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Equal Opportunity Sensitive Aggregate Wellbeing Measures: Food Security and Basic Household Income on Sub Saharan Africa Agricultural Irrigation Scheme Developments

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Abstract.

Underlying the inclusive growth and poverty reduction aspirations of the UN's sustainable development program, is the notion that all should have an equal chance of enjoying such advances. There is a need for wellbeing measures that accommodate such aspirations. Typically, inequality sensitive aggregate wellbeing measures do not distinguish between differences that are a matter of individual choice and action and those that are a consequence of the force of circumstance that individuals confront. Yet there are good philosophical reasons for making such distinctions and seeking policies to redress the latter "Unequal Opportunity" type inequalities but not the former "Different by Choice" type inequalities. Using 21st century data from family farms on four Zimbabwean and Tanzanian irrigation schemes, this study introduces and exemplifies new methods for measuring the extent of Inequality of Opportunity in a multivariate framework, assessing progress in that dimension and incorporating such measures in an overall Inequality of Opportunity sensitive wellbeing measure. Sub-Sahara African irrigation scheme developments have facilitated greater diversity in household income sources through improved crop yields, advancing household food security and poverty reduction. However, social and cultural dictates frequently cause females to be less educated with more household obligations than their male counterparts limiting their off farm opportunities and resulting in them managing the farm while their male spouse works of farm. This has an obvious inequality of opportunity interpretation with gender of the household headship and location of the farm defining the household circumstance typology and potentially influencing levels of command over land and crop based revenues. When equality of opportunity prevails, the equal chances principle dictates that outcome distributions of different circumstance typologies be identical, however significant revenue differences across household types suggest that this is not the case rendering assessment of distributional variation and its incorporation in an overall wellbeing measure of interest from policy and wellbeing measurement perspectives. Results indicate a deterioration in equality of opportunity in access to land, with an improvement in equality of opportunity in revenue generation over the period with the former outweighing the latter in a joint analysis. revealing significant progress toward the Equal Opportunity goal in that dimension.

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1 Introduction

In 2014 the United Nations Development Programs Sustainable Development Goals Fund was created in an effort to support sustainable development and inclusive growth initiatives around the world. “Equality of Opportunity”, “Participation in Growth By All” and “Gender Equity”, were key imperatives deemed fundamental to the inclusive growth program and there is should be incorporated in any metric of overall societal wellbeing. The Equality of Opportunity idea is founded upon philosophical notions of personal responsibility (see for example Arneson 1989, Dworkin 2002, and Roemer 1998). Inequalities resulting from individual choice and action are to be distinguished from inequalities that are a consequence of circumstances beyond individual control, only the latter type should form part of the inequality calculus. Conventional inequality sensitive wellbeing measures (see for example Blackorby and Donaldson 1978, and in particular Atkinson 1970, Sen 1976, Foster, Greer, Thorbeke 1984) typically do not discriminate between unequal by choice and unequal by circumstance typologies. While there has been much work on measuring the prevalence of unequal opportunity, there is a need for developing indices of its extent that can be incorporated into poverty and wellbeing measures in order to reflect Equal Opportunity aspirations. Here such measures are proposed and implemented in a study of farming households on irrigation schemes in Sub Saharan Africa.

The notion of Inclusive Growth, was in large part based upon the Capabilities Approach to human development (Sen 1985, 1993, Nussbaum 1997, 2011). Sen (1999) argues that development should be evaluated in terms of “the expansion of peoples ‘capabilities’ to lead the kind of lives they value - and have reason to value”. As a social justice imperative, the Capabilities Approach avers the primary importance of unconstrained attainment of basic wellbeing for all, in particular across the gender divide. Though not uniquely so, food security (in terms of access to or command over land) and income generation are important and integral components of the Capabilities Approach (Burchi and De Muro 2016, the United Nations Sustainable Development Goals UN 2015). Implicit in the Capabilities and Inclusive Growth paradigms, is the notion that all should have the same chance (equal opportunity) of basic wellbeing attainment. Despite its acknowledged importance, this equality of opportunity aspect is less frequently examined in evaluating development (Arneson 1989, Roemer 1998, Sen 2009, Atkinson 2012, Peragine, Palmisano, and Brunori 2014). Here the measurement problems associated with the equal opportunity paradigm are addressed in the context of Sub-Sahara African agricultural development by proposing and employing tools for assessing progress toward the Equal Opportunity Goal and incorporating them in an overall wellbeing measure.

Debates concerning notions of Equality of Opportunity and its measurement are still ongoing (see Ferreira and Peragine 2015 for a detailed discussion) they concern what constitutes circumstances, choices, and agents, here it is asserted that the agent or choice-maker is the household, its decision making structure (in terms of the gender of the de facto household head) and the households’ location are its defining circumstances for which the household is not responsible and command over land and household income are outcomes that are the result of its efforts and choices. In the first instance interest centers on measuring the extent to which these outcomes are a consequence of circumstance. In the ideal, transcendentally optimal, equal opportunity world, outcomes should not be dependent of circumstances so that groups defined by circumstances should have identical outcome distributions. Thus, in the present context, the Equal Opportunity policy target would have all circumstance groupings with identical distributions of command over land and income. However, in noting that such an ideal state is seldom attainable, Atkinson (2012) and Sen (2009) argued that the policy objective should be to progress toward the Equal Opportunity state, raising questions as to how such progress could be measured. The empirical question is how to evaluate progress toward equality of opportunity. In the Equal Opportunity state, since all outcome distributions are identical, it would not be possible to identify a household circumstance type by its outcomes. At the other extreme, when the collection of distributions is completely segmented with no overlapping or commonality between any and all pairs of distributions in the collection, knowing the outcome of a household would uniquely identify its type. The objective is to measure the extent to which the collection of distributions has moved away from, or toward, the identical distributional state where knowledge of a household outcomes yields no information as to its circumstance type.

Generally, the literature has followed two paths. Regression/Treatment Effect and Conditional Mean approaches to circumstance state income persistence (Mulligan 1997, Solon 1992, 2008, Peragine, Palmisano and Brunori 2014) employ differences in conditional location statistics to measure closeness of distributions. However, Carneiro, Hansen and Heckman (2002, 2003) and Durlauf and Quah (2002) demonstrate that, employing such summary statistics in this context to explore distributional variation can be misleading since it ignores important information about distributional differences that creates a “veil of ignorance" which can only be countervailed by comparing complete outcome distribution profiles in their entirety[1]. In this regard, Lefranc, Pistolesi and Trannoy (2009), proposed tests for equality of opportunity by exploring whether stochastic dominance relationships prevail between the circumstance-conditioned outcome distributions, with absence of dominance, implying equality of opportunity. The difficulty with this approach is that dominance tests are pairwise comparators and are cumbersome when it comes to many circumstance classes. Furthermore, they only reveal the existence or not of opportunity and give no sense or measure of proximity to the Equal Opportunity state, which Atkinson and Sen have argued for. Finally, they are not really a test of equality in distribution, since absence of dominance does not imply equality of distribution.

Here multilateral comparison techniques are proposed which facilitate the evaluation of such progress by utilizing unit free measures of the extent to which the conditional multivariate distributions differ. The questions being asked and answered here are "Are circumstance-conditioned distributions of land access and farm incomes similar across circumstance classes?", "To what extent are circumstance conditioned distributions becoming more or less similar?" and "how could such measures be incorporated in an overall wellbeing measure?". In the following, the new techniques for examining the extent of Equality of Opportunity are outlined in section 2. Section 3 discusses the background and the relationships that are to be considered. To anticipate the results presented section 4, in the face of significant and growing differences in command over land by circumstance group indicate a decline in equality of opportunity whereas, distributional variation in net crop revenue per hectare by circumstance group diminished over time indicating progress toward an Equal opportunity imperative. When command over land

[1] Simply put, absence of variation in conditional means would not reveal distributional differences engendered by variation in conditional variances.

access and income are considered jointly in an equal opportunity measure the diminishing equality of opportunity in land access outweighs the improved equality of opportunity in income generation.

2 Methods

The ultimate objective is an aggregate wellbeing measure that has food security and capability as a focus but which is sensitive to societal inequality of a particular type, namely that of inequality of opportunity. Inequality sensitive wellbeing measures have a long history (see for example Blackorby and Donaldson 1978). As an early example, Sen (1976) proposed reducing the level of average per capita income μ, by some function of the extent to which inequality is prevalent, specifically, he proposed $\boldsymbol{\mu(1-G)}$ where G is the Gini coefficient of income inequality. More generally, a family of inequality sensitive wellbeing indices which can accommodate a less aggressive reduction of income could be:

$$\boldsymbol{WI = \mu^{1-\alpha}(1-G)^{\alpha}\ for\ 0 \leq \alpha \leq 1}$$

Here α may be thought of as an inequality aversion parameter α = 0 implies no accommodation of inequality i.e. social indifference to inequality, whereas α = 1 implies an expression of ultimate concern for inequality i.e. wellbeing is based entirely on the absence of inequality. Other wellbeing indicators can be modified in a similar fashion. However, G does not distinguish between inequalities that are a matter of choice as opposed to inequalities that are a consequence of circumstance beyond an individual control. To reflect the latter, G could be replaced by an index of the extent of inequality of opportunity with similar properties to G.

In the present context the income measure μ will correspond to revenue from the land, which has two components, access to land (L) (measured in hectares) which reflects household food production capability and security, and net revenue per hectare (R) reflecting the households' ability to produce from the land, so that μ=L*R. It is decomposed in this fashion because, as will be evident, circumstances can constrain the two components in different ways. Ultimately, in order to compute the equality of opportunity component in this analysis, the joint distribution of these features has to be considered.

2.1 The Equal Opportunity Principle and Distributional Inequalities.

At the heart of the Equality of Opportunity principle is the idea that, while chances of different outcomes may vary, the chance of any particular outcome should be identical across all circumstance groups. Thus, when describing potential values for outcome variable "X" for K circumstance classes indexed $k = 1, .., K$ by conditional outcome distributions $f_{X,k}(x|k), k = 1, .., K$, the optimal state requires that $f_{X,k}(x|k) = f_X(x)\ for\ all\ x\ and\ all\ k$. Anderson et. al. (2019) propose distributional inequality measures (and their standard errors) which are bounded between 0 and 1 where, in the present context, 0 implies equality of opportunity (all distributions are identical) and 1 implies complete segmentation (absolutely no commonality of outcome values across groups)[2]. Furthermore, they can be shown to be asymptotically normal facilitating consistent tests for equality of opportunity and movement toward or away from the ideal state.

