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Distributional impact of yield increases: The case of cassava in Nigeria

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Seminar
IFPRI office, Lilongwe, Malawi
23 October 2019

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Motivation

- Agronomic research to increase yields has a very high rate of return
- However funding for public investment in research is finite
- Policymakers and development agencies have an interest in allocating research funding to maximize impact
- Impact can be measured in terms of income gains, but usually policymakers are also interested in the *distribution*: who gains and who loses?
  - Rural vs urban
  - Small farmers vs larger farmers
  - Impact in different regions
  - Impact by income group
  - Impact on poverty

Previous research

- Griliches (1958, 1964) pioneered work on returns to agricultural research, showing high returns to investment in US agriculture
- Cochrane (1958) proposed "treadmill" model, where yield increases cause farm prices to fall, but farmers are "forced" to continue adopting new varieties
- Hayami and Herdt (1977) estimated gains and losses from higher rice yields in the Philippines on large and small farmers and on consumers
- Similar studies in Colombia (Scobie and Posada, 1978), Bangladesh (Alauddin and Tisdell, 1986), Pakistan (Renkow, 1993), and multiple Asian countries (David and Otsuka, 1994)
- Weber et al (1988) pointed out that many rural households are net buyers of staple foods

Previous research

- Deaton (1989)
  - Examined effect of changes in rice prices in Thailand.
  - Instead of household categories, he examined impact on each household in national survey
  - Later called “microsimulation approach”
- Many studies adopted and extended Deaton’s approach
  - Ravallion (1990) added effect of wage changes on households
  - Minot and Goletti (1998) linked multi-sector model to household survey data
  - Ivanic and Martin (2008) applied model to many countries to study effect of 2007-08 price spikes
- Takeshima (2009) applied microsimulation to impact of cassava yield increases in Benin, but studied impact on income of household categories
- Martin et al (2019) used CGE and household survey data to examine distributional impact of yield increases in Rwanda

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Contribution of this study

1. It exploits the richness of the household survey data to examine the impact on a wide range of household types, defined by income, farm size, sex of head of household, region, and net position in cassava.
2. In addition to calculating the income effect, we estimate the impact of yield-increasing technology on the incidence of poverty overall and for each sub-group. Examined effect of changes in rice prices in Thailand.

- Unlike Takeshima, we estimate incidence of poverty overall and for different sub-groups
- Unlike Martin et al, we use partial-equilibrium approach, so that the method is more accessible and does not require a full CGE model

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Background on cassava in Nigeria

- Sub-Saharan Africa has 8 of the top 10 cassava producers in the world: Nigeria, Ghana, DRC, Angola, Mozambique, Malawi, Tanzania, and Cameroon.
- Nigeria is the largest cassava producers in the world
- Cassava, rice, maize, and yams are most important staples in Nigeria, each accounting for 10-11% of caloric intake
- In 2011, the government of Nigeria spent US$ 400 million on agricultural research and 10% of its researchers were working on cassava
- In addition, the IITA works on cassava breeding for yield and disease resistance

