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Poverty and Productivity

Small-Scale Farming in Tanzania, 1991-2007

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Poverty & Productivity: Small-Scale Farming in Tanzania, 1991-2007*

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Abstract

We examine the role of agriculture, and in particular smallholder farming, in economic growth and poverty reduction in Tanzania in the 1990s and 2000s. A large, but steadily declining majority of Tanzanians earned their living from farming over this period, and the *relative* poverty of farm households compared to non-farm households actually worsened. Household survey data from 1991 to 2007 reveals that occupational shifts away from the agriculture sector – what we refer to as structural change – made a larger contribution to overall consumption growth than did income growth within agriculture. Within the farming sector, we find that the very modest gains in maize output, for instance, are due entirely to area expansion rather than any increase in average crop-level productivity. Reinforcing this point, crop-level production functions for 2001 and 2007 indicate strong declines in total factor productivity for maize. Finally, we use these production-function results to investigate the determinants of productivity, and the potential for policies promoting inorganic fertilizer and hybrid seeds for staple crops to raise farm productivity and household incomes. These technologies appear profitable on average, but their viability is likely to vary with soil conditions and market access, areas meriting further research.

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Contents

List of Tables

List of Figures

"*Whereas eighty per cent of Tanzanians depend on agriculture for their livelihood, [and] recognizing that the greatest challenge facing Tanzania is to combat poverty, . . . this will be possible mainly through enhanced agricultural productivity.*"
– Tanzania Business Council under the Chairmanship of President Jakaya Kikwete, June 2009, *Kilimo Kwanza Declaration.*

"*Sustained growth is accompanied by structural transformation, that is, the manufacturing and service sector will grow faster than the agricultural sector. . . . [H]igher growth in Tanzania has to be mainly a result of faster growth of industry and services.*"
– R.J. Utz and B.J. Ndulu, 2002, "Pacemakers for Sustainable Economic Growth", in B.J. Ndulu and C.K. Mutalemwa, eds., *Tanzania at the Turn of the Century*, Washington D.C.: The World Bank, pp. 191-3.

1 Introduction

Tanzania's economy remains highly dependent upon agriculture. Agriculture accounts for 27% of GDP and employs the vast majority of the Tanzanian labor force. Poverty levels are highest among the rural population and among those who are mainly dependent upon agriculture for their livelihoods.

Agriculture's critical role in the lives of most Tanzanians is increasingly reflected in the government's policy agenda, in particular, through the promotion of modern technology adoption to raise smallholder agricultural productivity. In 2009 the Ministry of Agriculture (MAFC) launched an input voucher scheme which subsidizes hybrid maize seeds and nitrogenous fertilizer for smallholder farmers in roughly half of Tanzania's districts. In parallel, the Ministry's 2009 budget request included an increase of 2,000 agricultural extension agents, to be stationed in villages across the country to promote technology adoption by smallholders.

These policies appear to reflect a basic syllogism about agriculture and poverty, illustrated in the quote above from President Kikwete. As is clear in the second quote, the same facts may lead to very different policy conclusions. The goal of this paper is not to advocate one position or the other.[1] In either case, the evidence base necessary to draw firm policy conclusions is woefully lacking.

The goal of this paper is to fill in some of those empirical gaps in the logical chain from investments in smallholder farm productivity to poverty reduction. We bring together a wide range of nationally-representative household survey data to enable comparisons over time. This link between multiple rounds of household and farm surveys provides, to our knowledge, the most comprehensive picture of small-scale agricultural development in Tanzania available to date. Parallel work also commissioned by the International Growth Centre (Kirchberger and Mishili 2011) will focus on just one of Tanzania's twenty-one mainland regions, Kagera – for which more detailed longitudinal household survey data is available – to examine a similar set of issues.

Figure 1 shows the schematic structure of the paper, which revolves around a descriptive decomposition of consumption growth over the past two decades into its various sources. The steps in this decomposition correspond to the outline of the three main sections of the paper: first examining the role of agricultural in household consumption growth (Section 3); turning next to the role of yield growth in agricultural growth (Section 4); and finally investigating the roles of technology adoption and total-factor productivity (TFP) growth in yield growth (Section 5).

The various stages of this decomposition can be re-phrased in the form of three empirical questions.

Question 1. *Did smallholder productivity growth lift farm households out of poverty? Or did farmers exit to better opportunities?*

In Section 3 we assess the relative importance of these two channels empirically in recent Tanzanian history. We use household survey data from 1991 to 2007 to

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[1] Indeed, we would argue that these positions are not in fact contradictory, given the potential role for agricultural productivity to spur structural change, as emphasized in dual economy models.

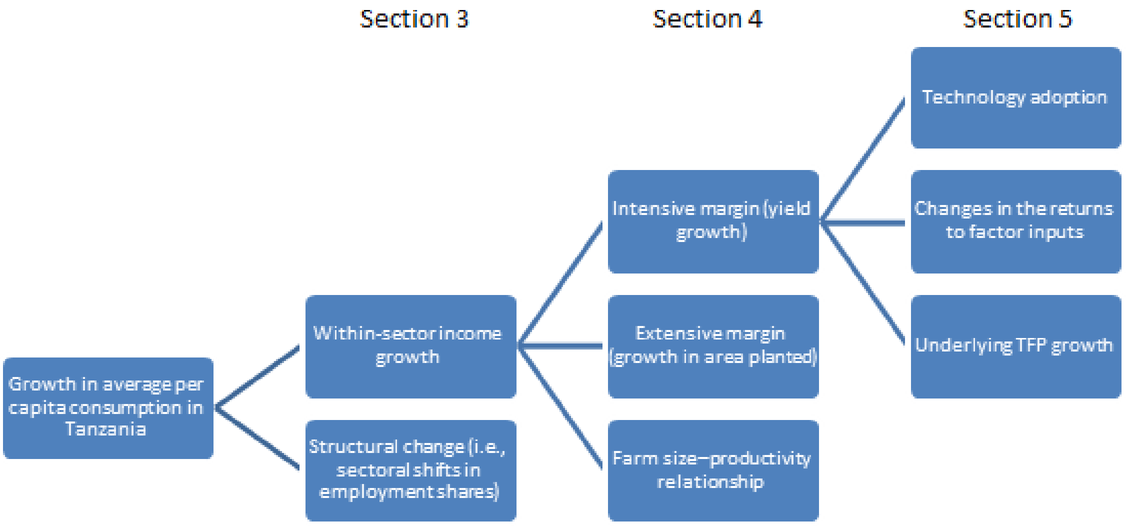

Figure 1: Schematic Structure of the Paper

estimate the contribution to overall poverty reduction from (a) consumption growth among small-scale farmers, and (b) occupational shifts out of the agriculture sector. To preview our results, we show that it has been the decline of the agricultural sector (in terms of employment shares) rather than growth within the sector (in per capita consumption terms) that has had the greatest impact on overall consumption levels in Tanzania over the past two decades.

Question 2. *How much has output of major crops increased over this period? Was the growth of, say, maize output due to (a) productivity increases, or (b) an expansion of the area planted?*

In Section 4 we zoom in on sources of output growth within the smallholder agriculture sector. In particular, we are interested in the role of growth on the extensive margin (increased area) versus the intensive margin (increased productivity), as it is the latter which has been the focus of the policy discussion and is key to long-term growth in many theoretical models. We combine data from two farm surveys of smallholder production to examine changes in farm income over time, and assess the role of productivity growth (i.e., growth in yields) and changes in area planted in explaining this income growth. For maize and most other major crops (rice paddy being the key exception), we find that average yields have actually declined, and where output growth is present it is primarily attributable to area expansion.

One variable conspicuously absent from this portion of the analysis is crop prices. We lack comparable data across time (2002-2008) and space (all regions of mainland Tanzania) on a full set of crops. Thus we are unable to aggregate total output value across crops or analyze shifts in the terms of trade. Instead we conduct the analysis separately by crop. We would note that this is one area where the longitudinal data used by Kirchberger and Mishili (2011) poses the greatest advantage despite its narrow geographic coverage, in that their survey data enables them to provide a single, farm-level output measure. Using this measure they document a dramatic decline of 46% in total crop value from 1991 to 2004 for their Kagera sample.

Question 3. *Has use of inorganic fertilizer, hybrid seeds, irrigation, etc. increased? Why or why not? Are these technologies profitable for smallholders at prevailing prices?*

Finally, in Section 5 we drill down yet another level, focusing on the underlying determinants of changes in farm yields. We examine changes in the use of improved farm inputs, and the evolution of the *returns* to these inputs over time. The latter task, measuring returns to fertilizer and other inputs, is a much more fraught econometric excercise. Careful alignment of production and input data across two farmer surveys (from 2002/03 and 2008/09) allows us to estimate a pooled, farm/crop-level production function. Even so, our results must be treated as correlations rather than precise evidence of causal parameters. We discuss potential endogeneity problems that may bias the estimated returns in this section, and compare our results to experimental (Duflo, Kremer, and Robinson 2009) and longitudinal (Suri 2011) work on fertilizer returns among maize farmers in neighboring Kenya that has addressed some of these concerns, looking for clues about what this parallel research can tell us about Tanzania in light of our more descriptive results.

2 Data sources

We draw on three principal data sources. The first is the series of Household Budget Surveys (HBS), conducted in 1991, 2000, and 2007. The HBS surveys are primarily designed to assess household welfare; we use increases in consumption for smallholder farmers as a first window into trends in agricultural productivity in the 1990s and 2000s, and show how agricultural growth and occupational shifts away from agriculture have contributed to poverty reduction.

The second and third primary data sources focus on agricultural production per se. Both are nationally representative, household surveys covering smallholder farmers. For reasons of comparability we were forced to exclude Zanzibar from the analysis. While the questionnaires for the two data sources differ, they both offer input and output data at the crop level for all major crops, allowing us to estimate household-level yields and production functions by crop in a comparable way over time, and to examine changes in cropping patterns and area planted.

2.1 Household Budget Surveys: 1991/92, 2000, 2007

Each round of the HBS is a nationally representative household survey covering all regions of mainland Tanzania, but not Zanzibar. The primary focus of the HBS is to measure household consumption, as a basis for poverty measurement. A comparable consumption aggregate has been compiled for three successive rounds of the HBS, spanning the period from 1991 to 2007. The basic needs poverty lines which have been constructed for each geographic stratum (Dar es Salaam, other urban areas, and rural areas) and each round of the HBS provide an estimate of the cost of acquiring a basic basket of essential food and non-food items. We use these poverty lines as the basis for deflating nominal consumption figures from each round.

The HBS also includes data on occupational status. We categorize households by the sector of the main occupation of the household head, which we divided into five sectors: agriculture, which includes crop farming, livestock and fishing; non-farm self-employment; wage employment in the public sector, which includes NGOs and international organizations; wage employment in the private sector which includes parastatal enterprises; and a category for heads of household who are not working, which encompasses both the unemployed as well as those outside the labor force. Our focus here is on the changes in consumption among households engaged in agriculture, as well as the changes in average consumption due to movements away from agriculture.

2.2 National Sample Census of Agricultural: 2002-03

The second primary data source is the National Sample Census of Agriculture (NSCA), 2002-03, conducted by the Ministry of Agriculture, Food Security and Cooperatives (MAFC) and the National Bureau of Statistics (NBS). The NSCA includes detailed production data for smallholder farmers, including land area, labor and capital inputs, yields and sales. The sample is large, covering over 48,000 households across 3,200 villages - sufficient to provide district-level estimates for all of Tanzania. One weakness of the NSCA which should be noted early on is the fairly coarse treatment of chemical fertilizer, improved seeds, pesticides and herbicides in the questionnaire. These are asked as binary response questions (used/did not use) rather than soliciting quantities or prices. (Additionally, the NSCA also includes a parallel survey of large-scale farmers. We provide basic comparisons between the smallholder and large-scale farm results, without conducting primary data analysis on the large farm sample, due to the lack of any comparable data for later time periods as noted below.)

2.3 National Panel Survey: 2008-09

Our third main data source is the baseline round of the National Panel Survey (NPS), 2008-09, also conducted by NBS with the collaboration of MAFC. The nationally representative sample of the NPS returned to a sub-set of the villages which participated in the 2002-03 NSCA. (Note this is not a panel of households, only of villages at this stage.) The NPS sample is relatively small, with approximately 2,000 rural households, but the questionnaire is fairly detailed, and overcomes many of the weaknesses of the NSCA questionnaire regarding details on input usage and cost.

