2019

IARIW-World Bank

Special IARIW-World Bank Conference "New Approaches to Defining and Measuring Poverty in a Growing World" Washington, DC, November 7-8, 2019

Equality of Opportunity in Food Security and Basic Household Incomes on Sub Saharan Africa Agricultural Irrigation Schemes

Gordon Anderson

Ana Manero

Henning Bjornlund

Paper Prepared for the IARIW-World Bank Conference

Washington, DC, November 7-8, 2019

Equality of Opportunity in Food Security and Basic Household Incomes on Sub Saharan Africa Agricultural Irrigation Schemes*.

Gordon Anderson — **University of Toronto**

Ana Manero — **University of Western Australia**

Henning Bjornlund — **University of South Australia**

April 21 2019

Abstract.

Underlying inclusive growth and poverty reduction aspirations, major components of the UN's sustainable development program, is the notion that all should have an equal chance of enjoying such advances and there is a need for measures that accommodate such aspirations. In promoting higher crop yields in household farms, Sub-Sahara African irrigation schemes have facilitated greater diversity in their income sources, which has played a key role in advancing household food security and poverty reduction in the region. However, since women are frequently less educated than their partners and have additional household obligations, their opportunities for off-farm work are more limited. In such cases, husbands work offfarm, leaving wives to manage the farm as the de facto household head which can complicate the units decision making process. This situation can be construed as an equal opportunity issue wherein the extent to which household types defined by their scheme location and household decision making structure predicament or circumstance influence the outcomes of access to, or command over, land and crop based incomes. When equality of opportunity prevails, the equal chances principle dictates that outcome distributions of different circumstance types be identical. However, the significant differences in incomes across household types noted in Bjornlund et. Al (2019) suggests that this may not the case. Non the less assessing progress toward the ideal state is of interest from policy, social evaluation and academic perspectives. This study introduces new methods for measuring the extent of distributional differences and assessing progress toward the equal opportunity state. Using 2014 and 2017 data from four Zimbabwean and Tanzanian irrigation schemes, the results indicate that, although there has been a deterioration in equality of opportunity in access to land, differences across circumstance types of crop based income distributions have diminished over the period, revealing significant progress toward the Equal Opportunity goal in that dimension.

*This work was supported by the Australian Centre for International Agricultural Research under project FSC2013-006.

1 Introduction

The Sustainable Development Goals Fund of the United Nations Development Program was created in March 2014 to bring together a range of entities, 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” are some of the key imperatives fundamental to the inclusive growth notion enunciated by the UNDP and there is a need for poverty alleviation measures that reflect such aspirations. The Foster Greer Thorbeke (1984) family of Intensity of Poverty measures are sensitive to inequality amongst the poor but they do not discriminate between inequalities that are a result of the forces of circumstance as opposed to inequalities founded upon personal choice and action. Here measures that reflect the extent to which inequalities are a consequence of circumstance are proposed and implemented, ultimately they can be employed to modify more standard poverty measures.

Global poverty rates have been steadily declining, from 42% 1981, to just under 10% in 2015 (World Bank 2018), as measured by the percentage of the population living on less than $PPP1.90/day. However, the global average has been driven predominantly by poverty 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). However measurement of these advances does not reflect the extent to which they have been made in accordance with the UNPD’s avowed imperatives.

At a global level, and in SSA in particular, rural areas tend to be the underdeveloped (UN 2014), and those depending exclusively on agriculture are often the worst-off among the rural poor

(Manero 2018; Senadza 2011). Development of agricultural land, including for irrigation, is recognized as a potentially effective strategy for rural welfare development and poverty reduction (Manero et al. 2019). However, 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.

The notion of Inclusive Growth, was in large part founded upon the Capabilities Approach to human development (Sen 1985, 1993, Nussbaum 1997, 2011). In his book, Development as Freedom, 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 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 equality of opportunity (or equal chances) for basic wellbeing attainment should prevail for all. 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 P. 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.

In the public policy - social choice - equal opportunity arena, a common core of the concept is the notion of agent responsibility, inequalities in agent outcomes should be addressed when they are a consequence of circumstances beyond an agents control (i.e. things for which the agent is not responsible such as gender, ethnicity etc.), whereas inequalities that are a consequence of actions and choices within an agent's responsibility (such as their work effort and application) do not require attention. Thus tools that distinguish inequalities that are a consequence of circumstances from inequalities that are a consequence of choice are required. Debates concerning various notions of Equality of Opportunity 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 defacto 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.

The policy evaluation perspective is measurement, so interest centers on the extent to which outcomes are a consequence of circumstance, in simple terms, in an ideal world, outcomes should be independent of circumstances so that groups defined by circumstances should have identical outcome distributions. Thus in the present context, the transcendentally optimal Equal

Opportunity state or policy target would have all circumstance groupings with identical distributions of command over land and identical income distributions.

However, in noting that this transcendentally optimal Equal Opportunity state is seldom attainable, Atkinson (2012) and Sen (2009) argued that the policy objective should be to progress toward the equal opportunity state, raising the question of how such progress could be measured. In this paper, new indices for measuring advancement toward an equal opportunity goal are introduced and applied to measured outcomes of farming household types on irrigation schemes in Sub-Saharan Africa. The index, DISGINI, is a Gini-like statistic with a value bounded between 0 and 1which measures the extent to which distributions within a collection differ from one another. When DISGINI=0, all the distributions in the collection are identical which corresponds to the equal opportunity ideal, when DISGINI=1 all of the distributions are completely segmented and have no common values, in essence, the other extreme where knowing an agents' outcome would completely identify its circumstance group.

Sub-Sahara African irrigation scheme developments have been a major contributor to the advancement of food security and household poverty reduction in recent times (Davis et al., 2017). However, small farm sizes within these schemes means that households need to have a diversified income strategy combining irrigation with dryland cropping and livestock as well as off farm household income earning activities (Bjornlund et. al 2019) but diversification opportunities 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, together with additional household responsibilities, made off-farm work less accessible for women than men. In such circumstances, a husband would typically be absent from the farm, working away and sending remittances (Cousins, 2013) leaving the wife as the principal farmer and *de-facto* head of household. 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) disagree 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[1]. This suggests that the decision-making processes between the absent husband and at-home the wife worked effectively.

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. While control over land may be thought of as a matter of choice for males, it could be construed as a circumstance beyond an agent's control for females. However, if the distribution of accessible land for female household heads is identical to that of male heads, it would be of no account in the equal opportunity calculus. In this context, the question is not so much whether female decision-makers have the same opportunities as males in access to land, but whether those

[1] 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.

opportunities are becoming more equal in some sense. 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. The real question is whether the productivity of the farm, in terms of net crop revenue (crop revenues less expenses) per hectare, 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 Opportunity would imply that, conditional on household type, the distribution of crop net revenue yield per hectare, which reflects these efforts and efficiencies, is common to all household types.

In responding to the entreaties of Atkinson (2012) and Sen (2009), the empirical question is how to evaluate progress toward equality of opportunity. In that state, the collection of circumstance-conditioned outcome distributions would all be identical, completely overlapping in absolute commonality. In such a state, it would not be possible to identify a household type by its outcome. At the other extreme, the collection of distributions would be completely segmented, each distribution with its own unique support with no overlap or measure of commonality between any and all pairs of distributions in the collection. In this case, 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 completely overlapping state.

Generally, the literature has followed two paths. Regression/Treatment Effect Approaches to circumstance state income persistence (Mulligan 1997, Solon 1992, 2008) seek reductions in statistical differences in conditional location measures. Such approaches have been subject to the criticism that differences in circumstance-conditioned distributions are not fully represented by differences in location measures, overlooking the full extent of distributional differences (Carniero, Hansen, Heckman 2003 and Durlauf, Quah 2002). This critique advocates multilateral comparison of distributional differences over their complete range. 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, which implies equality of opportunity. Problems with this approach are many. For example, dominance tests are pairwise comparators and are cumbersome when it comes to many circumstance classes. Furthermore, they only reveal whether the transcendental state has been achieved and give no sense or measure of proximity to the Equal Opportunity state, which Atkinson and Sen argue 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, which facilitate the evaluation of such progress by utilizing unit free measures of the extent to which the conditional distributions differ. The questions being asked is "Are circumstance-conditioned distributions of land access / farm incomes and expenditures, similar across circumstance classes?" and "To what extent are circumstance conditioned distributions becoming more or less similar?".

