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Sensitivity of Welfare Effects Estimated by Equilibrium Displacement Model

A Biological Productivity Growth for Semisubsistence Crops in Sub-Sahara African Market with High Transaction Costs

Hiroyuki Takeshima

Development Strategy and Governance Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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AUTHORS

Hiroyuki Takeshima, International Food Policy Research Institute
Postdoctoral Fellow
H.Takeshima@CGIAR.org

Notices

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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 EDM that reflects 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.

Keywords: equilibrium displacement model, pivotal shift, cassava, semisubsistence, market margins, double buffering

1. INTRODUCTION AND RESEARCH QUESTIONS

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

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

The literature often employs an EDM with several restrictive and inappropriate assumptions about semisubsistence producers; this model is called conventional EDM (CEDM). Among the key assumptions for CEDM, this discussion paper focuses on (1) the linear supply curve, (2) productivity growth as expressed by a parallel shift in supply curve, and (3) zero market margins (in which producers and consumers face a single price).[1] Due to its simplicity, CEDM is also subject to other restrictive assumptions, as discussed in Section 2.

The literature raises questions regarding these restrictive and inappropriate assumptions, even though they are often employed to facilitate the estimation of welfare gains. Market margins can be significantly large and can have complicated structures in the semisubsistence crop market (Barrett 2008). Several lines of theoretical reasoning can also invalidate assumptions that result when a linear supply curve and a parallel shift in the supply curve are used as opposed to other forms, such as pivotal shifts, particularly for biological productivity growth (Lindner and Jarrett 1978; Rose 1980). Little is known about how CEDM can cause biases in estimated benefits for these productivity growths and how big such biases can be. Pro-poorness of the distribution of benefit is another important measurement for productivity growth of crops like cassava (Nweke, Spencer, and Lynam 2002; Johnson, Masters, and Prekel, 2006); CEDM can provide an incorrect evaluation of such pro-poorness of the technology because it employs more restrictive assumptions on the heterogeneity of producers. An empirical exercise is thus valuable to assess how CEDM can bias the true nature of the benefits of biological cassava productivity growth.

The results in this work indicate that in the particular case of cassava producers in Benin, CEDM may significantly overestimate the aggregate benefit of virus-resistant biological productivity growth, while slightly underestimating the benefit for low-income producers who belong to the higher farmgate price zones because of their proximity to a major consumption market.[2] The latter finding is also important because CEDM can lead to an understatement of pro-poorness of cassava productivity growth as supported by several studies. Therefore ignoring biases of restrictive assumptions under CEDM can have serious implications for how we evaluate the overall benefit and the pro-poorness of virus-resistant cassava in Benin. Thus the use of a more data-intensive, less-restrictive, and realistic, but also labor-intensive, model, as described in this study, is worthwhile.

The results are obtained by a simulation approach that simultaneously relaxes or replaces the aforementioned assumptions and uses empirically estimated parameters, such as supply-and-demand elasticities. More specifically, this study modifies CEDM into a model with alternative assumptions

[1] Another implicit assumption in CEDM is a perfectly inelastic home consumption. The relaxation of the perfectly inelastic home consumption assumption, however, has relatively small effects on estimated welfare and is thus excluded from the subsequent discussion, although it is included in the actual estimation of alternative EDM.

[2] Although they sell cassava at a higher farmgate price, these producers are still low income because their production costs are high and their production is small.

(called alternative EDM [AEDM])—namely, (1) a supply curve in constant elasticity form; (2) productivity growth as expressed by a pivotal shift in supply curve; (3) nonzero market margins with structures indicated by Barrett (2008). This study empirically compares CEDM with AEDM, using the Benin Small Farmer Dataset collected by IFPRI[3] (Benin dataset, hereafter).

This study contributes to the literature by improving our understanding of how CEDM with restrictive assumptions on transaction 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 SSA countries.

[3] A more detailed description of the Benin dataset is given in Takeshima (2008).

2. CONCEPTUAL FRAMEWORK AND APPROACH

Overview of Conventional EDM versus Alternative EDM

The EDM, originally developed by Muth (1964), is one method used to evaluate ex ante the economic effects of scale-neutral productivity growth (Alston, Norton, and Pardey 1998) and has been applied to semisubsistence agriculture (Hayami and Herdt 1977; Norton, Ganoza, and Pomareda 1987; Qaim 1999, 2001; Andreu et al. 2006). Despite some limitations, EDM is still a powerful tool for measuring 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 EDM can be expressed as

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

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

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

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 producers themselves (q_{di}^{home}) and demand by the rest of the consumer (q_{di}^{market}); and δ_i is the production technology level that affects the marginal cost curve. CEDM assumes p = farmgate sales price = consumption price.

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

$$\Delta PW = p\sum_{i=1}^{n}\left[q_{s,i}\left(\frac{dp}{p}+K_i\right)\left(1+0.5\varepsilon_{s,i}\left(\frac{dp}{p}+K_i\right)\right)-\frac{dp}{p}q_{s,i}h_i\right] \tag{4}$$

$$\Delta CS = -pq_d\frac{dp}{p}\left(1+0.5\varepsilon_d\frac{dp}{p}\right)-\left(-dpq_d\sum_{i=1}^{n}\left(h_i ss_i\right)\right) \tag{5}$$

$$\frac{dp}{p} = \frac{\sum_{i=1}^{n}\varepsilon_{si} ss_i K_i}{\varepsilon_d - \sum_{i=1}^{n}\varepsilon_{si} ss_i} \, , \tag{6}$$

in which $\varepsilon_{s,i}$ is price elasticity of production by producer (or producer groups) i, ε_d is price elasticity of demand (including home consumption), K_i is percentage reduction in production costs, h_i is proportion of home consumption to production by i, and ss_i is the proportion of production by i to total production. Total welfare effect (ΔTotal) is simply

$$\Delta\text{Total} = \Delta PW + \Delta CS \, . \tag{7}$$

The advantage of CEDM is that given the basic information of productivity growth, welfare gains can be easily calculated using formulas (4) through (7). CEDM is, however, subject to assumptions that are questionable in the context of semisubsistence crops. Among those, three assumptions (listed in Table 1) are discussed in this section.

Table 1. Underlying assumptions for conventional EDM and alternative EDM

	CEDM	AEDM
Supply curve	Linear	Constant elasticity
Shift in supply curve	Parallel	Pivotal
Market margin	Zero	Positive

Source: Author.

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 1 is controversial. Any linear supply curve with elasticity less than 1 measured at the initial equilibrium has zero MC for up to some positive production quantity. Voon and Edwards (1991) also prefer to use the constant elasticity form with pivotal shifts, because it provides more conservative estimates of benefits than the linear form when supply elasticity is less than 1, as is the case of this study. AEDM assumes a supply curve in constant elasticity form, which avoids the problem of zero MC for positive production quantity.

AEDM uses a pivotal shift to express productivity growth for several reasons. 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, because for each unit of output, a farmer reduces the input by the same proportion (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 to do so in simulation, because the reduction in MC can be greater than the initial level of MC for some producers who have relatively low MC at the initial equilibrium production level.

High transaction costs in Africa have been widely reported in the literature, and significant margins exist both between the farmgate price and the local consumption market price and among the various consumption markets (Barrett 2008). AEDM incorporates positive market margins between the farmgate sales price and the consumption market price in a specific way. Although later sections describe this issue in more depth, *consumption market* is defined here as the end market of cassava, as opposed to intermediate markets like collection points.[4] One way to incorporate market margins so they reflect either the difference between farmgate price and end-market price or the difference among end-market prices in different regions is to keep those market margins constant and exogenous to productivity growth (Alston, Norton, and Pardey 1998), as is employed in the AEDM, as described in later sections.

Estimates from CEDM are proportional to the initial equilibrium price p_0 in formulas (4) through (6). Because plant breeding research is often justified based on the total benefit, the level of p_0 is critical in estimating welfare effects using EDM. Literature using CEDM generally uses farmgate prices reported by secondary sources like the Food and Agriculture Organization (FAO) or local governments as p_0 (Qaim 1999, 2001) or the average of the reported farmgate and wholesale prices (Andreu et al. 2006). The

[4] The terms *consumption market* and *collection point* are both used in the Benin dataset. Although the Benin dataset 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 the cassava to the consumption market. I distinguish between consumption market and collection point as follows: In the consumption market, cassava reaches consumers. 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, however, when I estimate the farmgate sales price of some cassava producers who report only the price at the collection point. Prices received at this collection point should include some margin in addition to the farmgate price. This margin is similar to the margin between the farmgate price and the price at the consumption market.

information of p_0 is, however, less accurate or simply unavailable for some developing countries and commodities.[5] For example, the estimation of p_0 for cassava is particularly difficult, because 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 CEDM, particularly embedded in formulas (4) through (6), is that when K_i is the same for all i, $\varepsilon_d < 0$ and $\varepsilon_{si} > 0$; at this point, CEDM tends to estimate more positive ΔPW_i for producers with larger production q_{si}.[6] As shown in the simulation, AEDM may be less affected by the restrictions mentioned here, though it may be rather difficult to generalize the results.

The Representation of Cassava Market with Double-Buffer Concept in Barrett (2008)

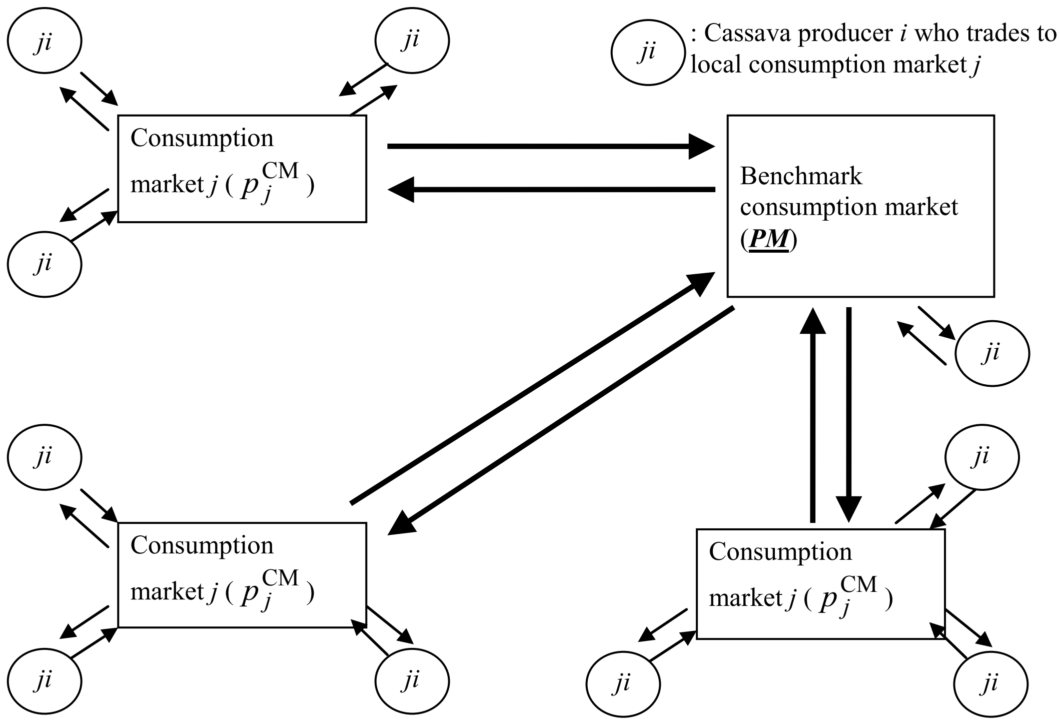
Market margin, which primarily comprises transportation costs, is relatively high in SSA countries, and individual, as well as aggregate, supply and demand can be significantly different from those countries under no market margin. This section first describes the supply-and-demand schedules for semisubsistence farmers facing high-market margins between farmgate and consumption market, following Minot (1999), and explains how welfare effects are measured.