2.4 Rainfall data: 2002 - 2008

Finally, to complement the farm and household survey data, we use data from the Tanzania Meteorological Agency (TMA) measuring monthly rainfall. The TMA data provides the total millimeters of rainfall from observation points covering nearly all of Tanzania's twenty-one mainland regions. Thus we have, roughly speaking, one rainfall observation per month per region from January 2002 to December 2008 which can be merged with the survey data to control for climate effects in the determination of farm output in the analysis below.

In order to keep the analysis simple and transparent, our preferred measure of rainfall is the cumulative millimeters of rainfall (and its square) in a given region for the months of March, April and May. These months (in 2003 for the NSCA, and 2008 for the NPS) constitute the peak months for the long-rainy season for which crop output is available. We experiment with more flexible and less parsimonious rainfall measures to ensure the robustness of the analysis.

Table 1: Definitions of Key Variables

Variable	Definition	Source
S_{jt}	Occupation: Share of household heads whose main occupation was in sector j at time t.	HBS
C_{jt}	Household consumption: Average, real, monthly household consumption per adult equivalent for households whose head was employed in sector j at time t. Expressed in 2007 Tanzania Shillings.	HBS
Y_{ict}	Crop output: Total output in kilograms on farm i of crop c at time t. $Y_{ict} = y_{ict}H_{ict}$.	
y_{ict}	Crop yields: Farm output expressed in physical output (kilograms) per unit of land (acre).	NSCA/NPS
H_{ict}	Crop area: Total area planted in acres on farm i of crop c at time t.	NSCA/NPS
ϕ_{ct}	Proportion of farmers growing any amount of crop c, i.e., for whom $Y_{ict} > 0$.	NSCA/NPS
L_{ict}	Labor input: Individuals who reported working on a household farm during the past 12 months. (It is not possible to disaggregate labor supply by crop in a comparable way across survey rounds.) For regressions using only NPS data it is possible to measure total days of labor supplied on a given farm.	NSCA/NPS
A_{ict}	TFP: Total factor productivity of farms, controlling for the contribution of land and labor.	
Z_{ict}	Technology usage: Vector of indicator variables for use of 'improved' farm technologies including inorganic fertilizer, improved seeds, pesticide, irrigation, tractors, fertilizer sprayers and oxen. For the estimates using only NPS data fertilizer, improved seeds and pesticide are measured in monetary terms and entered as continuous variables, in which case they are denoted F_1, F_2 and F_3.	NSCA/NPS

Subscripts indicate the level of observation: i = household, j = sector, c = crop and t = time. TFP (A_{ict}) is estimated using the NSCA and NPS data. The source field is left blank, as this variable is estimated rather than observed in the dataset. Crop yields, crop area, and labor input are used at various points in the analysis at both the disaggregated household level (indicated with an i subscript), and for the aggregate average level for the country.

Comparing rainfall across the two years, by almost any measure 2008 was a better year. Averaging over households in the sample the mean cumulative rainfall from March to April in 2003 was 268 millimeters, rising to 322 millimeters in 2008. The fifth and ninety-fifth percentiles also rose, from 77 to 196 millimeters and from 664 to 811 millimeters. Looking across the entire year, average rainfall rose for nine of the twelve months when comparing 2003 to 2008.

3 Growth and exit: two roles for agriculture in consumption growth

Most Tanzanian households earn their living through farming; to be precise, as of 1991 the main occupation of 82.1% of household heads was farming, livestock or fishing. By 2007 his share had fallen to 64.0%. Farm households are also significantly poorer than other households; in 1991 their real per capita consumption was just 68.6% of the average for non-farm households, and this deficit has widened over time to just 62.6% by 2007.

In a purely arithmetical sense, the concentration of poor households in the agricultural sector suggests two paths to poverty reduction in Tanzania: consumption growth among smallholder farmers, and structural change, i.e., movement out of agriculture into other sectors where average consumption is higher. The HBS data sets allow us to disentangle the relative importance of these channels in overall consumption growth, as well as the role of consumption growth in other sectors outside of agriculture.

We begin with a simple decomposition of overall average consumption levels:

$$\bar{C}_t = \sum_j S_{jt} \bar{C}_{jt} \tag{1}$$

Table 2: Occupational Shares and Average Consumption, 1991-2007

	1991	2000	2007	Annual Change
Share of Households (S_{jt})				
Farming	82.1%	72.4%	64.0%	-1.1%
Self-Emp.	4.4%	10.4%	16.4%	0.7%
Private Wage	5.1%	4.9%	6.8%	0.1%
Public Wage	5.3%	5.7%	5.6%	0.0%
None	3.1%	6.5%	7.2%	0.3%
Total	100.0%	100.0%	100.0%	.
Average Consumption ($\bar{C}_{jt}$)				
Farming	15,661	16,412	16,811	0.4%
Self-Emp.	23,726	26,988	25,245	0.4%
Private Wage	23,133	31,240	29,982	1.6%
Public Wage	26,313	31,017	34,592	1.7%
None	15,111	16,736	16,618	0.6%
Total	16,947	19,108	20,069	1.1%

The left hand side of the table shows the share of households in a given sector, divided by the main occupation of the household head. The right hand side of the table shows the average consumption level of households in each occupational category, expressed in real 2007 Tanzanian Shillings per adult equivalent per month.

where $\bar{C}_t$ is average household consumption per adult equivalent on mainland Tanzania at time t, S_{jt} is the proportion of households in sector j, and $\bar{C}_{jt}$ is average consumption of households in sector j at time t. Totally differentiating (1), we can express the changes in consumption over time as:

$$\Delta\bar{C}_t = \underbrace{\sum_j S_{j0}\Delta\bar{C}_{jt}}_{\text{Within-sector growth}} + \underbrace{\sum_j \bar{C}_{j0}\Delta S_{jt}}_{\text{Structural change}} + \underbrace{\sum_j \Delta S_{jt}\Delta\bar{C}_{jt}}_{\text{Residual}} \tag{2}$$

We refer to the first term in (2) as within-sector growth, the second part as occupational shifts or structural change, and the third part as the residual or interaction effect. By definition the average growth rate in consumption across the households is the sum of these three components.

Table 2 presents estimates of the parameters in this decomposition, based on the five occupation categories described in Section 2.1. The top panel shows shifts in the occupational structure over time. Households are classified into sectors based on the main occupation of the household head. The bottom panel shows average levels of monthly household consumption per adult equivalent for households in each sector. All figures are expressed in real 2007 Tanzanian Shillings, deflated using the official basic needs poverty lines published by the National Bureau of Statistics. The main messages from Table 2 are summarized in Figures 2 through 4.

3.1 Structural change: the decrease in peasant farming

Figure 2 illustrates the 'structural change' term from the decomposition. As seen, the share of the households whose head is engaged in agriculture has declined steadily over time. The share of farmer households has gone from 82.1% in 1991 to 64.0% in 2007, a decrease by a total of 18.1 percentage points, or a 1.1 percentage point decline per annum. This decline in the share of farmers has been offset primarily by an increase in non-farm self-employment, which grew from 4.4% of households in 1991 to 16.4% in 2007. Meanwhile, the share of households represented by the "none" and wage-employment categories has remained more or less unchanged.

3.2 Growth within agriculture: falling further behind

Figure 3 corresponds to the 'within-sector growth' term in the decomposition, showing the time path of average per capita consumption for households in each sector. Farming households consume considerably less than non-farm households in all other sectors except those not employed (TZS 15,661 per month for farm households in 1991, compared to TZS 26,313 for public sector employees) and the rate of consumption growth in farming has been relatively slow, particularly relative to wage employees (0.4% per annum in agriculture, versus 1.6% and 1.7% for private and public wage employees, respectively). This means that from 1991 to 2007 the per capita consumption increased by 5% in the farming sector, compared to 30% and 31% in the private and public wage sectors respectively.

Finally, Figure 4 summarizes the decomposition of total consumption growth given in Equation 2. Rather than attempting to graph the movements for all five sectors, we collapse the sectors into just two: farming and other. The slices of pie chart show the share of total consumption growth attributable to each of the three main terms of the decomposition. We split the 'within-sector growth' term into two parts, however, to highlight the separate contributions of growth within agriculture and within other sectors. This yields a total of four shares. The largest of these, accounting for 41.8% of total consumption growth is the occupation shift of households out of agriculture and into other sectors. Growth within agriculture – although slower than growth in other sectors – accounts for 30.3% of total consumption growth, due to the large initial size of the sector, while growth in other sectors accounts for just 17.2% of overall consumption growth. Finally, the residual term accounts for the remaining 10.8% of consumption growth.

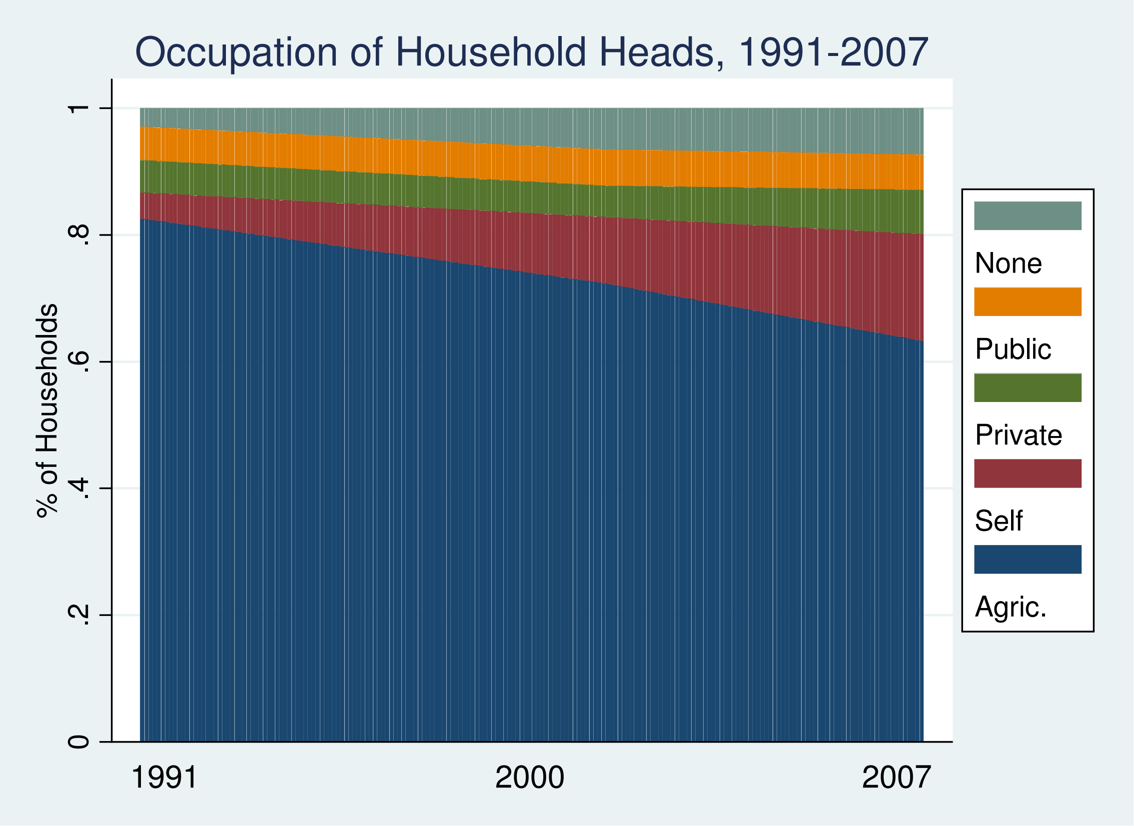

Figure 2: Structural Change, 1991-2007: Sector of Occupation in the HBS. The figure shows the sector of the main occupation of the household head across three rounds of the HBS, in 1991, 2000 and 2007, covering mainland Tanzania. “Agriculture” includes crop farming, livestock and fishing. “Self” refers to non-farm self-employment. “Public” and “Private” refer to wage employment in the public and private sectors, respectively, where parastatal enterprises are included in the private category. “None” encompasses both the unemployed as well as those outside the labor force. As seen, the share of the households whose head is engaged in agriculture has declined steadily over time, offset primarily by an increase in non-farm self-employment. The share of households represented by the “none” and wage-employment categories has remained more or less unchanged.