Method

- Deaton (1989)
  - Net benefit = $\Delta Y = \Delta P\,(Q-C)$

    where Q=quantity of production

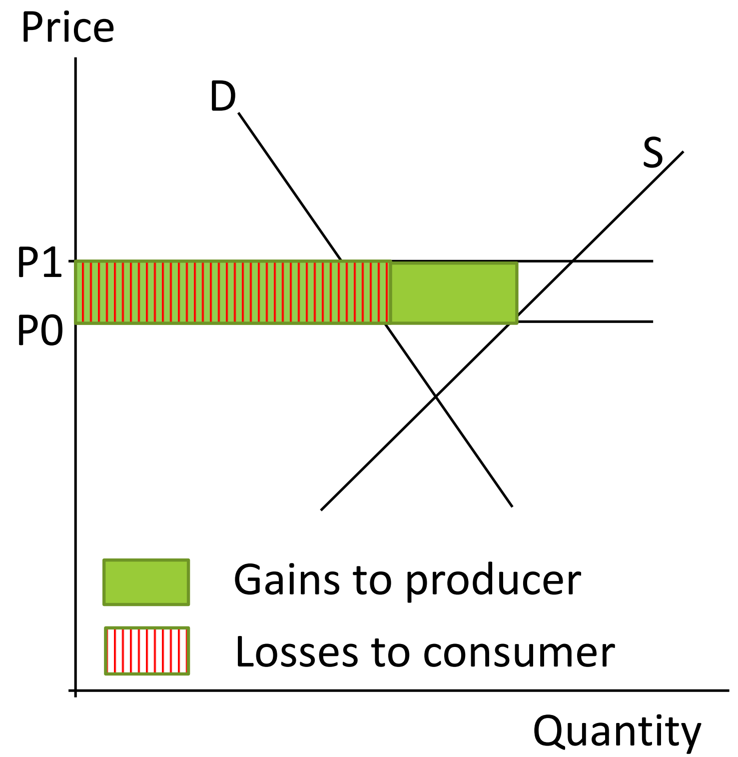
    C=quantity of consumption

    Y=income
  - Proportional welfare impact

$$\frac{\Delta Y}{Y} = \frac{(PQ-PC)}{Y}\,\frac{\Delta P}{P}$$

Net benefit ratio (NBR)

NBR can be considered the elasticity of welfare with respect to price



Method

- Extensions to Deaton (1989)
  - Take into account producer and consumer response to price change using price elasticities of supply and demand (add triangles)
  - Take into account that producers and consumer price changes are generally not be the same
  - Expand framework from just considering price changes to incorporating the effect of technology change (shift in supply curve)

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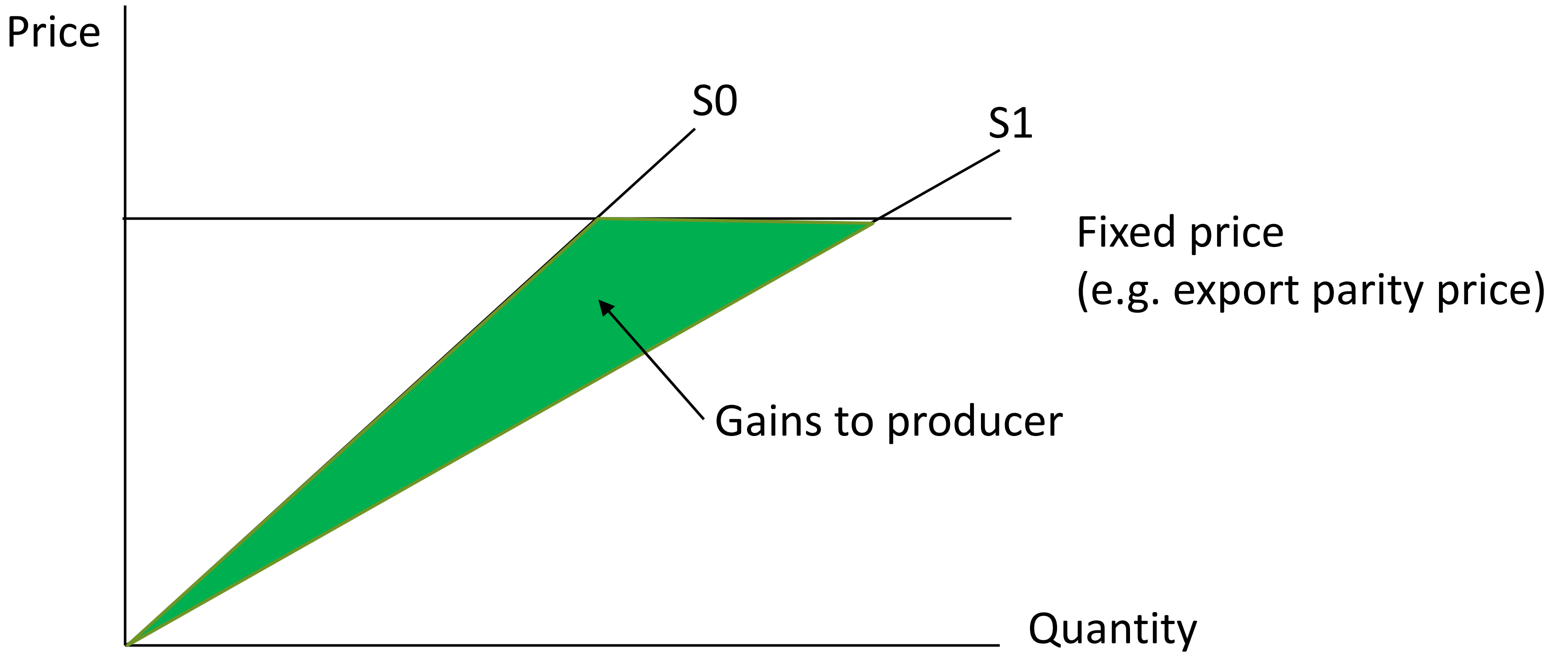
Method

