}_C$ have a relatively weak relationship, indicating that $\Delta \hat{PW}_C$ has relatively low power to approximate $\Delta \hat{PW}_A$. The low correlation coefficient thus implies that the power of conventional EDM to approximate the welfare gain estimates can be easily overwhelmed by the lack of some additional information such as the alternative assumptions on how the supply curve shifts or whether market margins are zero.

Secondly, actual deviations of $\Delta \hat{PW}_C$ from $\Delta \hat{PW}_A$, which are illustrated by the quantile smoothing spline (Koenker et al., 1994) in Figure 16, indicate the degree of the gap between $\Delta \hat{PW}_C$ and $\Delta \hat{PW}_A$ and the probability of exceeding certain levels of gap. For example, when the $\Delta \hat{PW}_A$ is US$ 5 million, $\Delta \hat{PW}_C$ can be estimated to be above US$ 10 million almost 50% of the time. US$ 5 million for Benin cassava-producing households in 1998 would be roughly 1% of their income. The US$ 5 million deviation of $\Delta \hat{PW}_C$ from $\Delta \hat{PW}_A$ may have important meaning in Benin, whose economy has grown approximately 5% a year in recent years. The findings in Figure 16 thus imply that $\Delta \hat{PW}_C$ can create bias in estimates that can be big enough to influence Benin’s agricultural policy.

4.4 Implications on welfare gain distributions across producers of different income levels

Another important question is how lower-income cassava producers benefit relative to higher-income cassava producers. Figure 17 illustrates the intervals of $\Delta PW$ (per capita, year) in different per capita annual income levels estimated from alternative EDM in scenario 2\(^20\). Figure 18 plots the 50\(^{th}\) percentile of $\Delta PW$ for producers estimated from the two EDMs to see how each estimate provides different implications regarding how welfare gains are shared across different income levels.

Figure 17 and Figure 18 essentially indicate the following. Lower-income cassava producers (below US$200) tend to benefit slightly more than do middle-income (above US$200) cassava producers (Figure 17). In addition, although the alternative EDM generally estimates slightly and insignificantly lower $\Delta PW$ for all producers than does conventional EDM, alternative EDM provides estimates of slightly higher $\Delta PW$ for low-income producers than does conventional EDM. Slightly higher estimates of $\Delta PW$ from conventional EDM may thus come mainly from the higher-income cassava producers (Figure 18).

\(^{20}\) The figure for scenario 1 is similar except for the overall level of welfare gains in that lower-income cassava producers seem to gain more than do middle-income cassava producers.
Although the result in Figure 18 cannot be fully explained by the aforementioned reasons, Figure 18 still indicates that conventional and alternative EDM may lead to different implications regarding whether or not GM cassava in Benin is pro-poor.

Future research will probably still rely on conventional EDM due to its parsimony. Conventional EDM can even be used to gain insights into how welfare is distributed across producer groups with different income levels and thus how technology aids the poor. The empirical results of this study, however, indicate that when the research question explores how the gains are distributed across producers with different income levels, or whether the technology is pro-poor, then conventional EDM may provide a distorted figure especially when the data suggests a great degree of heterogeneity among producers with different income levels.

5. **Summary and conclusion**

Productivity growth for orphan crops like cassava can significantly affect the welfare of cassava producers, who make up one of the most impoverished groups in the world. The actual welfare gain for cassava producers is, however, questionable because it depends on how much productivity growth can offset the fall in cassava price also brought by the productivity growth. Therefore, from the perspective of poverty reduction, one of the important research questions is how great a gain in welfare productivity growth in cassava can bring to cassava producers, particularly lower-income cassava producers.

Many past studies have conducted ex ante welfare effects estimations for similar subsistence crops using conventional EDM, which employs assumptions that may be unrealistic. These questionable assumptions, however, may not necessarily invalidate the estimates from conventional EDM as long as they provide good approximations of actual welfare gains brought by productivity growth. Whether it is important to question the assumptions in conventional EDM, therefore, should be determined by examining the estimates obtained from conventional EDM; the examination must also take into account how conventional EDM itself is calibrated by empirically estimated parameters.