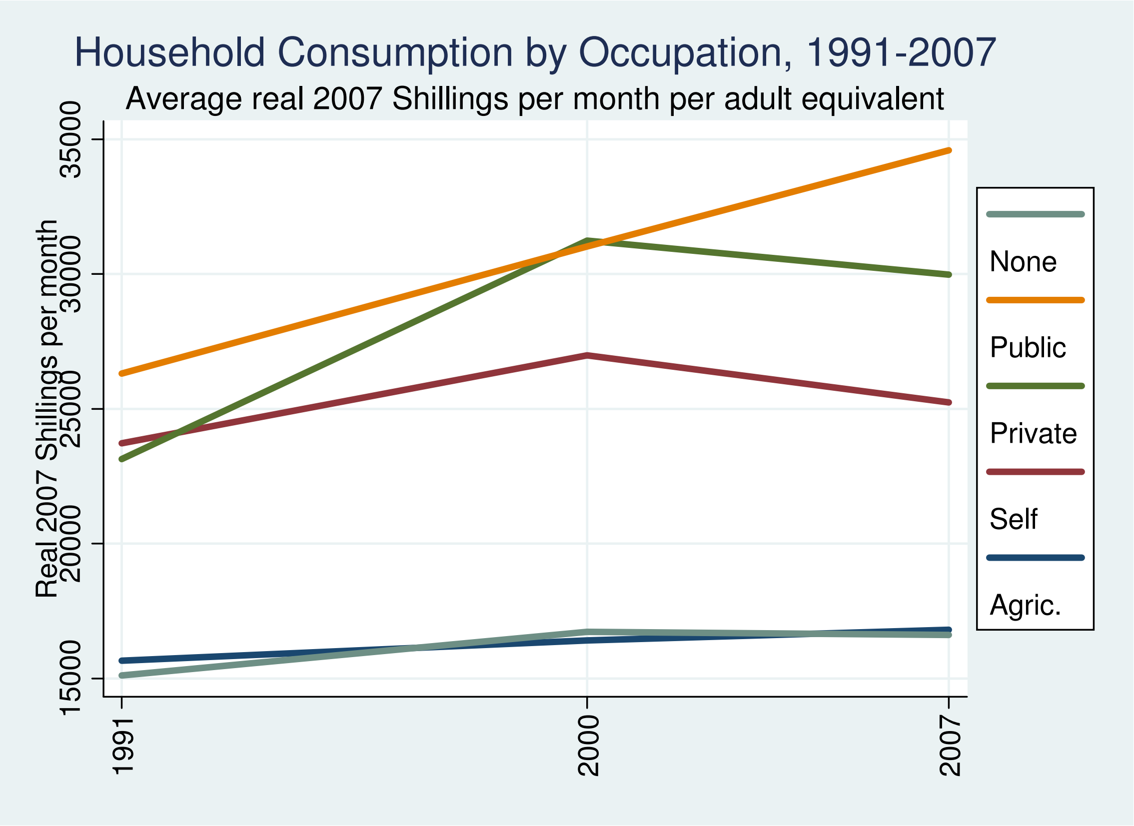

Figure 3: Consumption Growth by Occupation of Household Head: 1991-2007. The figure shows the average level of household consumption per adult equivalent in real 2007 Tanzanian Shillings, dividing households by the sector of the main occupation of the household head. The occupation categories correspond to those used in Figure 2. Nominal consumption levels are deflated with the official basic needs poverty line for each survey year and geographic stratum (Dar es Salaam, other urban areas, and rural areas), as published by the National Bureau of Statistics in consecutive HBS reports.

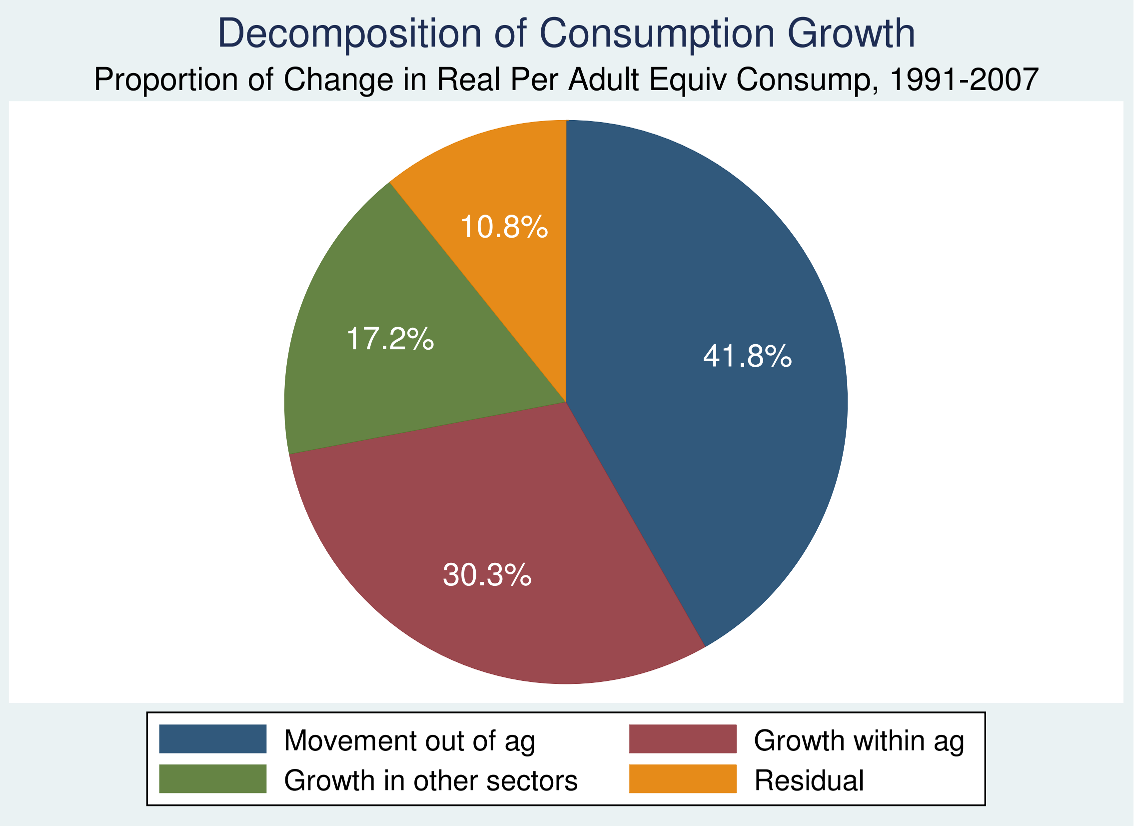

Figure 4: Sources of Consumption Growth, 1991-2007. The figure summarizes growth in average real consumption per adult equivalent from the starting to the ending points covered by the HBS: 1991 to 2007. The total increase in consumption over this period which is apportioned in the pie chart was T.Sh. 3,122 in real 2007 terms, representing an average annual rate of per capita growth in real consumption of 1.06%. The slices of the pie divide this 3,122 Shilling increase into various sources, corresponding to the terms in Equation 2 in the main text. For clarity of exposition, the occupation categories used in Figures 2 and 3 have been collapsed into just two: agriculture and all others. The first term in Equation 2 is divided into two slices, distinguishing within-sector consumption growth in agriculture versus other sectors. The second term represents the increase in consumption due to the movement out of agriculture, shown by the blue slice. The final term represents the residual, i.e., the third term in the decomposition.

4 Intensive and extensive margins: Sources of output growth within smallholder agriculture

The previous section looked at how much of the actual consumption growth achieved in Tanzania has been due to increases in consumption for households in the agricultural sector. This section drills down one step further, to look at the sources of that growth. To do so requires that we shift focus from consumption to production, and decompose output growth into its various components: expansion in the area planted, growth in farm yields, and changes in the correlation between these variables – i.e., the farm-size productivity relationship.

Ideally this analysis could be conducted both at the aggregate farm level, and by disaggregated crops. Aggregating production at the farm level requires crop prices that are comparable across time. While limited price data is available from the Ministry of Industry, Trade and Marketing (MITM) it is lacking in several respects: key crops such as paddy are missing; data is measured at markets rather than the farm gate, so may not reflect true returns to farmers; etc. At this time we present analysis exclusively at the individual crop level, and side-step all price calculations. Readers should keep in mind that changes in income (an intermediate step between production, as measured here, and consumption dealt with in the previous section) may also reflect price variation not measured here. Indeed, Kirchberger and Mishili (2011) observed declining terms of trade between 1991 and 2004 for farmers in the Kagera region in Tanzania. Such a change may affect farmers' incomes negatively, which may play a role in explaining the slow growth of per capita consumption found within that sector.

Total farm output of crop c in time t on farm i, Y_{ict}, is the product farm yields expressed in physical output per unit of land, y_{ict}, and total area planted for a given crop, H_{ict}. Decomposing output into yield and area planted requires careful attention to the proportion of farms who plant zero maize, for instance, and thus have no yield data. We use $\bar{Y}_{ct}$ to refer to average output of c, averaging across *all* farms – regardless of whether they planted any c. When referring to the average level of yield or area planted however, (denoted $\bar{y}_{ct}$ and $\bar{H}_{ct}$, respectively) we use *only* those observations with positive output. We use ϕ_{ct} to denote the proportion of farmers planting any of crop c in period t. Using this notation and the properties of expectations, we can write:

$$\begin{aligned} Y_{ict} &= y_{ict} H_{ict} \\ \Rightarrow \bar{Y}_{ct} &= \phi_{ct}[\bar{y}_{ct}\bar{H}_{ct} + \text{cov}(y_{ict}, H_{ict})] \end{aligned} \tag{3}$$

The term inside the square brackets is equivalent to the average output of farms that produce any of crop c. This is multiplied by ϕ_{ct}, the share of all farms growing any of crop c, making the expression as a whole a measure of total output averaged over all farms. Once again, totally differentiating 3 provides a useful decomposition of total changes in farm output into the changes of each of these underlying parts:

$$\begin{aligned} \Delta\bar{Y}_{ct} &= \underbrace{\phi_{c0}\bar{y}_{c0}\Delta\bar{H}_{ct} + \Delta\phi_{ct}[\bar{y}_{ct}\bar{H}_{ct} + \text{cov}(y_{ict}, H_{ict})]}_{\text{Extensive margin}} + \\ & \quad \underbrace{\phi_{c0}\Delta\bar{y}_{c0}\bar{H}_{ct}}_{\text{Intensive margin}} + \underbrace{\phi_{c0}\Delta\text{cov}(y_{ict}, H_{ict})}_{\text{Size-productivity rel'n}} + \varepsilon_{ic} \end{aligned} \tag{4}$$

The first two terms show the change in revenue due to expansion of the area planted, which we refer to as growth along the ‘extensive margin’. The first of these terms captures the change in the average area planted among households cultivating any of crop c, as captured by $\Delta\bar{H}_{ct}$, and the second term shows the change in the share of all households that cultivate crop c, as captured by the $\Delta\phi_{ct}$ parameter. The third term shows the change in revenue driven by increases in crop yields, which we refer to as growth along the ‘intensive margin’, and the fourth term shows the effect of changes in the covariance of area and yield, which we refer to as the ‘farm size–productivity relationship’. All of these terms individually rely on the other parameters remaining unchanged. For instance, the first term shows the change in revenue due to changes in the average area planted among cultivating households – as we stated above – only insofar as the share of households cultivating crop c and their average yields remain stable. As it is unlikely that these remain exactly unchanged, there is also a (relatively small) residual term, ε_{ic}, which consists of the cross-products in the total derivative.[2]

Our data for these calculations is based on the household surveys of smallholder farmers conducted in 2002/03 and 2008/09, i.e., the NSCA and NPS, respectively. These surveys effectively provide data on farm production; in contrast the previous section focused on consumption. While consumption is a more appropriate metric of household welfare, production data enables us to examine the sources of welfare gains and relate them to underlying economic activities.

4.1 The intensive margin: declining farm yields

Comparing columns (1) and (2) in Table 3 provides an indication of the relative importance of yield growth in total output growth for various crops at the national level, over the time period from 2002/03 to 2008/09.

The overall picture in Table 3 is one of gradually declining yields. Staring with maize in the upper left corner of the Table, average production among maize farmers in column (1) grew from 405 kg to 427 kg over this period, reflecting an increase of 21.2 kg over six years, or an annual growth rate in output of just 0.9% per annum.

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[2] To be explicit, the residual term is $\varepsilon = \phi_{c0}\Delta\bar{y}_{ct}\Delta\bar{H}_{ct} + \Delta\phi_{ct}[\Delta\bar{y}_{ct}\bar{H}_{c0} + \bar{y}_{c0}\Delta\bar{H}_{ct} + \Delta\bar{y}_{ct}\Delta\bar{H}_{ct} + \Delta\text{cov}(y_{ct}, H_{ct})]$. As seen, these terms are ‘second order’ in the sense that they are the product of changes. Normalizing yields and land area to unity at time zero, it is easy to see that their magnitude will be quite small for realistic growth rates in the underlying variables. Thus the four-part decomposition in equation 4 provides a fairly comprehensive picture of the source of output growth.