- Benefits to producers from improved technology (shift in supply curve)
- Simple case of a fixed price (e.g. export crop)



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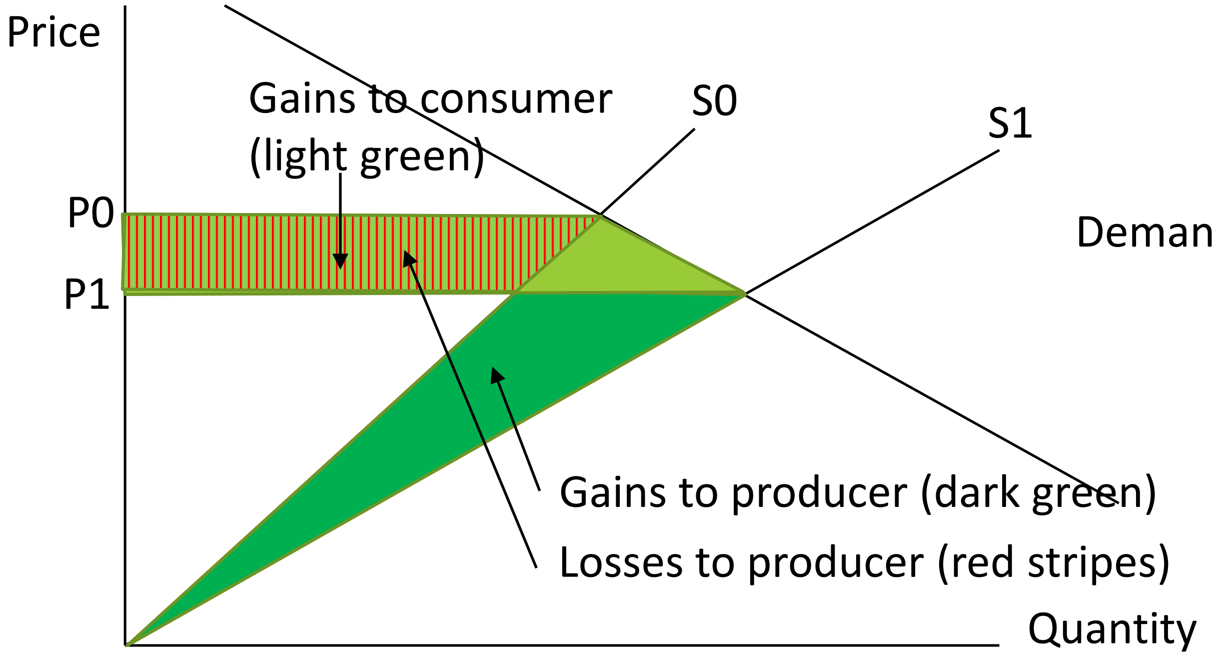
Method

- Benefits to producers from a shift in the supply curve
- Case of a non-fixed price (e.g. non-tradable crop)