This section then describes how the market for nontraded crops like cassava is cleared when the difference in equilibrium prices among multiple consumption markets is largely determined by the intermarket margins. More specifically, 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. Figure 1 illustrates a market structure behind the double buffering in Barrett (2008). Cassava is traded through two layers of channels—one channel between each cassava producer and the local consumption market and the other between different consumption markets. Barrett (2008) distinguishes the relationship between semisubsistence farmers and local markets from the relationship between semisubsistence local markets and other markets.

[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 B.

Figure 1. Cassava market structure in Benin: Extension of the double-buffer structure



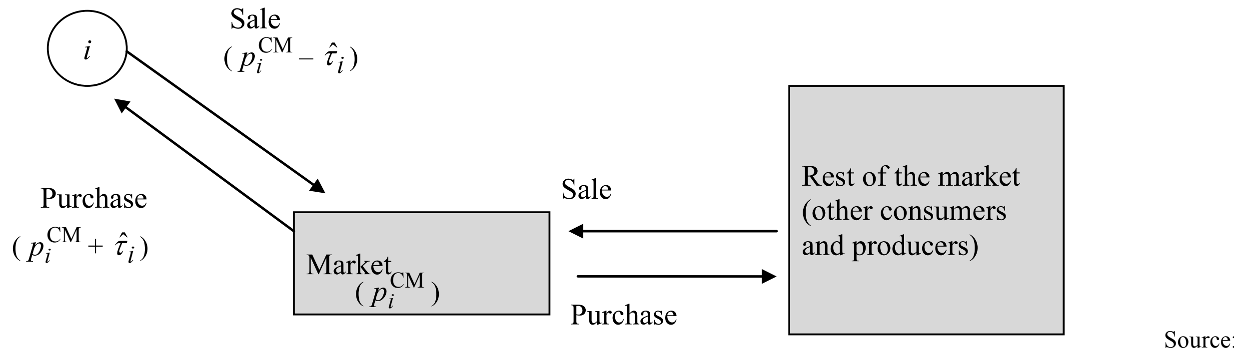
Source: Author.

The Effect of Market Margin between Farmgate and Consumption Markets

In the presence of a nonzero market margin between farmgate price and the price at the consumption market, household supply and home consumption curves can be derived in the following way.[7] Assume there is one cassava producing-household i and a large market in which a large quantity of cassava is traded at price p_i^{CM} (Figure 2) (which is the equivalent of p_j^{CM} in Figure 1, as discussed at the beginning of Section 2). For household i, the total cost (including opportunity cost of input factors) of producing q_p units of cassava $\$C(q_p)$ includes the opportunity cost of time required for planting seeds and weeding and the opportunity cost of land required. Because 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 that $\partial C(q_p)/ \partial q_p$ is strictly increasing in q_p.

[7] For simplicity, price and quantity in this section are measured as fresh-tuber equivalent.

Figure 2. Assumed relationships between a cassava-producing household and the market



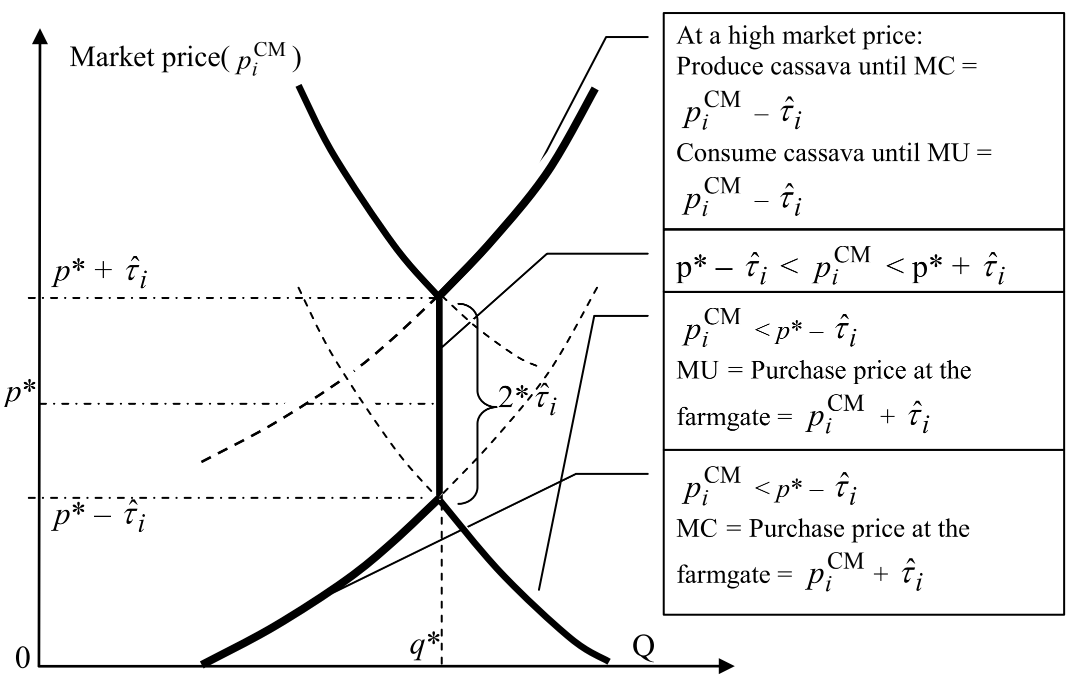
Source: Author.

Household i derives utility $U(q_C)$ from consuming q_C units of cassava. The household consumes cassava as food, gifts for the family, or in-kind payment for labor. 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 τ_i, then the farmgate sales price p_i^f for i is $p_i^f = p_i^{CM} - \hat{\tau}_i$. Similarly, the farmgate purchase price p_i^p for i is $p_i^p = p_i^{CM} + \hat{\tau}_i$. 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 3).

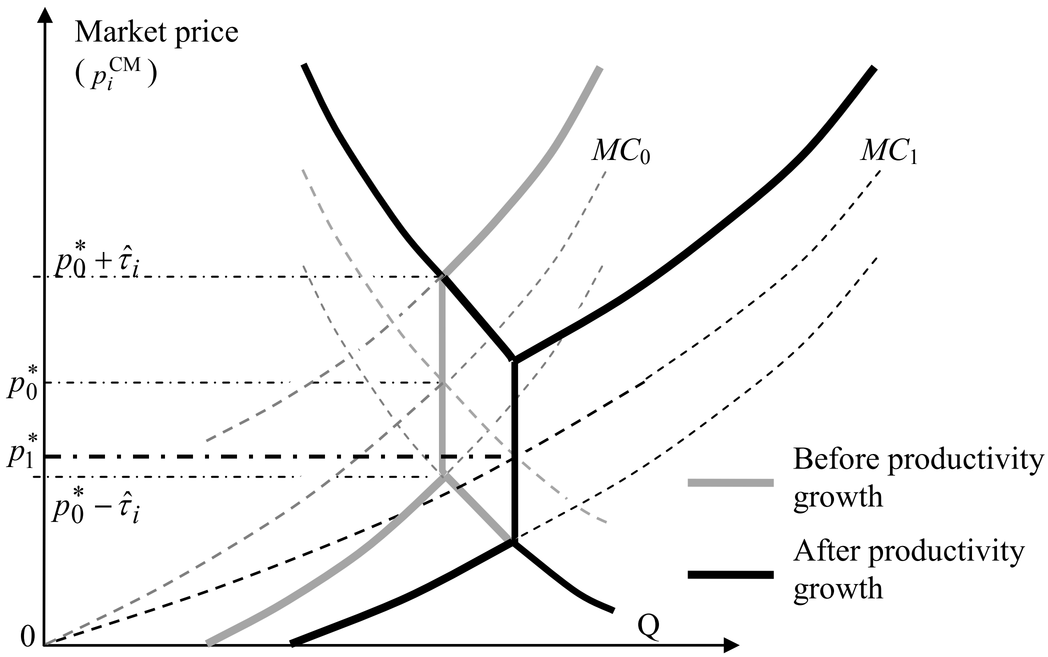
Figure 3. Production and home consumption curves for subsistence cassava-producing household



Source: Author.

With a productivity growth, the marginal cost curve shifts out, which then shift production and home consumption curves. How production and home consumption curves shift, however, also depend on the market margins. The production and home consumption curves under new production technologies are derived as in Figure 4.

Figure 4. Productivity growth and shifts in production and demand curve

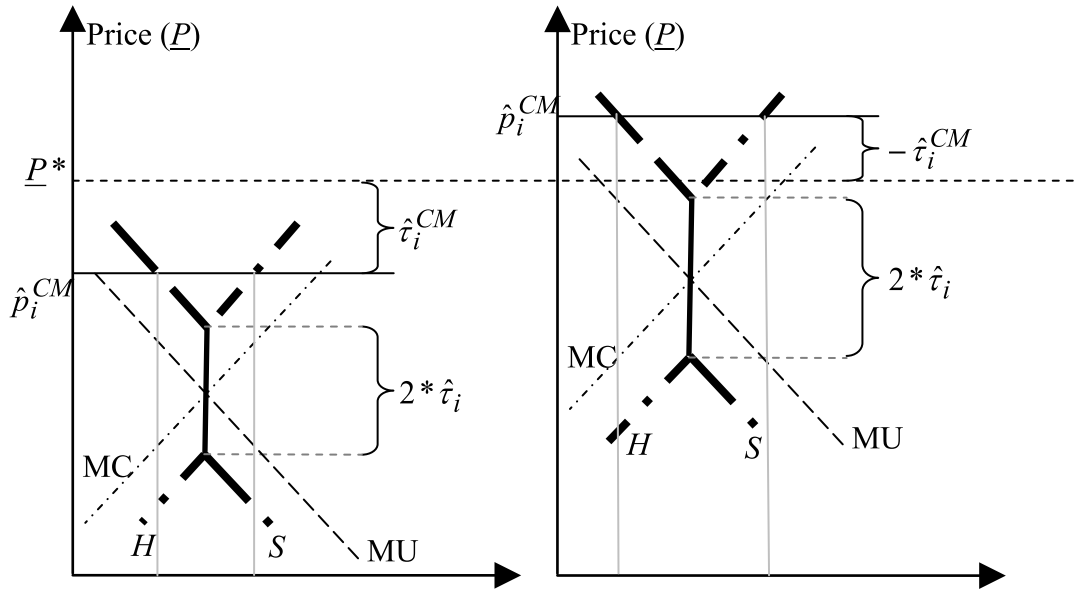


Source: Author.

The simulation presented in later sections 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, even though aggregated EDM in the 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 could be illustrated as in Figure 3, which is actually used for individual cassava producers, with a good approximation of market margin τ for the entire market. This paper, however, argues that Figure 3 is not a good representation of aggregated supply and demand. For example, Figure 3, if used for aggregate market, implies perfectly inelastic aggregate supply and demand when price is in a certain range, which not only is too restrictive but also requires the assumption that all producers face the same per-unit transaction costs. In addition, the Benin data suggest significant variations in price received by each cassava producer or heterogeneity in the characteristics of producers. Supply-and-demand curves for a semisubsistence cassava producer in Figure 3 can thus be linked to the average consumption price $\underline{P}$ (or its solution $\hat{\underline{P}}^*$), as in Figure 5.