In the following, the new techniques for examining Equality of Opportunity are outlined in section 1. Section 2 discusses the relationships that are to be considered. To anticipate the results presented section 3, in the face of significant and growing differences in command over land by circumstance group, distributional variation in net crop revenue per hectare by circumstance group were diminishing over time indicating progress toward an Equal opportunity imperative.

2 Methods

2.1 The Equal Opportunity Principle and Distributional Inequalities.

At the heart of the Equality of Opportunity principle is the idea that the force of circumstances beyond an individuals' control should not affect that individuals chance or probability of success. In this context, inequality of outcomes that are a matter of personal choice are of much less concern than outcome inequalities that are a consequence of circumstances beyond an individuals' control. Thus, in the ideal, socially just, transcendentally optimal state, while chances of different achievements or success outcomes may vary, the chance of any particular outcome should be the same for all circumstance groups. More formally, if outcome variable "X" for circumstance class k is described by the conditional outcome distribution $f_{X,k}(x|k)\ for\ k = 1,..,K$, circumstance classes, then the "Transcendentally Optimal" state requires that $f_{X,k}(x|k) = f_X(x)\ for\ all\ x\ and\ all\ k = 1,..,K$. Here distributional inequality measures (together with their asymptotic standard errors) are proposed which are bounded between 0 and 1; where 0 implies equality of opportunity in the sense that all distributions have to be identical, and 1 implies that the distributions are perfectly segmented having no values in common so that a particular outcome would completely identify a circumstance group. Furthermore, they can be shown to be asymptotically normal so that consistent tests for equality of opportunity and movement toward or away from the ideal state are viable.

2.2 Distributional Inequality Measurement and Subgroup Decomposition.

Measuring the extent to which there are differences in a collection of distributions requires a measure that reflects commonality in the collection or the extent to which the different distributions intersect or overlap. The most common and popular measure of differences in a collection of numbers is the average relative to the mean difference or Gini Coefficient (Gini 1921). Though Gini's original intent was for it to be used to measure differences in any collection of numbers it has predominantly been used to measure income inequality. It has its drawbacks, it does not work well with negative numbers (Manero 2017) and it is not generally subgroup decomposable (Bourguignon 1970) both of which are important in the present context. However, Mookherjee and Shorrocks (1982) demonstrated that, when each subgroup distribution is are completely segmented from all others and defined on unique, mutually exclusive, segments of the real line, it is subgroup decomposable. This can be an advantage in the present context, since it will yield a measure of the extent to which distributions overlap i.e. are not segmented. Given a 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:

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

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

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

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

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

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).

It is interesting to note that, since $\mu_k = \int_0^{\infty}(1-F_k(x))dx$, where $F_k(x)$ is the cumulative density of $f_j(x)$, BGINI, which compares differences in subgroup means, may be written as:

$$\frac{1}{\mu}\sum_{k=2}^{K}\sum_{j=1}^{k} w_k w_j\left|\int_0^{\infty}(F_j(x)-F_k(x))dx\right|$$

Since $\left|\int_0^{\infty}(F_j(x)-F_k(x))dx\right| \leq \int_0^{\infty}\left|(F_j(x)-F_k(x))\right|dx$, differences in means, a common instrument used in measuring distributional differences, will frequently understate the differences in respective cumulative densities of groups j and k.

Knowledge of the subgroup means, shares and Ginis' results in WGINI and BGINI being readily computed. Since G=WGINI+BGINI+NSF, this last term (NSF) can also be easily computed. Generally, all terms are bounded between 0 and 1, and the equation can be re-arranged to provide a convenient 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.

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[2] is considered a constraining factor in the agricultural production activity of a farming household. If 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)[3].

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,

[2] 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.

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

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, 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.

3 Data and Background

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.

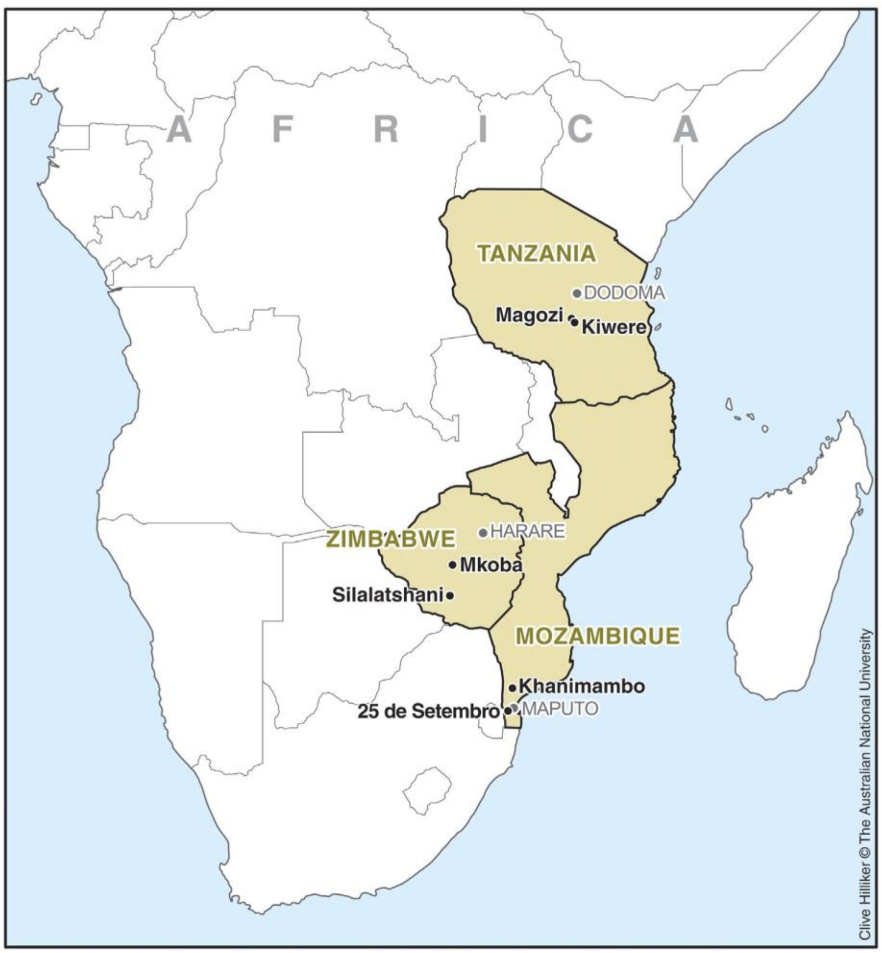


Figure 1 Locations of the six irrigation schemes. (Source: Mwamakamba et al. 2017)

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)

4 Results and discussion

4.1 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. 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.

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.

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

Disparities in command over land can be seen most clearly in the following Diagrams 1 and 2, recording the 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.

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.

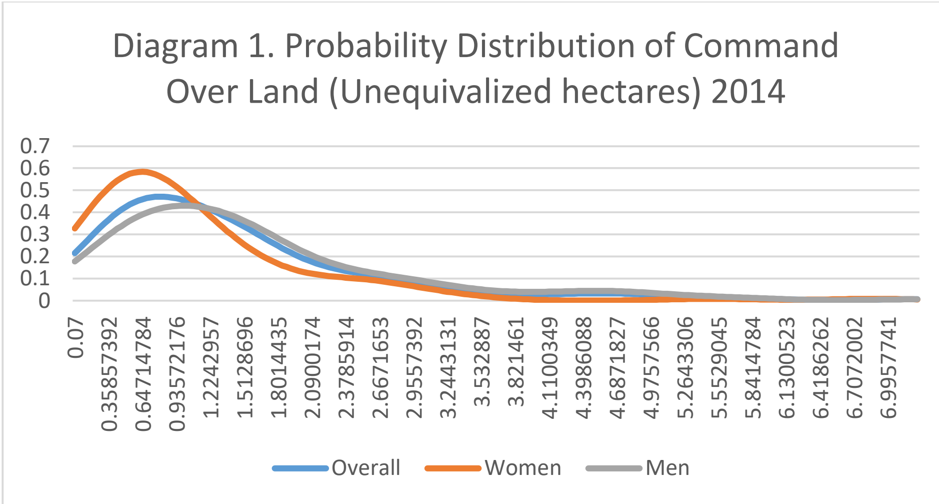


Diagram 1. Probability Distribution of Command Over Land (Unequivalized hectares) 2014
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.07
0.35857392
0.64714784
0.93572176
1.2242957
1.5128696
1.8014435
2.0900174
2.3785914
2.6671653
2.9557392
3.2443131
3.532887
3.821461
4.1100349
4.3986088
4.6871827
4.9757566
5.2643306
5.5529045
5.8414784
6.1300523
6.4186262
6.7072002
6.9957741
Overall
Women
Men