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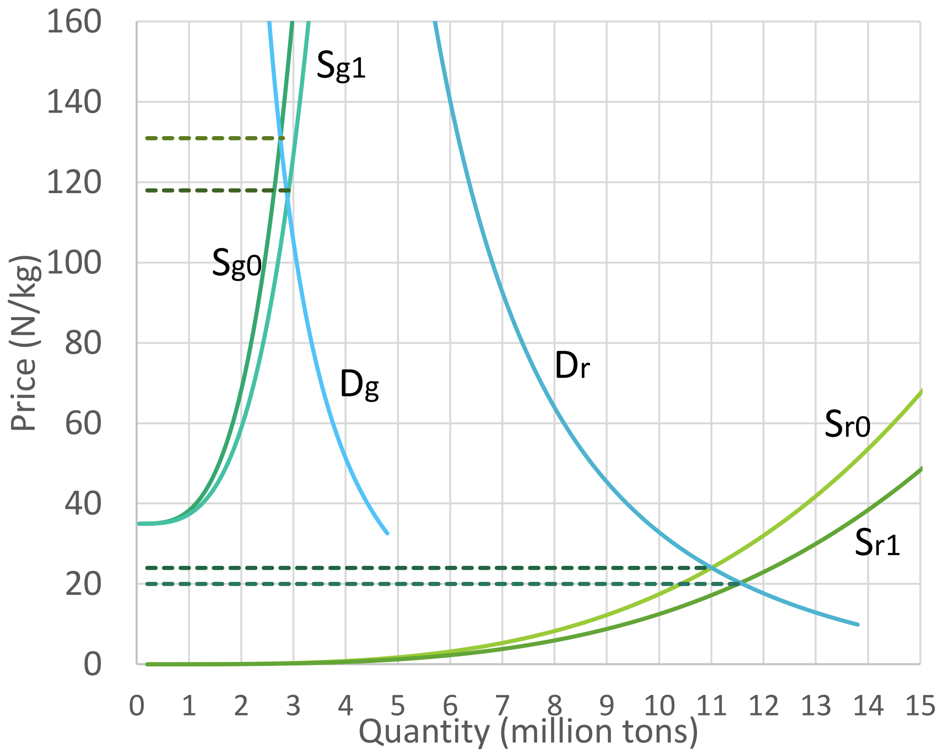
Method

- Benefits to producers from a shift in the supply curve
- Case of a non-fixed price, separate producer & consumer prices, and constant-elasticity supply and demand functions



Sg – Supply of gari
Dg – Demand for gari
Sr – Supply of cassava root
Dr – Demand for cassava root
Subscript 0 means before
Subscript 1 means after

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Method

- Calculating the net benefits

$$\frac{dY}{Y} = \frac{P_p Q}{Y}\pi\frac{dQ}{Q} + \frac{P_p(Q+dQ)}{Y}\frac{dP_p}{P_p} + \frac{1}{2}\varepsilon_S\frac{P_p Q}{Y}\left(\frac{dP_p}{P_p}\right)^2 - \frac{P_c C}{Y}\frac{dP_c}{P_c} - \frac{1}{2}\varepsilon_{HD}\frac{P_c C}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

where Y is household income,
P_p is the producer price of cassava root,
Q is the household production of cassava,
π is the ratio of producer surplus (profit) to gross revenue,
ε_S is the elasticity of supply,
P_c is the consumer price of cassava,
C is the quantity of cassava consumed by the household, and
ε_{HD} is the Hicksian price elasticity of cassava demand.

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Proportional change in income

Method

- Calculating the net benefits

$$\frac{dY}{Y} = \frac{P_pQ}{Y}\pi\frac{dQ}{Q} + \frac{P_p(Q+dQ)}{Y}\frac{dP_p}{P_p} + \frac{1}{2}\varepsilon_S\frac{P_pQ}{Y}\left(\frac{dP_p}{P_p}\right)^2 - \frac{P_cC}{Y}\frac{dP_c}{P_c} - \frac{1}{2}\varepsilon_{HD}\frac{P_cC}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

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ε_{HD} is the Hicksian price elasticity of cassava demand.