Table 3: Sources of Crop Output Growth: Changes in Yield, Area Planted and the Size-Productivity Relationship, 2002/03-2008/09

	$\bar{Y}_{ct}$ (1)	$\bar{Q}_{ct}$ (2)	$\bar{H}_{ct}$ (3)	ϕ_{ct} (4)	$\text{cov}(Q_{ict}, H_{ict})$ (5)
Maize					
2002	405	343	2.13	64.0%	-95
2008	427	317	2.52	63.2%	-126
Annual Growth	0.9%	-1.3%	2.9%	-0.1%	-5
Paddy					
2002	93	381	1.66	15.2%	-21
2008	115	569	1.76	13.0%	-116
Annual Growth	3.6%	6.9%	0.9%	-0.4%	-16
Sorghum					
2002	34	199	1.65	11.9%	-44
2008	34	191	2.10	10.7%	-85
Annual Growth	-0.1%	-0.7%	4.1%	-0.2%	-7
Sweet Potatoes					
2002	23	583	0.64	7.0%	-38
2008	37	522	1.10	11.1%	-238
Annual Growth	8.3%	-1.8%	9.5%	0.7%	-33
Irish Potatoes					
2002	16	906	0.90	1.9%	35
2008	17	746	0.97	2.0%	132
Annual Growth	0.7%	-3.2%	1.4%	0.0%	16
Beans					
2002	36	163	0.96	24.9%	-12
2008	28	98	1.63	24.4%	-45
Annual Growth	-4.1%	-8.1%	9.2%	-0.1%	-6
Sunflower					
2002	9	188	1.47	3.7%	-24
2008	30	185	1.82	9.1%	-11
Annual Growth	21.2%	-0.3%	3.6%	0.9%	2
Groundnut					
2002	28	200	1.04	15.1%	-26
2008	44	224	1.84	16.2%	-140
Annual Growth	8.2%	1.9%	10.0%	0.2%	-19
Tomatoes					
2002	17	1,978	0.53	1.9%	-142
2008	17	1,246	0.79	1.7%	40
Annual Growth	-0.1%	-7.4%	6.9%	0.0%	30

For each crop the first and second rows report the level of each variable in 2002 and 2008, respectively. The third row reports the "annual growth rate", measured in changes as a percentage of the base year, with two exceptions: column (4) reports percentage-point changes in absolute terms; column (5) reports absolute changes per annum in the covariance, assuming a linear rate of change.

Column (2) shows that average yields fell from 343 kg/acre to 317 kg/acre. Similar declines in average yields were seen in other major crops as well, including sorghum (-0.7% per annum), sweet potatoes (-1.8% p.a.), Irish potatoes (-3.2% p.a.), and beans (-8.1% p.a.).

The notable exception among major crops, where gains in output were driven by significant yield growth, was rice paddy. Average output increased 3.6% per annum over this period, while yields grew at 6.9% per annum.

4.2 The extensive margin: area expansion and fairly stable cropping patterns

Average area planted increased across almost all major crops – suggesting a general expansion in the planted area, rather than pure substitution between crops. Column (3) of Table 3 shows average area planted among growers (that is, the average of $E(H_{ict}|H_{ict} > 0)$), and column (4) shows the proportion of small farmers planting any amount of the given crop.

Area planted for maize grew at 2.9% per annum, from 2.13 acres to 2.52 acres. The proportion of farmers growing maize remained consistently high, slipping very slightly from 64.0% to 63.2%.

Looking across the full set of crops covered in the table, there were no major changes in the proportion of farmers growing a given crop. Maize remained dominant in terms of proportion of farmers growing, followed by beans, paddy and sorghum. Looking at area planted, the largest increases came for groundnut, sweet potatoes and beans.[3]

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[3] Some caution is warranted in interpreting the results for beans, for which yields declined rapidly and area planted increased rapidly. Beans are frequently intercropped. We have taken great care to standardize the area measurement for intercropping across the two surveys. However, small remaining differences (not apparent in the variable definitions) in how the intercropped area is recorded here could create a spurious trade-off between yield and area planted. Total output of beans should not be affected by this issue.

4.3 The farm size–productivity relationship

Total output of, say, maize in Tanzania depends not only on *average* yield and *average* area planted, but also on the relationship between farm size and productivity. Holding these average values constant, total output will depend on the nature of heterogeneity across farms: total output will be higher if bigger farms have higher productivity than small ones.

In matter of fact, the *negative* correlation between farm size and productivity is a robust stylized fact from data sets across the developing world. As we show in Table 3, Tanzania is no exception. We measure the farm size–productivity relationship using the covariance of yield and area planted, $\text{cov}(Y_{ict}, H_{ict})$, shown in column (5). As seen, the covariance is far below zero for most crops, including the main staples: maize, rice paddy, and sorghum.

What is perhaps more surprising is that the inverse relationship between farm size and productivity appears to be growing even more pronounced over time. Again, this pattern holds for maize, rice paddy, and sorghum, among others.

What does this increasingly inverse relationship mean? Binswanger, Deininger and Feder (1995) provide a comprehensive review of theoretical mechanisms which may explain the empirical regularity of the inverse size-productivity relationship. These include market failures in rural markets for land, labor and credit. The finding of an inverse relationship is generally interpreted as evidence that the effects of these market failures overpower the inherent advantages of large farmers in capitalizing on efficiencies of scale. By the same logic, a secular increase in the magnitude of the inverse size-productivity relationship would indicate a deterioration of rural market institutions. Further research in this area appears warranted, as detailed investigation of conditions in these factor markets is beyond the scope of this paper, but overall trends point to deeper underlying problems.

Combining all three of these forces, Figures 5 - 8 implement the decomposition of output growth presented in equation (4). Results are described in the footnote to each table. Once again, with the exception of rice paddy, small increases in total output are the net effect of area expansion (positive force) and declining yields and an increasingly negative farm size–productivity relationship (both driving output down).

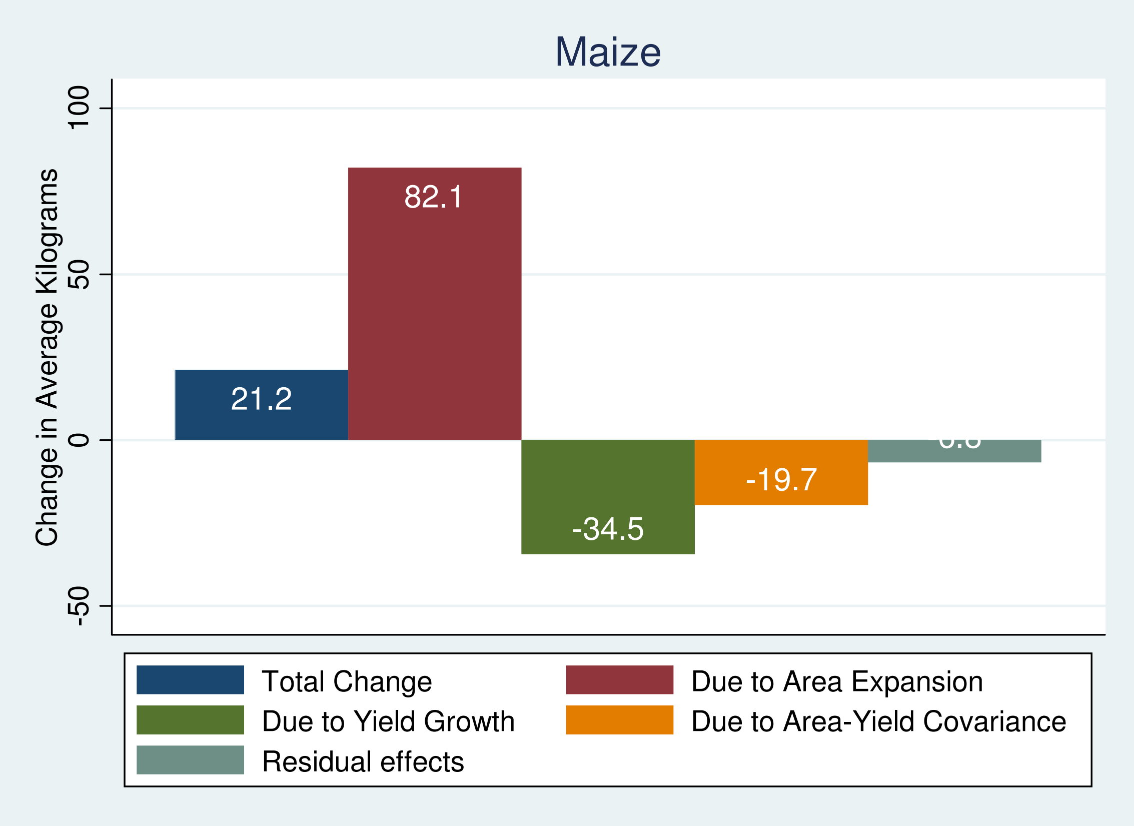

Figure 5: Intensive versus Extensive Growth: Maize. For maize, the extensive margin (area) expanded while the intensive margin (yield) contracted. The "Total Change" (blue bar) shows an overall, net increase in average maize harvests of 21.2 kg over this period. The other bars decompose this total change. Holding all other factors constant, the expansion in area of maize planted would have led to an 82.1 kg increase (red bar). Similarly, all else equal, the fall in yields would have led to a 34.5 kg decrease in average harvests.

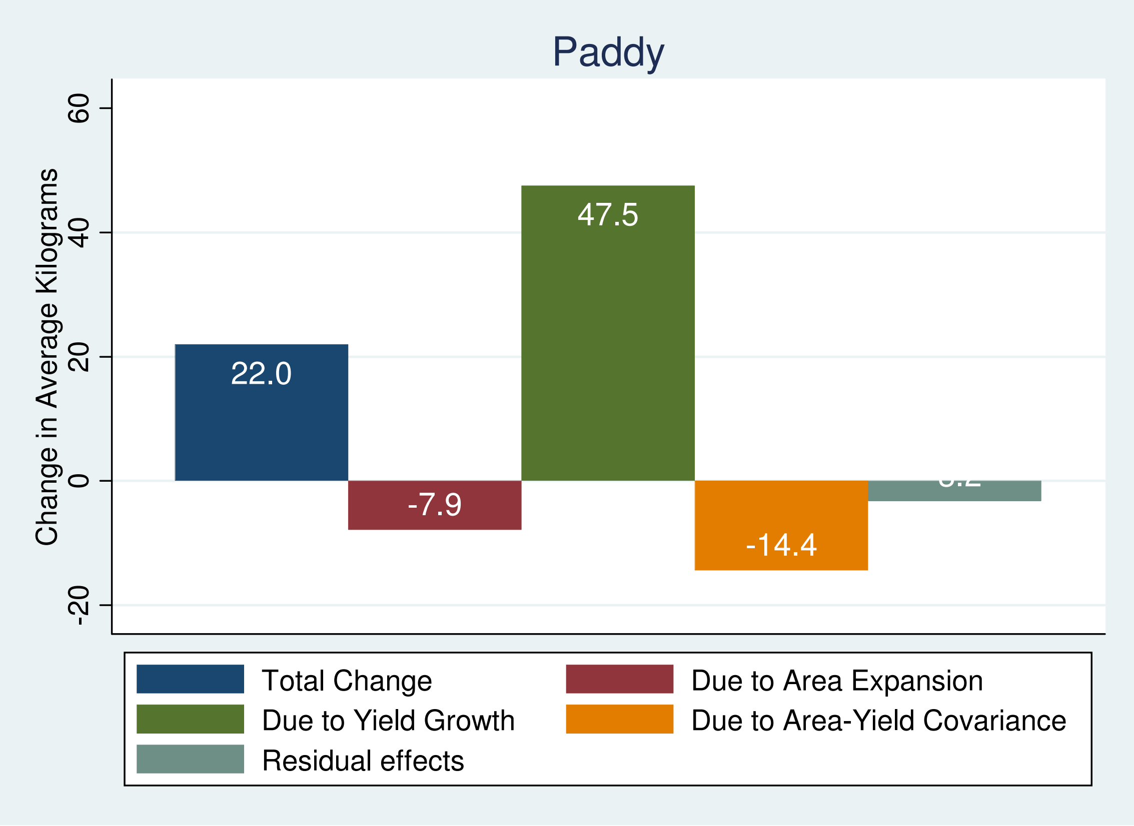

Figure 6: Intensive versus Extensive Growth: Paddy. For paddy (rice), the extensive margin (area) contracted while the intensive margin (yield) expanded – the opposite of the maize pattern. The "Total Change" (blue bar) shows an overall, net increase in average paddy harvests of 22 kg over this period. The other bars decompose this total change. Holding all other factors constant, the expansion in area of paddy planted would have led to an 7.9 kg decrease (red bar). Similarly, all else equal, the rise in yields would have led to a 47.5 kg increase in average harvests.