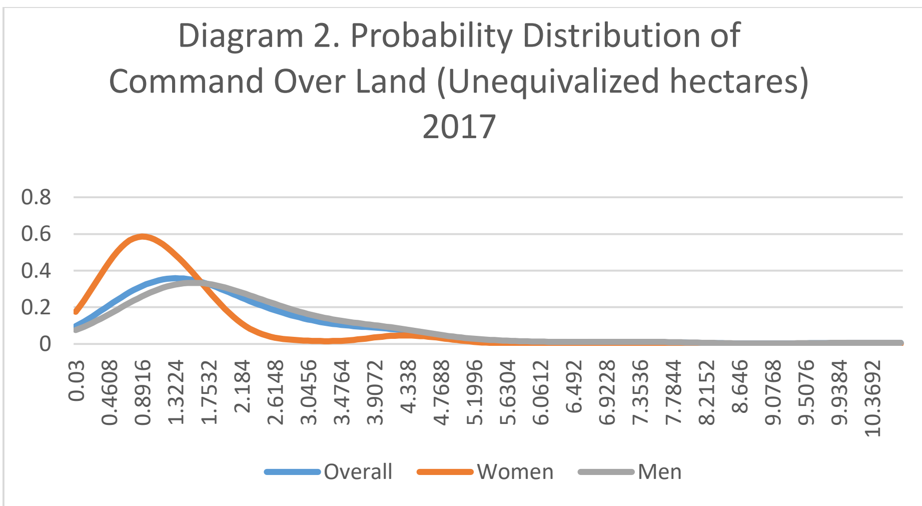


Diagram 2. Probability Distribution of Command Over Land (Unequivalized hectares) 2017
0.8
0.6
0.4
0.2
0
0.03
0.4608
0.8916
1.3224
1.7532
2.184
2.6148
3.0456
3.4764
3.9072
4.338
4.7688
5.1996
5.6304
6.0612
6.492
6.9228
7.3536
7.7844
8.2152
8.646
9.0768
9.5076
9.9384
10.3692
Overall
Women
Men

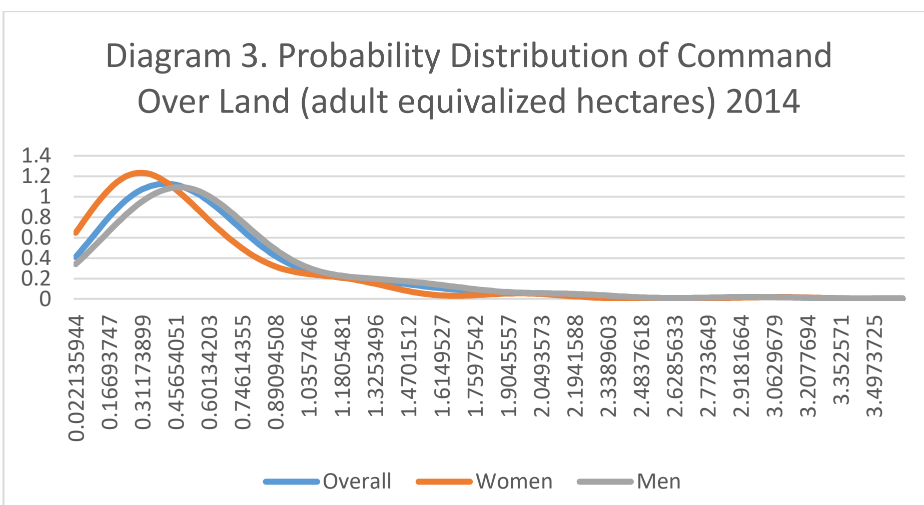
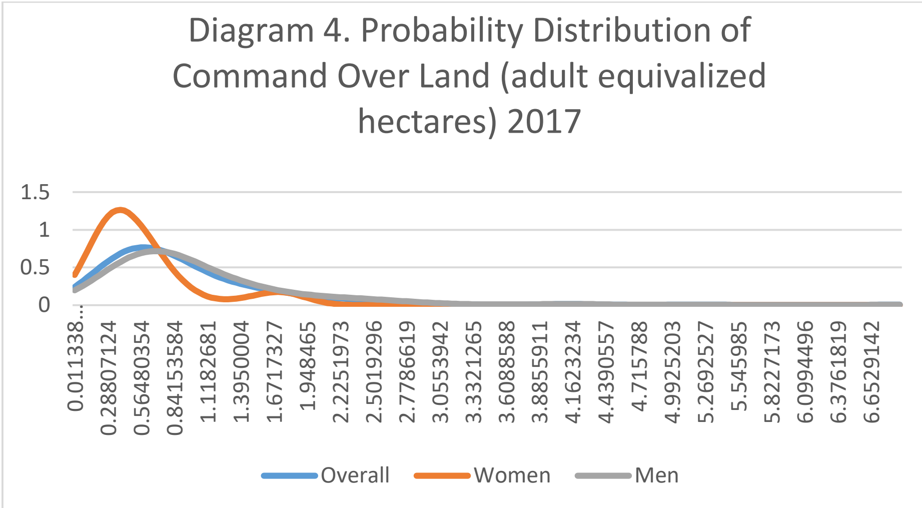


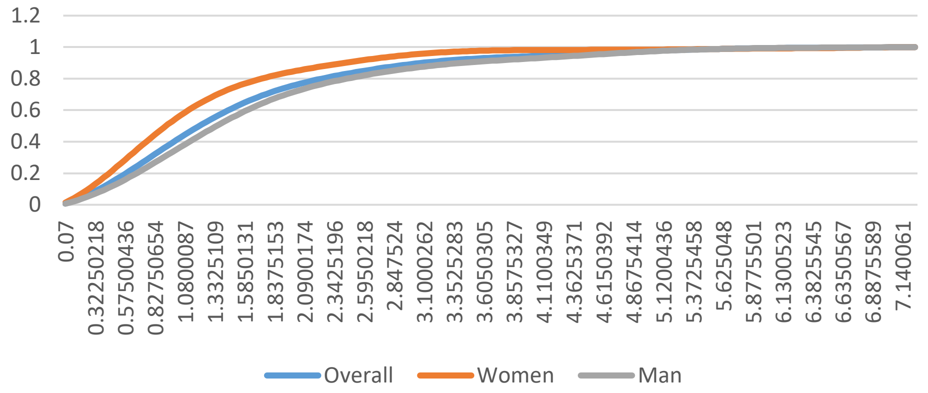
Diagram 3. Probability Distribution of Command Over Land (adult equivalized hectares) 2014
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.022135944
0.16693747
0.31173899
0.45654051
0.60134203
0.74614355
0.89094508
1.0357466
1.1805481
1.3253496
1.4701512
1.6149527
1.7597542
1.9045557
2.0493573
2.1941588
2.3389603
2.4837618
2.6285633
2.7733649
2.9181664
3.0629679
3.2077694
3.352571
3.4973725
Overall
Women
Men



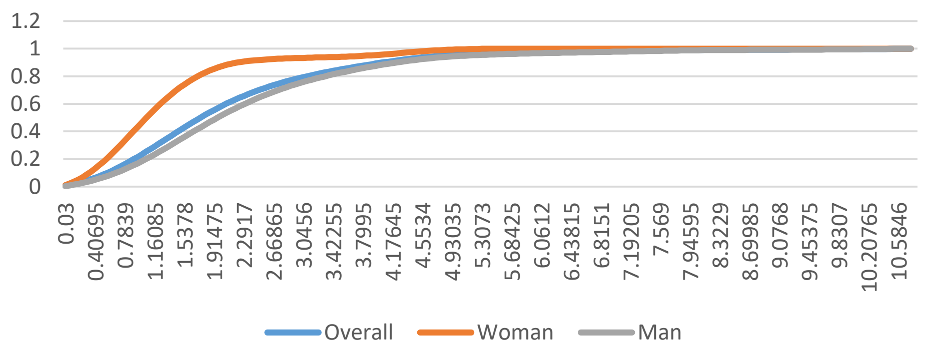
Indeed, in cumulative distribution terms, Diagrams 5 through 8 reveal that Male-headed household distribution functions first order stochastically dominate Female headed household functions ($F_f(x) \geq F_m(x)$ for all x with strict inequality holding at some points) and the extent of the dominance is growing. This implies that for any and all monotonically increasing preference functions for land access, Male-headed households would be better-off, on average, than their Female headed counterparts.[4]

[4] Noting that $E_{f(x)}(X) = \int_0^{Max\,x}(1 - F(x))dx$ so that $E_{f(x)}(X) - E_{g(x)}(X) = \int_0^{Max\,x}[(1 - F(x)) - (1 - G(x))]dx$ And thus$E_{f(x)}(X) - E_{g(x)}(X) = \int_0^{Max\,x}(G(x) - F(x))dx$ areas between curves nicely illustrate differences in means with higher curves indicating lower means.