This study contributes to the literature by providing one empirical example of aforementioned issues. The findings suggest that conventional EDM, which employs controversial assumptions for subsistence crops like cassava, may often provide significantly biased welfare gain estimates given the degree of reliability of the parameters used in the context of productivity growth for subsistence crops. It may also provide incorrect implications about whether such productivity growth is pro-poor.

Although the properties of both conventional and alternative EDM remain to be more fully analyzed, these methods are two different ways to estimate the welfare effects of many semi-subsistence crops with data similar to the Benin data. The literature often relies more on conventional EDM rather than the alternative EDM. This study provides an empirical example that shows that it may be important to use alternative EDM as well as conventional EDM for more informed policy making about investment in public research on semi-subsistence crops as a tool to reduce poverty.
Figure 1. Alternative assumption 1: heterogenous farmgate price

\( P_t \): reference price – equivalent to \( \hat{P} \) in (34)  \( P'_t, P''_t \): individual reference price

\( S \): production  \( H \): home consumption  \( D \): Consumption by non-producer

\( T \): difference between reference price and individual reference price – equivalent to \( \hat{\zeta}_i^{CM} \) in (35)
$P_t$: reference price – equivalent to $\hat{P}$ in (36)  
$P'_t, P''_t$: individual reference price

$S$: production  
$H$: home consumption  
$D$: Consumption by non-producer

Figure 2. Alternative assumption 2: constant elasticity form and pivotal shi
$P_t$: reference price – equivalent to $\hat{P}$ in (37)  
$P_t', P_t''$: individual reference price

$S$: production  
$H$: home consumption  
$D$: Consumption by non-producer

t: difference between farmgate price and relevant consumption market price for each household – equivalent to $\hat{\tau}_i$ in (38)

Figure 3. Alternative assumption 3: supply and demand curves in the presence of market margins between farmgate and consumption marke
Figure 4. Illustrations of alternative EDM as a combination of each assumption in Figure 1 through Figure 3
Figure 5. Assumed relationships between a cassava producing household and the market

At a high market price:
- Produce cassava until $MC = p_{i}^{CM} - \hat{\tau}_i$
- Consume cassava until $MU = p_{i}^{CM} - \hat{\tau}_i$

p* - $\hat{\tau}_i < p_{i}^{CM} < p* + \hat{\tau}_i$

Figure 6. Supply and demand curves for subsistence cassava-producing household
Figure 7. Supply and demand curves for subsistence cassava-producing household.

Figure 8. Cassava market structure in Benin – extension of double buffer structure.
Figure 9. Assumption of no-autarkic consumption market(s)

Figure 10. Relevant price for semi-subsistence cassava producers group $i$ facing two transportation costs
Figure 11. Proportion of population in cassava-producing households\textsuperscript{21}

Figure 12. Median of estimated farmgate price (US cent / kg, fresh tuber) by income

Figure 13. Production (ton / per capita, year) by income levels

Figure 14. Home consumption (kg / per capita, day) by income level

\textsuperscript{21} Proportion is calculated using number of observations (household) * household size * survey weights for each observation
Figure 15. Calibration of supply and demand curves for autarkic producers
Figure 16. Comparison of $\Delta \hat{PW}_A(\Theta)$ and $\Delta \hat{PW}_C(\Theta)$ for each $\Theta = \hat{\Theta}$ (lines in the figure are the quantile smoothing spline developed by Koenker et al. (1994))
The 50% line (solid bold line) in Figure 17 is equivalent to the solid line in scenario 2 of Figure 18. Two lines appear different since different functions are used in the software. The purpose of Figure 17 is to illustrate the interval of welfare gains from alternative EDM for different income levels, while Figure 18 compares the median of intervals for different models.