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Gain to producers from higher yield

Method

- Calculating the net benefits

$$\frac{dY}{Y} = \frac{P_pQ}{Y}\pi\frac{dQ}{Q} + \frac{P_p(Q+dQ)}{Y}\frac{dP_p}{P_p} + \frac{1}{2}\varepsilon_S\frac{P_pQ}{Y}\left(\frac{dP_p}{P_p}\right)^2 - \frac{P_cC}{Y}\frac{dP_c}{P_c} - \frac{1}{2}\varepsilon_{HD}\frac{P_cC}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

where Y is household income,
P_p is the producer price of cassava root,
Q is the household production of cassava,
π is the ratio of producer surplus (profit) to gross revenue,
ε_S is the elasticity of supply,
P_c is the consumer price of cassava,
C is the quantity of cassava consumed by the household, and
ε_{HD} is the Hicksian price elasticity of cassava demand.

Method

- Calculating the net benefits

Loss to producers from lower price without supply response to price change

$$\frac{dY}{Y}=\frac{P_pQ}{Y}\pi\frac{dQ}{Q}+\frac{P_p(Q+dQ)}{Y}\frac{dP_p}{P_p}-\frac{1}{2}\varepsilon_S\frac{P_pQ}{Y}\left(\frac{dP_p}{P_p}\right)^2-\frac{P_cC}{Y}\frac{dP_c}{P_c}-\frac{1}{2}\varepsilon_{HD}\frac{P_cC}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

where Y is household income,
P_p is the producer price of cassava root,
Q is the household production of cassava,
π is the ratio of producer surplus (profit) to gross revenue,
ε_S is the elasticity of supply,
P_c is the consumer price of cassava,
C is the quantity of cassava consumed by the household, and
ε_{HD} is the Hicksian price elasticity of cassava demand.

Method

Gains to producers due to supply response to lower price (reduced supply)

- Calculating the net benefits

$$\frac{dY}{Y} = \frac{P_p Q}{Y}\pi\frac{dQ}{Q} + \frac{P_p(Q+dQ)}{Y}\frac{dP_p}{P_p} + \frac{1}{2}\varepsilon_S\frac{P_p Q}{Y}\left(\frac{dP_p}{P_p}\right)^2 - \frac{P_c C}{Y}\frac{dP_c}{P_c} - \frac{1}{2}\varepsilon_{HD}\frac{P_c C}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

where Y is household income,

P_p is the producer price of cassava root,

Q is the household production of cassava,

π is the ratio of producer surplus (profit) to gross revenue,

ε_S is the elasticity of supply,

P_c is the consumer price of cassava,

C is the quantity of cassava consumed by the household, and

ε_{HD} is the Hicksian price elasticity of cassava demand.

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Gains to consumers from price reduction before consumer response to price change

Method

- Calculating the net benefits

$$\frac{dY}{Y} = \frac{P_p Q}{Y}\pi\frac{dQ}{Q} + \frac{P_p(Q+dQ)}{Y}\frac{dP_p}{P_p} + \frac{1}{2}\varepsilon_S\frac{P_p Q}{Y}\left(\frac{dP_p}{P_p}\right)^2 - \frac{P_c C}{Y}\frac{dP_c}{P_c} + \frac{1}{2}\varepsilon_{HD}\frac{P_c C}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

where Y is household income,

P_p is the producer price of cassava root,

Q is the household production of cassava,

π is the ratio of producer surplus (profit) to gross revenue,

ε_S is the elasticity of supply,

P_c is the consumer price of cassava,

C is the quantity of cassava consumed by the household, and

ε_{HD} is the Hicksian price elasticity of cassava demand.