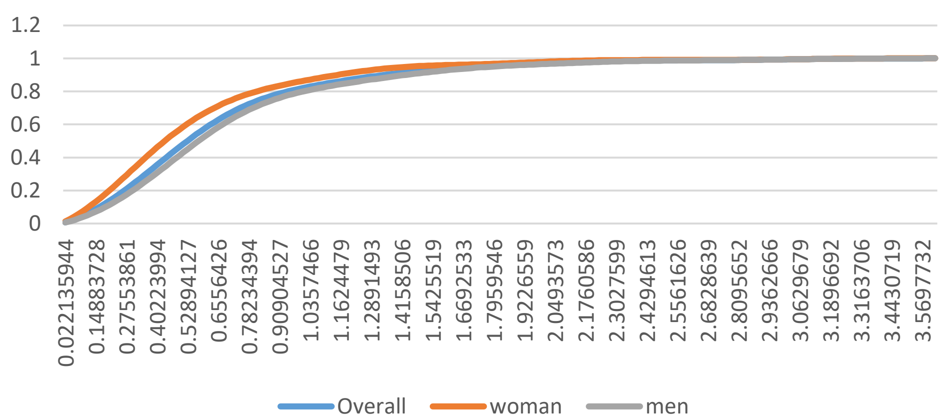
Diag. 5 Cumulative Densities Un-Equivalized land access (hectares) 2014

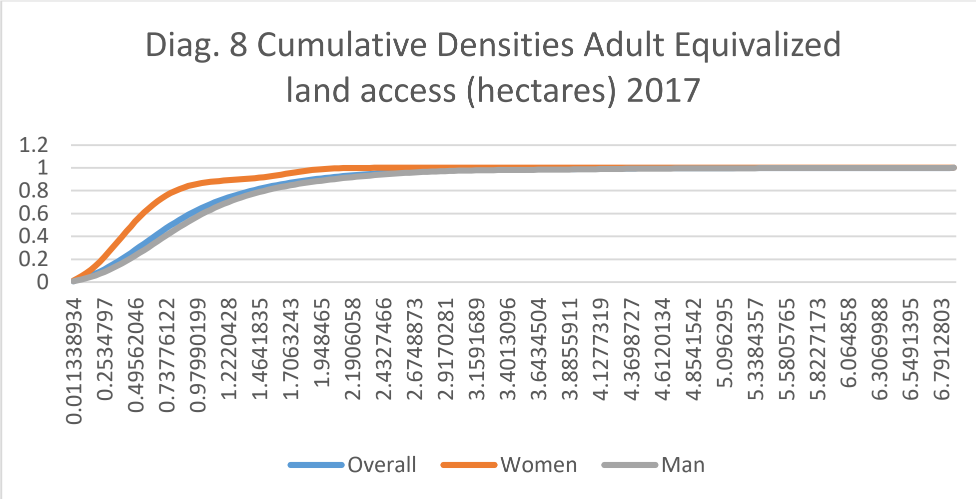


Diag. 6 Cumulative Densities Un Equivalized land access (Hectares) 2017



Diag. 7 Cumulative Densities Adult Equivalized land access (Hectares) 2014





5. Results. Inequalities in Household Agricultural Revenues and Expenses.

Having established that female and male household heads confront increasingly different situations with respect to their command over land, attention turns to distributional differences in agricultural incomes and expenditures. 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 9 through 12.

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

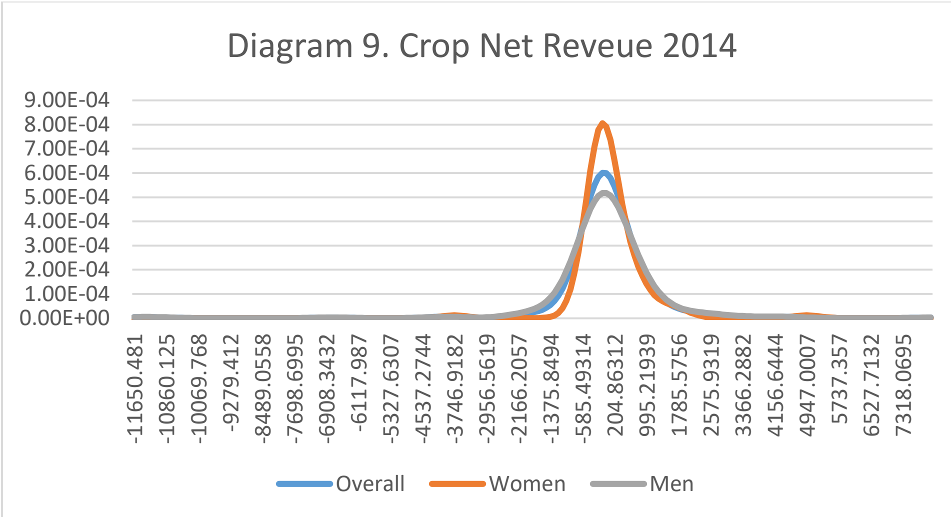


Diagram 9. Crop Net Reveue 2014
9.00E-04
8.00E-04
7.00E-04
6.00E-04
5.00E-04
4.00E-04
3.00E-04
2.00E-04
1.00E-04
0.00E+00
-11650.481
-10860.125
-10069.768
-9279.412
-8489.0558
-7698.6995
-6908.3432
-6117.987
-5327.6307
-4537.2744
-3746.9182
-2956.5619
-2166.2057
-1375.8494
-585.49314
204.86312
995.21939
1785.5756
2575.9319
3366.2882
4156.6444
4947.0007
5737.357
6527.7132
7318.0695
Overall
Women
Men

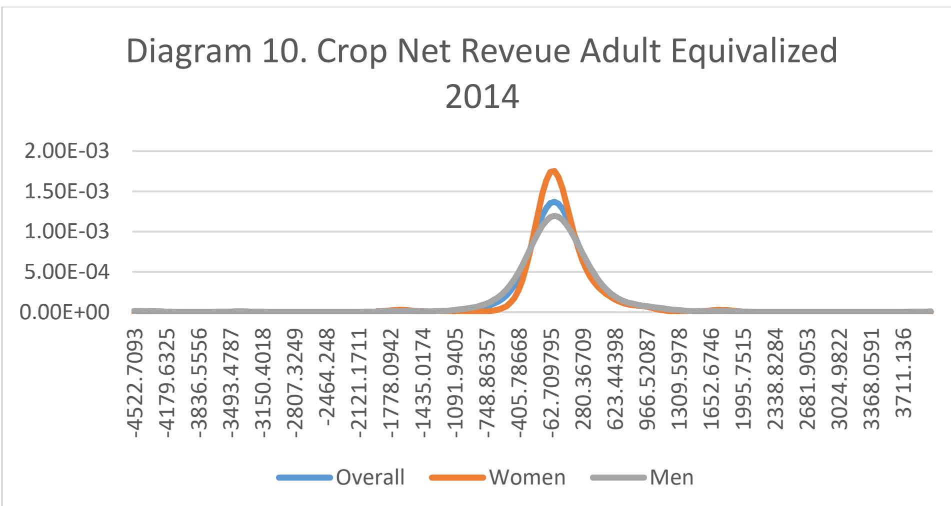


Diagram 10. Crop Net Reveue Adult Equivalized 2014
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-4522.7093
-4179.6325
-3836.5556
-3493.4787
-3150.4018
-2807.3249
-2464.248
-2121.1711
-1778.0942
-1435.0174
-1091.9405
-748.86357
-405.78668
-62.709795
280.36709
623.44398
966.52087
1309.5978
1652.6746
1995.7515
2338.8284
2681.9053
3024.9822
3368.0591
3711.136
Overall
Women
Men