2.2 Distributional Inequality Measurement and Subgroup Decomposition.

Measuring the extent to which there are differences in a collection of distributions requires quantification of the commonality in the collection or measurement of the extent to which the various distributions overlap with one another. The most popular measure of difference in a collection of numbers is the average relative to the mean difference or Gini Coefficient (Gini 1921).. It has drawbacks, it does not work well with negative numbers (Manero 2017) and it is

[2] These indices can be shown to satisfy the anonymity, scale and translation invariance and normalization axioms popular in the inequality literature, furthermore when sub-distributions are posited to be the atomistic equivalents of the sub-distributions employed in Duclos, Esteban and Ray (2004) and subjected to the same transformations, they comply with the polarization axioms posed therein. However, it should be noted that they do not generally comply with the principle of transfers (Dalton 1920) since counter examples are easy to contrive.

not generally subgroup decomposable (Bourguignon 1970). However, the lack of subgroup decomposability is an advantage in the present context since the fact that it is subgroup decomposable when subgroup distributions are completely segmented (Mookherjee and Shorrocks 1982) can be used to yield a measure of the extent to which distributions are not segmented. Given the collection of K subgroups as outlined above with corresponding means and population shares μ_k and w_k, following Anderson and Thomas (2019), the overall income distribution f(x), mean income μ, and Gini coefficient G, may be written as:

$$f(x) = \sum_{k=1}^{K} w_k f_k(x)$$

$$\mu = \sum_{k=1}^{K} w_k \mu_k \quad [1]$$

$$G = \frac{1}{E(x)} \int_0^\infty \int_0^\infty f(y) f(x) |x-y| dxdy =$$

$$\frac{1}{\sum_{k=1}^{K} w_k \mu_k} \int_0^\infty \int_0^\infty \sum_{k=1}^{K} w_k f_k(y) \sum_{k=1}^{K} w_k f_k(x) |x-y| dxdy = \sum_{k=1}^{K} w_k^2 \frac{\mu_k}{\mu} G_k + \frac{1}{\mu} \sum_{k=2}^{K} \sum_{j=1}^{k} w_k w_j \left| \mu_k - \mu_j \right|$$

$$+ \frac{2}{\mu} \sum_{k=2}^{K} \sum_{j=1}^{k-1} w_k w_j \int_0^\infty f_k(y) \int_y^\infty f_j(x) (x-y) dxdy$$

Thus, the Gini can be seen to be a sum of three terms: (i) a weighted sum of within subgroup Ginis' (WGINI), (ii) a term which is the equivalent of a between group Gini coefficient of subgroup means (BGINI), and (iii) a term measuring the extent to which subgroups overlap or are not segmented (NSF).

Note that, since $\mu_k = \int_0^\infty (1 - F_k(x)) dx$, where $F_k(x) = \int_0^x f_k(z) dz$, BGINI, which compares differences in subgroup means, may be written as $\frac{1}{\mu} \sum_{k=2}^{K} \sum_{j=1}^{k} w_k w_j \left| \int_0^\infty (F_j(x) - F_k(x)) dx \right|$ and since $\left| \int_0^\infty (F_j(x) - F_k(x)) dx \right| \leq \int_0^\infty \left| (F_j(x) - F_k(x)) \right| dx$, the differences in means measures, commonly employed in measuring distributional differences, will frequently understate the differences in respective cumulative densities of groups j and k.

Knowledge of subgroup means, shares and Gini coefficients facilitate computation of WGINI and BGINI and, since G=WGINI+BGINI+NSF, the last term (NSF) can be computed given G. Generally, all terms are bounded between 0 and 1, and the equation can be re-arranged to provide a statistic measuring the extent to which distributions are similar or different i.e.:

$$SI = 1 - NSF/G \qquad [2]$$

A limitation of the Gini coefficient (and by implication SI) is its difficulty in handling negative values (Manero 2017b), in addition, from the current perspective, it hinges on differences in conditional means and does not directly compare distributions which falls foul of the veil of ignorance critique (Carneiro, Hansen and Heckman 2002, 2003). However, the extent to which distributions differ when they cover negative possibilities can be measured by using Multilateral Transvariation extensions of Gini's Transvariation coefficient and a Distributional Gini coefficient (Anderson et. al. 2019) each of which compare collections of distributions directly over their whole range which are outlined in Appendix 1.

2.3 Equality of opportunity in basic food security, who and what should be compared?

In considering food security and basic income wellbeing, the circumstances facing a household are the decision-making structure it confronts and the irrigation scheme upon which its farm is located, households will be grouped accordingly. In the present model, command over land[3] is considered a constraining factor in the agricultural production activity of a farming household. If

[3] The phrase "command over land" is employed rather than land ownership since some land is rented rather than owned and here title is of less concern than access.

distributions of farmable land differ over circumstance groupings this will clearly affect their opportunity for food security and basic income wellbeing. In terms of command over land, the obvious metric would be the area of farmable land that the household has access to. If the scale of operation is of any consequence in agricultural production, farm size relative to the size of the household would also matter. Thus the instruments of comparison will be farmable hectares and adult equivalized farmable hectares which is calculated using the square root rule (Brady and Barber 1948) familiar in household consumer demand analysis (Anderson 2003)[4].

The common approach to the Equal Opportunity question with respect to outcomes is to compare net household incomes. However, in the subsistence farming activity that is the component of overall household net income of interest here, households and farms vary in size and structure, and the agricultural component of overall income will vary accordingly. It is natural for larger farms and larger workforces (i.e. households) to engender larger revenues and expenses and, if command over land varies by head of household type, this will engender corresponding differences in the agricultural component by household type that are not related to capability. For this reason, the per hectare contribution will be considered in adult-equivalised and un-equivalised terms. Again, Adult Equivilization will be based upon the square root rule implying an output scale / family size elasticity of 0.5, i.e. there are some economies of scale in both production and consumption.

Anderson et. al. (2019) proposed two types of Distributional Gini coefficient, each based on Ginis transvariation which for probability density functions j and j:

$$GT_{i,j} = \frac{1}{2}\int_0^\infty \left|f_i(x) - f_j(x)\right| dx = \frac{1}{2}\int_0^\infty [\max\left(f_i(x), f_j(x)\right) - min\left(f_i(x), f_j(x)\right)] dx$$

[4] The rule simply divides hectares by the square root of household size.

One, which involves the relative size of the circumstance groups, weights each group according to its relative size in the overall population. The other unweighted version, corresponds to a representative agent model, compares circumstance-group outcome distributions directly. Both are reported for comparison purposes together with the aforementioned multilateral transvariation coefficient.

$$DISGINI = \frac{1}{(1-\sum_{k=1}^{K} w_k^2)} \sum_{i=1}^{K} \sum_{j=1}^{K} w_i w_j (GT_{ij}) \qquad [3]$$

An attraction of Gini's transvariation, and consequently the Distributional Gini is it can easily accommodate multivariate distributions. In the 2 variable x, y case reported later, the $f_i(x,y), f_j(x,y)$ transvariation:

$$GT_{i,j} = \frac{1}{2}\int_0^{\infty}\int_0^{\infty}[\max\left(f_i(x,y), f_j(x,y)\right) - min\left(f_i(x,y), f_j(x,y)\right)]dx$$

is simply inserted into equation [3].

3 Data and Background

As measured by the percentage of the population living on less than $PPP1.90/day, global poverty rates have been steadily declining, from 42% 1981, to just under 10% in 2015 (World Bank 2018). However, this has been largely driven by declines in East and South Asia. In Sub-Saharan Africa (SSA), poverty dropped from 56% to 43% over the decade leading to 2012, yet, because of high population growth, the total number of extreme poor remained practically unchanged (UN 2013). Generally, and in SSA in particular, rural areas are underdeveloped (UN 2014), with those depending exclusively on agriculture often the worst-off (Manero 2018; Senadza 2011). Agricultural land development (including irrigation), is recognized as an effective strategy for rural welfare development and poverty reduction (Manero et al. 2019).

However, measurement of these advances does not reflect the extent to which they have been made in accordance with the UNPD's avowed imperatives.

Disparities in access to the necessary natural resources, such as land and water, have prompted a body of literature to question its implications for equity, social justice and inclusive growth (Giordano & de Fraiture 2014; Gorantiwar & Smout 2005; Hasmath 2015 Manero et al. 2019; Van Den Berg & Ruben 2006). In developing countries, disparities in opportunities to access and use farm resources across the gender divide are considerable. (Bjornlund et al. 2017; Bjornlund et al. 2019; Cleaver & Hamada 2010; FAO 2004; Hussain 2007; Koppen & Hussain 2007; Lecoutere 2011; O'Sullivan et al. 2014; van Koppen et al. 2013). This is often due to differences in wealth and education levels, as well as social norms and inheritance traditions[5].

Sub-Sahara African irrigation scheme developments have been a major contributor in advancing food security and household poverty reduction in recent times (Davis et al., 2017). However, small farm sizes within these schemes means that households need a diversified income strategy, combining irrigation with dryland cropping and livestock as well as off farm household income earning activities (Bjornlund et. al 2019). However, diversification make the decision-making process more complex (Davis et al., 2017; Ellis, 2000; Ellis and Allison, 2004; Manero, 2017; Bjornlund et al., 2019). In many households, lower female education levels and additional household responsibilities, make off-farm work less accessible for women than men. In such circumstances, husbands are typically absent from the farm, working away and sending

[5] Following traditions of many rural communities across SSA, male offspring are the preferred inheritors of land and wealth. Young women, on the other hand, are expected to acquire access to further assets by marrying a well-resourced groom. However, once in wedlock, women still face barriers to acquiring land of their own, as family assets are not often (although increasingly) co-owned. Moreover, lower education levels and domestic workloads hinder women's ability to engage in paid work, which could be a pathway for saving towards a land purchase.

remittances (Cousins, 2013) leaving wives as principal farmers and *de-facto* household heads. This altered the structure and dynamic of the household decision-making process with an implication that it was rendered less effective (Bryceson, 2002; FAO of the United Nations, 2011a). In the context of Sub-Sahara Africa, the findings of Bjornlund et. al. (2019) disagreed with this. While they found that female-only decision-making households had the lowest total and farm income and households where a male made all the decisions had the highest total and farm income; households where a husband was present but the wife was the principal decision maker, came a close second[6] suggesting that the decision-making processes between the absent husband and at-home the wife worked effectively.

With regard to access to basic income wellbeing, when the distribution of farm size, or adult equivalent farm size, varies by household type (here determined by the irrigation scheme and the gender of the household head), it will contribute to variation in the crop income generation of those types since income from crops will naturally vary with the amount of land that is rented or owned. Also of account is the productivity of the farm, in terms of net crop revenue (crop revenues less expenses) or crop revenues per hectare and whether that productivity is dependent upon, or independent of, household type and the concomitant decision-making process. To be clear, the Equality of Opportunity imperative does not require crop productivity per hectare to be the same for all households of a particular type. There will naturally be some variation in managerial efficiencies and efforts amongst households of a given type, but those abilities are assumed to be distributed similarly over household types. In this context, Equality of

[6] Here, especially on smaller farms, income source diversification could be necessary in order to maintain food security for households of a given size, increasing the likelihood of a husbands' absence from the farm with the wife left as the principal decision maker on smaller farms. Thus, regarding food security, the scale of the farm relative to the size of the household may also be a factor so that adult equivalent measures could be relevant in the ensuing calculus.

Opportunity would imply that, conditional on household type, the distribution of crop (net) revenue per hectare, which reflects these efforts and efficiencies, is common to all household types.