Figure 5. Relevant price for semisubsistence cassava producers *i* facing two transportation costs



Source: Author.

Having derived the supply and home consumption curves, we now define the welfare for the cassava-producing households. The welfare measurement in this study is similar to the concept of the *Marshallian surplus.*[8] Let us define Q^* as $Q^* = \max[Q^P, Q^C]$, in which Q^P and Q^C denote quantity produced and quantity consumed, respectively. 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

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

in which MU and MC are marginal utility curve and marginal cost curve, respectively.

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

[8] The benefit of using the Marshallian demand curve instead of the Hicksian demand curve is that the former can be estimated with less information, like income elasticity, than can the Hicksian demand curve (Alston, Norton, and Pardey, 1998). The welfare effects using the Marshallian demand curve are biased, because it ignores the income effect caused by cassava productivity growth. However, Alston and Larson (1993) argue that bias may be larger from using Hicksian demand curve if Hicksian demand curve is recovered using empirically estimated elasticities which often contain errors. That is why this study continues using the Marshallian demand curve to conduct EDM, even though the estimation of demand curves in the previous section includes the income effects as well.

The Effect of Market Margins between Consumption Markets: Application of Double Buffering (Barrett 2008) and Required Assumptions

Applying Barrett's (2008) argument, the price of the commodity in each nonautarkic market *j* differs from the prices in other markets by the difference in the margin between each market *j* and the border price, or the international price. The "geographic specificity" of price (Barrett 2008) has been observed for many commodities in Africa and appears consistent with the Benin dataset. It therefore seems appropriate to employ assumption (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] (9)

Assumption (9) relates to the theory of market integration, widely studied in the literature, regarding the efficiency of intermarket price transmissions. This assumption is generally supported for West African countries, including Benin (Kuiper, Lutz, and Tilburg 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, because this crop is generally not traded internationally and no border price exists for cassava. Second, it remains to be seen how assumption (9) facilitates the inclusion of market margins to EDM with certain limitations associated with the Benin dataset, even though the assumption requires that no local market *j* is autarkic.

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

$$\begin{aligned} p_j^{CM} &= p^{cb} + \hat{\tau}_j^M(G,Q), && \text{if; } j \text{ is an importing market} \\ p_j^{CM} &= p^{cb} - \hat{\tau}_j^M(G,Q), && \text{if; } j \text{ is an exporting market} \\ p_j^{CM} &= p_j^{CM,a}, && \text{if; } j \text{ is autarkic} \end{aligned} \tag{10}$$

in which p^{cb} is the border price, or the price at the international market; $\hat{\tau}_j^M$ is market-specific transaction costs; *G* is "the state of public goods and services (e.g., communication and transport infrastructure, property rights, and so on)" (Barrett 2008, p. 302); *Q* is "the aggregate throughput in the local market" (Barrett 2008, p. 302); and $p_j^{CM,a}$ is "the local market price that equates local market demand […] with local market supply" (Barrett 2008, p. 302).[10]

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

$$\underline{\hat{P}} = \sum_j \left(\hat{p}_j^{CM} \cdot \frac{\hat{D}_j}{\sum_j \hat{D}_j} \right), \tag{11}$$

[9] Assumption (9) is expressed as a sentence, instead of in mathematical form, because it introduces a set of assumptions discussed below, and it is rather difficult to be expressed mathematically in a concise form.

[10] Notations are modified from those in Barrett (2008) to fit this paper.

in which $\hat{D}_j$ is the fresh-tuber equivalent quantity of cassava consumed in consumption market *j*. As is clear from (11), $\underline{\hat{P}}$ 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. We then define the relationship between $\hat{p}_j^{CM}$ and $\underline{\hat{P}}$ as

$$\hat{p}_j^{CM} = \underline{\hat{P}} + \hat{\tau}_j^{CM} , \tag{12}$$

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

$$\hat{D}_j = \sum_i \left(\hat{S}_{ji} - \hat{H}_{ji}\right) + \sum_{k \neq j} \hat{X}_{kj} , \tag{13}$$

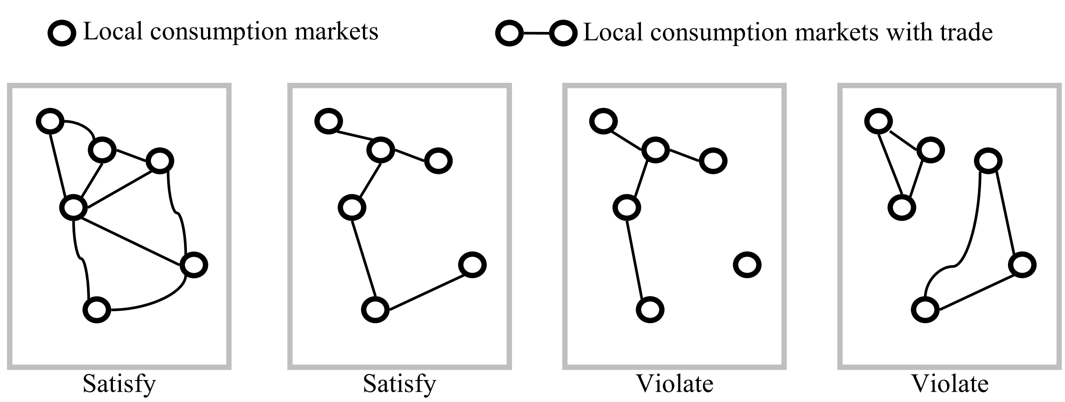
in which $\hat{S}_{ji}$ and $\hat{H}_{ji}$ are production and home consumption by producer *i*, respectively, and $\hat{X}_{kj}$ is the net trade between consumption market *j* and *k* for all $k \neq j$. $\hat{X}_{kj}$ must satisfy the following conditions:

$$\begin{aligned} &\hat{X}_{kj} \geq 0 \text{ (cassava is traded from } k \text{ to } j \text{ if trade exists) if } \hat{p}_j^{CM} > \hat{p}_k^{CM} \\ &\hat{X}_{kj} \leq 0 \text{ (cassava is traded from } j \text{ to } k \text{ if trade exists) if } \hat{p}_j^{CM} < \hat{p}_k^{CM} \\ &\hat{X}_{kj} = 0 \text{ (cassava is not traded between } j \text{ and } k\text{)} \quad \text{if } \hat{p}_j^{CM} = \hat{p}_k^{CM} . \end{aligned} \tag{14}$$

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

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 6 presents some of the examples that satisfy or violate the requirement.

Figure 6. Assumption of nonautarkic consumption markets



Source: Author.

Summary Specification of Alternative EDM (AEDM)

In summary, AEDM can be defined as the counterpart of (1) through (3). The previous discussion of different consumption market prices can be extended to the case in which each observation in the Benin dataset trades cassava at its corresponding consumption market.[11] Therefore, from this point on, we replace notation *j*, used to indicate consumption market in the previous sections, with *i*, which indicates each household observation.

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

$$\sum_i^I \left[S_i\left(\underline{\hat{P}} + \hat{\tau}_i^{CM}, \hat{\tau}_i\right) - H_i\left(\underline{\hat{P}} + \hat{\tau}_i^{CM}, \hat{\tau}_i\right)\right] - \sum_i^I D_i\left(\underline{\hat{P}} + \hat{\tau}_i^{CM}\right) = 0 \quad , \qquad (15)$$

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

$$S_i\left(p_i^{CM}, \hat{\tau}_i\right) = \begin{cases} \hat{\alpha}_i^s (p_i^{CM} - \hat{\tau}_i)^{\hat{\varepsilon}_{si}} (1 + A_i \Delta Y_i), & \text{if } p_i^{CM} - \hat{\tau}_i \geq p_i^* \\ \hat{C}_i, & \text{if } p_i^* - 2\hat{\tau}_i < p_i^{CM} - \hat{\tau}_i < p_i^* \\ \hat{\alpha}_i^s (p_i^{CM} + \hat{\tau}_i)^{\hat{\varepsilon}_{si}} (1 + A_i \Delta Y_i), & \text{if } 0 < p_i^{CM} - \hat{\tau}_i \end{cases}$$

$$H_i\left(p_i^{CM}, \hat{\tau}_i\right) = \begin{cases} \hat{\alpha}_i^h (p_i^{CM} - \hat{\tau}_i)^{\hat{\varepsilon}_{hi}} (1 + \hat{r}_i), & \text{if } p_i^{CM} - \hat{\tau}_i \geq p_i^* \\ \hat{C}_i, & \text{if } p_i^* - 2\hat{\tau}_i < p_i^{CM} - \hat{\tau}_i < p_i^* \\ \hat{\alpha}_i^h (p_i^{CM} + \hat{\tau}_i)^{\hat{\varepsilon}_{hi}} (1 + \hat{r}_i), & \text{if } 0 < p_i^{CM} - \hat{\tau}_i \end{cases} \quad , \qquad (16)$$

in which $\ddot{\omega}_i^s$ and $\ddot{\omega}_i^h$ are individual specific scalars for production and home consumption, A_i is the adoption rate of a new GM variety among producer group *i*, and ΔY_i is the yield growth expressed as the horizontal shift in supply curve. In the context of a structure as shown in (10), $\hat{p}_i^{CM}$ should, in theory, be determined through condition (17). In this study, however, (17) is simplified as (17'):

$$\begin{aligned} &\hat{p}_i^{CM} = \underline{\hat{P}} + \hat{\tau}_i^M, && \text{if } p_i^{CM*} \geq \underline{\hat{P}} + \hat{\tau}_i^M \\ &\hat{p}_i^{CM} \text{ satisfies } S_i\left(\hat{p}_i^{CM}, \hat{\tau}_i\right) - H_i\left(\hat{p}_i^{CM}, \hat{\tau}_i\right) = D_i\left(\hat{p}_i^{CM}\right), && \text{if } \underline{\hat{P}} - \hat{\tau}_i^M < p_i^{CM*} < \underline{\hat{P}} + \hat{\tau}_i^M \\ &\hat{p}_i^{CM} = \underline{\hat{P}} - \hat{\tau}_i^M, && \text{if } p_i^{CM*} \leq \underline{\hat{P}} - \hat{\tau}_i^M \end{aligned} \quad , \qquad (17)$$

$$\hat{p}_i^{CM} = \underline{\hat{P}} + \hat{\tau}_i^{CM} \quad . \qquad (17')$$

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 $\underline{\hat{P}}$ for each *i* (= $\hat{\tau}_i^{CM}$) is set constant in the simulation, because 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 that is consistent with the dataset, which is why this study employs (17') instead of (17). The difference between AEDM and CEDM is illustrated in Figure 7.