Figure 17. Intervals of welfare gains for producers in different income levels (scenario 2)

Figure 18. Median of welfare effects for producers in different income levels (conventional and alternative EDM)
Table 2. Models used in welfare effects estimation

<table>
<thead>
<tr>
<th>Market margin</th>
<th>Linear or constant elasticity</th>
<th>Shifts in supply curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional EDM</td>
<td>No</td>
<td>Linear</td>
</tr>
<tr>
<td>Model 1</td>
<td>No</td>
<td>Constant elasticity</td>
</tr>
<tr>
<td>Alternative EDM</td>
<td>Yes</td>
<td>Constant elasticity</td>
</tr>
</tbody>
</table>

Table 3. Structure of the model

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual supply and home consumption schedule</td>
<td>(16), (17')</td>
</tr>
<tr>
<td>Market clearing condition</td>
<td>(18)</td>
</tr>
<tr>
<td>Measurement of welfare effects for population group $i$</td>
<td>(19), (20)</td>
</tr>
</tbody>
</table>

Table 4. Important variables estimated (calibrated) from the dataset

<table>
<thead>
<tr>
<th>Definition</th>
<th>Variables used to calculate</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{p}_i^f$</td>
<td>Farmgate sales price</td>
<td>Regression (25), (27)</td>
</tr>
<tr>
<td>$\hat{\tau}_i$</td>
<td>Market margin (for individual producers)</td>
<td>Regression (26), (28)</td>
</tr>
<tr>
<td>$\hat{p}_i^{CM}$</td>
<td>Price at local consumption market</td>
<td>$\hat{p}_i^f$, $\hat{\tau}_i$ (29)</td>
</tr>
<tr>
<td>$\hat{P}^*$</td>
<td>Average consumption price</td>
<td>$\hat{S}_i, \hat{H}_i, \hat{w}_i, \hat{p}_i^{CM}$ (22)</td>
</tr>
<tr>
<td>$\hat{\tau}_i^{CM}$</td>
<td>Market margin (between local consumption markets)</td>
<td>$\hat{P}^*, \hat{p}_i^{CM}$ (12)</td>
</tr>
<tr>
<td>$\hat{\epsilon}_{si}$</td>
<td>Elasticity of production</td>
<td>Regression (Takeshima, 2008)</td>
</tr>
<tr>
<td>$\hat{\epsilon}_{hi}$</td>
<td>Elasticity of home consumption</td>
<td>Regression (Takeshima, 2008)</td>
</tr>
<tr>
<td>$\hat{\epsilon}_d$</td>
<td>Elasticity of demand</td>
<td>Regression (Takeshima, 2008)</td>
</tr>
<tr>
<td>$S_i\left(\hat{p}_i^{CM}, \hat{\tau}_i\right)$</td>
<td>Production curve</td>
<td>(16) 0</td>
</tr>
<tr>
<td>$H_i\left(\hat{p}_i^{CM}, \hat{\tau}_i\right)$</td>
<td>Home consumption curve</td>
<td>(16) 0</td>
</tr>
</tbody>
</table>