The data used in this study was obtained from a research project entitled 'Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms' (ACIAR 2013). and focused on two smallholder irrigation schemes in each country (Figure 1). Limited number of observations on female headed-households in Mozambique preclude their adequate kernel estimation of distributions. Therefore, the two schemes there were not included in this study. The data were collected through two rounds of household surveys. The first, was carried out between May and July 2014, while the second occurred between March and May 2017. The questionnaire included questions relative to household structure and economic activities, over the 12 months prior to the interviews (Manero, 2018). Sampling methods varied depending on the size of the population of each irrigation scheme. In the smallest schemes − Mkoba (Zimbabwe) − the aim was to interview the whole population, yet some irrigators asked to be excused and others were absent. In the three largest schemes - Silalatshani (Zimbabwe), Kiwere and Magozi (Tanzania) - the population was sampled using a stratified approach. Households were categorised according to gender of the household head and wealth category (poor, medium and well-resourced) and then randomly sampled (Moyo et al. 2017). A summary of the population and samples is provided in Table 1.

Table 1 Characteristics of the irrigation schemes

Country	Irrigation scheme	Total area (ha)	Number of irrigating households	Average household landholding	Surveyed households	Main crops
Zimbabwe	Mkoba	10	75	0.13	68	Maize, horticulture
	Silalabuhwa	110	212	0.52	100	Maize, wheat, sugar beans, vegetables
Tanzania	Kiwere	139	168	0.95	100	Vegetables, maize
	Magozi	939	578	1.62	99	Rice

Source: Adapted from Manero (2017)

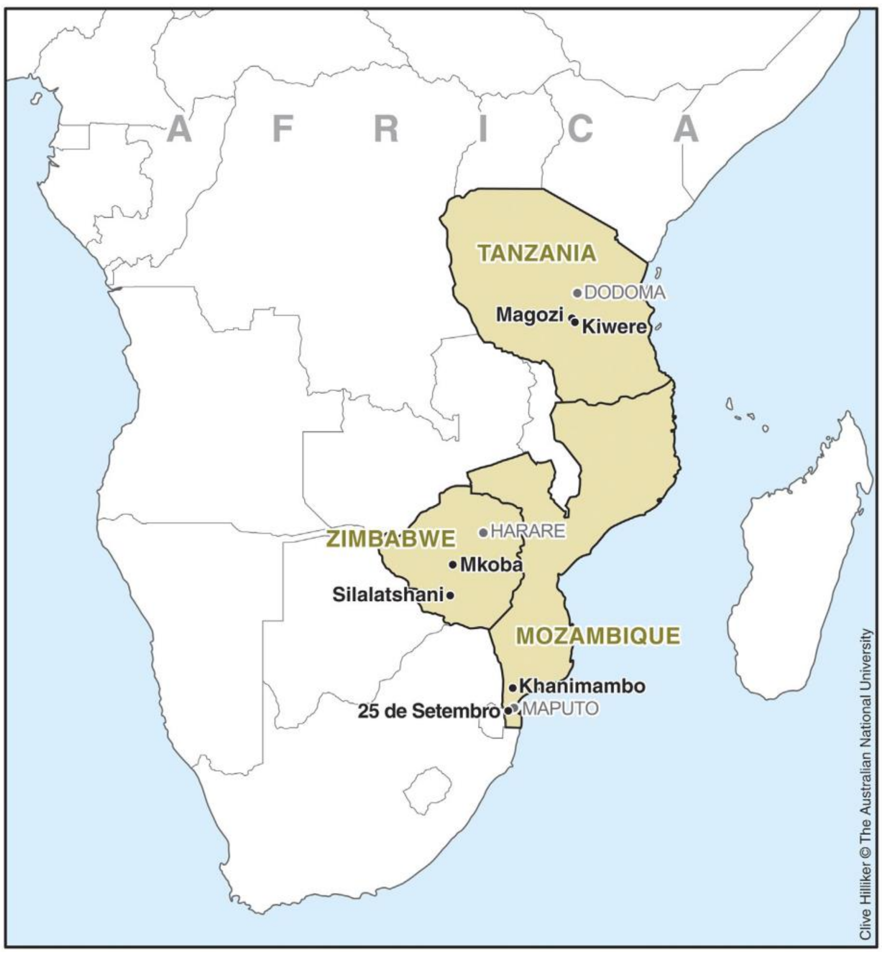


Figure 1 Locations of the six irrigation schemes. (Source: Mwamakamba et al. 2017)

4 Results and discussion.

In order to explore the possibility that circumstances affect equality of opportunity differentially in terms of access to land as opposed to productive capability, initially the issues are discussed in terms of their marginal distributions, as though they were influenced independently, then finally they are considered jointly. First a gender based decomposition is considered followed by a gender and irrigation scheme breakdown and then finally a gender-nation breackdown is explored in the jointly distributed analysis.

4.1a Inequality in the distribution of command over land.

If there are no significant differences in command over land across household type, there will be no question to answer with respect to equality of opportunity in respect of this capability/food security indicator. Table 2 reports the summary statistics for household command over land overall and by gender. By most of the standard tests of differences it may be readily seen that the mean and median command over land are significantly different by gender with female headed households typically being smaller in size and commanding smaller land parcels. The fact that 78.2% of male and 58.3% of female household heads have at least completed primary education in 2014 with 84.2% of male and 69.2% of female household heads having a similar status in 2017 supports the view that females had fewer off farm work opportunities.

Preliminary decomposition with respect to head of household of the Gini coefficient of both unadjusted and household size adjusted command over land reported in Table 3 suggests that, while overall inequality is increasing between observation years, it is in large part due to substantial increasing segmentation of the respective distributions. What this means is that male and female headed household farms are becoming increasingly unalike in scale in both adult equivalized and unequivalized senses. Basically command over land is polarizing with respect to the gender of the head of household. Disparities in command over land can be seen most clearly in Diagrams 1 and 2, which record distributions of access to land (unequivalized) respectively for Female and Male Household heads across all irrigation schemes. Recalling that Gini's Transvariation is the absolute value of the area between two curves, it can be seen to have increased between 2014 and 2017 from 0.3180 to 0.7021, with approximate standard error for the difference of 0.0331 the increase in distributional inequality over the period is significant.

Table 2. Distribution of Land (Irrigated + Dry) by gender of household head.

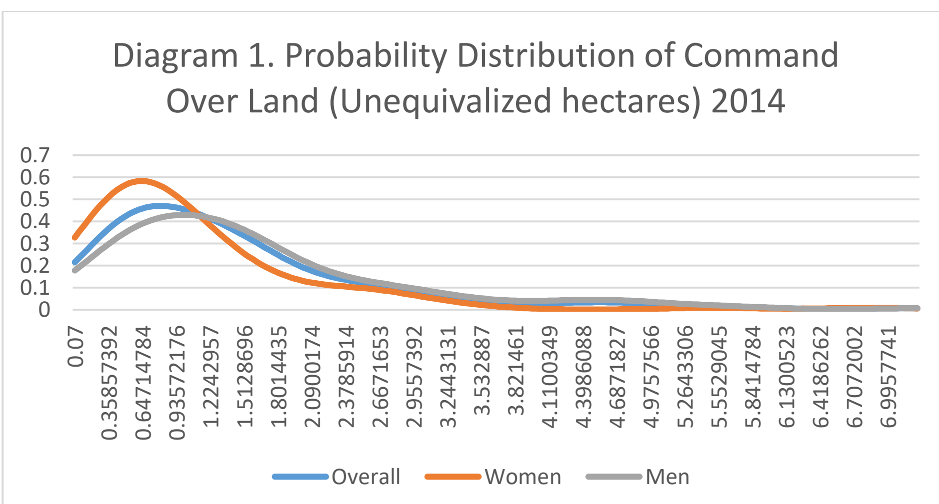
Overall	Household Size	Irrigated Area	Dry Area	Total Area	Irrigated Share	Total Area Adult Eqv
2014						
Mean	5.5603	0.7425	0.7181	1.4605	0.5921	0.6398
Median	5.0000	0.5000	0.4047	1.1750	0.5000	0.5008
Max	10.000	4.8562	6.8797	7.2843	1.0000	3.6422
Min	1.0000	0.0000	0.0000	0.0700	0.0000	0.0221
Std Dev.	2.3239	0.7628	0.9660	1.2285	0.3425	0.5246
Coef of v.	0.4179	1.0274	1.3453	0.8411	0.5785	0.8201
2017						
Mean	5.6120	1.0167	1.2946	2.3113	0.5332	1.1009
Median	5.0000	0.8000	0.8000	1.6000	0.5000	0.7155
Max	10.000	6.8000	41.600	42.800	1.0000	41.600
Min	1.0000	0.0000	0.0000	0.0300	0.0000	0.0113
Std Dev.	2.2918	0.8475	3.2541	3.4124	0.2650	2.4089
Coef of v.	0.4084	0.8336	2.5136	1.4764	0.4970	2.1881
Female HH head	Household Size	Irrigated Area	Dry Area	Total Area	Irrigated Share	Total Area Adult Eqv
2014						
Mean	5.0536	0.4178	0.6607	1.0786	0.5030	0.5121
Median	5.0000	0.3518	0.4000	0.7750	0.4226	0.3500
Max	10.000	2.4281	5.6656	6.8797	1.0000	3.0767
Min	1.0000	0.0700	0.0000	0.0700	0.0299	0.0221
Std Dev.	2.1386	0.3792	0.9244	1.0094	0.3442	0.4656
Coef of v.	0.4232	0.9075	1.3990	0.9359	0.6843	0.9092
2017						
Mean	5.2794	0.5836	0.6521	1.2356	0.5347	0.5745
Median	5.0000	0.4875	0.4000	1.0000	0.4286	0.4422
Max	10.000	1.7500	3.2000	4.7500	1.0000	1.7963
Min	1.0000	0.0300	0.0000	0.3000	0.0140	0.1342
Std Dev.	2.1499	0.4026	0.7619	0.9239	0.2836	0.4284
Coef of v.	0.4072	0.6899	1.1684	0.7477	0.5304	0.7456
Male HH head	Household Size	Irrigated Area	Dry Area	Total Area	Irrigated Share	Total Area Adult Eqv
2014						
Mean	5.7587	0.8696	0.7406	1.6101	0.6270	0.6897
Median	6.0000	0.6000	0.4047	1.2141	0.6000	0.5429

Max	10.000	4.8562	6.8797	7.2843	1.0000	3.6422
Min	1.0000	0.0000	0.0000	0.1000	0.0000	0.0378
Std Dev.	2.3667	0.8348	0.9825	1.2750	0.3360	0.5386
Coef of v.	0.4110	0.9600	1.3267	0.7918	0.5360	0.7808
2017						
Mean	5.6929	1.1219	1.4506	2.5725	0.5328	1.2287
Median	6.0000	0.8500	0.8500	1.8000	0.5000	0.8066
Max	10.000	6.8000	41.600	42.800	1.0000	41.600
Min	1.0000	0.0000	0.0000	0.0300	0.0000	0.0113
Std Dev.	2.3215	0.8930	3.5924	3.7319	0.2608	2.6626
Coef of v.	0.4078	0.7960	2.4764	1.4507	0.4895	2.1669

Table 3. Gini Subgroup Decomposition.