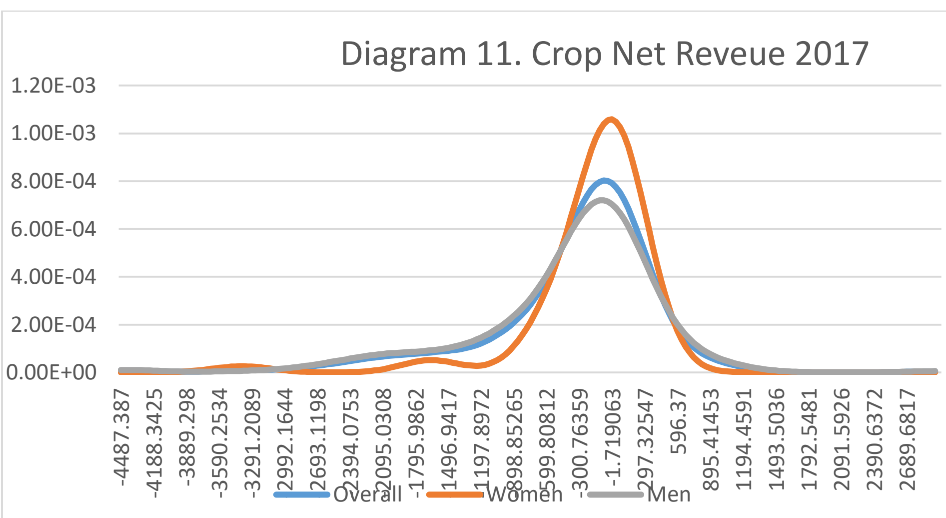
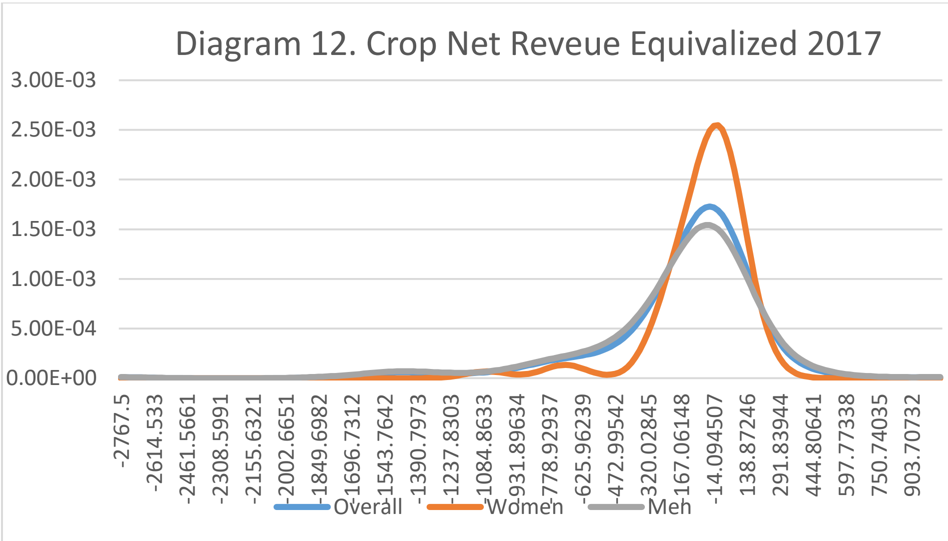


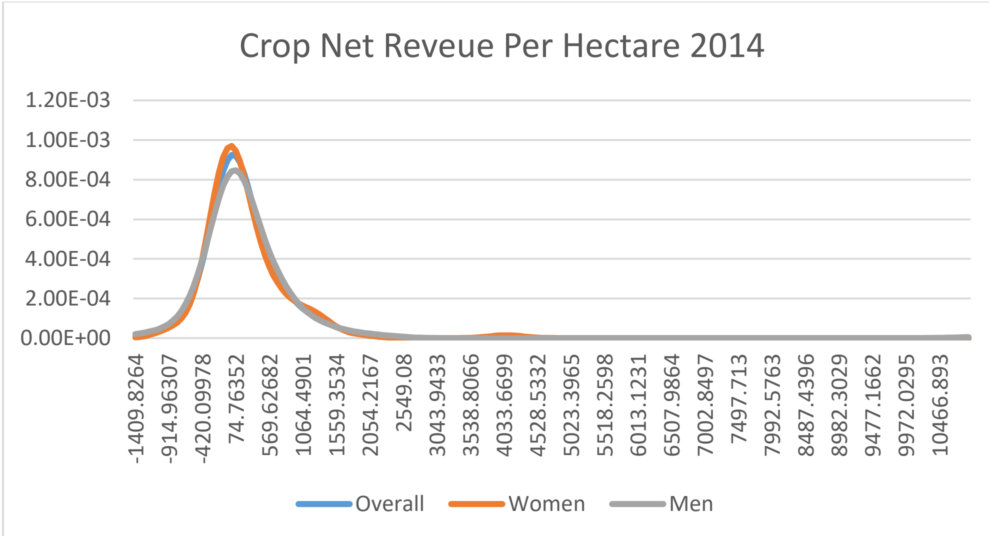
Diagram 11. Crop Net Reveue 2017
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
-4487.387
-4188.3425
-3889.298
-3590.2534
-3291.2089
2992.1644
2693.1198
2394.0753
2095.0308
-1795.9862
1496.9417
1197.8972
898.85265
599.80812
-300.76359
-1.719063
297.32547
596.37
895.41453
1194.4591
1493.5036
1792.5481
2091.5926
2390.6372
2689.6817
Overall
Women
Men



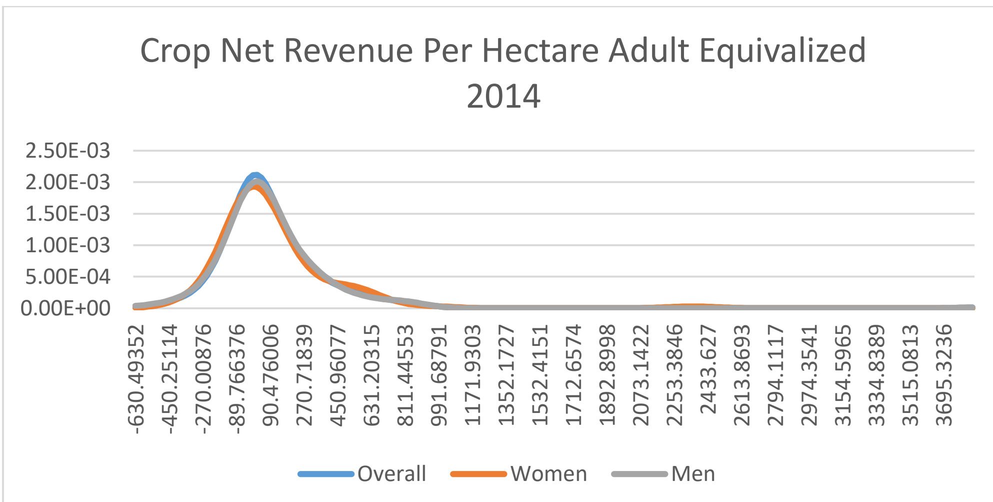
As far as management structure influencing farm net revenue is concerned, there is a case for arguing that total net revenue is not the appropriate measure. In essence it is a productivity issue, if female household heads are associated with smaller scale farms than male heads but are equally efficient 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 13 through 16 following Table 4 with diagrams 9 through 12. What can be deduced is that male headed households net revenues in both levels and per hectare paradigms are more variable than those of female household heads.