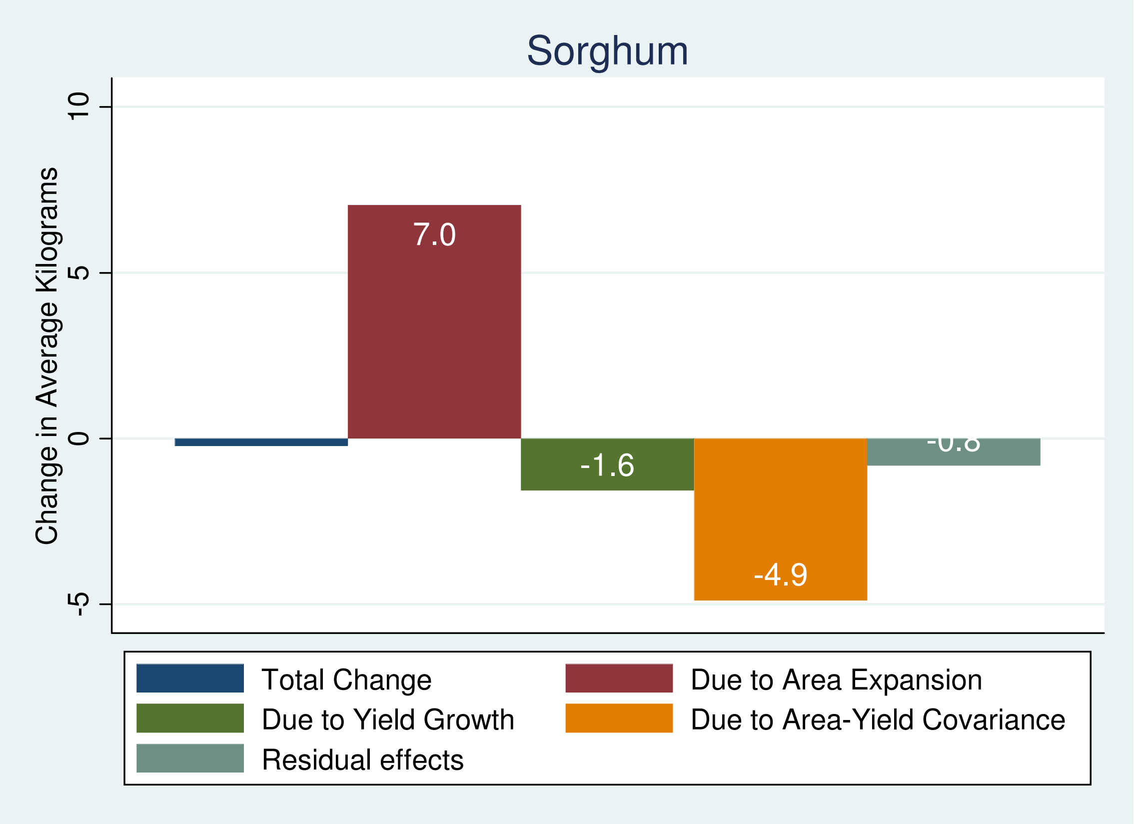

Figure 7: Intensive versus Extensive Growth: Sorghum. For sorghum, the extensive margin (area) expanded while the intensive margin (yield) contracted. The notable feature here is the change in the covariance of area and yield over time, i.e., the farm size-productivity relationship. The "Total Change" (blue bar) shows that overall, there was virtually zero change in average sorghum harvests over this period. The other bars decompose this total change. Holding all other factors constant, the expansion in area of sorghum planted would have led to an 7.0 kg decrease (red bar). Similarly, all else equal, the fall in yields would have led to a 1.6 kg decrease in average harvests. The change in farm size-productivity relationship reduced harvests by 4.9 kg, *ceteris paribus*.

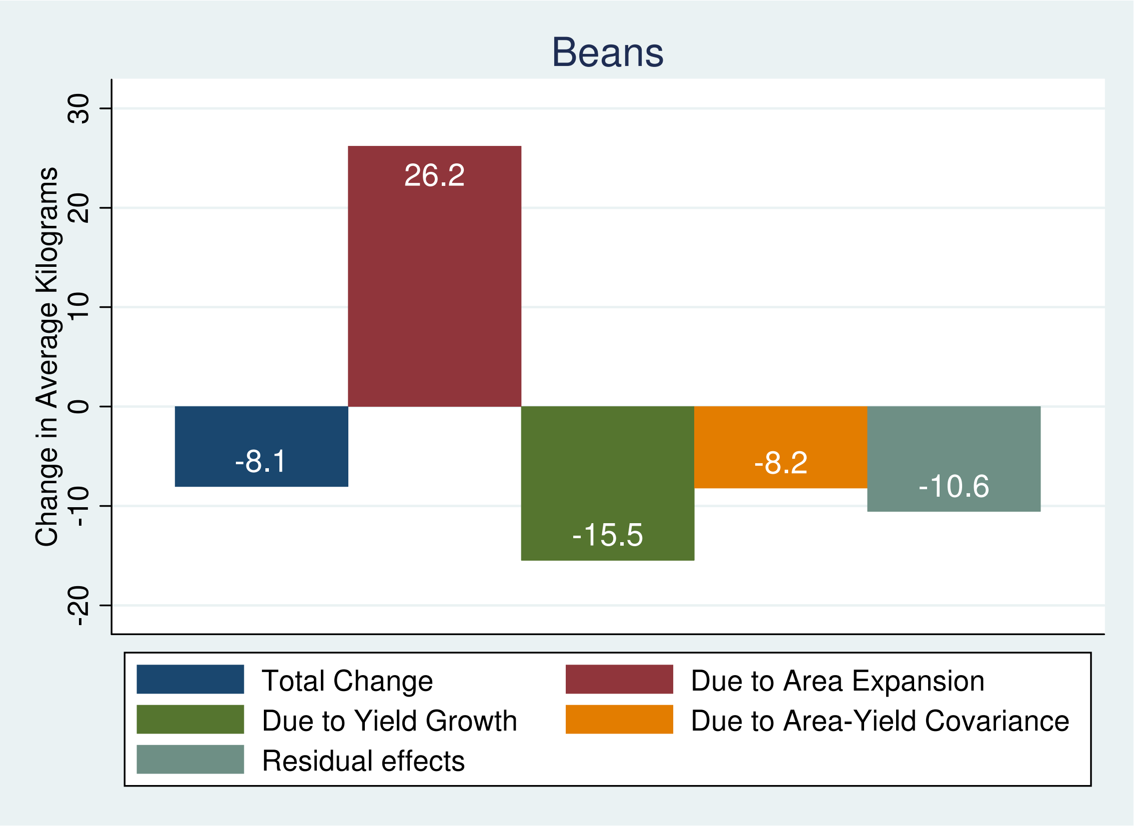

Figure 8: Intensive versus Extensive Growth: Beans. For beans, the extensive margin (area) expanded while the intensive margin (yield) contracted. The "Total Change" (blue bar) was negative, due to a combination of declining yields and an increasingly-negative correlation between farm size and productivity. Holding all other factors constant, the expansion in area of beans planted would have led to an 26.2 kg increase in total output (red bar). Similarly, all else equal, the fall in yields and the growing disparity in yields between small and large farms, led to a 15.5 kg and 8.2 kg decrease in average harvests, respectively.

5 Technology adoption and TFP

The previous section showed that farm yields have been relatively stagnant since 2002/03. In this section we attempt to explain this stagnation by looking at the determinants of crop yields, and in particular, patterns of technology adoption by smallholders. Our first task is descriptive: in Section 5.2 we draw on data from the NSCA and the NPS to measure trends in adoption of new farming techniques between 2002/03 and 2008/09, and in Section 5.3 we estimate comparable crop-level production functions for both years to enable measurement of trends in farm-level total factor productivity over time. Our second, more ambitious task is to explain why technology adoption has stagnated, which we explore through more detailed analysis of crop-level production functions in Section 5.4.

5.1 Empirical model

We posit a Cobb-Douglas production function for total farm output of crop c on farm i, Y_{ict}, with inputs of labor, L_{ict}, and land, H_{ict}. The factor A_{ict} denotes total factor productivity (TFP), which varies between households, and υ_{ict} is an error term.

$$Y_{ict} = A_{ict} L_{it}^{\alpha_{ct}} H_{ict}^{\beta_{ct}} e^{\upsilon_{ict}} \tag{5}$$

We model individual TFP as a combination of three components:

$$A_{ict} = A_{ct} e^{\mathbf{Z}_{it}\theta_{ct} + \mu_{ict}} \tag{6}$$

First, A_{ct} is a constant, common to all farmers growing c in time t (i.e. a 'benchmark' rate at which inputs are transformed into output). Second, there is a vector of factors thought to proportionally affect the productivity of the household's farming, denoted Z_{it}. (Note that the lack of c subscripts on L and Z reflects our inability to observe these variables disaggregated by crop in the NSCA; data for these variables is at the household level.) This vector includes indicators of organic or inorganic fertilizer usage, of using improved seeds for sowing, of irrigating some of the household's plots, and of household characteristics. Finally, there is a residual term, μ_{ict}.

Substituting the expression in (6) for A_{ct} in equation (5) gives us the following production function

$$Y_{ict} = A_{ct} L_{ict}^{\alpha_{ct}} H_{ict}^{\beta_{ct}} e^{Z_{ict}\theta_{ct}+\upsilon_{ict}+\mu_{ict}}$$

Dividing both sides by land area, H_{ict}, and denoting divisions by H_{ict} with lower case letters, we get

$$y_{ict} = A_{ct} l_{ict}^{\alpha_t} H_{ict}^{\alpha_t+\beta_t-1} e^{Z_{ict}\theta_{ct}+\varepsilon_{ict}}$$

where the composite error term $\varepsilon_{ict} = \upsilon_{ict} + \mu_{ict}$. Taking logs of both sides we have a linear equation, which is the basis for our econometric estimation:

$$\ln(y_{ict}) = \ln(A_{ct}) + \alpha_{ct}\ln(l_{ict}) + \gamma_{ct}\ln(H_{ict}) + \mathbf{Z}_{ict}\theta_{ct} + \varepsilon_{ict} \tag{7}$$

where $\gamma_{ct} = \alpha_{ct} + \beta_{ct} - 1$, and $H_0 : \gamma_{ct} = 0$ is a test for constant returns to scale, with values of $\hat{\gamma} < 0$ indicating decreasing returns to scale and $\hat{\gamma} > 0$ indicating increasing returns. The residual term, ε_{ict}, will pick up any variation in unobserved factors important for production, such as unobserved variation in the individual households' TFP (in μ_{ict}), and other factors related to farming such as rainfall (in υ_{ict}).

Endogeneity is a serious concern here. There may be legitimate reasons to suspect that some of the factors picked up by the error term (μ_{ict}, the unobserved part of the household's TFP), such as the innate ability, efficiency, health, etc., of individual farmers may be correlated with the explanatory variables in the regression. Most importantly, the decision to adopt improved farming methods may be corre-

Table 4: Percent of households using ‘improved’ farming techniques

	2002/03 (NSCA)			2008/09 (NPS)		
	Estimate	95% confidence interval		Estimate	95% confidence interval	
Tractor	3	2.8	3.1	2.6	1.8	3.3
Improved seeds	17.2	16.8	17.6	15.9	14.1	17.7
Pesticides	11.9	11.6	12.2	12.9	11.3	14.5
Irrigation	6	5.8	6.2	3.9	3	4.8
Fertilizer	27.3	26.8	27.7	25.3	23.2	27.5

The estimates presented above are nationally representative estimates of the share of all Tanzanian rural farm households engaged in respective farming method (in percent). Point estimates are in bold letters. 95% confidence intervals are reported for both surveys. Fertilizer refers to usage of organic and/or inorganic fertilizer, as the NSCA does not completely distinguish between the two. The more narrow confidence intervals for the NSCA survey are due to its much larger sample size.

lated with unobserved TFP, potentially biasing the coefficients on the technology vector, $\mathbf{Z}_{ict}$. We return to this issue at length in Section 5.4 below.