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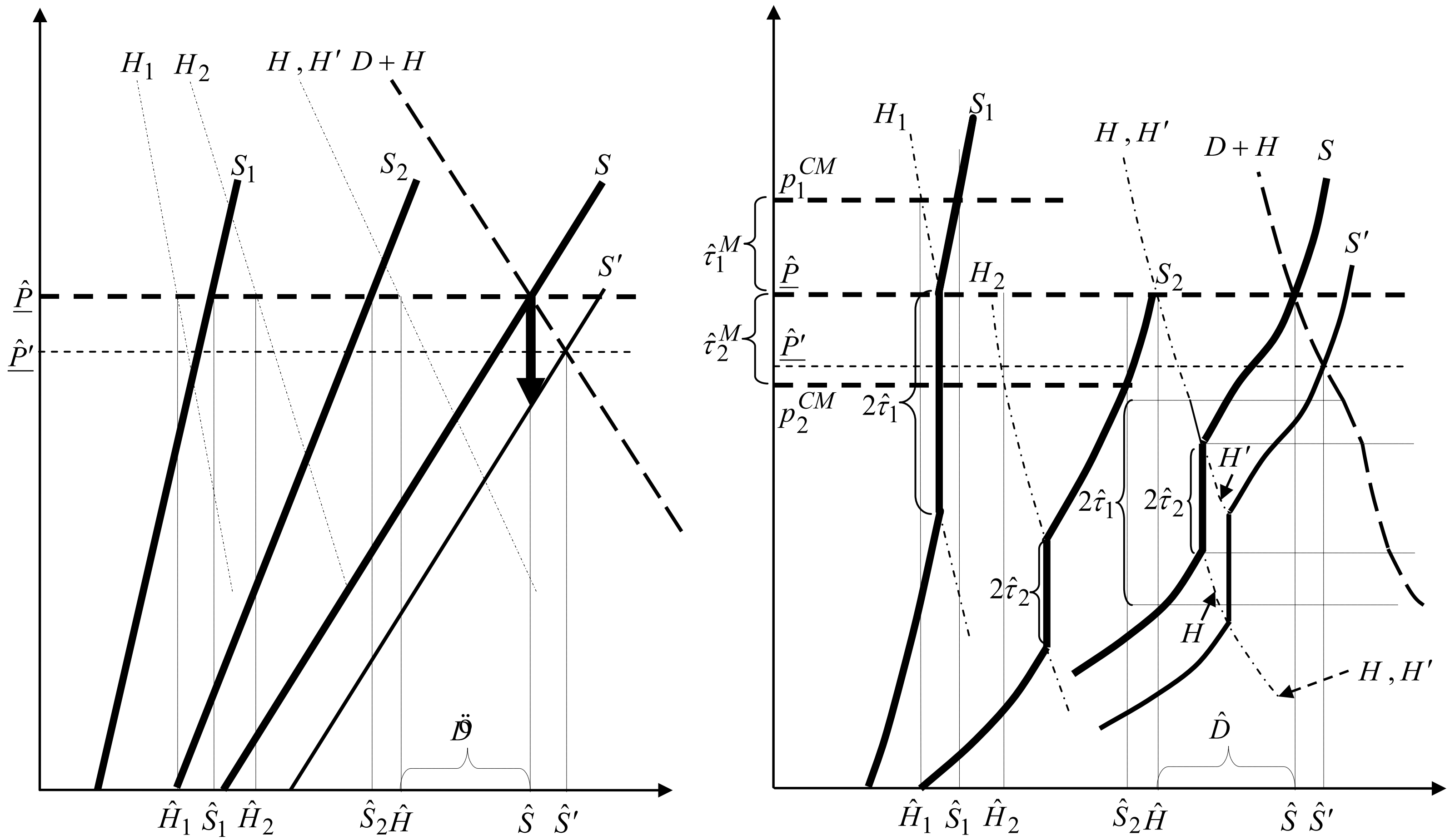
[11] This is reasonable, because the data are collected in such a way that each observation represents a group of farmers in the same village.

Figure 7. CEDM (left) and AEDM (right)[a]



Source: Author.

Note: [a]All notations are from (15) and (16), except $H = H_1 + H_2$, $S = S_1 + S_2$. H' and S' are counterparts of *H* and *S*, in which *H* and *S* are those before the GM-led productivity growth, while H' and S' are those after the GM-led productivity growth. Similarly, $\underline{\hat{P}}'$ is the counterpart of $\underline{\hat{P}}$ after productivity growth. $\hat{D}$ is the aggregate consumption by noncassava producers.

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

$$\sum_{i}^{I}\left[S_i\left(\hat{\underline{P}}-\hat{\tau}_i^{CM},\hat{\tau}_i\right)-H_i\left(\hat{\underline{P}}-\hat{\tau}_i^{CM},\hat{\tau}_i\right)\right]-D(\underline{P})=0 \qquad (18)$$

in which we use the aggregate demand function $D(\underline{P})$ instead of $\sum_i D_i\left(\hat{\underline{P}}-\hat{\tau}_i^{CM}\right)$, because the information is only available for aggregate cassava consumption by nonproducers.[12]

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 ($W_i^{\mathrm{No\ GM}}$). For convenience, we expand the notation for Q_i^*, p_i^{CM}, and $MC(q)$, which change between "with GM" cassava and "without GM" cassava, to $Q_i^{*,\mathrm{GM}}$, $p_i^{\mathrm{CM,GM}}$, and $MC^{\mathrm{GM}}(q)$ for "with GM cassava" and $Q_i^{*,\mathrm{No\ GM}}$, $p_i^{\mathrm{CM,No\ GM}}$, and $MC^{\mathrm{No\ GM}}(q)$ for "without GM" cassava. W_i^{GM} and $W_i^{\mathrm{No\ GM}}$ are then

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

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

The welfare effect for producer group i (ΔPW_i) for AEDM is therefore

$$\Delta PS_i=W_i^{\mathrm{GM}}-W_i^{\mathrm{No\ GM}} \qquad (19)$$

The welfare effects for consumers, or noncassava producers, (ΔCS) in AEDM is

$$\Delta CS=\int_{\hat{\underline{P}}^{\mathrm{GM}}}^{\hat{\underline{P}}^{\mathrm{No\ GM}}}D(p)dp\ , \qquad (20)$$

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

As summarized in Table 2*,* AEDM consists of individual supply and home consumption schedules (equations [16] and [17']) and market-clearing conditions (18). Welfare measurements ΔPW and ΔCS in AEDM are generally expressed as (19) and (20).

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

$$D(\underline{P})=A\underline{P}^{\eta}\neq\sum_i^I D_i\left(\underline{P}-\tau_i^{CM}\right)=\sum_i^I A_i\left(\underline{P}-\tau_i^{CM}\right)^{\eta}.$$

Therefore the assumption of $D(\underline{P})=A\underline{P}^{\eta}$ 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.

Table 2. Structure of the model

Conditions	Equation
Individual supply and home consumption schedule	(16), (17')
Market-clearing condition	(18)
Measurement of welfare effects for population group *i*	(19), (20)

Source: Author.

3. EMPIRICAL APPLICATION AND MODEL COMPARISON

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

Before going into the technical details, Table 3 summarizes the Benin cassava market structure inferred from the Benin dataset and the annual population growth rate in 1997 (see Appendix B for detailed definitions). Cassava-producing households accounted for 45 percent of the total population in Benin in 1997. On average, producers consume 20 percent of their produce and sell the rest to market.

Table 3. Structure of Benin cassava market

	On-farm type	Off-farm type	Nonproducers
Production (*t*)	424,519	423,028	
Consumption (*t*)	77,524	100,555	669,468
% of subsistence consumption	18	24	
Population growth rate (%)	2.5	2.5	2.5
Estimated population (million)	2.75		3.34

Sources: Production, consumption, and percentage of subsistence consumption are calculated by the author from IFPRI 2004. The estimation population and population growth rate are from FAO 2006.

Structure and Calibration of the Models

This section describes how the study uses the Benin dataset to calibrate the parameters introduced in the conceptual framework above. The description here is for the AEDM in Table 4. This section also briefly summarizes an additional model that is included due to reasons explained later.

Table 4. Models used in welfare effects estimation

	Market margin	Linear or constant elasticity	Shifts in supply curve
CEDM	No	Linear	Parallel
Other Model	No	Constant elasticity	Pivotal
AEDM	Yes	Constant elasticity	Pivotal

Source: Author.

The structural parameters used in the AEDM are listed in Table 5. Some of these parameters are estimated from the dataset, whereas others are calculated as described below, using specific assumptions in manners consistent with the discussions in Section 2.

Table 5. Important variables estimated (calibrated) from the dataset

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

Source: Author.

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

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

in which $\hat{S}_i$ and $\hat{H}_i$ are production and home consumption quantities reported by producer *i*, respectively, and $\hat{w}_i$ is the sample weight for observation *i* in the Benin dataset. In other words, $\left(\hat{S}_i - \hat{H}_i\right) \cdot \hat{w}_i$ 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 earlier, each observation *i* represents the group of $\hat{w}_i$ similar producers who all sell cassava to the same consumption market *i*. $\underline{\hat{P}}$ is therefore approximated to $\underline{\hat{P}}^*$ in the simulation as

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

in which $\hat{p}_i^{CM}$ is estimated from the dataset (discussed in equation [29]). From (12) and (22), we know that

$$\hat{\tau}_i^{CM} = \hat{p}_i^{CM} - \underline{\hat{P}}^* \tag{23}$$

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 interregionally is small relative to total production (Gabre-Madhin et al. 2001).

Section 2 discussed how the choice of p is important in CEDM and that Qaim (1999, 2001) used farmgate price for this value. In this simulation, because the representative farmgate price is unavailable, p is defined as the weighted average of farmgate price $\underline{\hat{P}}^f$ estimated for each i, with weights as fresh-tuber equivalent production by i. More explicitly,

$$\underline{\hat{P}}^f = \sum_i \left(\hat{p}_i^f \cdot \frac{\hat{S}_i}{\sum_i \hat{S}_i} \right). \qquad (24)$$

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

$$\ln\left(p_i^f\right) = x_i^{pf} \beta^{pf} + u_i^{pf}, \qquad \forall\, i = \text{on farm sellers} \qquad (25)$$

$$\ln\left(\tau_i\right) = x_i^{\tau} \beta^{\tau} + u_i^{\tau}, \qquad \forall\, i = \text{off farm sellers} \qquad (26)$$

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

$$\hat{p}_i^f = \exp\left(x_i^{pf} \hat{\beta}^{pf}\right), \qquad \forall i \neq \text{on-farm sellers} \qquad (27)$$

$$\hat{\tau}_i = \exp\left(x_i^{\tau} \hat{\beta}^{\tau}\right), \qquad \forall i \neq \text{off-farm sellers} \qquad (28)$$

$$\hat{p}_i^{CM} = \hat{p}_i^f + \hat{\tau}_i, \qquad (29)$$

in which (29) indicates the assumption that for every producer group i, there is a consumption market i that is an end market for cassava, and the price at consumption market i ($\hat{p}_i^{CM}$) also satisfies condition (12). (See Appendix B for the detailed results for [25] through [29].)

Using (29) and formula (22), we calculate $\underline{\hat{P}}$, or the price that satisfies the market-clearing conditions in the AEDM in (18). Although $\hat{S}_i - \hat{H}_i = Sales_i = 0$ for i = autarkic producers, $\hat{p}_i^{CM}$ is still defined for such markets in (29).[13] $\hat{\tau}_i^{CM}$ is then obtained as the difference between $\hat{p}_i^{CM}$ and $\underline{\hat{P}}$ for each i and is kept constant before and after productivity growth.

[13] Extending the assumption in Section 2, for i = 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 that price $\hat{p}_i^{CM}$ does not affect the average consumption price $\underline{P}$.