	Gini	Non Segmentation Factor	Segmentation Index	Between Group Gini
2014				
Farm Hectares	0.83442	0.25530	0.69404	0.07360
Farm Hectares Adult Equ.	0.79829	0.26327	0.68448	0.05613
2017				
Farm Hectares	0.85677	0.15177	0.82286	0.09094
Farm Hectares Adult Equ.	0.93861	0.07823	0.90869	0.09342

It may be the case that smaller households command smaller farms and, since female headed households were typically smaller, differences in the female and male household headed distributions may be a consequence of that. However, a similar story prevails in Diagrams 3 and 4 where hectares are adjusted for household size, with Transvariations of 0.4153 and 0.7671 in 2014 and 2017 respectively, with an approximate standard error for the difference of 0.0332 distributional inequalities are clearly increasing over the period.



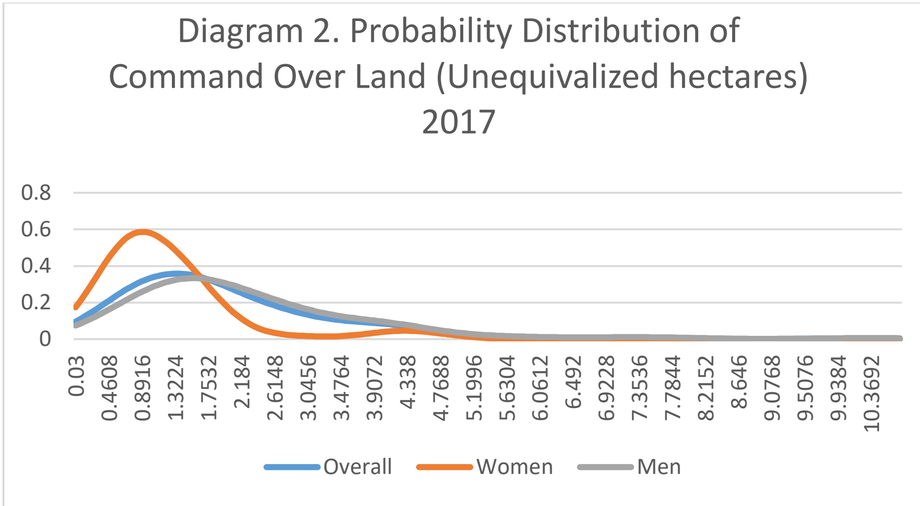


Diagram 2. Probability Distribution of Command Over Land (Unequivalized hectares) 2017
0.8
0.6
0.4
0.2
0
0.03
0.4608
0.8916
1.3224
1.7532
2.184
2.6148
3.0456
3.4764
3.9072
4.338
4.7688
5.1996
5.6304
6.0612
6.492
6.9228
7.3536
7.7844
8.2152
8.646
9.0768
9.5076
9.9384
10.3692
Overall
Women
Men

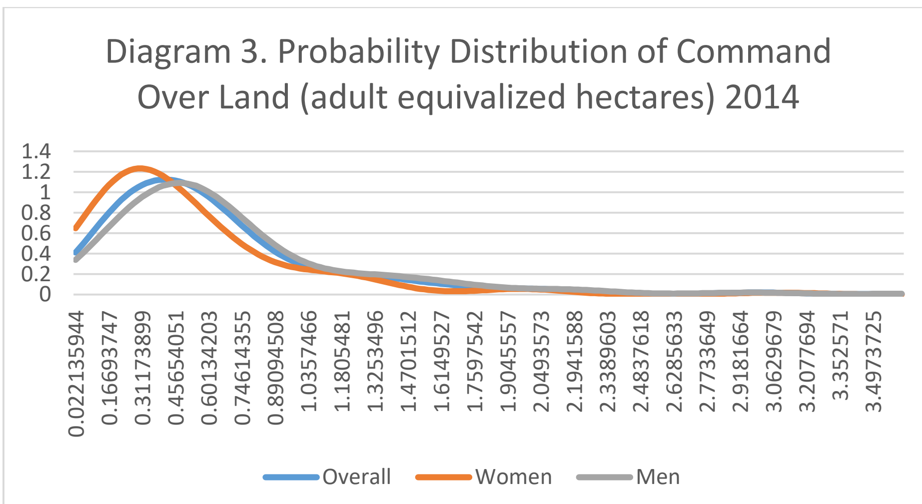


Diagram 3. Probability Distribution of Command Over Land (adult equivalized hectares) 2014
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.022135944
0.16693747
0.31173899
0.45654051
0.60134203
0.74614355
0.89094508
1.03574660
1.1805481
1.3253496
1.4701512
1.6149527
1.7597542
1.9045557
2.0493573
2.1941588
2.3389603
2.4837618
2.6285633
2.7733649
2.9181664
3.0629679
3.2077694
3.352571
3.4973725
Overall
Women
Men

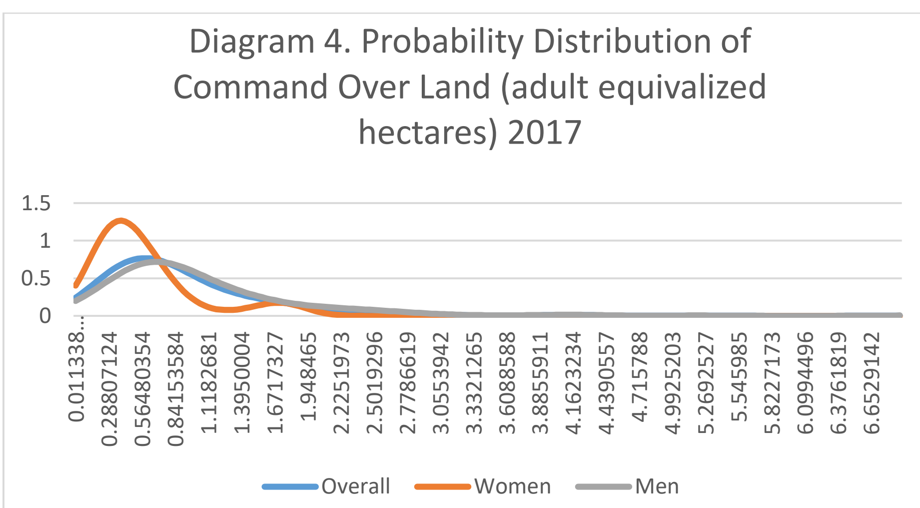


Diagram 4. Probability Distribution of Command Over Land (adult equivalized hectares) 2017
1.5
1
0.5
0
0.011338...
0.28807124
0.56480354
0.84153584
1.1182681
1.3950004
1.6717327
1.948465
2.2251973
2.5019296
2.7786619
3.0553942
3.3321265
3.6088588
3.8855911
4.1623234
4.4390557
4.715788
4.9925203
5.2692527
5.545985
5.8227173
6.0994496
6.3761819
6.6529142
Overall
Women
Men

4.2 Inequalities in Household Agricultural Net Revenue.

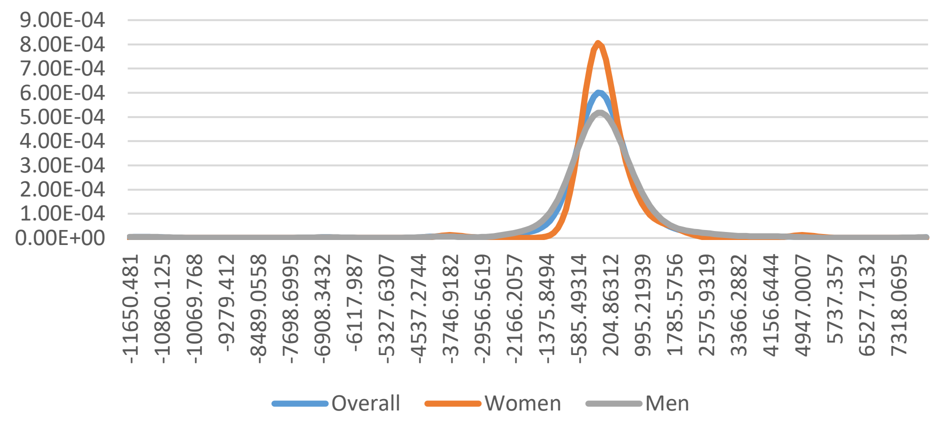
Since information on off-farm activities is not available in 2017 the only comparable outcomes in both periods are crop revenues and expenses and their difference which will be referred to as Crop Net Revenue. Table 3 records the summary statistics for Crop net revenues in levels and adult equivalent terms. The subsistence nature of the agricultural activity in the irrigation schemes frequently results in negative Net Revenue values, ruling out Gini coefficients as an option for analysis. However, the Distributional Gini, Transvariation and Stochastic Dominance Comparison measures are not hampered by negative values. Turning first to Crop Net Revenues, because household size may be an issue, all calculations have been pursued in actual levels as well as adult equivalized terms using Brady and Barber (1948) square root rule for adult equivalization (which implies economies of scale in consumption and production). Distributional differences are best visualized in diagrams 5 through 8.

Table 3. Distribution of Crop Net Revenues by Gender of Household Head.

Overall	Revenue Adult equiv	Expense Adult equiv	Revenue	Expense	Net Revenue Adult Equiv	Net Revenue
2014						
Mean	359.36	162.22	577.05	237.60	217.69	75.379
Median	210.00	98.288	173.00	79.993	0.0000	0.0000
Max	3826.6	1913.3	53233	18821	52962	18725
Min	0.0000	0.0000	-3214.0	-1607.0	-6773.8	-3386.9
Std Dev.	511.23	228.00	2895.4	1052.5	2917.6	1068.8
Coef of v.	1.4226	1.4054	5.0177	4.4294	13.402	14.179
2017						
Mean	742.06	340.34	385.96	175.09	-356.10	-165.24
Median	459.60	198.79	273.60	126.83	-153.95	-67.619
Max	4885.8	3037.5	3943.2	1394.1	2988.7	1056.7
Min	0.0000	0.0000	12.000	4.2426	-4487.4	-2767.5
Std Dev.	865.79	427.45	390.66	176.44	805.87	385.42
Coef of v.	1.1667	1.2560	1.0122	1.0077	2.2630	2.3324
Female HH head	Revenue Adult equiv	Expense Adult equiv	Revenue	Expense	Net Revenue Adult Equiv	Net Revenue
2014						
Mean	195.77	98.018	302.20	141.27	106.42	43.255
Median	142.17	67.441	73.790	38.234	0.0000	0.0000
Max	2230.3	997.41	5127.1	1812.7	4960.0	1753.6
Min	0.0000	0.0000	-1509.9	-675.25	-3740.2	-1672.7