5.2 Trends in technology adoption

Raising small-farm productivity is an avowed priority of the Tanzanian government. Adoption of ‘modern’ inputs and farming technologies by smallholders – including inorganic fertilizer, improved seed varieties, irrigation, etc. – was chosen as a key metric of success for the national Agricultural Sector Development Strategy (ASDS). Subsidization of fertilizer and other inputs has been a hallmark of agricultural policy since independence, and this approach has been massively scaled-up recently with a World Bank credit line to support the Ministry of Agriculture’s (MAFC) National Agricultural Input Voucher Scheme (NAIVS).[4]

Despite this focus on technology adoption, even basic statistics on fertilizer and improved seed usage are not readily available on a comparable basis over time. By aligning variable definitions from the NSCA and NPS data sets, we are able to

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[4] We should note that the initial voucher distribution for the NAIVS took place simultaneously with the data collection for the National Panel Survey – the end point of our data series. Thus the crop statistics we present in this report do not reflect any impact of the voucher scheme, analysis of which must wait until further rounds of the NPS data are available.

produce comparable statistics on the usage of such 'improved' farming techniques, providing a first glimpse of technology adoption patterns over the past several years.

In Table 4 we present estimates of the share of rural Tanzanian farming households that use improved seeds, fertilizer, pesticides (including fungicides and herbicides), irrigation of plots and tractors. The results in Table 4 show very small changes in adoption of improved farming methods between the two survey years. The estimates of adoption are generally low, with about one in four farmers using some kind of fertilizer (organic or inorganic), about one in six use improved seeds, one in eight use some kind of pesticide/herbicide/fungicide, and only about three percent reports using a tractor in farming. While the point estimates on tractor use, improved seeds and fertilizer are somewhat lower in 2008 than in 2002, and that of pesticides shows a small increase, the differences between the two years are statistically insignificant. There is, however, a statistically significant decline from the already rather low level of six percent of households irrigating plots in 2002 to 3.9 percent in 2008. Of course, estimates of irrigation usage may vary between years depending on differing needs to irrigate plots due to variation in the amount of rainfall. Still, the low and decreasing figure for irrigation is hardly a good sign, especially given that a little more than 20 percent of the households reported not harvesting the entire area they had planted due to droughts in 2008.

Overall, this comparison of farming techniques between 2002/03 and 2008/09 shows consistently low levels of adoption, and lends no support to the hypothesis of increased productivity in farming due to adoption of more modern farming methods among small-scale farmers between the survey years.

5.3 Trends in TFP

We measure trends in total factor productivity (TFP) over time by estimating equation (7) using pooled data from the two survey rounds (i.e., the NSCA and the NPS).

We carry out separate estimation for the three most common crops for which we have comparable data, namely maize, beans and rice paddy. The results of these estimations are presented in Tables 5-7 below.[5] The dependent variable in all these estimations are yields (i.e. output per acre).

The tables are organized as follows. For each crop, column (1) pools data for both years and regresses log yields on a constant and a dummy for the 2008 season. The coefficient on the 2008 dummy represents approximate percentage change in yields over this period. Columns (2) and (3) present the full production function specification from equation (7), estimated separately for each survey round. Column (4) lists the difference in point coefficients between the two years and tests for differences in these returns to factor inputs. The F-test at the bottom of column (4) is a test for pooling, i.e., whether the data rejects common factor coefficients across years. The null hypothesis of equality of parameters is rejected for all crops. Nevertheless, for the sake of transparency, column (5) presents the results from a pooled regression where all parameters except the intercepts are restricted to be the same in both years.

Column (1) replicates the findings from Section 4. As noted in Table 3, yields have generally been found to be decreasing (with the notable exception of paddy), whereas area cultivated has increased between the survey years. The new land taken into use for crop growing is likely less productive than that previously in use (worse soil quality, steeper slopes of plots, longer distances from home, etc.). To the extent that previously farmed plots have been expanded, a decrease of the land parameter

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[5] Our ability to empirically measure the variables in equation (7) is much better in the 2008/09 NPS than the 2002/03 NSCA. In Tables 5-7 we take the 'lowest common denominator' of both surveys, limiting ourselves to the somewhat crude indicators measured comparably over time to estimate pooled production functions for 2002/03 and 2008/09. The most detailed variables in these estimations are measured at the household-crop level (as opposed to the plot-crop level which would have been desirable); fertilizer usage is measured by a dummy indicator rather than being treated as a quantity input; and labor is measured as the number of people in the household involved in agriculture during the past year. In Section 5.4 we are able to estimate more precise production functions using only the NPS 2008/09 data.

between columns (2) and (3), indicating more decreasing returns to scale, should follow. Likewise, to the extent that new, less productive plots have been brought under cultivation, a decrease in farm efficiency should follow. Hence the results here corroborate the trends reported in the previous section. [6]

Looking at the tables for maize and beans, the both statistically and economically significant decreases in yields between the years in column (1) in Tables 5 and 7 can only to a small extent be explained by the inclusion of the other explanatory variables in column (5). This means that the decline in TFP does not seem to be due to changes in the input, technology or human capital variables included. However, as the pooling restrictions for the estimations of column (5) were rejected for all three crops, columns (2) and (3) of tables 5 to 7 removes those restrictions and allows the parameters of all variables to vary between the two surveys.

The parameters of the variables on improved farming techniques included - i.e. the use of fertilizer, improved seeds, pesticides, irrigation and tractors - remain rather stable between the survey years. Noteworthy deviations from that result are the estimated coefficients of pesticide usage in maize production and fertilizer usage in paddy production. In both cases, one should note that the variables included are dummy indicators (due to the limits of survey compatibility), so differences in parameters may be due to changing quantities of pesticides and fertilizer used among the households that have adopted fertilizer or pesticides. Furthermore, the coefficient on the pesticide variable should vary between years, depending on the existence of pests. With few pests present, the effect of pesticide usage should be negligible.

Up to this point we have ignored the role of rainfall, which is obviously an important determinant of farm yields. Apparent differences in TFP as measured in column (5), for instance, may be due to differences between years in rainfall patterns.

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[6] Unfortunately, as the NSCA data does not include any information at the plot level, we cannot investigate to what extent the area expansion is due to larger plots or due to more plots.

Columns (6) and (7) address this issue by testing whether our estimates of TFP changes are affected by controlling for regional rainfall measures from the Tanzanian Meteorological Agency. Column (6) reproduces the specification in column (5), but limited to the set of regions for which rainfall is available. Because the rainfall coverage is somewhat incomplete (note the drop in the observation count), we also add regional dummies in these last two columns to adjust for any inconsistencies in the sample coverage over time. Finally, column (7) includes cumulative rainfall from March to April as a regressor, as well as rainfall squared.

As seen in Tables 5 and 7, the changes in TFP measured in column (5) are either unchanged or reinforced by controlling for rainfall. TFP fell by 27% for maize, rose by 22% for rice paddy, and fell by 65% for beans. While not shown here in the interests of space, replicating these regressions using a more flexible functional form – i.e., by including the linear and quadratic measure of rainfall in each of the 12 months of the relevant year, 24 additional regressors in all – also produces qualitatively similar trends in underlying TFP. These results are also consistent with the findings of Kirchberger and Mishili (2011) who find that the 46% decline in total farm output in Kagera from 1991 to 2004 is not explained by changes in input usage, but instead is larger after controlling for inputs.

To summarize the results from these regressions, while pooling is formally rejected, there is broad consistency in the determinants of crop yields from 2002/03 to 2008/09. Apart from the decreasing returns to land size becoming more accentuated, we find very little evidence of any systematic change in the returns to factor inputs or farming technologies over time. On the contrary, the secular decline in maize and bean yields appears almost entirely due to a significant decline in underlying total factor productivity.

5.4 Is fertilizer profitable?

Section 5.2 showed that there has been little or no increase in the use of modern inputs by smallholders over the past several years in Tanzania. This begs the fundamental question of *why* small farmers fail to adopt modern inputs? There is stark disagreement in the academic literature on this issue. At risk of oversimplification, the camps can be grouped into advocates of two broad propositions (acknowledging that the answer may differ across crops, technologies, regions, etc.):

1. Modern technologies are, on average, profitable for smallholders, but farmers fail to adopt these profitable new inputs because of the uninsured risks associated with high-volatility technologies (Dercon and Christiaensen 2010), an inability to save up for lumpy inputs (Duflo, Kremer, and Robinson 2009), etc.

2. Regardless of the average returns across the population, modern technologies are simply not profitable for smallholders given their scale, soil type, market access and/or ability to afford other complementary inputs (Suri 2011, Zeitlin, Teal, Caria, Dzene, and Opoku 2010).

In either case, input subsidies such as the NAIVS, discussed above, may succeed in raising technology adoption rates. The question is whether this is desirable. If the first proposition is true in the case of fertilizer and improved maize seeds in Tanzania, then the NAIVS will be socially welfare improving by helping to overcome market failures and raising national output.[7] If, on the other hand, the second proposition is true, NAIVS will be a net loss. Though such subsidies may still be justified as a form of welfare redistribution, they will detract from overall economic efficiency and, in all likelihood, growth.

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[7] Of course, even if the policy is welfare improving it may not be 'desirable' in competition with other policies if the government has limited resources. Such an evaluation of desirability naturally falls outside the scope of this study.

This section asks whether – and for whom – adopting modern technologies is profitable. We build on the production function specification from Section 5.3, but restrict ourselves to the 2008/09 NPS data. Doing so allows us to exploit the finer detail of this newer data, measuring fertilizer and pesticides as continuous variables alongside land and labor. Hence, we revise the specification in (5) and adopt the following production function :

$$Y_{ic} = A_c L_{ic}^{\alpha} F_{1,ic}^{\lambda_1} F_{2,ic}^{\lambda_2} F_{3,ic}^{\lambda_3} H_{ic}^{\beta} e^{\mathbf{Z}_{ic}\theta_c + \upsilon_{ic} + \mu_{ic}}, \tag{8}$$

where F_1, F_2 and F_3 are quantities of inorganic and organic fertilizer and pesticides respectively. In the cases of inorganic fertilizer and pesticides, these are not homogenous inputs, and hence we measure these by their costs (in thousands of TSH) rather than physical quantities.

Dividing by land area and taking logs, we get the equivalent of equation (7):

$$\ln(y_{ic}) = \ln(A_c) + \alpha \ln(l_{ic}) + \lambda_1 \ln(f_{1,ic}) + \lambda_2 \ln(f_{2,ic}) + \lambda_3 \ln(f_{3,ic}) + \gamma H_{ic} + \mathbf{Z}_{ic}\theta_c + \varepsilon_{ic}. \tag{9}$$

OLS estimates of equation (9) for maize, beans and paddy are presented in Table 9. While the coefficients of the estimations here are not strictly comparable to those in Tables 5-7 above, the results remain qualitatively similar. There are decreasing returns to scale, as the parameter of on land is negative and statistically significant for all crops; the usage use of inorganic and organic fertilizer, pesticides and tractors are each significantly correlated with higher yields, except in the case of beans where small samples undermine statistical significance for some inputs. Somewhat surprisingly, the parameter on improved seed usage are is statistically insignificant in all estimates and even negative for both maize and paddy.

Interpreting these estimates further is difficult without taking careful account of possible endogeneity concerns. Some of these concerns are beyond the limits of our data set to address. However, the empirical model in equations (8) and (9) provides a framework to structure our discussion of existing empirical research on the returns to fertilizer, which we organize around three types of heterogeneity that may affect our results:

1. Unobserved fixed effects, μ_{ic}
2. Heterogeneity in the returns to inputs, e.g., variation over i in θ_{ic}
3. Price variation affecting the profitability of fertilizer at a given marginal product.

The following sections discuss these three issues, placing the results of our relatively simple, cross-section, OLS production function estimates for Tanzania in the context of earlier experimental and longitudinal research for other countries.

5.4.1 Are adopters & non-adopters comparable?

Our estimation of the return to fertilizer derives from a comparison of yields between 'adopters' (i.e., fertilizer users) and non-adopters, controlling for observed factor inputs. These groups may be non-comparable in ways unobserved to the econometrician. As already noted, OLS estimates of $\hat{\theta}$ will be biased upward if farmers' idiosyncratic TFP, μ_{ict}, is positively correlated with fertilizer usage.

In order to estimate the financial return to fertilizer and overcome this source of bias, Duflo et al. (2009) exploit a randomized field experiments of fertilizer application in maize production. Randomization ensures complete comparability between adopters and non-adopters. Relative to many similar agronomic experiments, this particular trial is attractive in that it takes place on real-world, small-scale farms.

In this highly controlled setup, Duflo et al. find that application of inorganic fertilizer produces significant physical returns and that these are – with a specific set of prices, discussed more below – highly profitable. The optimal level of fertilization has a mean financial return of about 36 percent over one season. They explore non-linearities in the return, and find that applying the officially recommended amount of improved seeds and fertilizer (twice the amount of the most profitable level in the study) is highly unprofitable. Likewise, applying too little fertilizer (half the optimal level) is highly unprofitable for most farmers.