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

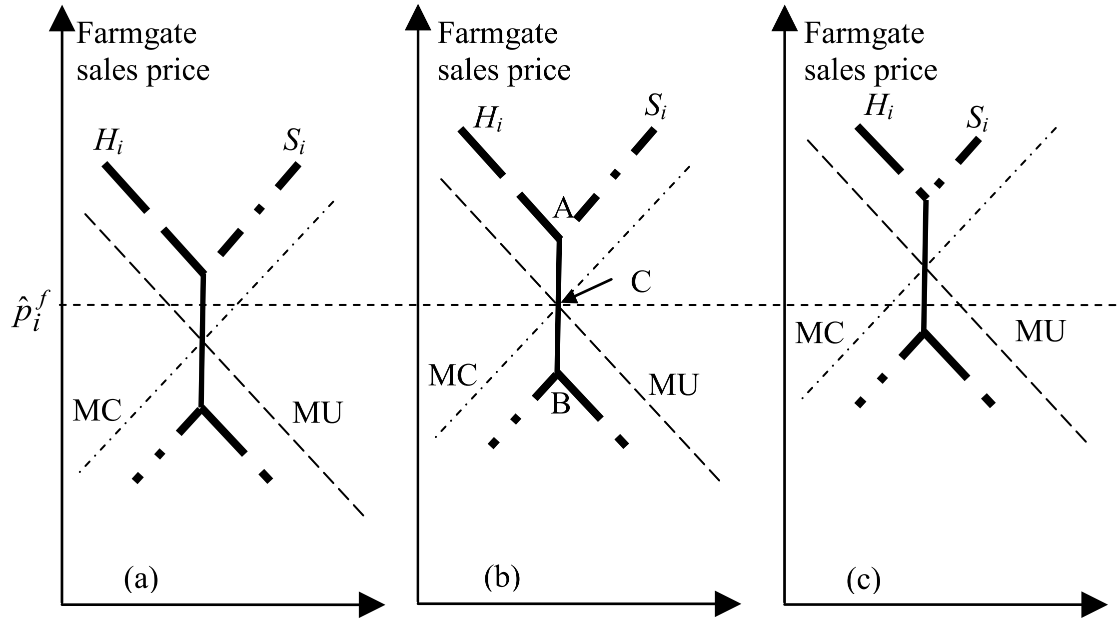
Supply and consumption curves (S_i and H_i, respectively, in [16]) can be calibrated using $\hat{p}_i^f$; production and consumption elasticities ($\hat{\varepsilon}_{si}$, $\hat{\varepsilon}_{hi}$) as estimated in Takeshima (2008), which are shown in Table 6 (see Appendix B for detailed definitions); reported production ($\hat{S}_i$); and home consumption quantity ($\hat{H}_i$). Calibration for autarkic producers is more complicated. As illustrated in Figure 8, given $\hat{p}_i^f$, $\hat{\tau}_i$, $\hat{S}_i$ $(=\hat{H}_i)$, and $\hat{\varepsilon}_{si}$, S_i and H_i can be any of (a) through (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 $\underline{P}$; thus the welfare effects estimation.

Table 6. Important variables estimated (calibrated) from the dataset[a]

	On-farm seller types	Off-farm seller types	Sources
$\ln\left(\hat{p}_i^f\right)$	$N\left(\hat{\mu}_i^{\text{pf}}, \hat{v}_i^{\text{pf}}\right)$ in which $\hat{\mu}_i^{\text{pf}} = \left(X^{\text{pf}}\right)^{-1}\hat{B}^{\text{pf}} = [x_{1,i}^{\text{pf}} \cdots x_{k,i}^{\text{pf}}]\begin{bmatrix}\hat{\beta}_1^{\text{PF}} \\ \vdots \\ \hat{\beta}_k^{\text{PF}}\end{bmatrix}$ $\hat{v}_i^{\text{pf}} = \left(X^{\text{pf}}\right)^{-1}\hat{V}^{\text{pf}}X^{\text{pf}} = [x_{1,i}^{\text{pf}} \cdots x_{k,i}^{\text{pf}}]\begin{bmatrix}\text{Var}(\hat{\beta}_1^{\text{pf}}) & \cdots & \text{Cov}(\hat{\beta}_1^{\text{pf}}, \hat{\beta}_k^{\text{pf}}) \\ \vdots & \ddots & \vdots \\ \text{Cov}(\hat{\beta}_1^{\text{pf}}, \hat{\beta}_k^{\text{pf}}) & \cdots & \text{Var}(\hat{\beta}_k^{\text{pf}})\end{bmatrix}\begin{bmatrix}x_{1,i}^{\text{pf}} \\ \vdots \\ x_{k,i}^{\text{pf}}\end{bmatrix}$	$\forall i$ = Autarkic producers	Regression (25)
$\ln\left(\hat{\tau}_i\right)$		$N\left(\hat{\mu}_i^{\tau}, \hat{v}_i^{\tau}\right)$ in which $\hat{\mu}_i^{\tau} = \left(X^{\tau}\right)^{-1}\hat{B}^{\tau}$ $\hat{v}_i^{\tau} = \left(X^{\tau}\right)^{-1}\hat{V}^{\tau}X^{\tau}$	Regression (26)
δ (in equation [30])	U [0, 2]		
$\hat{\varepsilon}_{si}$	$N^+(.53, .19)$	$N^+(.10, .22)$	Takeshima (2008)
$\hat{\varepsilon}_{hi}$	$N^-(-.89, .19)$	$N^-(-.39, .25)$	Takeshima (2008)
$\hat{\varepsilon}_d$	U[-.91, -.46]		Deaton (1988), Tsegai and Kormawa (2002)
$\hat{A}$ (% adoption rate)	100		
Shifts in supply curve	Shifts out horizontally by 30% (scenario 1) Shifts down vertically by 30% (scenario 2)		

Source: Author.
Note: [a]N: Normal distribution, N^+:Positively truncated normal distribution, U:Uniform distribution

Figure 8. Calibration of supply-and-demand curves for autarkic producers



Source: Author.

Due to a lack of information, this study assumes

$$\hat{\alpha}_i^s = \frac{\hat{S}_i}{\left(\hat{p}_i^f + \delta\hat{\tau}_i\right)^{\hat{\varepsilon}_{si}}}, \quad \hat{\alpha}_i^h = \frac{\hat{S}_i}{\left(\hat{p}_i^f + \delta\hat{\tau}_i\right)^{\hat{\varepsilon}_{si}}} \quad \text{for } i = \text{autarkic}, \tag{30}$$

in which $\delta \sim$ U [0, 2], which is one of the stochastic parameters included in the simulation (see Table 6). To be more precise, $\delta = 1$ in Figure 8b, $\delta = 0.5$ in Figure 8a, and $\delta = 1.5$ in Figure 8c. With $\delta \sim$ U [0, 2], we assume MC and MU for autarkic producers such that *C* is uniformly distributed in A and B. Alternative methods are available but have little practicality.[14]

In addition to CEDM and AEDM, one additional model (called Other Model hereafter) is estimated. Three models are therefore compared, as characterized in Table 4. The differences between each model are the shape of the supply curve, how the supply curve shifts, and whether the model includes nonzero market margin.

Other Model is included so that the quantitative difference between estimates from CEDM and AEDM can be more easily understood. For example, the total gains from AEDM are expected to be much smaller than those from CEDM. This is not only because of market margins but also because AEDM uses pivotal shift, whereas CEDM uses parallel shifts in the supply curve; switching from parallel shift to pivotal shift often reduces the estimated total welfare gains (Alston, Norton, and Pardey 1998). Therefore if the focus is on the inclusion of market margins, then the comparison of Other Model with AEDM may be more informative than the comparison of conventional EDM with AEDM.

Comparisons of AEDM and Other Model may provide some picture of how relaxing assumptions on market margin and home consumption curves alter the estimation results. However, this study does not

[14] For example, it is possible to predict $\hat{\alpha}_i^s$ and $\hat{\alpha}_i^h$ using regression results from the previous section. With $\hat{\alpha}_i^s$ and $\hat{\alpha}_i^h$ estimated this way and $\hat{p}_i^f$ and $\hat{\tau}_i$, however, many producers fall outside autarky. This occurs because the estimation of MC and MU using regression results from Takeshima (2008) is unreliable due to the data limitation.

examine in detail the difference between the two models, because Other Model is rarely used in the literature. In addition, Other Model is not preferred over AEDM, because of the former's restrictive assumptions about zero market margins or home consumption curves. In addition, findings from comparing AEDM with Other Model are only empirical and cannot be easily generalized, because the differences depend on many other structural parameters used in the model.

Other Model is similar to CEDM and begins with conditions (1) through (3), with $p = \underline{\hat{P}}^f$ (weighted average of farmgate sales price) as obtained in (24). The only difference between Other Model and CEDM is that for the latter both $q_{s,i}$ and q_d are in constant elasticity forms, whereas for Other Model,

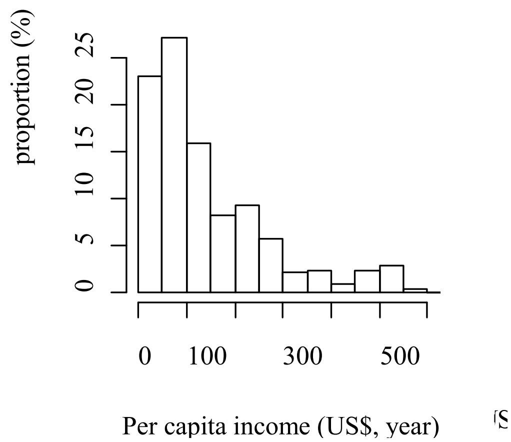
$$q_d(p) = q_d^{\text{market}}(p) + \sum_i^I q_{d,i}^{\text{home}}(p) \quad . \tag{2'}$$

The differences between CEDM and AEDM may lead to different implications for the pro-poorness of GM cassava. How these two models differ can be partly inferred from the characteristics of cassava producers. Some insights are gained by analyzing formulas (4) through (7) for ΔPW, combined with how relevant characteristics of cassava producers vary across different income levels.

Figures 9 through 12 show the most salient characteristics of cassava producers across different income levels. Figure 9 shows the proportion of the population that belongs to a cassava-producing household with a particular income range. Figures 10 through 12 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 intrahousehold income allocations, Figure 9 indicates that almost half of the cassava-producing households earned less than US$100 per capita; 75 percent earned less than $200 in 1997[15]. Figures 10 through 12 suggest that lower-income cassava producers tend to produce and consume less and face higher farmgate prices.

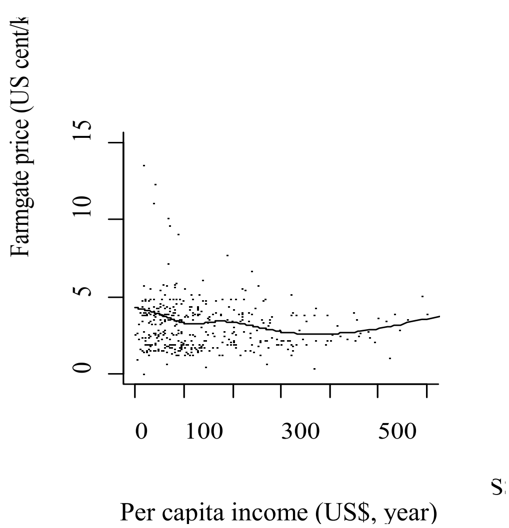
[15] Per capita GDP for Benin in 1997 was around US$300 (World Bank, 2008).