Table 5. Structure of Benin cassava market

<table>
<thead>
<tr>
<th>On-farm type</th>
<th>Off-farm type</th>
<th>Non-producers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production ($t$)</td>
<td>424519</td>
<td>423028</td>
</tr>
<tr>
<td>Consumption ($t$)</td>
<td>77524</td>
<td>100555</td>
</tr>
<tr>
<td>% of subsistence consumption</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Population growth rate (%)</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Estimated population (million)</td>
<td>2.75</td>
<td></td>
</tr>
<tr>
<td>Dependent variables</td>
<td>Regression (25)</td>
<td>Regression (26)</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td></td>
<td>$\ln(\hat{p}_i^f)$</td>
<td>$\ln(\hat{\tau}_i)$</td>
</tr>
<tr>
<td>Region 2</td>
<td>.076</td>
<td>-</td>
</tr>
<tr>
<td>Region 3</td>
<td>-.328</td>
<td>-</td>
</tr>
<tr>
<td>Region 4</td>
<td>.619</td>
<td>-</td>
</tr>
<tr>
<td>Region 5</td>
<td>.503</td>
<td>-</td>
</tr>
<tr>
<td>Fresh-tuber (yes = 1)</td>
<td>-.646</td>
<td>-</td>
</tr>
<tr>
<td>Flour (yes = 1)</td>
<td>1.116***</td>
<td>-</td>
</tr>
<tr>
<td>Dried tuber (yes = 1)</td>
<td>.437</td>
<td>-</td>
</tr>
<tr>
<td>January</td>
<td>.139</td>
<td>-</td>
</tr>
<tr>
<td>February</td>
<td>-.171</td>
<td>-</td>
</tr>
<tr>
<td>March</td>
<td>.189</td>
<td>-</td>
</tr>
<tr>
<td>April</td>
<td>-.171</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>-.079</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>.157</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>-.175</td>
<td>-</td>
</tr>
<tr>
<td>August</td>
<td>-.063</td>
<td>-</td>
</tr>
<tr>
<td>September</td>
<td>-.048</td>
<td>-</td>
</tr>
<tr>
<td>October</td>
<td>-.068</td>
<td>-</td>
</tr>
<tr>
<td>November</td>
<td>-.503</td>
<td>-</td>
</tr>
<tr>
<td>Distance to paved road (10km)</td>
<td>-.003</td>
<td>-</td>
</tr>
<tr>
<td>Distance to passable road (10km)</td>
<td>-.006</td>
<td>-</td>
</tr>
<tr>
<td>Distance to phone (10km)</td>
<td>1.483</td>
<td>-</td>
</tr>
<tr>
<td>Off farm type seller (yes = 1)</td>
<td>.309***</td>
<td>-</td>
</tr>
<tr>
<td>Membership to cooperative (yes = 1)</td>
<td>-.061</td>
<td>-</td>
</tr>
<tr>
<td>Household head education (year)</td>
<td>3.397***</td>
<td>-</td>
</tr>
<tr>
<td>Constant</td>
<td>3.397***</td>
<td>-</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.708</td>
<td>-</td>
</tr>
<tr>
<td>Number of observation</td>
<td>192</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 7. Summary statistics of estimated prices, per-unit transactions costs (US cents / kg, fresh-tuber)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmgate sales price ($\hat{p}_f^i$)</td>
<td>5.22</td>
<td>3.47</td>
<td>0.28</td>
<td>40.09</td>
</tr>
<tr>
<td>Consumption market price ($\hat{p}_{CM}^i$)</td>
<td>12.92</td>
<td>5.49</td>
<td>0.55</td>
<td>119.94</td>
</tr>
<tr>
<td>Per-unit transactions costs ($\hat{\tau}_i$)</td>
<td>7.70</td>
<td>1.01</td>
<td>0.16</td>
<td>118.58</td>
</tr>
<tr>
<td>Weighted farmgate sales price ($\hat{P}_{P}^f$)</td>
<td>2.50</td>
<td>2.47</td>
<td>1.93</td>
<td>3.54</td>
</tr>
<tr>
<td>Weighted consumption market price ($\hat{P}_{P}$)</td>
<td>3.35</td>
<td>3.32</td>
<td>2.67</td>
<td>4.48</td>
</tr>
</tbody>
</table>

Table 8. Important variables estimated (calibrated) from the dataset

$N$ : Normal distribution, $N^+$: Positively truncated normal distribution
$U$ : Uniform distribution