Std Dev.	251.81	127.56	713.00	306.67	783.67	342.05
Coef of v.	1.2863	1.3013	2.3594	2.1708	7.3637	7.9077
2017						
Mean	424.52	182.92	238.28	111.10	-186.24	-71.813
Median	232.78	115.31	208.00	98.509	-43.988	-22.592
Max	3830.0	1211.2	1084.4	442.71	393.00	225.64
Min	0.0000	0.0000	40.000	18.699	-3378.0	-1068.2
Std Dev.	625.67	226.02	170.09	80.685	571.37	212.24
Coef of v.	1.4738	1.2357	0.7138	0.7262	3.0679	2.9554
Male HH head	Revenue Adult equiv	Expense Adult equiv	Revenue	Expense	Net Revenue Adult Equiv	Net Revenue
2014						
Mean	813.17	375.59	419.03	189.42	-394.14	-186.17
Median	486.94	227.24	299.00	133.72	-190.20	-96.279
Max	4885.8	3037.5	3943.2	1394.1	2988.7	1056.7
Min	0.0000	0.0000	12.000	4.2426	-4487.4	-2767.5
Std Dev.	896.59	453.52	417.77	188.58	845.79	411.81
Coef of v.	1.1026	1.2075	0.9970	0.9956	2.1459	2.2121
2017						
Mean	813.17	375.59	419.03	189.42	-394.14	-186.17
Median	486.94	227.24	299.00	133.72	-190.20	-96.279
Max	4885.8	3037.5	3943.2	1394.1	2988.7	1056.7
Min	0.0000	0.0000	12.000	4.2426	-4487.4	-2767.5
Std Dev.	896.59	453.52	417.77	188.58	845.79	411.81
Coef of v.	1.1026	1.2075	0.9970	0.9956	2.1459	2.2121

Diagram 5. Crop Net Reveue 2014



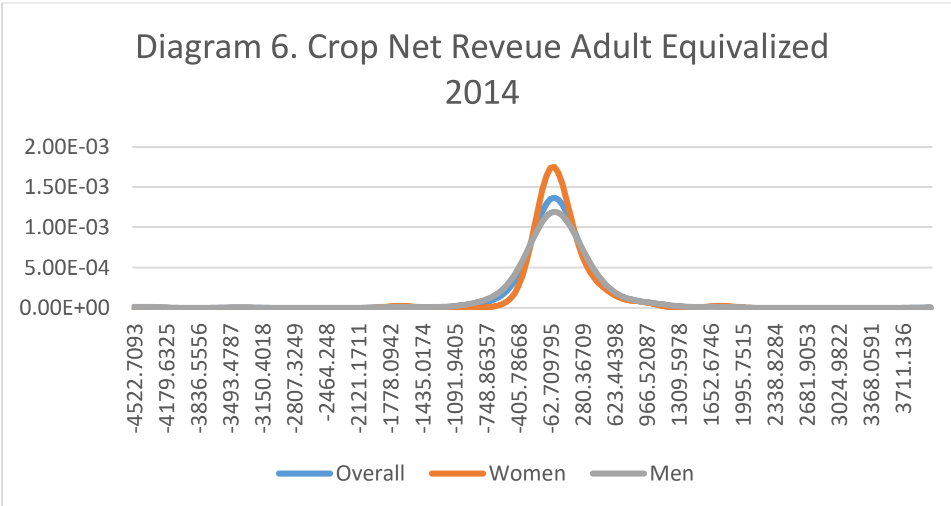


Diagram 6. Crop Net Reveue Adult Equivalized 2014
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-4522.7093
-4179.6325
-3836.5556
-3493.4787
-3150.4018
-2807.3249
-2464.248
-2121.1711
-1778.0942
-1435.0174
-1091.9405
-748.86357
-405.78668
-62.709795
280.36709
623.44398
966.52087
1309.5978
1652.6746
1995.7515
2338.8284
2681.9053
3024.9822
3368.0591
3711.136
Overall
Women
Men

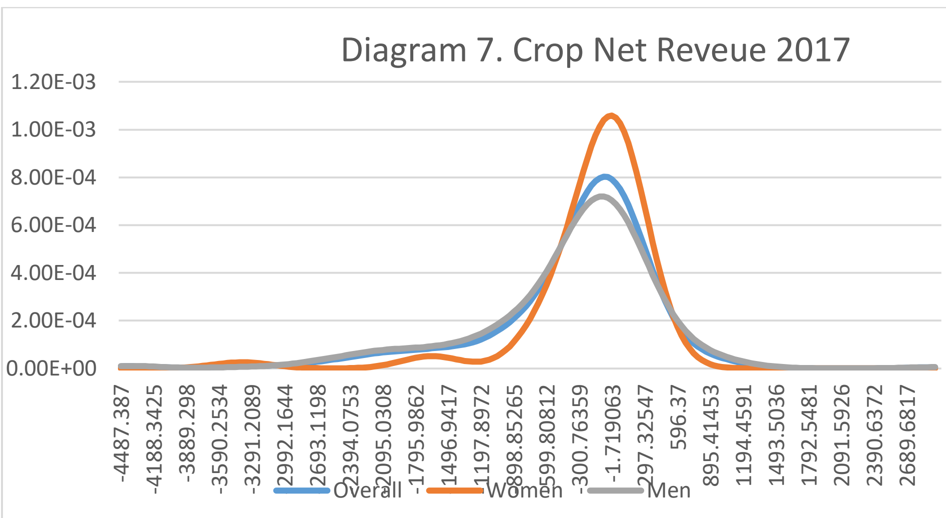


Diagram 7. Crop Net Reveue 2017
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
-4487.387
-4188.3425
-3889.298
-3590.2534
-3291.2089
2992.1644
2693.1198
2394.0753
2095.0308
-1795.9862
1496.9417
1197.8972
898.85265
599.80812
-300.76359
-1.719063
297.32547
596.37
895.41453
1194.4591
1493.5036
1792.5481
2091.5926
2390.6372
2689.6817
Overall
Women
Men

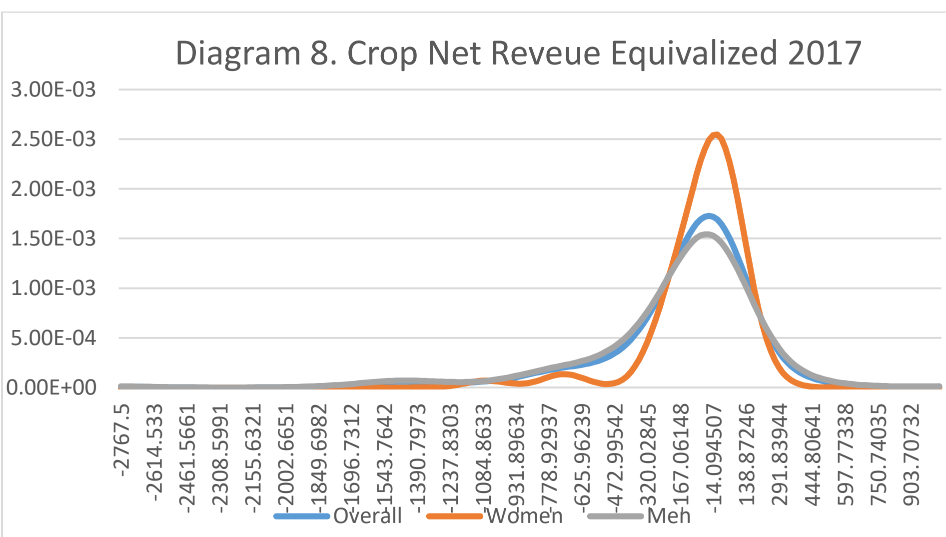


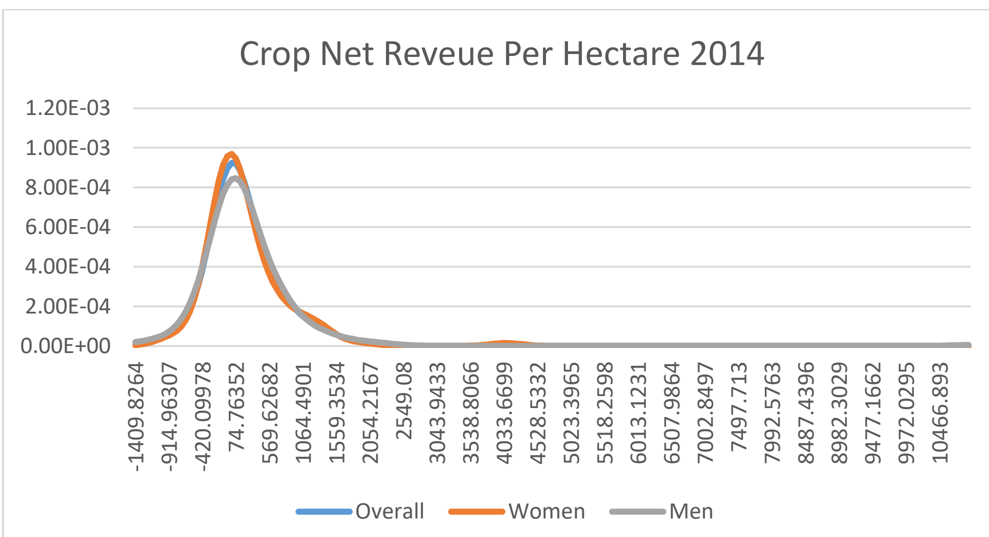
Diagram 8. Crop Net Reveue Equivalized 2017
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-2767.5
-2614.533
-2461.5661
-2308.5991
-2155.6321
-2002.6651
-1849.6982
1696.7312
1543.7642
-1390.7973
-1237.8303
1084.8633
-931.89634
-778.92937
-625.96239
-472.99542
-320.02845
167.06148
-14.094507
138.87246
291.83944
444.80641
597.77338
750.74035
903.70732
Overall
Women
Men

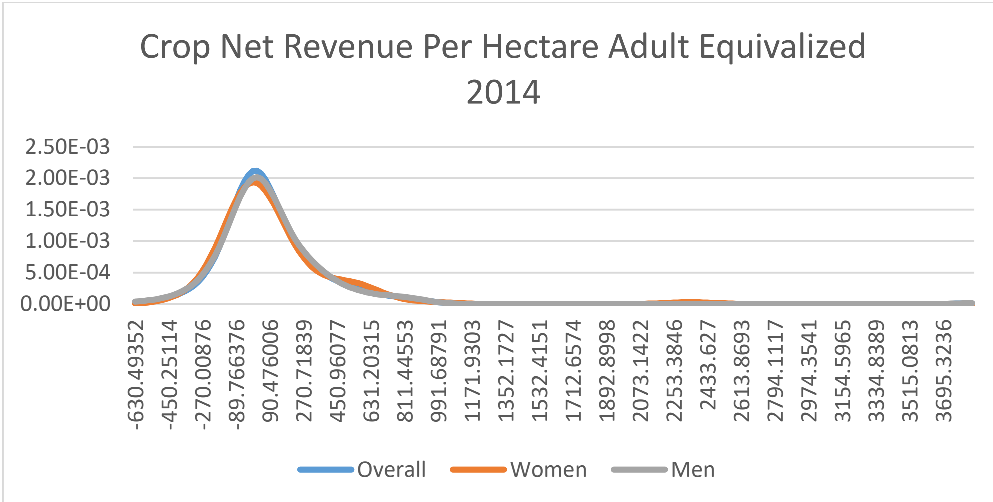
With regard to the influence of circumstances on farm net revenue, it can be argued that total net revenue is not the appropriate measure. In essence it is a productivity issue, if female household heads are associated with smaller scale farms than male heads but are equally efficient at management, females will automatically be associated with smaller farm revenues, but this does not reflect any inefficiencies in organizational structure. Following the notion that equally efficient units with equal opportunities should generate the same product per unit of land but wouldn't necessarily produce the same total product if the quantity of the constraining factor (land) varies across units, it makes sense to measure product per hectare. Table 4 reports the relevant statistics in "per hectare" terms. Basically working in revenues per hectare appears to engender even less variation in distribution than working in levels of net revenues. This can be seen more clearly by comparing diagrams 9 through 12 where male headed households net revenues in both levels and per hectare measures appear more variable than female.