Figure 9. Proportion of population in cassava-producing households[16]



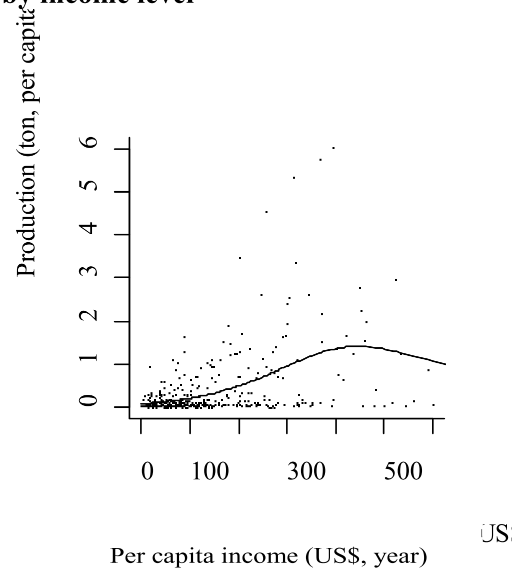
Source: IFPRI (2004)

Figure 10. Median of estimated farmgate price (US cent/kilgram, fresh tuber) by income



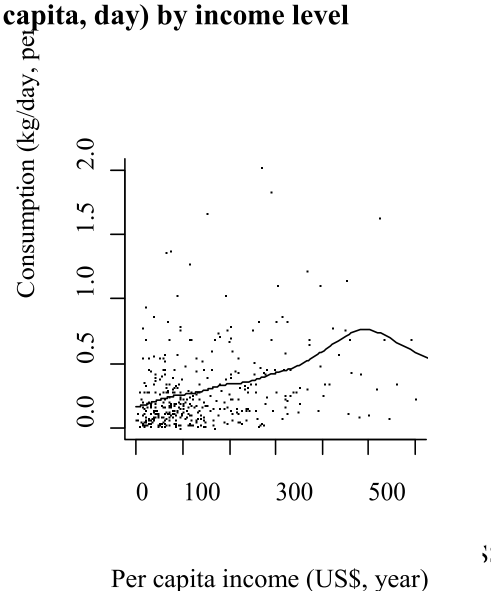
Source: IFPRI (2004) and Author.

Figure 11. Production (ton/per capita, year) by income level



Source: IFPRI (2004) and Author.

Figure 12. Home consumption (kilogram/per capita, day) by income level



Source: IFPRI (2004) and Author.

[16] Proportion is calculated using number of observations (household) * household size * survey weights for each observation.

Section 2 indicated that ΔPW in CEDM tends to be more positive for cassava producers who have a larger quantity of production and home consumption. In addition, because CEDM assumes only one price, and ΔPW in CEDM uses the relative change in equilibrium price dp/p for all types of producers, CEDM may overstate dp/p for cassava producers who have a relatively higher farmgate price when dp is the same for all producers. Thus CEDM may underestimate the welfare gains for producers who have higher farmgate prices[17].

Just because lower-income cassava producers tend to produce and consume less and face higher farmgate prices does not necessarily indicate the differences between AEDM and CEDM, because AEDM includes additional structural parameters not present in CEDM. The characteristics of lower-income cassava producers, however, do indicate that although AEDM is likely to lead to less positive welfare gains for most cassava producers than is CEDM, the former may lead to more positive welfare gains for lower cassava producers than would CEDM.

Estimation of Welfare Effects and Approach for Comparing CEDM and AEDM

Many recent studies using EDM deal with the uncertainty in market structures, such as supply-and-demand elasticities, by adding idiosyncratic errors to some of the structural parameters. The then analyze the sensitivity of estimates of 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) and (26), assigns the distributions for some parameters in Table 6. We have run 1,000 simulations, each of which uses different combinations of parameters drawn from the distributions specified in Table 6. The simulation results are then presented as the range, rather than the point estimates.

This study does not explicitly model the adoption rates over time, as has been done in the literature. Instead this study assumes, for the following reasons, that all cassava producers will adopt a new GM variety after a certain period . First, the purpose of this study is to compare the estimates from conventional EDM with those from AEDM. Thus, including an adoption trend may add more uncertainty to each model, making it more difficult to interpret the difference between conventional EDM and AEDM. 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 percent.

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 of cassava 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 percent for virus-resistant cassava in Uganda,[18] while loss due to virus is up to 60 percent in Ghana [Horna, Smale, and Falck-Zepeda 2007]). Assuming that the average loss in cassava yield in Ghana is 30 percent (which is the midpoint of 0 percent and 60 percent), a similar yield growth for a virus-resistant variety of cassava in Benin should be around 30 percent.

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[17] As mentioned in Section 2, AEDM follows Alston, Norton, and Pardey (1998) and treats market margins between consumption markets and farmgate price as exogenous and constant ((9)) Assumption (9) therefore assumes that the change in farmgate sales price is the same for the entire cassava producer group i. In AEDM, the similar value for dp/p is smaller for producers who have a higher farmgate price (dp is negative, because productivity growth lowers the price). On the other hand, AEDM also follows the suggestions of Lindner and Jarrett (1978) and assumes that GM cassava lowers the marginal cost for all cassava producers by the same proportion. This assumption 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 AEDM is more positive for producers with a higher farmgate price; thus assuming the same dp/p as in CEDM will underestimate $dp/p + K_i$. From CEDM formula (4), we can see that the larger $dp/p + K_i$ leads to more positive ΔPW (see Appendix A).

[18] Based on conversations at the Donald Danforth Center in Saint Louis, which spearheads the research in the development of GM cassava.

Complications arise when information about a new GM variety is given in terms of cost reduction instead of yield growth, because a 30 percent cost reduction is not necessarily a 30 percent yield growth, unless the supply elasticity is 1. AEDM therefore uses two scenarios: (1) 30 percent yield growth for all producers, or (2) 30 percent reduction in MC relative to the initial farmgate sales price. For (1), the supply curve is shifted out by 30 percent horizontally, whereas for (2) the supply curve is shifted down by 30 percent vertically. Because the elasticity of supply is less than 1, the supply curve shifts down by more than 30 percent in case (1) and shifts out less than 30 percent in case (2).[19]

This study thus considers two scenarios. Scenario 1 assumes $y_i = 0.3$ (30 percent increase in yield); scenario 2 assumes $k_i = 0.3$, as shown in Table 6, 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 percent. Therefore this study shifts out the demand curve horizontally by 2.5 percent from the initial demand curve, as suggested by Norton, Ganoza, and Pomareda (1987). Using a 100 percent adoption rate and shifting the demand curve by 2.5 percent mean that the estimated welfare gains assume that all cassava producers will adopt GM cassava after one year. This assumption may be unrealistic, however, so it might be wise to use the population level in 10 years as it would be possible to reach 100 percent adoption by then. However, explicitly assuming when 100 percent is reached does not make the model more realistic for several reasons. First, it is unclear how population growth can lead to a shift in the demand curve. Second, many studies apply rather arbitrary discount factors for welfare gains in the future. From these perspectives, assuming a 100 percent adoption rate in one year may not be so problematic, particularly where the comparison of CEDM with AEDM is concerned.

CEDM and AEDM are then compared to assess how the estimates from CEDM deviate from AEDM, how significant the bias is given the accuracy of parameters used to calibrate both models, and how the magnitude and direction of bias vary for households with different income levels to see the difference in implications for pro-poorness suggested by the two models. The simulation is programmed using statistical software R version 2.7.0, an open-source software developed by R Development Core Team.

[19] At the median, the supply curve shifts down by 50 percent in scenario 1 and shifts out by around 15 percent in scenario 2.

4. RESULTS AND INTERPRETATIONS

The results of interest are summarized in Tables 7 through 9 and in Figure 13. Tables 7 and 8 show the percentage of estimated welfare effects from CEDM and AEDM for scenarios 1 and 2. For example, Table 7 says that the total welfare effects (ΔTotal) estimated by AEDM are above $13.9 million for 50 percent of the time; and between $9.5 million and $27.3 million for 95 percent of the time. Tables 7 and 8 indicate the following: (1) Consumer welfare effects that were estimated using CEDM ($\Delta\hat{CS}_C$) are more positive than those estimated using AEDM ($\Delta\hat{CS}_A$); (2) total welfare effects that were estimated using CEDM ($\Delta Total_C$) are generally more positive than those estimated using AEDM ($\Delta Total_A$); (3) determining whether producer welfare effects estimated using CEDM ($\Delta\hat{P}W_C$) are more positive or more negative than those estimated using AEDM ($\Delta\hat{P}W_A$) is less obvious, and the intervals for both $\Delta\hat{P}W_C$ and $\Delta\hat{P}W_A$ are large relative to the median of $\Delta\hat{P}W_C$ and $\Delta\hat{P}W_A$ (high coefficient of variations).

Table 7. Scenario 1 (million US$)

Percentile	2.5%	**50%**	97.5%	% change in price
		ΔTotal		
CEDM	17.3	**31.5**	58.1	–50.6
Other Model	7.4	**9.5**	12.3	–23.6
AEDM	9.5	**13.9**	27.3	–12.3
		Δ*CS*		
CEDM	8.7	**22.3**	49.5	
Other Model	7.0	**9.8**	14.0	
AEDM	3.1	**6.2**	11.3	
		Δ*PW*		
CEDM	4.8	**10.0**	15.2	
Other Model	–3.9	**-0.2**	1.4	
AEDM	1.8	**7.5**	20.5	

Source: Author.
Note: *US$1 = 588 FCFA (Franc Communauté Financière Africaine) on July 1997.

Table 8. Scenario 2 (million US$)

Percentile	2.5%	**50%**	97.5%	% change in price
		ΔTotal		
CEDM	13.3	**16.3**	20.0	–27.5
Other Model	2.4	**4.6**	8.2	–12.4
AEDM	3.3	**7.8**	16.9	–6.4
		Δ*CS*		
CEDM	8.0	**10.9**	16.9	
Other Model	2.3	**4.7**	8.3	
AEDM	0.7	**2.9**	5.9	
		Δ*PW*		
CEDM	0.5	**5.0**	8.4	
Other Model	–1.4	**–0.2**	0.7	
AEDM	0.5	**4.5**	12.3	