<table>
<thead>
<tr>
<th>On farm Sellers Types</th>
<th>Off farm Sellers Types</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N(\hat{\mu}<em>{pf}^i, \hat{\nu}</em>{pf}^i)$</td>
<td>$\forall i = Autarkic producers$</td>
<td></td>
</tr>
<tr>
<td>$\ln(\hat{p}<em>f^i) = (X</em>{pf})^{-1} \hat{B}_{pf}$</td>
<td>$\begin{bmatrix} \hat{\mu}<em>{pf}^i \ \hat{\nu}</em>{pf}^i \end{bmatrix} = [\begin{bmatrix} x_{1,i}^{pf} \ \vdots \ x_{k_i}^{pf} \end{bmatrix}]$</td>
<td>Regression (25)</td>
</tr>
<tr>
<td>$\ln(\hat{\tau}<em>i) = (X</em>{\tau})^{-1} \hat{B}_{\tau}$</td>
<td>$\begin{bmatrix} \hat{\mu}<em>{\tau}^i \ \hat{\nu}</em>{\tau}^i \end{bmatrix} = [\begin{bmatrix} x_{1,i}^{\tau} \ \vdots \ x_{k_i}^{\tau} \end{bmatrix}]$</td>
<td>Regression (26)</td>
</tr>
<tr>
<td>$\delta$ (in equation (31))</td>
<td>$U[0, 2]$</td>
<td></td>
</tr>
<tr>
<td>$\hat{\varepsilon}_{hi}^i$</td>
<td>$N^-(.53, .19)$</td>
<td>$N^+(.10, .22)$</td>
</tr>
<tr>
<td>$\hat{\Lambda}$ (% adoption rate)</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Shifts in supply curve</td>
<td>Shifts out horizontally by 30% (scenario 1)</td>
<td>Shifts down vertically by 30% (scenario 2)</td>
</tr>
</tbody>
</table>
### Table 9. Scenario 1 (million US$)

<table>
<thead>
<tr>
<th>Percentile</th>
<th>2.5%</th>
<th>50%</th>
<th>97.5%</th>
<th>% change in price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ΔTotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional EDM</td>
<td>17.3</td>
<td>31.5</td>
<td>58.1</td>
<td>-50.6</td>
</tr>
<tr>
<td>Model 1</td>
<td>7.4</td>
<td>9.5</td>
<td>12.3</td>
<td>-23.6</td>
</tr>
<tr>
<td>Alternative EDM</td>
<td>9.5</td>
<td>13.9</td>
<td>27.3</td>
<td>-12.3</td>
</tr>
</tbody>
</table>

| **ΔCS** |      |     |       |                  |
| Conventional EDM | 8.7  | 22.3 | 49.5  |                  |
| Model 1     | 7.0  | 9.8 | 14.0  |                  |
| Alternative EDM | 3.1  | 6.2 | 11.3  |                  |

| **ΔPW** |      |     |       |                  |
| Conventional EDM | 4.8  | 10.0 | 15.2  |                  |
| Model 1     | -3.9 | -0.2 | 1.4   |                  |
| Alternative EDM | 1.8  | 7.5 | 20.5  |                  |

*US $1 = 588 FCFA on July 1997.*

### Table 10. Scenario 2 (million US$)

<table>
<thead>
<tr>
<th>Percentile</th>
<th>2.5%</th>
<th>50%</th>
<th>97.5%</th>
<th>% change in price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ΔTotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional EDM</td>
<td>13.3</td>
<td>16.3</td>
<td>20.0</td>
<td>-27.5</td>
</tr>
<tr>
<td>Model 1</td>
<td>2.4</td>
<td>4.6</td>
<td>8.2</td>
<td>-12.4</td>
</tr>
<tr>
<td>Alternative EDM</td>
<td>3.3</td>
<td>7.8</td>
<td>16.9</td>
<td>-6.4</td>
</tr>
</tbody>
</table>

| **ΔCS** |      |     |       |                  |
| Conventional EDM | 8.0  | 10.9 | 16.9  |                  |
| Model 1     | 2.3  | 4.7 | 8.3   |                  |
| Alternative EDM | 0.7  | 2.9 | 5.9   |                  |

| **ΔPW** |      |     |       |                  |
| Conventional EDM | 0.5  | 5.0 | 8.4   |                  |
| Model 1     | -1.4 | -0.2 | 0.7  |                  |
| Alternative EDM | 0.5  | 4.5 | 12.3  |                  |