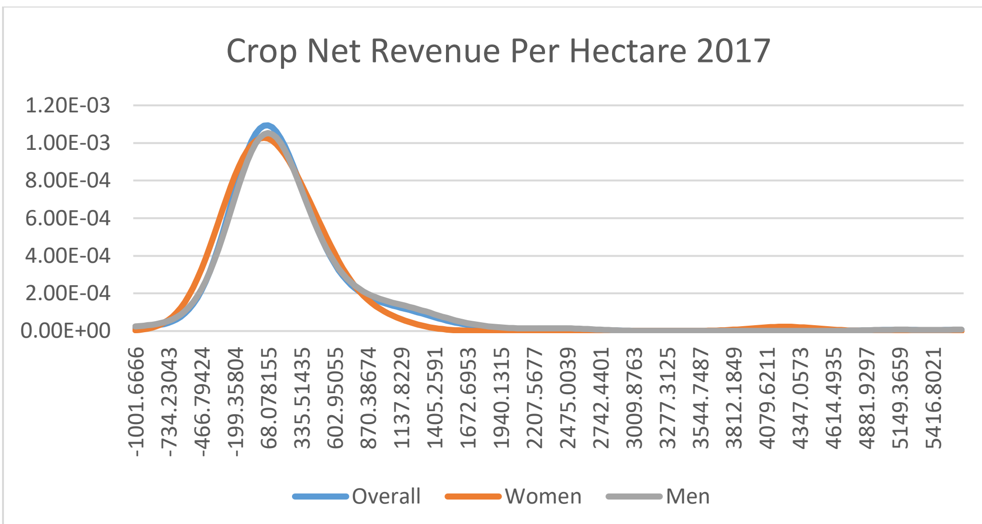
Table 4. Distribution of Crop Surplus Income Per Hectare by gender of household head.

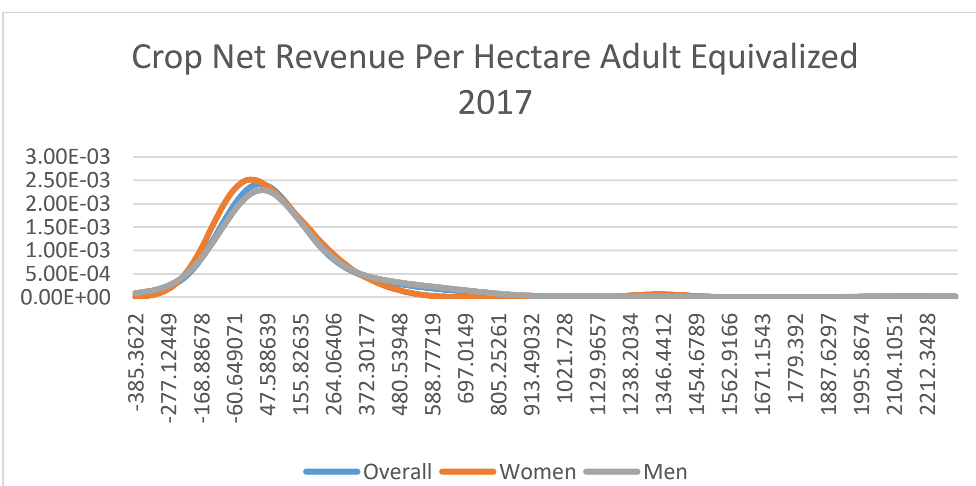
Overall	Revenueph	Expenseph	Surplusph	Revenuephaeq Adult equiv	Expensepheq Adult equiv	Ssurpluspheq Adult equiv
2014						
Mean	478.66	262.12	216.54	223.22	125.66	97.565
Median	235.86	188.79	64.708	98.406	82.870	28.589
Max	11018	1438.	10961.	3895.3	1100.0	3875.6
Min	0.0000	0.0000	-1409.8	0.0000	0.0000	-630.494
Std Dev.	762.58	268.41	765.72	334.42	143.19	321.66
Coef of v.	1.5932	1.0240	3.5362	1.4981	1.1395	3.2969
2017						
Mean	508.63	253.02	255.60	231.37	112.87	118.50
Median	289.87	164.60	104.22	132.71	77.380	46.992
Max	9038.0	10008.	5684.2	3416.2	3782.5	2320.6
Min	0.0000	0.0000	-1001.7	0.0000	0.0000	-385.36
Std Dev.	826.38	569.40	640.10	364.22	222.28	294.96
Coef of v.	1.6247	2.2504	2.5042	1.5741	1.9692	2.4891
Female HH head	Revenueph	Expenseph	Surplusphа	Revenuepheq Adult equiv	Expensepheq Adult equiv	Ssurpluspheq Adult equiv
2014						
Mean	425.57	215.75	209.82	216.95	110.97	105.98
Median	130.75	169.44	36.254	69.215	77.471	15.971
Max	4272.2	1082.0	4072.8	2466.6	1082.0	2351.5

Min	0.0000	0.0000	-920.00	0.0000	0.0000	-384.60
Std Dev.	615.67	217.44	600.29	346.05	137.49	313.55
Coef of v.	1.4467	1.0078	2.8610	1.5951	1.2390	2.9586
2017						
Mean	419.00	234.56	184.44	183.80	109.98	73.813
Median	304.38	218.37	43.000	136.10	83.300	24.184
Max	4787.5	903.68	4222.5	1513.9	482.60	1335.3
Min	0.0000	30.000	-332.98	0.0000	12.247	-144.64
Std Dev.	620.06	165.57	576.96	222.62	85.087	204.54
Coef of v.	1.4799	0.7059	3.1282	1.2112	0.7736	2.7711
Male HH head	Revenueph	Expenseph	Surplusphа	Revenuephae Adult equiv	Expensephaeq Adult equiv	Ssurplusphеq Adult equiv
2014						
Mean	499.16	280.03	219.13	225.65	131.33	94.316
Median	271.95	197.95	74.897	107.46	88.328	33.191
Max	11018.	1438.3	10961.	3895.3	1100.0	3875.6
Min	0.0000	0.0000	-1409.8	0.0000	0.0000	-630.49
Std Dev.	812.28	283.99	821.66	330.39	145.16	325.21
Coef of v.	1.6273	1.0141	3.7497	1.4642	1.1053	3.4481
2017						
Mean	530.39	257.51	272.89	242.93	113.58	129.35
Median	286.58	158.63	117.87	130.26	73.433	54.065
Max	9038.5	10007.	5684.2	3416.2	3782.6	2320.6
Min	0.0000	0.0000	-1001.7	0.0000	0.0000	-385.36
Std Dev.	868.67	629.72	654.30	390.38	244.35	312.33
Coef of v.	1.6378	2.4455	2.3977	1.6070	2.1514	2.4146




Crop Net Revenue Per Hectare Adult Equivalized 2014
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-630.49352
-450.25114
-270.00876
-89.766376
90.476006
270.71839
450.96077
631.20315
811.44553
991.68791
1171.9303
1352.1727
1532.4151
1712.6574
1892.8998
2073.1422
2253.3846
2433.627
2613.8693
2794.1117
2974.3541
3154.5965
3334.8389
3515.0813
3695.3236
Overall
Women
Men


Crop Net Revenue Per Hectare 2017
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
-1001.6666
-734.23043
-466.79424
-199.35804
68.078155
335.51435
602.95055
870.38674
1137.8229
1405.2591
1672.6953
1940.1315
2207.5677
2475.0039
2742.4401
3009.8763
3277.3125
3544.7487
3812.1849
4079.6211
4347.0573
4614.4935
4881.9297
5149.3659
5416.8021
Overall
Women
Men


Crop Net Revenue Per Hectare Adult Equivalized 2017
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-385.3622
-277.12449
-168.88678
-60.649071
47.588639
155.82635
264.06406
372.30177
480.53948
588.77719
697.0149
805.25261
913.49032
1021.728
1129.9657
1238.2034
1346.4412
1454.6789
1562.9166
1671.1543
1779.392
1887.6297
1995.8674
2104.1051
2212.3428
Overall
Women
Men

The lack of distributional variability in net revenues that contrasts with the distributional variability that prevails in access to land is borne out by standard Kolmogorov-Smirnov (K-S) two sample tests reported in Table 5. These test reveals significant differences in the distribution of land by gender of head of household in both years whereas there are differences in the distribution of net revenues in 2017 but not in 2014 and no differences in either year when net revenues are considered in per hectare terms.

The K-S test, when used directionally, can be used as a stochastic dominance test which Lefranc, Pistolesi and Trannoy (2009) employ as a test of equality of opportunity (since equality of opportunity implies equality of circumstance conditioned outcome distributions). In this respect the test suggests there is equality of opportunity when production is considered in per hectare terms but is more equivocal when considered in terms of net revenue levels (EO appears to prevail in 2014 but not in 2017). However, these results come with some reservations. The aggregated of Female Headed Household distribution has been compared with the aggregated Male Headed Household distribution, the circumstance of scheme location has been ignored and much variation could therefore be lost in convolution. In addition, a problem with using dominance relations as an equality of opportunity test is that if the null of equality of opportunity is rejected, it gives no sense of proximity to the transcendental state of Equal Opportunity, either a state of Equality of Opportunity is declared, or it is not. Another problem is that it is only a pairwise comparator so that illuminating the equality or otherwise of a large collection of distributions becomes extremely cumbersome.