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

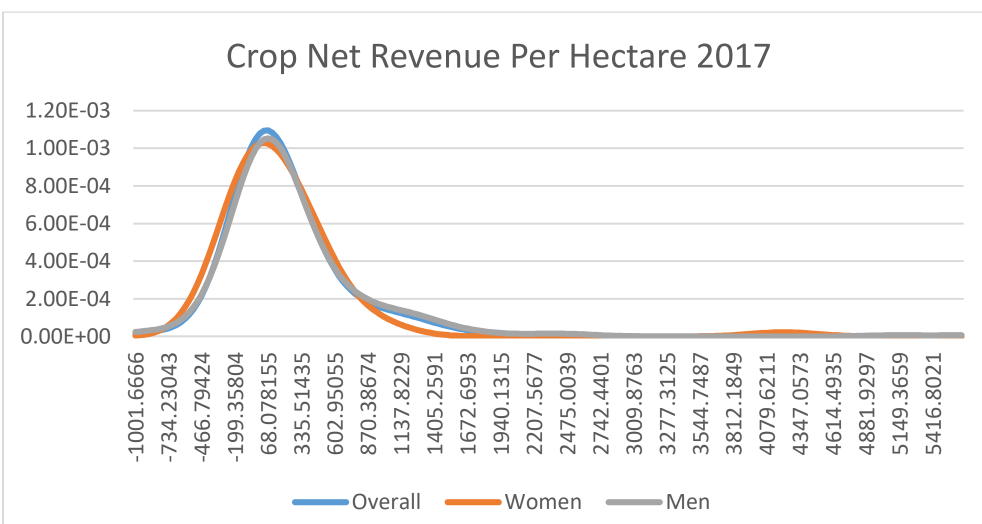
Overall	Revenueph	Expenseph	Surplusph	Revenuephaeq Adult equiv	Expensepheq Adult equiv	Ssurpluspheq Adult equiv
2014						
Mean	478.66	262.12	216.54	223.22	125.66	97.565
Median	235.86	188.79	64.708	98.406	82.870	28.589
Max	11018	1438.	10961.	3895.3	1100.0	3875.6
Min	0.0000	0.0000	-1409.8	0.0000	0.0000	-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	Ssurpluspheq 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



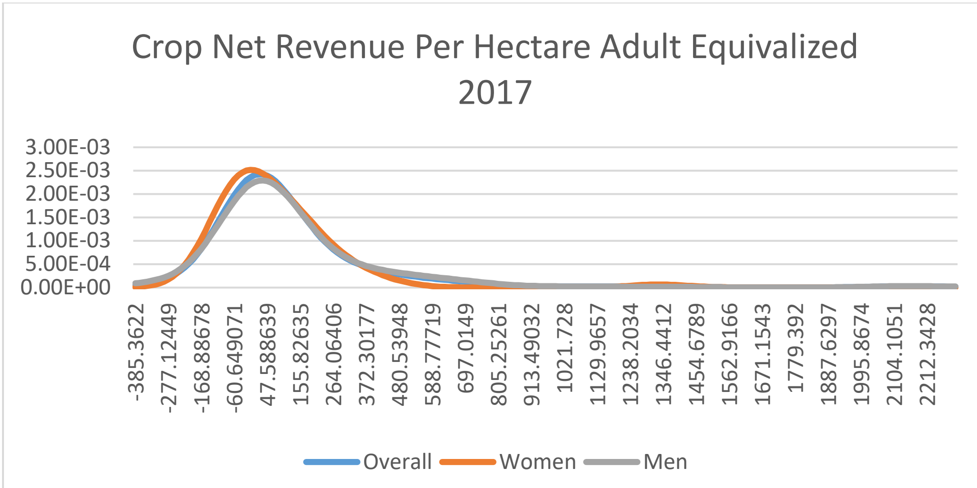
Crop Net Reveue Per Hectare 2014
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
-1409.8264
-914.96307
-420.09978
74.76352
569.62682
1064.4901
1559.3534
2054.2167
2549.08
3043.9433
3538.8066
4033.6699
4528.5332
5023.3965
5518.2598
6013.1231
6507.9864
7002.8497
7497.713
7992.5763
8487.4396
8982.3029
9477.1662
9972.0295
10466.893
Overall
Women
Men



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



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. $D(\hat{F}_a(x),\hat{F}_b(x)) = \sup_x \left|\hat{F}_a(x) - \hat{F}_b(x)\right|$ 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.

4.2 Results. 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

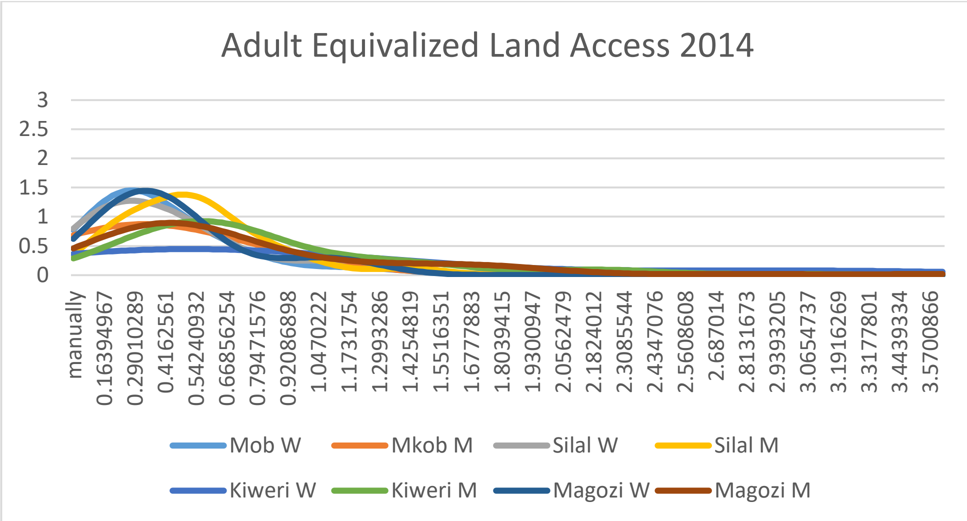
2014	Land	return perhct	Land Adult Equivt	returnperhct Adult Equivt
Mkobi Women n=43				
Means	0.85622	61.3015	0.43653	27.7048
Medians	0.60000	-50.0000	0.30411	-23.5052
Standard Deviations	0.69064	414.075	0.36351	197.367
Mkobi Men n=25				
Means	0.88762	-139.209	0.50045	-49.3915
Medians	0.60000	-83.3333	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

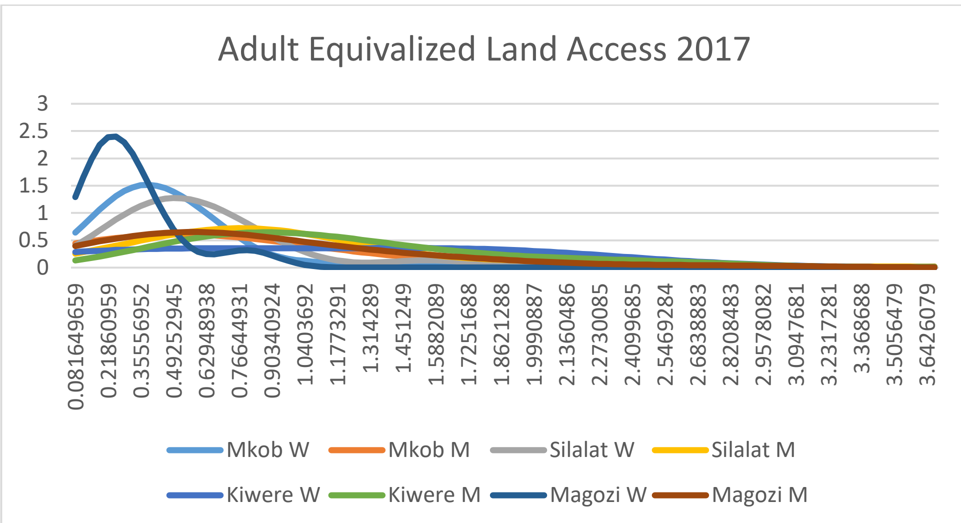
Table 6

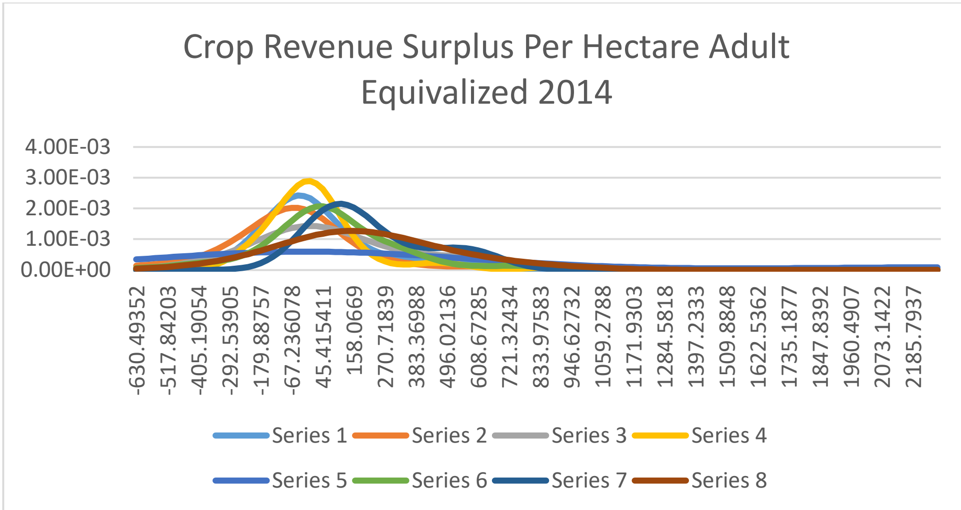
2017	Land	return perhct	Land Adult Equivt	returnperhct Adult Equivt
Mkobi Women n=28				
Means	0.94225	100.758	0.47971	55.8484
Medians	0.80500	3.24396	0.38957	-0.29937
Standard Deviations	0.53780	296.942	0.31235	146.867
Mkobi Men n=26				
Means	1.54115	373.258	0.86763	168.232
Medians	1.27500	121.075	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