Nevertheless, the main result to take away from the Duflo, et al. experiment is that high physical returns to fertilizer on actual smallholder farmers in East Africa are not entirely due to selection or unobserved TFP.

5.4.2 Can new adopters expect the same returns?

Even if adopters and non-adopters have comparable TFP levels, both OLS and IV estimates will only capture the return to fertilizer for farmers who are observed using fertilizer – i.e., a "local average treatment effect" or the "average treatment for the treated" to adopt the treatment effects terminology. If such heterogeneity is (positively) correlated with adoption, then finding that fertilizer is profitable does not

Suri (2011) studies the heterogeneity of returns to adopting modern farm technologies in the form of using improved seeds. She allows for heterogeneity in both the costs and benefits to technology adoption across farmers (i.e. differing returns). Using panel data from Kenya, she finds that the persistent lack of adoption can be explained by these differences; farmers are rational and complete adoption is undesirable. There is more than one side to this story though. Some farmers with very high returns to technology are supply constrained, i.e. their costs for adoption is high due to underdeveloped supply. Developing the supply side of such technologies would yield adoption profitable for these farmers.

Turning to our estimates from Tanzania, we lack the data to allow for the scope of heterogeneity modeled in Suri's Kenyan data. However, the basic Cobb-Douglas specification we employ implicitly allows for limited heterogeneity in the return to fertilizer across farmers. To see this, note that assuming the production function specification in equation (9) the marginal effect of using inorganic fertilizer in equation is given by:

$$\frac{\partial Y_{ic}}{\partial F_{1,ic}} = \lambda_1 \frac{y_{ic}}{f_{1,ic}} \tag{10}$$

This marginal effect depends on the parameter on inorganic fertilizer, λ_1, as well as the level of yield on the plot, y_{ic}, and the intensity of fertilizer usage, f_{ic}. As the marginal effect varies with yield, we evaluate the 'effect' of fertilizer use at the median of y_{ict} for all households, for fertilizing households, and for non-fertilizing households separately. As the effect also varies with the intensity of fertilization, we evaluate the discrete increase of fertilization from zero to the mean of intensity among the households using fertilization. The results of these calculations can be seen in Table 10 below.

Table 10 shows that the median yield among households using inorganic fertilizer is substantially higher than among non-fertilizer for maize and rice paddy.[8] The observed differences in average yields between the households may come about because of the difference in fertilization itself, differences in other inputs, or different TFP's. As we cannot completely disentangle these factors, we present yields 'as is' here. In the calculations of profitability we will rely on the median yield of all households as this is the most robust measure.

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[8] Deducting the estimated 'effect' of fertilization, the adjusted yield for the median household among those using fertilizer is much closer to that of the non-users. For maize, the whole difference in yields virtually disappears, indicating that the doubling of median yield among users seems to stem from fertilization. However, for beans we see the opposite pattern, with fertilizing households having lower yields than others – a picture that is reinforced when adjusting for the effect of fertilization.

Table 10 also shows estimates of returns to fertilizer based on the Cobb-Douglas production function given in in equation (9). Looking at the return to inorganic fertilizer, an investment of 1,000 TSH in inorganic fertilizer will increase production by almost 7 kg's for maize, between 5.2 and 6.5 kg's for paddy and between 1.25 and 2 kg's for beans base. Hence, looking at the median yield of all non-fertilizing households, the price of output required for an inorganic fertilizer investment to bear its cost is about 150 TSH per kg of maize, just below 200 TSH per kg of paddy, and just over 500 TSH per kg of beans.

5.4.3 Which crop price is relevant for profitability?

Crop prices vary considerably over the growing season and across regions at a given point in time. Within a given region, the farm-gate price available to a remote producer may be far below the sale price in urban market centers. The profitability of fertilizer will hinge to a large degree on which price is used.

Lack of relevant price data is a major shortcoming of much existing research on this topic. Table 8 lists the existing measures of the return to fertilizer that we were able to locate for Tanzania. The value to cost ratio, defined as the increase in gross income from application of inorganic fertilizer divided by the marginal cost of the input, is the measure comparable to those of Duflo et al. (2009) and Suri (2011) discussed above. The returns vary between 100 to 1400 percent depending on location of study. Moreover, these estimates of price incentives relies on price data from published FAO data, and hence provide a quite crude guide to the potential viability of a fertilizer program.

Similar concerns arise with respect to the experimental evidence from Duflo et al. (2009) discussed above. The authors' calculations of a profitable return to fertilizer use assume farmers sell (and/or forego purchase of) maize just before the next cropping season, when the maize price is at its highest. If sales occurred at any other time, the returns would decrease substantially, as market prices for maize vary considerably over the year.

The NPS data allows us to compare various relevant prices for smallholder farmers in Tanzania. These are presented in Table 11. The median sales price for maize is just over 200 TSH, about 400 TSH for paddy and 500 TSH for beans. The sales prices are somewhat higher among the fertilizing households, especially in the case of beans. As many of the households are net buyers of crop, one can make a case for valuing the output at purchasing prices instead, as an increased harvest may make less purchases needed. Hence, we also present the median price paid for maize, paddy and beans by the maize, paddy and beans growing households respectively. It is evident from Table 11 that with the exception of paddy, quite a few of the households have bought some quantity of a crop (consumed in the week just before the interview) that they are growing themselves. The median prices paid are, unsurprisingly, higher than the sales prices.

In view of this evidence, given that the different prices reported by the households are often higher than the price required to break even, it seems that investment in inorganic fertilizer has the potential of being profitable for farmers. In order to see exactly how profitable, and to be able to compare these results to those of previous researchers, we calculate the return to inorganic fertilizer as the value to cost ratio. That is, using the six different output prices in Table 11, we value the estimated increase in output due to fertilization, and divide this by the cost of fertilization. The results are presented in Table 12.

Based on our estimations of the return to inorganic fertilizer, and the three different categories of sales prices reported in the NPS, it seems from Table 12 that inorganic fertilizer usage is in a strict economic sense on average economically profitable for farmers. The only exception to this rule is when including the non-fertilizing households in the selling price of beans, which makes the investment in fertilizer just pay back its cost. If one considers the purchasing prices, which are higher than sales prices, the returns grow even larger. However, a common rule of thumb is that an estimated value-to-cost ratio of about 2 is needed for small-holder farmers to start using fertilizer, as fertilization not only brings higher average revenues but also a high variation in revenues. This is true both between farmers and between seasons: between farmers as the estimated adoption rates may, as mentioned, reflect the benefits only among those who can be expected to benefit the most; between seasons as the fertilizers do not give the same effect each season, potentially even making adoption non-profitable in some years. Hence, while fertilization may be profitable on average for the individual farmer, there may still be rational grounds for why fertilization has not been picked up by more households.

Returning to the value-to-cost ratios, which of the prices in Table 12 makes most sense to use will vary from household to household. For instance, the fact that fertilizing households have both higher sales and higher consumption prices indicate that they are situated in areas where crop prices are higher. This highlight the fact that location is an important aspect to consider. Moreover, whether a household is a net buyer or net seller of crops will be highly important for the valuation of the harvest. From the high variability in returns to fertilizer presented in Table 12, it is evident that taking all these factors into consideration is key when assessing profitability.

Table 5: OLS production functions for NPS and NSCA for Maize

	Pooled	NSCA	NPS	Diff	Pooled	Pooled–Rainfall Sample	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	5.474	5.211	5.047	-.164	5.204	5.052	4.430
	(0.007)***	(0.015)***	(0.079)***	(0.08)**	(0.041)***	(0.074)***	(0.094)***
y2008	-.201				-.146	-.208	-.272
	(0.034)***				(0.032)***	(0.035)***	(0.042)***
Log labor (persons)		0.071	0.103	0.031	0.085	0.087	0.084
		(0.011)***	(0.066)	(0.067)	(0.031)***	(0.038)**	(0.037)**
Log land (acres)		-.280	-.273	0.007	-.274	-.291	-.278
		(0.008)***	(0.037)***	(0.038)	(0.022)***	(0.024)***	(0.024)***
Tractor (0/1)		0.289	0.579	0.29	0.434	0.592	0.541
		(0.032)***	(0.164)***	(0.166)*	(0.073)***	(0.078)***	(0.079)***
Improved seed (0/1)		0.091	-.047	-.138	0.003	0.087	0.076
		(0.019)***	(0.093)	(0.094)	(0.05)	(0.052)*	(0.052)
Fertilizer (0/1)		0.391	0.477	0.086	0.437	0.326	0.324
		(0.014)***	(0.068)***	(0.069)	(0.035)***	(0.041)***	(0.041)***
Irrigation (0/1)		0.162	0.142	-.020	0.153	0.135	0.13
		(0.033)***	(0.147)	(0.15)	(0.09)*	(0.104)	(0.103)
Pesticide (0/1)		0.458	0.215	-.243	0.323	0.256	0.268
		(0.017)***	(0.086)**	(0.087)***	(0.049)***	(0.049)***	(0.049)***
Completed primary		0.162	0.178	0.016	0.165	0.148	0.148
		(0.013)***	(0.064)***	(0.065)	(0.034)***	(0.037)***	(0.037)***
Completed secondary		0.001	-.249	-.250	-.091	0.017	0.033
		(0.03)	(0.23)	(0.231)	(0.086)	(0.09)	(0.085)
Rainfall							0.006
							(0.0009)***
Rainfall sq.							-8.16e-06
							(1.29e-06)***
Obs.	29972	28856	1116	29972	29972	20808	20808
R^2	0.964	0.97	0.967	0.968	0.968	0.974	0.974
P-value of F-test				.043			

Table 6: OLS production functions for NPS and NSCA for Rice Paddy

	Pooled	NSCA	NPS	Diff	Pooled	Pooled–Rainfall Sample	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	5.675 (0.013)***	5.386 (0.036)***	5.258 (0.17)***	-.128 (0.171)	5.180 (0.094)***	5.493 (0.235)***	5.055 (0.277)***
y2008	0.08 (0.081)				0.17 (0.076)**	0.15 (0.081)*	0.22 (0.084)***
Log labor (persons)		0.11 (0.023)***	0.201 (0.149)	0.091 (0.149)	0.192 (0.065)***	0.053 (0.077)	0.037 (0.076)
Log land (acres)		-.140 (0.017)***	-.464 (0.096)***	-.325 (0.095)***	-.295 (0.046)***	-.307 (0.053)***	-.301 (0.053)***
Tractor (0/1)		0.097 (0.078)	0.663 (0.57)	0.566 (0.565)	0.319 (0.243)	0.307 (0.236)	0.219 (0.244)
Improved seed (0/1)		0.102 (0.049)**	-.226 (0.3)	-.328 (0.299)	-.060 (0.124)	-.147 (0.121)	-.167 (0.113)
Fertilizer (0/1)		0.119 (0.036)***	0.516 (0.152)***	0.397 (0.154)**	0.358 (0.089)***	0.304 (0.091)***	0.308 (0.092)***
Irrigation (0/1)		0.564 (0.043)***	0.461 (0.197)**	-.103 (0.198)	0.602 (0.083)***	0.439 (0.111)***	0.422 (0.117)***
Pesticide (0/1)		0.005 (0.085)	-.046 (0.251)	-.051 (0.261)	-.054 (0.195)	0.03 (0.175)	0.055 (0.179)
Completed primary		0.202 (0.027)***	0.634 (0.151)***	0.432 (0.151)***	0.419 (0.076)***	0.351 (0.08)***	0.34 (0.081)***
Completed secondary		-.055 (0.062)			-.169 (0.075)**	-.017 (0.083)	-.009 (0.082)
Rainfall							0.004 (0.002)**
Rainfall sq.							-7.30e-06 (2.55e-06)***
Obs.	6982	6735	247	6982	6982	4975	4975
R^2	0.963	0.97	0.968	0.969	0.968	0.973	0.973
P-value of F-test				.001			