Table 5. Kolminogorov-Smirnov* 2 Sample Tests Male vs Female household head distributions

Land Distributions	Unequivalized 2014	Unequivalized 2017	Equivalized 2014	Equivalized 2017
Differences	0.20448	0.38357	0.15800	0.35114
Stochastic Dominance “+”	0.20448	0.38357	0.15800	0.35114
Stochastic Dominance “-“	0.00317	0.00000	0.00000	0.00000

Household Net Revenue				
Differences	0.12205	0.16011	0.10749	0.18703
Stochastic Dominance "+"	0.06220	0.04354	0.05146	0.05917
Stochastic Dominance "-"	0.12205	0.16011	0.10749	0.18703
Household Net Revenue per hectare				
Differences	0.03141	0.06454	0.02508	0.07720
Stochastic Dominance "+"	0.03141	0.06454	0.01712	0.07720
Stochastic Dominance "-"	0.02414	0.00944	0.02508	0.01280

Critical Values for Alpha =	0.10	0.05	0.025	0.01	0.005	0.001
2014	0.12613	0.14389	0.15964	0.17833	0.19137	0.21841
2017	0.15672	0.17877	0.19834	0.22156	0.23778	0.27137

*The comparator. $D(\hat{F}_a(x), \hat{F}_b(x)) = \sup_x |\hat{F}_a(x) - \hat{F}_b(x)|$ is compared to a critical value $c(n_a n_b \alpha) = \sqrt{-0.5\ln(\alpha)} \left(\frac{n_a+n_b}{n_a n_b}\right)$, where n_a and n_b are the respective sample sizes and α is the chosen size of the test. The null hypothesis of commonality is rejected if $D > c$. Stochastic dominance tests can be contrived using $D(\hat{F}_a(x), \hat{F}_b(x)) = \sup_x \left(\hat{F}_a(x) - \hat{F}_b(x)\right)$ and $D\left(\hat{F}_a(x), \hat{F}_b(x)\right) = \inf_x \left(\hat{F}_a(x) - \hat{F}_b(x)\right)$. Rejection of one together with non-rejection of the other indicates a first order dominance relation.

4.3. Irrigation Scheme / Gender Based Comparisons.

Turning to an analysis of distributional inequalities over the combined circumstances of irrigation scheme and gender of household head, Tables 5 and 6 report the means medians and standard deviations of the respective schemes for Female and Male headed households in 2014 and 2017. Since the results are similar only the Land and Net Revenues per Hectare Output variables are reported, they reveal substantially more variation over the decomposition than the preceding decomposition by gender alone. Apart from Magozi, female headed households' command over land generally increased over the period, with male headed households advancing more than female headed households. Net revenue per hectare presents a very different story

Table 5

2014	Land	Net Revenue Per hectare	Land Adult Equiv	Net Rev.perhct Adult Equiv
Mkobi Women n=43				
Means	0.85622	61.3015	0.43653	27.7048
Medians	0.60000	-50.0000	0.30411	-23.5052
Standard Deviations	0.69064	414.075	0.36351	197.367
Mkobi Men n=25				

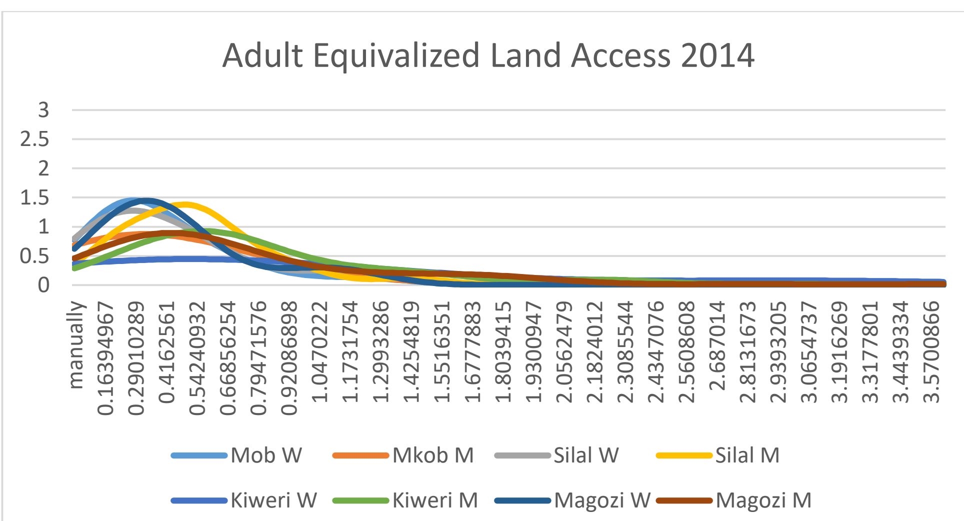
Means	0.88762	-139.209	0.50045	-49.3915
Medians	0.60000	-83.3333	0.35777	-31.1464
Standard Deviations	0.76313	406.134	0.61150	235.667
Sililatshan Women n=30				
Means	0.88083	206.963	0.44278	122.658
Medians	0.75000	67.0000	0.35907	23.4878
Standard Deviations	0.62445	617.443	0.34102	308.312
Sililatshan Men n=70				
Means	1.26061	47.3418	0.54061	20.4399
Medians	1.29000	-22.8889	0.52314	-7.64868
Standard Deviations	0.75034	388.383	0.29950	182.270
Kiwere Women n=8				
Means	1.99814	498.290	0.89493	286.496
Medians	0.91054	-5.69627	0.51238	-2.71392
Standard Deviations	2.21771	1450.68	0.96488	836.381
Kiwere Men n=92				
Means	1.93765	186.549	0.80360	72.1299
Medians	1.61874	134.201	0.66085	50.2798
Standard Deviations	1.40363	590.647	0.55473	238.781
Magozi Women n=18				
Means	1.10727	491.809	0.46180	218.936
Medians	0.91054	370.427	0.39354	135.112
Standard Deviations	0.75429	408.300	0.30817	199.896
Magozi Men n=82				
Means	1.66933	549.432	0.72923	244.469
Medians	1.21406	396.959	0.52574	172.441
Standard Deviations	1.42576	1280.94	0.62805	480.672

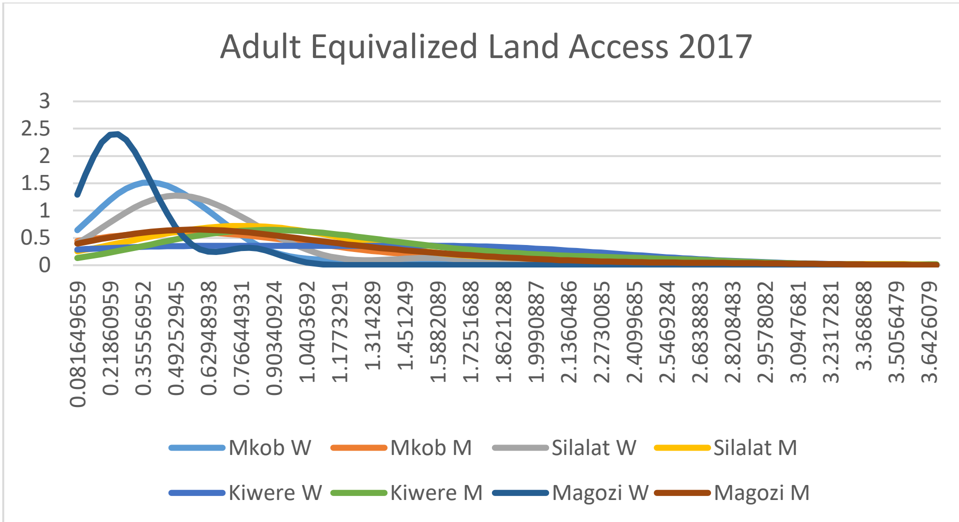
Table 6

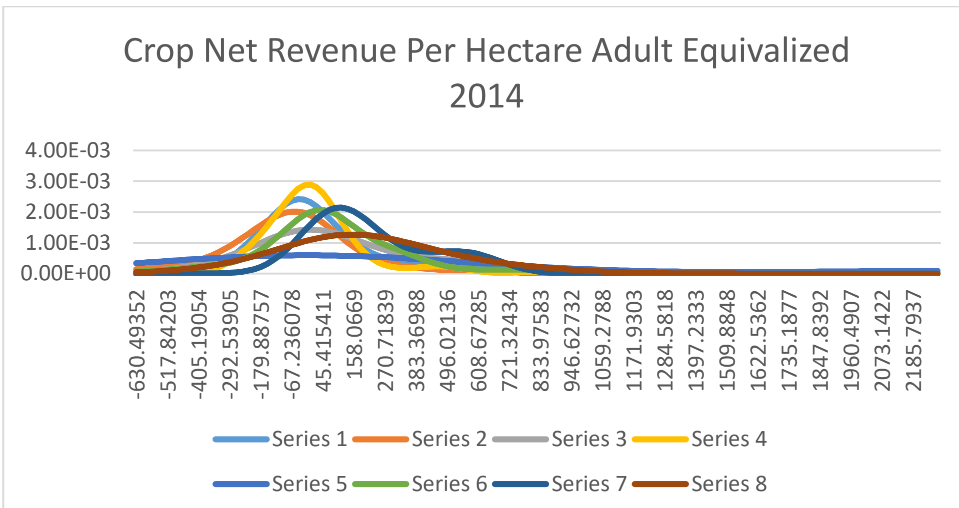
2017	Land	return perhct	Land Adult Equivt	returnperhct Adult Equivt
Mkobi Women n=28				
Means	0.94225	100.758	0.47971	55.8484
Medians	0.80500	3.24396	0.38957	-0.29937
Standard Deviations	0.53780	296.942	0.31235	146.867
Mkobi Men n=26				
Means	1.54115	373.258	0.86763	168.232
Medians	1.27500	121.075	0.54390	56.8308
Standard Deviations	1.11854	1039.99	0.90828	436.214
Sililatshan Women n=15				
Means	1.25467	355.972	0.59867	119.262
Medians	1.32000	-30.0000	0.49891	-12.2474
Standard Deviations	0.41177	1115.50	0.33050	364.761
Sililatshan Men n=56				
Means	2.32875	220.242	1.02698	121.313

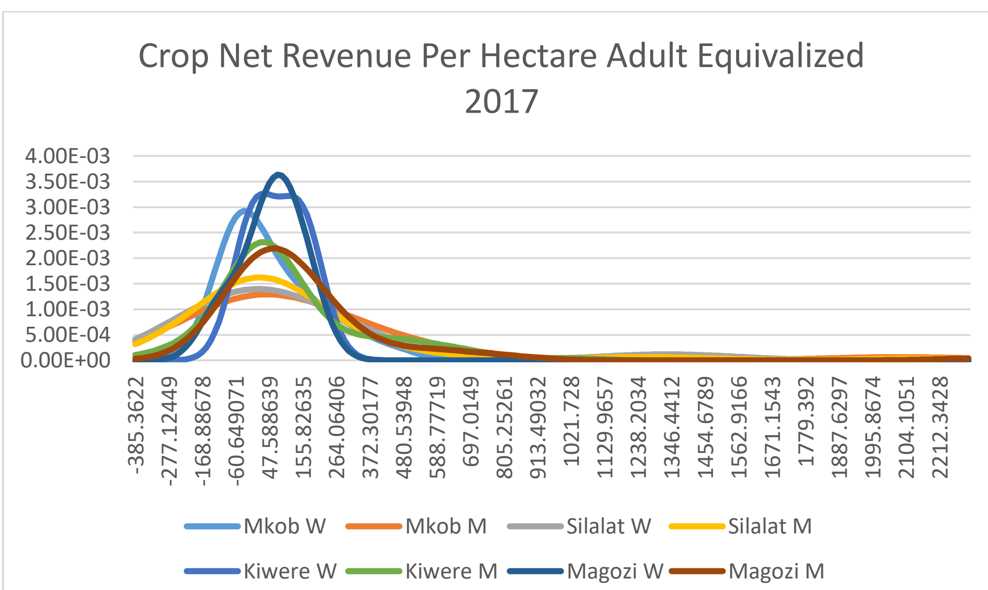
Medians	1.87500	30.1371	0.83434	12.4515
Standard Deviations	1.60122	648.184	0.81090	397.953
Kiwere Women n=4				
Means	2.62500	183.154	1.07165	74.7725
Medians	2.70000	172.693	1.10227	70.5017
Standard Deviations	1.94658	214.153	0.79469	87.4278
Kiwere Men n=92				
Means	2.78239	244.589	1.23718	112.987
Medians	2.40000	118.780	1.06738	48.1766
Standard Deviations	1.66482	503.048	0.73954	236.242
Magozi Women n=10				
Means	0.70500	137.210	0.31020	52.7823
Medians	0.55000	137.352	0.20813	53.6457
Standard Deviations	0.37301	225.635	0.18883	97.6249
Magozi Men n=90				
Means	1.91833	323.056	0.90546	150.532
Medians	1.60000	182.222	0.69785	87.8684
Standard Deviations	1.50690	680.925	0.88503	297.766

with households in the Mkobi scheme advancing (male headed households more so than female) while at Silalatshan, female headed household returns diminished their male counterparts advanced. The Tanzanian schemes of Kiwere and Magozi both saw average crop net revenue yields per hectare diminish over the period. These location effects only partially summarize the distributional differences illustrated in the following diagrams where increasing distributional variation in land access and diminishing variation per hectare in crop net revenues is evidenced.