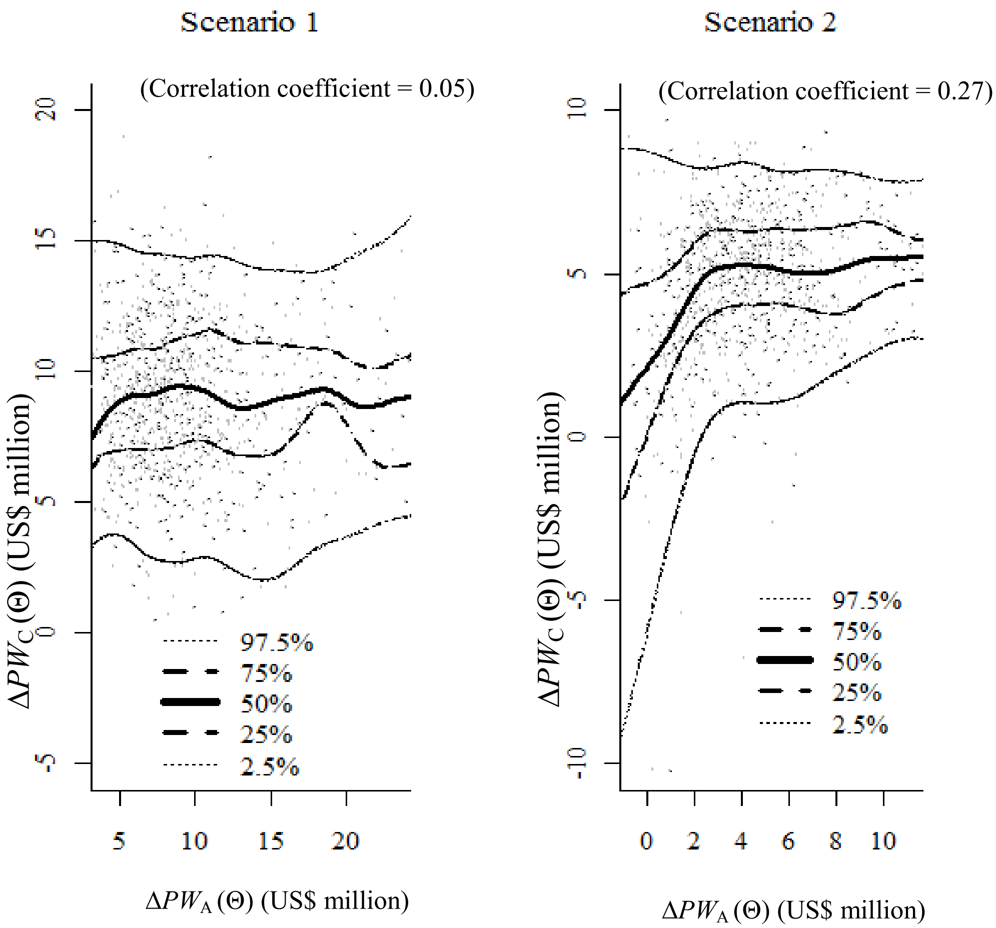
Source: Author.

Table 9. Difference between $\hat{w}_A(\Theta)$ and $\hat{w}_C(\Theta)$ ($(\hat{w}_A(\Theta) - \hat{w}_C(\Theta) \mid \Theta = \hat{\theta})$)

	Scenario 1 $\hat{y} = 0.3$	**Scenario 2** $k_i = 0.3$
Prob ($\Delta\text{Total}_C > \Delta\text{Total}_A$)	100%	99%
Prob($\Delta\hat{P}W_C > \Delta\hat{P}W_A$)	72%	55%
Prob($\Delta\hat{C}S_C > \Delta\hat{C}S_A$)	100%	100%

Source: Author.

Figure 13. Comparison of $\Delta\hat{P}W_A(\Theta)$ and $\Delta\hat{P}W_C(\Theta)$ for each Θ = $\hat{\theta}$ (lines in the figure are the quantile smoothing spline developed by Koenker, Ng, and Portnoy [1994])



Source: Author.

At the median (50 percent) of the estimates, the bias for ΔTotal_C is roughly

$$\text{Bias for } \Delta\text{Total}_C = \frac{\Delta\text{Total}_C - \Delta\text{Total}_A}{\Delta\text{Total}_A} = \frac{31.5 - 13.9}{13.9} \approx 127\% \text{ (scenario 1)}, 109\% \text{ (scenario 2)}. \tag{31}$$

Because Benin's GDP in 1998 was approximately \$2 billion (World Bank), the difference in ΔTotal_C and ΔTotal_A is roughly 1.6 percent or 0.7 percent of GDP for scenario 1 and 0.8 percent or 0.4 percent of GDP for scenario 2, which can be substantial. The results indicate that at the median level, the difference between conventional EDM and AEDM can be significantly large and may lead to serious policy implications.

The results in Tables 7 and 8 indicate how the estimated welfare effects can drop from CEDM to Other Model. The reason for the much lower estimate from Other Model compared with CEDM is mainly that Other Model assumes pivotal shift in the linear supply curve while CEDM assumes parallel shift. Although the estimate from Other Model is not directly comparable with that from AEDM, they both indicate that the important result for AEDM is a relatively high ΔPW compared with ΔTotal and ΔCS[20]. One reason for the relatively high ΔPW 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 AEDM.

The inference made at the median, however, is 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 $\Delta\hat{P}W_C$ and $\Delta\hat{P}W_A$, whose coefficient of variation seems high. The focus thus shifts to how the estimates from CEDM differ from those from AEDM given each combination of structural parameters. We first define a variable, $\hat{w}_D(\hat{\theta}_C, \hat{\theta}_A) = \lfloor \hat{w}_{\text{conventional EDM}}(\hat{\theta}_C) - \hat{w}_{\text{alternative EDM}}(\hat{\theta}_C, \hat{\theta}_A) \rfloor = \hat{w}_{\text{C}}(\hat{\theta}_C) - \hat{w}_{\text{A}}(\hat{\theta}_C, \hat{\theta}_A)$, in which $\hat{\theta}_C = (\hat{\varepsilon}_{si}, \hat{\varepsilon}_d, \hat{A}, \hat{y})$ and $\hat{\theta}_A = (\hat{\tau}_i, \hat{\tau}_i^{CM}(\hat{p}_i^f), \hat{\varepsilon}_{hi}, \delta)$ as in Table 6, and $\hat{w}_{\text{C}}(\hat{\theta}_C)$ and $\hat{w}_{\text{A}}(\hat{\theta}_C, \hat{\theta}_A)$ are the general notation for the welfare effects (total, producer, consumers) estimated using CEDM (which is a function of $\hat{\theta}_C$ alone) and AEDM (which is a function of $\hat{\theta}_C$ and $\hat{\theta}_A$), respectively.

Table 9 shows the probability of $\hat{w}_{\text{D}}(\hat{\theta}_C, \hat{\theta}_A) > 0$, or the probability that $\hat{w}_{\text{C}}(\hat{\theta}_C) > \hat{w}_{\text{A}}(\hat{\theta}_C, \hat{\theta}_A)$ from the simulation. For more than 99 percent of the time, $\Delta\text{Total}_C > \Delta\text{Total}_A$ in both scenarios 1 and 2. ΔTotal_C may be larger than ΔTotal_A in part because, as was mentioned by Voon and Edwards (1991), the constant elasticity form with pivotal shift often leads to more conservative estimates than are achieved with the linear form, and thus it may be predictable. The particular result obtained here is, however, still important, because how ΔTotal_C compares with ΔTotal_A depends on the empirically estimated structural parameters and their accuracy. The fact that ΔTotal_C is larger than ΔTotal_A with such a high probability provides one reason for why policy implications based only on CEDM may not be reliable and that a model such as AEDM should thus also be considered.

As in Table 9, whether ΔPW_C is more positive than ΔPW_A is unclear. The importance of comparison between ΔPW_C and ΔPW_A instead relates to their estimated intervals, which reflect their accuracy given the precisions of estimated structural parameters. Figure 13 shows how each combination of structural parameters $\hat{\theta}_C$ and $\hat{\theta}_A$ results in different $\Delta\hat{P}W_A(\hat{\theta}_C, \hat{\theta}_A)$ and $\Delta\hat{P}W_C(\hat{\theta}_C)$. Figure 13

[20] Other Model is not comparable with AEDM for several reasons, including the issues discussed in Footnote 12. AEDM assumes individual demand curves at each consumption market calibrated from respective market price $\underline{P} - \tau_i^{CM}$, in which not all demand curves have constant elasticity form, as explained in Footnote 32. Other Model, however, implicitly assumes the same price for all consumption markets and for farmgate sales price.

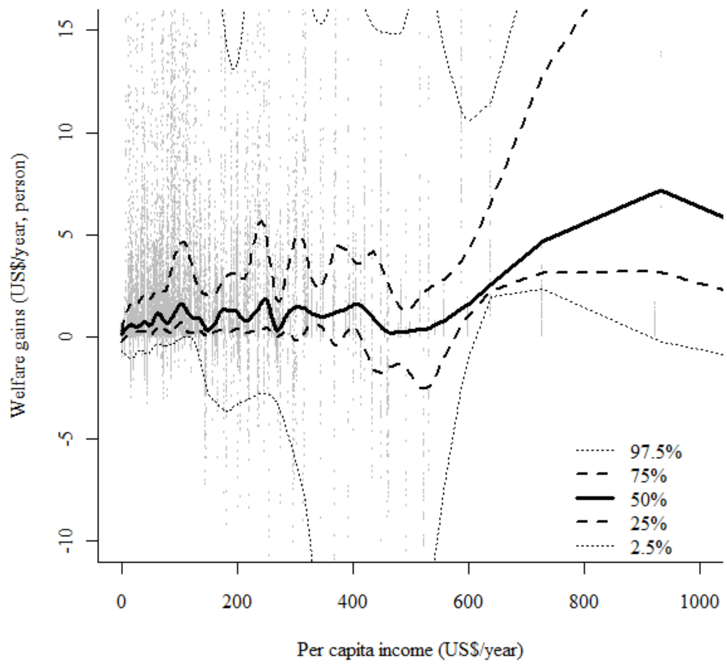
indicates two important points. First, as is shown by the correlation coefficient, $\Delta\hat{P}W_{\mathrm{A}}$ and $\Delta\hat{P}W_{\mathrm{C}}$ have a relatively weak relationship, indicating that $\Delta\hat{P}W_{\mathrm{C}}$ has a relatively low power to approximate $\Delta\hat{P}W_{\mathrm{A}}$. The low correlation coefficient thus implies that the power of CEDM to approximate the welfare gain estimates can be easily overwhelmed by the lack of some additional information, such as alternative assumptions regarding how the supply curve shifts or whether market margins are zero.

Second, actual deviations of $\Delta\hat{P}W_{\mathrm{C}}$ from $\Delta\hat{P}W_{\mathrm{A}}$, which are illustrated by the *quantile smoothing spline* (Koenker, Ng, and Portnoy 1994) in Figure 13, indicate the degree of the gap between $\Delta\hat{P}W_{\mathrm{C}}$ and $\Delta\hat{P}W_{\mathrm{A}}$ and the probability of exceeding certain levels of that gap. For example, when $\Delta\hat{P}W_{\mathrm{A}}$ is \$5 million, $\Delta\hat{P}W_{\mathrm{C}}$ can be estimated to be above \$10 million almost 50 percent of the time. For Benin cassava-producing households in 1998, \$5 million would be roughly 1 percent of their income. The \$5 million deviation of $\Delta\hat{P}W_{\mathrm{C}}$ from $\Delta\hat{P}W_{\mathrm{A}}$ may have important meaning in Benin, whose economy has grown approximately 5 percent a year in recent years. The findings in Figure 13 thus imply that $\Delta\hat{P}W_{\mathrm{C}}$ can create bias in estimates, and that this bias can be big enough to influence Benin's agricultural policy.

Another important question is how lower-income cassava producers benefit relative to higher-income cassava producers. Figure 14 illustrates the intervals of ΔPW (per capita, year) in different per capita annual income levels as estimated from AEDM in scenario 2.[21] Figure 15 plots the 50th percentile of ΔPW for producers estimated from the two EDMs to see how each estimate provides different implications of how welfare gains are shared across different income levels.

[21] The figure for scenario 1 is similar, except for the overall level of welfare gains; lower-income cassava producers seem to gain more than do middle-income cassava producers.