Table 7: OLS production functions for NPS and NSCA for Beans

	Pooled	NSCA	NPS	Diff	Pooled	Pooled–Rainfall Sample	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	4.867	4.688	4.033	-.655	4.615	4.214	4.272
	(0.008)***	(0.023)***	(0.132)***	(0.132)***	(0.07)***	(0.223)***	(0.234)***
y2008	-.729				-.567	-.678	-.652
	(0.052)***				(0.051)***	(0.052)***	(0.061)***
Log labor (persons)		0.036	0.053	0.018	0.046	0.08	0.078
		(0.016)**	(0.11)	(0.11)	(0.05)	(0.054)	(0.054)
Log land (acres)		-.192	-.469	-.278	-.362	-.392	-.390
		(0.011)***	(0.059)***	(0.059)***	(0.036)***	(0.037)***	(0.037)***
Tractor (0/1)		-.030	-.028	0.002	-.024	0.057	0.054
		(0.046)	(0.271)	(0.272)	(0.079)	(0.059)	(0.059)
Improved seed (0/1)		0.045	0.185	0.14	0.071	0.126	0.118
		(0.028)	(0.496)	(0.491)	(0.11)	(0.109)	(0.109)
Fertilizer (0/1)		-.053	0.023	0.077	-.026	0.126	0.131
		(0.02)***	(0.099)	(0.1)	(0.055)	(0.055)**	(0.055)**
Irrigation (0/1)		0.005	0.18	0.175	0.089	0.053	0.042
		(0.043)	(0.235)	(0.236)	(0.107)	(0.113)	(0.111)
Pesticide (0/1)		0.083	-.058	-.140	0.0005	0.093	0.092
		(0.031)***	(0.129)	(0.131)	(0.082)	(0.079)	(0.079)
Completed primary		0.135	0.141	0.006	0.135	0.129	0.127
		(0.017)***	(0.099)	(0.099)	(0.052)***	(0.052)**	(0.052)**
Completed secondary		0.0006	-.338	-.338	-.103	-.077	-.076
		(0.039)	(0.212)	(0.213)	(0.084)	(0.093)	(0.094)
Rainfall							-.0006
							(0.001)
Rainfall sq.							3.25e-07
							(1.21e-06)
Obs.	11285	10886	399	11285	11285	9144	9144
R^2	0.96	0.973	0.955	0.965	0.964	0.969	0.969
P-value of F-test				.000			

Table 8: Returns to Fertilizer Usage: Results from On-Farm Verification in Tanzania

Source	Location	Seed Type	O/N Ratio	I/O Ratio	V/C Ratio
Heisey & Mwangi (1996)	S. Highlands	NR	18-43, mean 25	5.25	NR
Heisey & Mwangi (1996)	North	NR	13 to 18, mean 15	5.25	6 to 15
Heisey & Mwangi (1996)	Dry	NR	8 to 10, mean 9	5.25	2.7 to 3.4
Lele, Christianesen, Kadiresan (1989)[a]	NR	Local	6	5.25	2
Lele, Christianesen, Kadiresan (1989)	NR	Hybrid	11 to 16	5.25	4 to 5

O/N Ratio = Output-Nutrient Ratio (kilograms of additional output produced by 1 kilogram of additional nutrient)

I/O Ratio = Input-Output Price Ratios (kilograms of output required to purchase 1 kilogram of input at prevailing prices)

V/C Ratio = Value-Cost Ratio (Increase in gross income from application of input divided by marginal cost of the input)

'NR' indicates details not reported in the original citation.

[a] Cited in Yanggen, et al. (1998)

Table 9: OLS production functions for NPS only: maize, paddy, and beans

	maize	paddy	beans
	(1)	(2)	(3)
Log land	-.157	-.260	-.208
	(0.029)***	(0.071)***	(0.053)***
Log labor	0.353	0.337	0.354
	(0.026)***	(0.065)***	(0.04)***
Log organic fert.	0.056	0.087	0.011
	(0.012)***	(0.033)***	(0.026)
Log inorganic fert.	0.195	0.117	0.11
	(0.023)***	(0.047)**	(0.041)***
Log pesticide	0.156	0.208	0.11
	(0.054)***	(0.065)***	(0.082)
Tractor (0/1)	0.615	1.105	-.256
	(0.076)***	(0.235)***	(0.227)
Irrigation (0/1)	0.429	0.267	0.58
	(0.157)***	(0.197)	(0.462)
Improved seed (0/1)	-.075	-.068	0.475
	(0.078)	(0.158)	(0.373)
Soil=good (0/1)	0.343	0.516	0.391
	(0.102)***	(0.19)***	(0.165)**
Soil=average (0/1)	0.266	0.317	0.3
	(0.099)***	(0.194)	(0.163)*
Soil type=loam (0/1)	0.243	0.186	0.251
	(0.062)***	(0.157)	(0.148)*
Soil type=clay (0/1)	0.152	0.212	0.037
	(0.091)*	(0.166)	(0.181)
Soil type=other (0/1)	0.179	0.271	0.291
	(0.189)	(0.332)	(0.242)
Age of head	-.035	-.037	-.023
	(0.013)***	(0.018)**	(0.015)
Age squared	0.0003	0.0003	0.0001
	(0.0001)**	(0.0002)*	(0.0001)
Female head (0/1)	-.125	-.055	0.055
	(0.06)**	(0.115)	(0.104)
Primary educ (0/1)	0.068	0.383	0.008
	(0.056)	(0.115)***	(0.093)
Secondary educ (0/1)	-.039	-.451	-.256
	(0.165)	(0.284)	(0.171)
Obs.	1564	442	477
R^2	0.328	0.309	0.397

The dependent variable is the log of yield (kg/acre). Log labor days, fertilizer and pesticide are measured per acre. Robust standard errors in parentheses. Omitted categories are sandy soil, bad soil quality, and no education. All regressions are weighted using inverse sampling probabilities.

Table 10: Physical returns to inorganic fertilizer implied by Cobb-Douglas specification

	Obs. count	Median yield (Kg/Ha)	% using inorganic fert.	Marginal product of ave. fert. dose	Zero-profit crop price
Maize					
All growers	1682	213.3	28.1	7	143.8
Non-fertilizing growers	1459	200		6.5	153.4
Fertilizing growers	223	400		13	76.7
Paddy					
All growers	480	320	30.1	5.2	192.3
Non-fertilizing growers	433	320		5.2	192.3
Fertilizing growers	47	600		9.7	102.6
Beans					
All growers	524	72	11.0	2	504.3
Non-fertilizing growers	432	72		2	504.3
Fertilizing growers	92	60		1.7	605.2

Calculations are based on the econometric estimates in Table 9. The table shows estimations of the additional kilograms of output of maize, paddy and beans that farmers would receive by using the average level of fertilization rather than none. As this varies with the yield of the farmer, we present these statistics for the median yield among all farmers, non-fertilizing farmers and fertilizing farmers separately. Average fertilization usage is measured among fertilizing households and is in in thousands of TSh per acre. The estimated additional kilograms of output is per 1,000 TSh invested. The zero-profit price is the price of of output required to make the fertilizer investment just pay back its cost.

Table 11: Median sales and consumption prices reported in the NPS

	Median sales price	Obs.	Median consumption price	Obs.
Maize				
All growers	222.2	545	350	77
Non-fertilizing growers	233.3	99	566.7	14
Fertilizing growers	222.2	446	305.6	63
Beans				
All growers	500	182	1000	101
Non-fertilizing growers	750	40	1200	13
Fertilizing growers	500	142	1000	88
Paddy				
All growers	388.9	167	500	1
Non-fertilizing growers	400	25	-	0
Fertilizing growers	388.9	142	500	1

Median prices are presented for all households, fertilizing households and non-fertilizing households growing respective crop separately. Sales prices are based on reported sales prices and quantities from the long-rainy season 2008. Consumption prices are for purchases of ‘maize (grain)’, ‘rice (paddy)’ and ‘Peas, beans, lentils and other pulses’ reported to be consumed the week before interview.

Table 12: Value-to-cost ratios of fertilizer usage for different crops and prices

	Population	Price	Marginal Y per 1,000 TSh	VC Ratio	Financial Return
Maize					
Sales price	All growers	222	7.00	1.55	54.6%
	Fertilizer growers	233	--	1.62	62.3%
	Non-fertilizing growers	222	--	1.55	54.6%
Consump. price	All growers	350	--	2.43	143.4%
	Fertilizer growers	567	--	3.94	294.1%
	Non-fertilizing growers	306	--	2.13	112.5%
Beans					
Sales price	All growers	500	1.99	0.99	-0.9%
	Fertilizer growers	750	--	1.49	48.7%
	Non-fertilizing growers	500	--	0.99	-0.9%
Consump. price	All growers	1000	--	1.98	98.3%
	Fertilizer growers	1200	--	2.38	137.9%
	Non-fertilizing growers	1000	--	1.98	98.3%
Paddy					
Sales price	All growers	389	5.20	2.02	102.2%
	Fertilizer growers	400	--	2.08	108%
	Non-fertilizing growers	389	--	2.02	102.2%
Consump. price	All growers	500	--	2.60	160%
	Fertilizer growers	-	--	-	-
	Non-fertilizing growers	500	--	2.60	160%

Calculations are based on the econometric estimates in Table 9, combining the physical returns calculated in Table 10 and median prices reported in Table 11. Median prices are presented for all households, fertilizing households and non-fertilizing households growing respective crop separately. Sales prices are based on reported sales prices and quantities from the long-rainy season 2008. Consumption prices are for purchases of ‘maize (grain)’, ‘rice (paddy)’ and ‘Peas, beans, lentils and other pulses’ reported to be consumed the week before interview.

6 Conclusions

To summarize our findings, we return to the three empirical questions posed in Section 1.

Question 1. *Did smallholder productivity growth lift farm households out of poverty? Or did farmers exit to better opportunities?*

In Section 3 we used data from three rounds of the Household Budget Surveys to show that it has been the decline of the agricultural sector (in terms of employment shares) rather than growth within the sector (in per capita consumption terms) that has had the greatest impact on overall consumption levels in Tanzania over the past two decades. While the overall rate of average consumption growth has been slow, at approximately 1.1% per annum from 1991 to 2007, over 40% of this growth was attributable to structural change, i.e., movement out of agriculture and primarily into non-farm self-employment.

As noted in the introduction, the fact that most poor people in Tanzania earn their living through small-scale farming does not imply that raising smallholder productivity is a policy priority for poverty reduction – though other facts may indeed justify such a focus (Jayne, Mason, Myers, Ferris, Mather, Beaver, Lenski, Chapoto, and Boughton 2010). Income diversification and rural to urban migration might be equally valid strategies, as our findings regarding structural change reinforce. Conversely though, international experience showing a close connection between poverty reduction and a declining share of agriculture in GDP does not provide justification for focusing policy on industrial sectors. A variety of theoretical and empirical evidence suggests that agricultural productivity growth may be a pre-condition for structural transformation and industrial development (Dercon 2009, Datt and Ravallion 2002). We emphasize that our descriptive findings alone cannot provide an answer to this sequencing debate.

Question 2. *How much has output of major crops increased over this period? Was the growth of, say, maize output due to (a) productivity increases, or (b) an expansion of the area planted?*

Very little comparable data on crop yields over time exists for Tanzania. Aligning the NSCA 2002/03 and NPS 2008/09 sources of yield information was one of the major objectives of this paper. For maize and most other major crops (rice paddy being the key exception), we find that average yields have actually declined, and where output growth is present it is primarily attributable to area expansion. While our analysis was conducted on individual crops, area expansion is found across almost all major crops, suggesting an expansion in total area planted rather than substitution between crop varieties. Finally, we also find that an increasingly inverse relationship between farm size and productivity explains part of the decline in output for staple crops such as maize and sorghum. This trend is consistent with exacerbated input market failures in rural areas, though this hypothesis requires further investigation and more direct corroboration to complement our fairly indirect evidence on this front.

Question 3. *Has use of inorganic fertilizer, hybrid seeds, irrigation, etc. increased? Why or why not? Are these technologies profitable for smallholders at prevailing prices?*

Beginning with secular trends, we find no increase in use of key modern technologies such as inorganic fertilizer, hybrid seeds, irrigation, etc. Adoption of these technologies is low and stable over time. Estimating pooled production functions across the two rounds of data, we find fairly stable returns to these technologies. This implies that the declining yields measured in the previous section are primarily attributable to falling total factor productivity (TFP). This can possibly be explained by the area expansion, if the new land cultivated is less suited for farming than that previously used. Given the importance of this issue further investigation to explain the decline of the TFP is needed.

The final question posed in the paper was whether modern inputs, and in particular inorganic fertilizer, is potentially profitable for smallholder farmers? Estimates of the rate of return to inorganic fertilizer from the NPS 2008/09 data suggest that it is. However, our simple estimates of this return are subject to a number of econometric concerns. Viewing our results in light of existing research from other countries that has addressed many of these methodological concerns, there is some cause for optimism that our simple estimates may accurately reflect the true average return. However, this average return may not be attainable by all farmers due to heterogeneity in returns and variation in prices. More precise measurement of this heterogeneity is needed before making a general assessment of the viability of schemes to promote new technology adoption.

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