Adult Equivalized Land Access 2017
3
2.5
2
1.5
1
0.5
0
0.081649659
0.21860959
0.35556952
0.49252945
0.62948938
0.76644931
0.90340924
1.0403692
1.1773291
1.314289
1.451249
1.5882089
1.7251688
1.8621288
1.9990887
2.1360486
2.2730085
2.4099685
2.5469284
2.6838883
2.8208483
2.9578082
3.0947681
3.2317281
3.368688
3.5056479
3.6426079
Mkob W
Mkob M
Silalat W
Silalat M
Kiwere W
Kiwere M
Magozi W
Magozi M


Crop Net Revenue Per Hectare Adult Equivalized 2014
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
-630.49352
-517.84203
-405.19054
-292.53905
-179.88757
-67.236078
45.415411
158.0669
270.71839
383.36988
496.02136
608.67285
721.32434
833.97583
946.62732
1059.2788
1171.9303
1284.5818
1397.2333
1509.8848
1622.5362
1735.1877
1847.8392
1960.4907
2073.1422
2185.7937
Series 1
Series 2
Series 3
Series 4
Series 5
Series 6
Series 7
Series 8


Crop Net Revenue Per Hectare Adult Equivalized 2017
4.00E-03
3.50E-03
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-385.3622
-277.12449
-168.88678
-60.649071
47.588639
155.82635
264.06406
372.30177
480.53948
588.77719
697.0149
805.25261
913.49032
1021.728
1129.9657
1238.2034
1346.4412
1454.6789
1562.9166
1671.1543
1779.392
1887.6297
1995.8674
2104.1051
2212.3428
Mkob W
Mkob M
Silalat W
Silalat M
Kiwere W
Kiwere M
Magozi W
Magozi M

In terms of equality of opportunity, Table 7 confirms that while the distribution of land has become significantly more unequal over the 2014-2017 period household net crop revenue returns to the land have equalized significantly. With the exception of adult equivalized net crop revenue per hectare, this is true for both unweighted and weighted Distributional Gini measures in absolute, per hectare and per hectare adult equivalized terms indicating that, while equality of opportunity appears to have regressed with respect to access to land, there has been some progress toward the Equal Opportunity State with respect to food security. However, in terms of overall wellbeing, it is the joint effect of these two dimensions that matters and so it is the joint distribution of access to land and net crop revenue that is relevant.

Table 7. Gender/Scheme Disginis and (Standard Deviations).

	Land		Net Crop Revenue		Net Crop Revenue per Hectare		Net Crop Revenue per Hectare ad equ	
	Disgin	WDisgin	Disgin	WDisgin	Disgin	WDisgin	Disgin	WDisgin
2014	0.2058 (0.0165)	0.1692 (0.0174)	0.3024 (0.0149)	0.2409 (0.0176)	0.4167 (0.0161)	0.4371 (0.0133)	0.3835 (0.0165)	0.3993 (0.0137)
2017	0.3382 (0.0159)	0.2698 (0.0145)	0.2433 (0.0145)	0.1750 (0.0166)	0.3249 (0.0162)	0.2662 (0.0149)	0.3572 (0.0159)	0.2983 (0.0145)
Difference Asymp Z P(Z>|z|)	-0.1324 5.7781 0.0000	-0.1006 4.4416 0.0000	0.0591 2.8426 0.0022	0.0659 2.7239 0.0032	0.0918 4.0193 0.0000	0.1709 8.5568 0.0000	0.0263 1.1478 0.1255	0.1010 5.0631 0.0000

The Multivariate Analysis.

Due to the paucity of female observations on some of the schemes (for example there are only 4 female household heads on the Kiwere scheme in 2017), kernel estimates of all of the subgroup joint distributions is not really viable so, for the joint distribution analysis, a four subgroup, nation-gender analysis is performed the results of which are reported in Table 8. Table 9 reports a selection of equality of opportunity sensitive overall wellbeing indices.

Table 8.

	2014		2017	
	Weighted	Unweighted	Weighted	Unweighted
Multivariate Distributional Gini	0.2895	0.2866	0.4379	0.4187
Standard Error	0.0156	0.0170	0.0175	0.0162

Clearly from Table 8, under a jointly distributed analysis, the negative impact on equality of opportunity resulting from changes in command over land has outweighed the positive impact on productive capability so that overall equality of opportunity has diminished over the period. For illustration purposes inequality of opportunity sensitive wellbeing measures, inspired by those suggested in Sen (1978) for a selection of inequality sensitivity parameter values are reported in Table 9.

Table 9.

	$\boldsymbol{\mu}^{\mathbf{1}-\boldsymbol{\alpha}}(\mathbf{1}-\text{DISGINI})^{\boldsymbol{\alpha}}$		
	$\alpha = 0$	$\alpha = 0.5$	$\alpha = 0.2$
2014	2.2481	1.2638	1.786
2017	1.8383	1.0165	1.450

Conclusions.

Lower farm income levels of female headed households in South East African Irrigation schemes (Bjornlund et. al. 2019) can be construed as a lack of equality of opportunity, a consequence of unequal access to resources, in particular the command over land. Data on the activities of household farms in 4 irrigation schemes in Tanzania and Zimbabwe in 2014 and 2017 were employed to consider the issue. Disparities in land access and household agricultural revenues and expenses per hectare were examined in a purely gender based Equality of Opportunity context and, since household size may have been a factor, due attention was paid to the impact of household size. Employing Kolmogorov – Smirnov two sample tests, distributional disparities in the command over land (a constraining factor in farm output) and farm related crop net revenues on absolute and per hectare bases were examined to see if equality of opportunity prevailed in this regard in that gender-based circumstance groups had similar experiences. Overall, while command over land was seen to be distributed differently over circumstance groups, and the differences are widening over the observation period, crop related outcome distributions by circumstance group did not exhibit the same significant differences and consequently there were no significant between period changes, suggesting a lack of significant progress. However, when the relationships were studied at a gender based / Irrigation scheme 8 circumstance group level, while distributions of land were seen to be significantly different and increasingly so over time, distributions of crop net revenue yields by circumstance groups, though significantly far apart, were converging over the observation period, indicating significant progress toward an equality of opportunity state in that dimension. When the two factors were combined in a joint analysis the deterioration in equality of opportunity in command over land outweighed any advances in productive capability so that overall equality of opportunity was seen to have deteriorated over time. These results were incorporated into an inequality of opportunity sensitive wellbeing index which duly recorded a decline in wellbeing standards over the period.

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Appendix 1: tools for analyzing multilateral differentness in collections of distributions

Gini (1916, 1959) provides a measure of the difference between two distributions in his Transvariation measure GT which, for two distributions $f_i(x)\ and\ f_j(x)$, is given by:

$$GT_{i,j} = \frac{1}{2}\int_0^{\infty}\left|f_i(x) - f_j(x)\right|dx = \frac{1}{2}\int_0^{\infty}[\max\left(f_i(x), f_j(x)\right) - min\left(f_i(x), f_j(x)\right)]dx \qquad [1]$$

GT will be 0 when the two distributions are identical and 1when they have mutually exclusive support. It can be readily shown that $GT_{i,j} = 1 - OV_{i,j}$ where $OV_{i,j}$ is the overlap measure $\int \min\left(f_i(x), f_j(x)\right) dx$ measuring the degree to which two distributions have common values. Generalizing (1) to K distributions indexed k=1,..,K (Anderson, Linton, Thomas 2017), a Multilateral Transvariation measure MGT can be contemplated where:

$$MGT = \frac{1}{K}\int_0^{\infty}[\max\left(f_1(x), f_2(x), \ldots, f_K(x)\right) - min\left(f_1(x), f_2(x), \ldots, f_K(x)\right)]dx \qquad [1a]$$

When distributions have mutually exclusive support and have no values in common MGT = 1 and when the distributions are identical MGT = 0 (weighted versions of MGT, MGTW are also possible). A problem with MGT is, its similarity to a multilateral range statistic, it is not very reflective of bi-lateral distributional differences and similarities in the mid range of the domain. It camouflages overlapping overlaps in the center of the collection of distributions – another veil of ignorance problem. Anderson, Linton, Pittau, Whang and Zelli (2019) provide a solution (together with asymptotic standard errors) to this in a distributional Gini coefficient DISGINI:

$$DISGINI = \frac{1}{(1-\sum_{k=1}^{K} w_k^2)} \sum_{i=1}^{K} \sum_{j=1}^{K} w_i w_j (1 - OV_{ij})$$

$$= \frac{1}{(1-\sum_{k=1}^{K} w_k^2)} \sum_{i=1}^{K} \sum_{j=1}^{K} w_i w_j (GT_{ij}) \qquad [4]$$

This statistic measures similarities and differences multilaterally. Again, it is an index between 0 and 1 measuring the lack of commonality over all distributions. It has an un weighted counterpart:

$$DISGINIUW = \frac{\mathrm{K}-1}{K^3} \sum_{i=1}^{K} \sum_{j=1}^{K} (1 - OV_{ij}) = \frac{\mathrm{K}-1}{K^3} \sum_{i=1}^{K} \sum_{j=1}^{K} (GT_{ij}) \qquad [4a]$$

which may be interpreted as a representative agent version of [4]. This statistic is perhaps more appropriate for an equality of opportunity comparisons since it compares the circumstance conditioned distributions without regard to their importance in the population. However, in what follows in the application both statistics are provided for comparison purposes and it turns out that it does not matter which statistic is used.