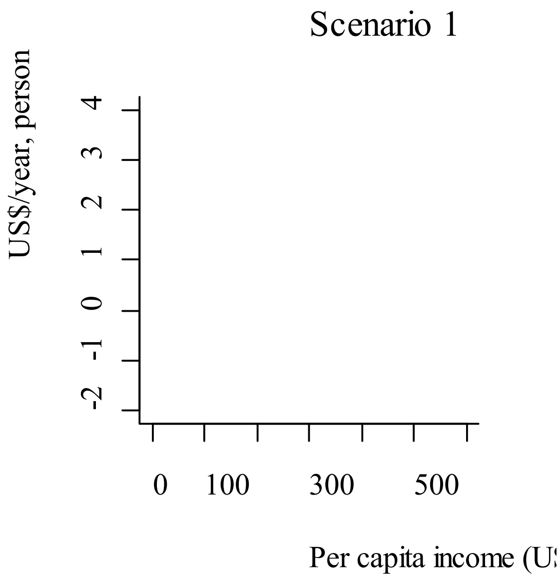
Figure 14. Intervals of welfare gains for producers in different income levels (scenario 2)



The 50 percent line (solid bold line) in Figure 14 is equivalent to the solid line in scenario 2 of Figure 15. The two lines appear different because different functions are used in the software. The purpose of Figure 14 is to illustrate the interval of welfare gains from AEDM for different income levels, whereas Figure 15 compares the median of intervals for different models.

Source: Author.

Figure 15. Median welfare effects for producers in different income levels (CEDM and AEDM)



Source: Author.

Figures 14 and 15 essentially indicate the following: Lower-income cassava producers (below $200) tend to benefit slightly more than do middle-income (above $200) cassava producers (Figure 14). In addition, although AEDM generally estimates slightly and insignificantly lower ΔPW for all producers than CEDM, AEDM provides estimates of slightly higher ΔPW for low-income producers than does CEDM. Slightly higher estimates of ΔPW from CEDM may thus result mainly from the higher-income cassava producers (Figure 15). Figure 15 thus indicates that CEDM and AEDM may lead to different implications of whether GM cassava in Benin is pro-poor.

Overall, all the results discussed in Section 4 suggest that CEDM can lead to significantly large biases in aggregate welfare gains estimates and the wrong interpretation of the pro-poorness of cassava productivity growth as compared with AEDM. Conversely, although AEDM requires more time and work, it is much stronger than CEDM in maintaining richness in the heterogeneity across producers, which is captured by varying marketing margins, farmgate cassava prices, and initial varying distribution of incomes and which reflects such heterogeneity in the estimation of welfare gains and pro-poorness of cassava productivity growth.

5. SUMMARY AND CONCLUSION

Productivity growth for 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 prices, which is also brought by productivity growth. Therefore, from the perspective of poverty reduction, one of the important research questions is how great a gain in welfare cassava productivity growth can bring to cassava producers, particularly lower-income cassava producers.

Many past studies have conducted ex ante welfare effect estimations for similar subsistence crops using CEDM, which employs assumptions that may be unrealistic. Although CEDM has the benefit of being simpler than AEDM and can be useful for estimating approximated welfare gains, little has been studied on how large the biases hidden in CEDM can be as a consequence of its unrealistic assumptions.

This study contributes to the literature by providing one empirical example of the aforementioned issues. The findings suggest that CEDM, 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 that are used for productivity growth for subsistence crops. CEDM may also provide incorrect implications about whether such productivity growth is pro-poor. The results and discussions in the previous section indicate that the use of AEDM may be recommended over CEDM when there are good reasons to believe that the supply curve is in constant elasticity and is inelastic rather than linear, and when the nature of technology is better represented by the pivotal shift rather than the parallel shift. In addition, the use of AEDM may be recommended over CEDM when the market margins are significantly large and consequently there is either a positive or negative relationship between the farmgate price of commodity for each producer and each producer's income level. This is because AEDM can better translate such information into an assessment of the pro-poorness of the productivity growth at issue.

Although the properties of both CEDM and AEDM still need to be more fully analyzed, they offer two different ways to estimate the welfare effects of many semisubsistence crops with data similar to the Benin data. The literature often relies more on CEDM than on AEDM. This study provides an empirical example of when it may be important to use AEDM as well as CEDM for more informed policymaking about investment in public research on semisubsistence crops as a tool to reduce poverty.

APPENDIX A: IMPORTANT PROPERTIES OF CONVENTIONAL EDM

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

$$\frac{dp}{p} = \frac{\sum_{i=1}^{n}(ss_i \varepsilon_{si} K_i)}{\varepsilon_d - \sum_{i=1}^{n}(ss_i \varepsilon_{si})} = \frac{\sum_{i=1}^{n}(ss_i \varepsilon_{si})}{\varepsilon_d - \sum_{i=1}^{n}(ss_i \varepsilon_{si})} K \qquad (6')$$

When $\varepsilon_d < 0$ and $\varepsilon_{si} > 0$, we have $-1 < \frac{\sum_{i=1}^{n}(ss_i \varepsilon_{si})}{\varepsilon_d - \sum_{i=1}^{n}(ss_i \varepsilon_{si})} < 0$, or $-K < \frac{dp}{p} < 0$ from (6') because $ss_i \geq 0$, $\sum_{i=1}^{n}(ss_i \varepsilon_{si}) > 0$. Therefore we have $\frac{dp}{p} + K > 0$, which is (1). For producer group *i*, the expression of ΔPW_i in (4) can be rewritten as

$$\Delta PW_i = p_i q_{s,i}\left(\frac{dp}{p_i} + K\right)\left(1 + 0.5\varepsilon_{si}\left(\frac{dp}{p_i} + K\right)\right) - dp q_{s,i} h_i \qquad (4')$$

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

$$\Delta PW_i = p_i q_{s,i}\left(\frac{dp}{p_i} + K\right)\left(1 + 0.5\varepsilon_{si}\left(\frac{dp}{p_i} + K\right)\right) - dp q_{s,i} h_i > 0 \qquad (4'')$$

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

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

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

$$= q_{s,i}\left(1 - h_i + \varepsilon_{s,i}\left(\frac{dp}{p} + K_i\right)\right) \qquad (32)$$

We know from discussion in Appendix A that $dp/p + K > 0$ for $\varepsilon_d < 0$ and $\varepsilon_{si} > 0$; therefore for any $dp/p > K$, (32) > 0. This proves that a larger $dp/p + K_i$ leads to a more positive ΔPW, and thus the explanation in Footnote 15 holds.

APPENDIX B: DISTINCTION OF ON-FARM AND OFF-FARM TYPE PRODUCERS IN TAKESHIMA (2008)

This study is partly based on the empirical results in Takeshima (2008). Although many results in Takeshima (2008) are irrelevant to this study, those that are relevant are discussed here.

Separation of On-farm Sellers and Off-farm Sellers

Takeshima (2008) builds a hypothesis that cassava farmers who plan to sell cassava can be categorized into two types: on-farm sellers, who plan to sell cassava at the farmgate, and off-farm sellers, who plan to sell cassava at the market. Each type of farmer exhibits different elasticity of production and home consumption. Each type also tests the alternative hypothesis that both types of farmers do not exhibit different production and home consumption elasticity. Takeshima (2008) supports the former hypothesis.

This study follows the findings in Takeshima (2008) and applies different elasticities and empirical distributions for two types of cassava producers, as was shown in Table 6. Autarkic farmers are categorized into one of the aforementioned seller types by using the regression results for probit in Takeshima (2008); an autarkic producer i is assumed an on-farm seller if

$$\text{Prob}(i = \text{on farm seller} \mid x_i^{\text{pr}}) > 0.5 \text{, or } x_i^{\text{pr}} \hat{\gamma}_{\text{pr}} < 0.5 \qquad (33)$$

and otherwise is an off-farm seller.

The assumption of separate types of farmers, however, should not significantly affect the key findings in this study, as both CEDM and AEDM are calibrated based on this assumption.

Estimation of Farmgate Price for Off-farm Seller

The results of (25) and (26) are shown in Table 10; Table 11 shows the summary statistics of $\hat{p}_i^f$ $\hat{p}_i^{CM}$ $\hat{\tau}_i$ and the calculated prices $\underline{\hat{P}}^f$ and $\underline{\hat{P}}$.

Table 10. Regressions (25) and (26)

Dependent variables	Regression (25) $\ln(\hat{p}_i^f)$		Regression (26) $\ln(\hat{\tau}_i)$	
	$\hat{\beta}^{pf}$	$S(\hat{\beta}^{pf})$	$\hat{\beta}^{\tau}$	$S(\hat{\beta}^{\tau})$
Region 2	.076	(.383)		
Region 3	–.328	(.497)		
Region 4	.619	(.379)		
Region 5	.503	(.394)		
Region 6	.437	(.362)		
Fresh-tuber (yes = 1)	–.646	(.193)		
Flour (yes = 1)	1.116***	(.208)		
Dried tuber (yes = 1)	.026	(.309)		
January	.139	(.157)		
February	–.366***	(.116)		
March	.189	(.119)		
April	–.171	(.121)		
May	–.079	(.127)		
June	.157	(.173)		
July	–.175	(.200)		

Table 10. Continued

Dependent variables	Regression (25) $\ln\left(\hat{p}_i^f\right)$		Regression (26) $\ln\left(\hat{\tau}_i\right)$	
	$\hat{\beta}^{pf}$	$S\left(\hat{\beta}^{pf}\right)$	$\hat{\beta}^{\tau}$	$S\left(\hat{\beta}^{\tau}\right)$
August	–.063	(.174)		
September	–.048	(.291)		
October	–.068	(.239)		
November	–.503	(.326)		
Distance to paved road (10km)	–.003	(.009)		
Distance to passable road (10km)	–.006	(.007)		
Distance to phone (10km)			1.483	(3.219)
Off farm type seller (yes = 1)	.203*	(.109)		
$\sqrt{\text{Distance to sales point (10km)}}$			.309***	(.088)
Membership to cooperative (yes = 1)			–.460	(.307)
Household head education (year)			–.061	(.050)
Constant	3.397***	(.409)	.702**	(.336)
R^2	.708		.387	
Number of observations	192		53	

Source: Author.

Table 11. Summary statistics of estimated prices, per-unit transaction cost (US cents/kilogram, fresh-tuber)

	Mean	Median	Min.	Max.
Farmgate sales price ($\hat{p}_i^f$)	5.22	3.47	0.28	40.09
Consumption market price ($\hat{p}_i^{CM}$)	12.92	5.49	0.55	119.94
Per-unit transaction costs ($\hat{\tau}_i$)	7.70	1.01	0.16	118.58
Weighted farmgate sales price ($\underline{\hat{P}}^f$)	2.50	2.47	1.93	3.54
Weighted consumption market price ($\underline{\hat{P}}$)	3.35	3.32	2.67	4.48

Source: IFPRI (2004) and Author.

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2033 K Street, NW
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Fax: +1-202-467-4439
Email: ifpri@cgiar.org

IFPRI ADDIS ABABA

P. O. Box 5689
Addis Ababa, Ethiopia
Tel.: +251 11 6463215
Fax: +251 11 6462927
Email: ifpri-addisababa@cgiar.org

IFPRI NEW DELHI

CG Block, NASC Complex, PUSA
New Delhi 110-012 India
Tel.: 91 11 2584-6565
Fax: 91 11 2584-8008 / 2584-6572
Email: ifpri-newdelhi@cgiar.org