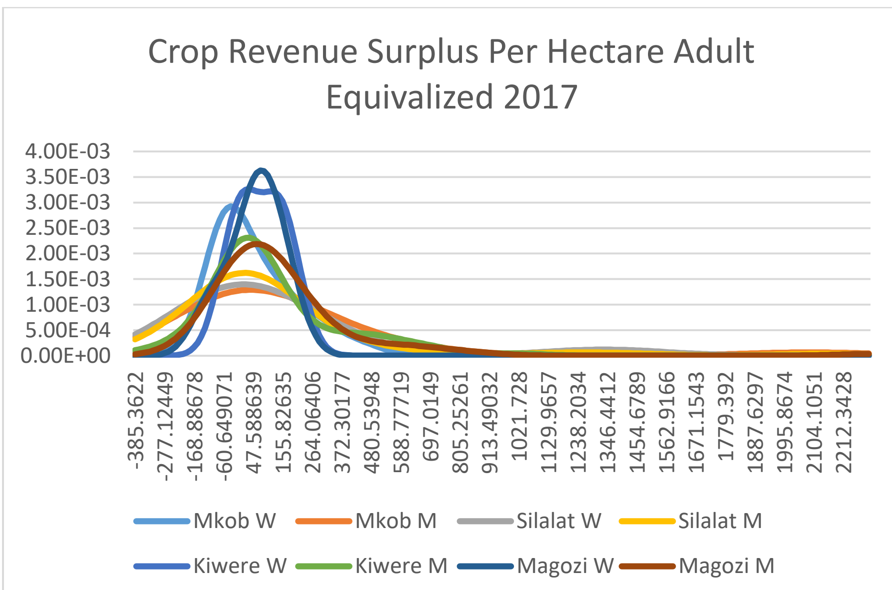
with households in the Mkobi scheme advancing (male headed households more so than female) while at Silalatshan female headed household returns diminished their male counterparts advanced. The Tanzanian schemes of Kiwere and Magozi both saw average crop net revenue yields per hectare diminish over the period.

These distributional location effects only partially summarize the distributional differences evidenced in the following diagrams where increasing distributional variation in land access and diminishing distributional variation per hectare in crop net revenue returns is evidenced.









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 significant progress toward an Equal Opportunity State with respect to food security.

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	-0.1324	-0.1006	0.0591	0.0659	0.0918	0.1709	0.0263	0.1010
Asymp Z	5.7781	4.4416	2.8426	2.7239	4.0193	8.5568	1.1478	5.0631
P(Z>|z|)	0.0000	0.0000	0.0022	0.0032	0.0000	0.0000	0.1255	0.0000

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.

References.

Anderson G.J. (2003) "Poverty in America 1970-1990: Who Did Gain Ground?" Journal of Applied Econometrics. 18, Issue 6 621-734

Anderson G.J., Linton O., Pittau G.M., Whang, Y-J and Zelli R. (2019) Segmentation or convergence in European household income distributions? New tools for analyzing the differentness in collections of distributions. Mimeo University of Toronto.

Anderson G.J. and J. Thomas (2019) "Measuring Multi-Group Polarization, Segmentation and Ambiguity: Increasingly Unequal Yet Similar Constituent Canadian Income Distributions. Journal of Social Indicators Research https://doi.org/10.1007/s11205-019-02121-z

Arneson R. (1989) "Equality and Equality of Opportunity for Welfare" Philosophical Studies 56: 74-94.

Atkinson, A.B. (2012). "Public economics after the idea of justice". Journal of Human Development and Capabilities, 13(4), 521–536.

Bjornlund, H., Parry, K., Pittock, J.,Stirzaker, R., van Rooyen, A., Moyo, M., Mdemu, M., de Sousa, W., Cheveia, E., Munguambe, P., Kimaro, E., Kissoly, L., Chilundo, M., Zuo, A. and P. Ramshaw (2018) TRANSFORMING SMALLHOLDER IRRIGATION INTO PROFITABLE AND SELF-SUSTAINING SYSTEMS IN SOUTHERN AFRICA

Bjornlund, H, van Rooyen, A, and Stirzaker, R 2017, Profitability and productivity barriers and opportunities in small-scale irrigation schemes, International Journal of Water Resources Development, vol. 33, no. 5, pp. 685-689.

Bjornlund, H, Zuo, A, Wheeler, SA, Parry, K, Pittock, J, Mdemu, M & Moyo, M (2019) "The dynamics of the relationship between household decision-making and farm household income in small-scale irrigation schemes in southern Africa." Agricultural Water Management Volume 213, 1 March 2019, Pages 135-145

Bjornlund, H., Zuo, A., Wheeler, S., & Parry. 2017. ‘Exploring the influences on gender decision-making and household income amongst small-scale irrigators in Sub-Saharan Africa’. Manuscript in preparation

Bourguignon F. (1979) “Decomposable Income Inequality Measures” Econometrica, Vol. 47, No. 4 901-920.

Brady, D.S., Barber, H.A. (1948). “The Pattern of Food Expenditures", Review of Economics and Statistics, 30, 198{206.

Burchi F. and P. De Muro (2016) “From food availability to nutritional capabilities: Advancing food security analysis” Food Policy 60 (2016) 10–19

Carneiro, P., K. T. Hansen and J. J. Heckman (2003) “2001 Lawrence R. Klein Lecture Estimating Distributions of Treatment Effects with an Application to the Returns to Schooling and Measurement of the Effects of Uncertainty on College Choice.” International Economic Review 44 361-422

Carneiro, P., K. T. Hansen and J. J. Heckman (2002) Removing the Veil of Ignorance in Assessing the Distributional Impacts of Social Policy. NBER Working Paper 8840.

Cleaver, F., & Hamada, K. 2010. ‘‘Good’ water governance and gender equity: a troubled relationship’. Gender & Development, 18(1), 27-41. doi: 10.1080/13552071003599996
.
Cousins, B., 2013. Smallholder irrigation schemes, agrarian reform and’ accumulation from above and below in South Africa. J Agrar. Change 13, 116–139.

Davis, B., di Giuseppe, S., Zezza, A., 2017. Are African households (not) leaving agriculture? Patterns of households’ income sources in rural Sub-Saharan Africa. Food Policy 67, 153–174.

de Sherbinin, A., VanWey, L.K., McSweeney, K., Aggarwal, R., Barbieri, A., Henry, S., Hunter, L.M., Twine, W., Walker, R., 2008. Rural household demographics, livelihoods and environment. Glob. Environ. Change 18, 38–53.

de Sousa, W., Ducrot, R., Munguambe, P., Bjornlund, H., Cheveia, E., Faduco, J., 2017. Irrigation and crop diversification at 25 de Setembro irrigation scheme, Mozambique. Int. J. Water Resour. Dev. 33, 705–724.

Durlauf, S.N. and D. Quah (2002). The New Empirics of Economic Growth, Chapter 4 in Handbook of Macroeconomics, J.B. Taylor and M. Woodford (eds), North Holland.

Ellis, F., 2000. The determinants of rural livelihood diversification in developing countries. J. Agric. Econ. 51, 289–302.