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Method

Gains to consumers from response to lower price

- Calculating the net benefits

$$\frac{dY}{Y} = \frac{P_p Q}{Y}\pi\frac{dQ}{Q} + \frac{P_p(Q+dQ)}{Y}\frac{dP_p}{P_p} + \frac{1}{2}\varepsilon_S\frac{P_p Q}{Y}\left(\frac{dP_p}{P_p}\right)^2 - \frac{P_c C}{Y}\frac{dP_c}{P_c} - \frac{1}{2}\varepsilon_{HD}\frac{P_c C}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

where Y is household income,

P_p is the producer price of cassava root,

Q is the household production of cassava,

π is the ratio of producer surplus (profit) to gross revenue,

ε_S is the elasticity of supply,

P_c is the consumer price of cassava,

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Data

- 2012-13 Nigeria General Household Survey
  - Implemented as part of the World Bank Living Standards Measurement Surveys
  - Stratified random sample of 4,802 households
  - Two rounds: November 2012 and April 2013
  - Agricultural module has information on crop production and sales
  - Consumption and expenditure module covers 100 food items including fresh cassava root, cassava flour, yellow gari, and white gari
- Assumptions
  - 10% increase in cassava yield
  - Supply elasticity of cassava root 0.4 (Obayelu and Ebute, 2016)
  - Demand elasticity of gari of 0.4 (Tsegai and Kormawa, 2009)
  - Producer surplus is 71% of gross revenue of cassava production

Data

- Source for each parameter in equation

Calculated from yield increase and elasticities

$$\frac{dY}{Y} = \frac{P_p Q}{Y}\pi\frac{dQ}{Q} + \frac{P_p(Q + dQ)}{Y}\frac{dP_p}{P_p} + \frac{1}{2}\varepsilon_S\frac{P_p Q}{Y}\left(\frac{dP_p}{P_p}\right)^2 - \frac{P_c C}{Y}\frac{dP_c}{P_c} - \frac{1}{2}\varepsilon_{HD}\frac{P_c C}{Y}\left(\frac{dP_c}{P_c}\right)^2$$

Nigeria General Household Survey

Yield increase assumption

Elasticity assumptions

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Results

Characteristics of four types of households based on cassava production and consumption

Net position in cassava	Total number of households (million)	Total population (million)	Cassava production as fraction of income (PQ/Y)	Cassava consumption as fraction of income (PC/Y)	Average net benefit ratio (PQ-PC)/Y
Grower, net seller	3.53	19.98	0.340	0.073	0.268
Grower, net buyer	3.03	19.30	0.060	0.187	-0.127
Consumer	14.56	83.02	0.000	0.051	-0.051
Non-participant	10.06	70.20	0.000	0.000	0.000
Total	31.18	192.50	0.044	0.050	-0.006

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Results

	Category	Grower, net seller	Grower, net buyer	Consumer	Non-participant	Total
Sector	Urban	4	6	67	23	100
	Rural	16	13	33	39	100
Zone	North Central	11	14	44	32	100
	North East	3	2	11	84	100
	North West	2	0	23	76	100
	South East	23	35	40	2	100
	South South	25	12	62	2	100
	South West	8	4	73	15	100
Expenditure quintile	Poorest	10	13	23	53	100
	2nd	15	14	32	40	100
	3rd	12	12	45	32	100
	4th	12	9	56	24	100
	Richest	9	4	67	20	100
Sex of head of household	Male	10	9	45	36	100
	Female	17	13	57	13	100
Farm size	No land	0	0	77	23	100
	Less than 0.5 ha	27	35	24	14	100
	0.5 - 1.0 ha	24	25	15	37	100
	1 - 2 ha	25	15	18	42	100
	2 - 5 ha	17	6	24	52	100
	More than 5 ha	12	7	18	63	100
Total		11	10	47	32	100

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Results

Impact of 10% cassava yield increase on aggregate income (US$ million per year)