### Table 11. Difference between \( \hat{\omega}_A(\Theta) \) and \( \hat{\omega}_C(\Theta) \) \((\hat{\omega}_A(\Theta) - \hat{\omega}_C(\Theta) | \Theta = \hat{\Theta})\)

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y = 0.3 )</td>
<td>( k_i = 0.3 )</td>
</tr>
<tr>
<td>Prob ( (\Delta \text{Total}_C &gt; \Delta \text{Total}_A) )</td>
<td>100 %</td>
</tr>
<tr>
<td>Prob( (\Delta \text{PW}_C &gt; \Delta \text{PW}_A) )</td>
<td>72 %</td>
</tr>
<tr>
<td>Prob( (\Delta \text{CS}_C &gt; \Delta \text{CS}_A) )</td>
<td>100 %</td>
</tr>
</tbody>
</table>
Reference


Appendix

A. 1 Important properties of conventional EDM

We first start from formula (6). When $K_i = K$ for all producer groups, formula (6) can be modified as

$$\frac{dp}{p} = \frac{\sum_{i=1}^{n} (ss_i e_{si} K_i)}{\varepsilon_d - \sum_{i=1}^{n} (ss_i e_{si})} = \frac{\sum_{i=1}^{n} (ss_i e_{si})}{\varepsilon_d - \sum_{i=1}^{n} (ss_i e_{si})} K$$

(6')

when $\varepsilon_d < 0$ and $e_{si} > 0$, since $ss_i \geq 0$, $\sum_{i=1}^{n} (ss_i e_{si}) > 0$ and thus $-1 < \frac{\sum_{i=1}^{n} (ss_i e_{si})}{\varepsilon_d - \sum_{i=1}^{n} (ss_i e_{si})} < 0$, or $-K < \frac{dp}{p} < 0$ from (6'). Therefore we have $\frac{dp}{p} + K > 0$, which is 1). Next, for producer group $i$, the expression of $\Delta PW_i$ in (4) can be rewritten as

$$\Delta PW_i = p_i q_{s,i} \left( \frac{dp}{p_i} + K \right) \left( 1 + 0.5 e_{si} \left( \frac{dp}{p_i} + K \right) - dp q_{s,i} h_i \right)$$

(4')

In (4'), since $dp < 0$, $p_i$, $q_{s,i}$, $e_{si}$, $h_i > 0$, we then have

$$\Delta PW_i = p_i q_{s,i} \left( \frac{dp}{p_i} + K \right) \left( 1 + 0.5 e_{si} \left( \frac{dp}{p_i} + K \right) - dp q_{s,i} h_i \right) > 0$$

(4'')

Equation (4'') also shows that a larger $q_{s,i}$ and $q_{s,i} h_i$ lead to a larger $\Delta PW_i$ since $dp < 0$, which together proves 2).

A. 2 Proof of footnote 15

We show that (4) becomes more positive as $dp/p + K_i$ increases for any $dp/p > K_i$. To see this,

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

(39)

$$= q_{s,i} \left( 1 - h_i + e_{si} \left( \frac{dp}{p} + K_i \right) \right)$$

We know from discussion in A. 1 that $dp/p + K > 0$ for $\varepsilon_d < 0$ and $e_{si} > 0$, and therefore for any $dp/p > K$, (39) > 0. This proves that a larger $dp/p + K_i$ leads to more positive $\Delta PW$, and thus the explanation in footnote 15 holds.