Ellis, F., Allison, E., 2004. Livelihood Diversification and Natural Resource Access. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2004. 'Gender and rice'. http://www.fao.org/rice2004/en/f-sheet/factsheet9.pdf

Ferreira F.H.G and V. Peragine 2015 “Individual responsibility and Equality of Opportunity” Chapter 25 in the Oxford Handbook of Wellbeing and Public Policy edited by M.D. Adler and M. Fluerbaey.

James Foster, J., Greer J. and E. Thorbecke (1984) “A Class of Decomposable Poverty Measures” Econometrica, 52, 761-766.

James Foster, J., Greer J. and E. Thorbecke (2010), “The Foster–Greer–Thorbecke (FGT) poverty measures: 25 years later” Journal of Economic Inequality 4, 491–524

Gini, C. (1921). "Measurement of Inequality of Incomes". The Economic Journal. Blackwell Publishing. 31 (121): 124–126.

Gini, C (1916) Il concetto di transvariazione e le sue prime applicazioni, Giornale degli Economisti e Rivista di Statistica, in C Gini (1959): 1-55.

Gini, C.: Transvariazione. Libreria Goliardica, Rome (1959)

Giordano, M., & de Fraiture, C. 2014. ‘Small private irrigation: Enhancing benefits and managing trade-offs’. Agricultural Water Management, 131, 175-182. doi: 10.1016/j.agwat.2013.07.003.

Gorantiwar, S. D., & Smout, I. K. 2005. ‘Performance assessment of irrigation water management of heterogeneous irrigation schemes: 1. A framework for evaluation’. Irrigation and Drainage Systems, 19(1), 1-36. doi: 10.1007/s10795-005-2970-9.

Hasmath, Reza, ed. (2015). Inclusive Growth, Development and Welfare Policy: A Critical Assessment. Routledge. pp. 2–3. ISBN 9781138840799

Hussain, I. 2007. ‘Understanding gender and diversity dimensions of irrigation management for pro-poor interventions’. Irrigation and Drainage, 56(2-3), 299-305. doi: 10.1002/ird.295.

Ianchovichina, E., and S. Lundstrom Gable, 2012, ―What is Inclusive Growth?‖ in Commodity Prices and Inclusive Growth in Low-Income Countries, ed. by Rabah Arezki, Catherine Pattillo, Marc Quintyn, and Min Zhu, International Monetary Fund

Kolmogorov A (1933). "Sulla determinazione empirica di una legge di distribuzione". G. Ist. Ital. Attuari. 4: 83–91.

Koppen, B. V., & Hussain, I. 2007. ‘Gender and irrigation: overview of issues and options’. Irrigation and Drainage, 56(2-3), 289-298. doi: 10.1002/ird.296.

Lecoutere, E. 2011. ‘Institutions under construction: resolving resource conflicts in Tanzanian irrigation schemes’. Journal of Eastern African Studies, 5(2), 252-273. doi: 10.1080/17531055.2011.571388.

Lefranc, A., Pistolesi, N., and Trannoy, A. (2009). “Equality of Opportunity and Luck: Definitions and Testable Conditions, with an Application to Income in France". Journal of Public Economics, 93, 1189-1207.

Manero, A., (2016). Income inequality within smallholder irrigation schemes in sub-Saharan Africa. Int. J. Water Resour. Dev. 33, 770–787.

Manero A. (2017) The limitations of negative incomes in the Gini coefficient decomposition by source, Applied Economics Letters, 24:14, 977-981,

Manero, A. 2018. Water distribution within smallholder irrigation schemes in Tanzania and its implications for economic inequality (Doctorate), Australian National University, Canberra. https://openresearch-repository.anu.edu.au/bitstream/1885/142347/1/Manero%20Thesis%202018.pdf

Manero, A., Wheeler, S., Zuo, A., & Mdemu, M. 2019. ‘Exploring the Head vs. Tail-End Dichotomy on Yield and Farm Incomes in Smallholder Irrigation Schemes in Tanzania’. Water Resources Research

Mdemu, M., Mziray, N., Bjornlund, H., Kashaigili, J., (2017). Productivity barriers and opportunities at the Kiwere and Magozi irrigation schemes in Tanzania. Int. J. Water Resour. Dev. 33, 725–739.

Mookherjee, D. and A. Shorrocks (1982). A decomposition analysis of the trend in UK income inequality. Economic Journal 92(368), 886–902.

Moyo, M., van Rooyen, A., Moyo, M., Chivenge, P., Bjornlund, H., (2017). Irrigation development in Zimbabwe: understanding productivity barriers and opportunities at Mkoba and Silalatshani irrigation schemes. Int. J. Water Resour. Dev. 33, 740–754.

Mulligan, Casey B. (1997). Parental Priorities and Economic Inequality. Chicago: University of Chicago Press.

Nussbaum M.C. (1997). “Capabilities and Human Rights". Fordham Law Review, 66, 273-300

Nussbaum, M.C. (2011). Creating Capabilities: The Human Development Approach, Harvard University Press.

O’Sullivan, M., Rao, A., Banerjee, R., Gulati, K., & Vinez, M. 2014. 'Levelling the field: Improving opportunities for women farmers in Africa'. T. W. Bank: http://one.org.s3.amazonaws.com/pdfs/ONE_Levelling_The_Field_Report_EN.pdf

Peragine, V., Palmisano, F., and P. Brunori (2014) “Economic Growth and Equality of Opportunity” The World Bank Economic Review, 28, 247–281

Roemer, J. E. (1998). Equality of Opportunity. Cambridge, Massachusetts: Harvard University Press.

Roemer, J. E. (2006). Democracy, Education and Equality: Graz Schumpeter Lectures. Cambridge University Press. Econometric Society Monographs No. 40.

Roemer, J. E., Aaberge, R., Colombino, U., Fritzell, J., Jenkins, S., Lefranc, A., Marx, I., Page, M., Pommer, E., Ruiz-Castillo, J., Segundo, M. J. S., Tranaes, T., Trannoy, A., Wagner, G. G., Zubiri, I. (2003). “To What Extent do Fiscal Regimes Equalize Opportunities for Income Acquisition Among Citizens". Journal of Public Economics, 87, 539-565.

Sen A. 1999 Development as Freedom . New York: Alfred A. Knopf

Sen, A.K. (1985). “Wellbeing and Freedom: The Dewey Lectures 1984". The Journal of Philosophy, 82, 169-221.

Sen, A.K. (1993). “Capability and Well-Being”, in Nussbaum, M. and Sen A.K. (Eds.): The Quality of Life. Oxford: Clarendon Press, 30-53.

Sen, A.K. (2009). The Idea of Justice. Harvard University Press.

Senadza, B. 2011. ‘Does Non-farm Income Improve or Worsen Income Inequality? Evidence from Rural Ghana’. African Review of Economics and Finance, 2(2), 104-121 http://www.african-review.com

Solon, Gary (1992). Intergenerational Income Mobility in the United States. American Economic Review, Vol. 82, No. 3 (June), pages 393-408.

Solon, Gary (2008). “Intergenerational Income Mobility.” In Steven Durlauf and Lawerence Blume (editors). The New Palgrave Dictionary of Economics. Second Edition. London: Palgrave Macmillan.

Smirnov N (1948). "Table for estimating the goodness of fit of empirical distributions". Annals of Mathematical Statistics. 19 (2): 279–281.

UN. 2013. ‘We can end poverty’. viwed 31 March 2014. http://www.un.org/millenniumgoals/pdf/Goal_1_fs.pdf

UN. 2014. ‘Rural Poverty in the Developing World’. viwed 27 May 2014. http://www.un.org/en/globalissues/briefingpapers/ruralpov/developingworld.shtml

UN. 2015. ‘Sustainable Development Goals’. viwed 16 July 2017. https://sustainabledevelopment.un.org/sdg10

Yitzhaki S. (1982) “Stochastic Dominance, Mean-Variance and Gini’s Mean Difference” American Economic Review 72 178-185

Van Den Berg, M., & Ruben, R. 2006. ‘Small-Scale irrigation and income distribution in Ethiopia’. The Journal of Development Studies, 42(5), 868-880. doi: 10.1080/00220380600742142.

van Koppen, B., Hope, L., & Colenbrander, W. 2013. 'Gender aspects of small-scale private irrigation in Africa' (Report No. 9290907673).
http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR153.pdf

World Bank. 2018. ‘Understanding poverty’. viwed 27 March 2019. http://www.worldbank.org/en/topic/poverty/overview

Appendix 1: tools for analyzing multilateral di derentness 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:

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

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.