		Yield effect	Overall effect
Net position in cassava	Grower, net seller	207	-157
	Grower, net buyer	27	113
	Consumer	0	263
	Non-participant	0	0
Sector	Urban	29	152
	Rural	206	67
Zone	North Central	13	46
	North East	3	4
	North West	1	15
	South East	29	81
	South South	151	3
	South West	38	71
Expenditure quintile	Poorest	27	37
	2nd	53	29
	3rd	44	57
	4th	68	35
	Richest	43	61
Sex of head of household	Male	201	172
	Female	34	47
Farm size	No land	0	203
	Less than 0.5 ha	43	57
	0.5 - 1.0 ha	35	20
	1 - 2 ha	86	-44
	2 - 5 ha	54	-18
	More than 5 ha	17	1
Total		235	219

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Results

Impact of 10% cassava yield increase on poverty rate (percent)

		Poverty rate before (%)	Poverty rate after (%)	Change in poverty rate
Net position	Grower, net seller	22.1	23.1	1.0
In cassava	Grower, net buyer	29.6	28.6	-1.0
	Consumer	12.1	11.6	-0.5
	Non-participant	36.1	36.1	0.0
Sector	Urban	7.9	7.5	-0.4
	Rural	32.9	32.8	-0.1
Zone	North Central	17.0	16.7	-0.3
	North East	26.9	26.9	0.0
	North West	51.5	51.4	-0.1
	South East	27.9	27.3	-0.7
	South South	14.8	15.4	0.6
	South West	5.2	4.6	-0.6
Sex of head	Male	24.4	24.1	-0.3
of household	Female	14.1	14.4	0.3
Farm size	No land	9.6	9.2	-0.4
	Less than 0.5 ha	24.6	23.8	-0.7
	0.5 - 1.0 ha	35.5	35.5	-0.0
	1 - 2 ha	39.5	40.1	0.6
	2 - 5 ha	38.3	38.3	0.0
	More than 5 ha	34.6	34.6	0.0
Total		22.7	22.5	-0.2

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Results

- Sensitivity of poverty results to alternative supply and demand elasticities (change in poverty rate due to yield increase)

		Net position in cassava				
Supply elasticity of root	Demand elasticity of gari	Grower, net seller	Grower, net buyer	Consumer	Non-participant	Total
0.2	-0.2	3.4	-1.9	-0.8	0.0	-0.2
0.2	-0.4	1.6	-1.3	-0.5	0.0	-0.2
0.2	-0.6	1.0	-1.0	-0.5	0.0	-0.2
0.4	-0.2	1.6	-1.0	-0.5	0.0	-0.2
0.4	-0.4	1.0	-1.0	-0.5	0.0	-0.2
0.4	-0.6	0.5	-1.0	-0.5	0.0	-0.3
0.6	-0.2	1.0	-1.0	-0.5	0.0	-0.2
0.6	-0.4	0.5	-1.0	-0.5	0.0	-0.3
0.6	-0.6	0.5	-1.0	-0.4	0.0	-0.2

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Summary

- Results confirm that the benefits of technology that increases yield of a staple crop generates large aggregate benefits
- In case of cassava in Nigeria, 10% increase in cassava yield generates estimated benefits of US$ 219 million per year
- Because cassava is non-tradable, the yield increase results in a lower price, hurting net sellers and benefiting net buyers
- In this case, farmers retain 31% of overall benefits and consumers receive 69% of total
- In spite of transfer of benefits to consumers, the new technology is pro-poor, reducing national poverty rate by 0.2 percent and lifting 385 thousand people out of poverty
- This is because net buyers include many rural households and poor urban consumers

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Summary

- Broader implications
  - The consumption pattern of the crop is at least as important as the grower characteristics and adoption patterns in determining the distributional effect
  - To estimate the impact of yield increases, it is not enough to look at the composition of growers. It is necessary to estimate the impact on prices and study effect of prices on farmers and consumers.
  - Fortunately, this is not too difficult if one has household survey data and supply and demand elasticities of price
- Limitations of this approach
  - Assumes the new technology does not affect wages, land rents, and other input prices
  - Assumes the new technology does not affect other crops
  - Assumes new technology does not affect exchange rates
  - If it does, need to move to general equilibrium modeling