

Agricultural Intensification

The Status in Six African Countries

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Abstract

The Boserup-Ruthenberg framework has long been used to explain and understand the determinants of agricultural growth, the nature of the intensification of farming systems, investment, and technology adoption. The literature has produced an extensive body of evidence that summarizes or tests the hypothesis in Africa and often found it confirmed. However, in the past two decades, rapid population growth has put African farming systems under stress. At the same time, there has been a sharp increase in urbanization and economic growth that is providing new market opportunities for farmers. It is therefore necessary to investigate whether this has resulted in rapid intensification of farming systems, permitting rapid agricultural growth and maintenance or increase in the incomes of the farming population. This paper describes the status

of intensification in six African countries using the first round of data from the Living Standards Measurement Study–Integrated Surveys on Agriculture. In addition, the paper (i) develops internationally comparable measures of overall agro-ecological crop potential and urban gravity in the farmers' location and (ii) estimates the causal impact of agro-ecological potential and urban gravity on population density, infrastructure, and market access and on a range of agricultural intensification variables. The paper shows that the new measures have relevant explanatory power. The descriptive analysis shows that the patterns of intensification observed across countries suggest several inconsistencies with Boserup-Ruthenberg. The paper also finds that urban gravity, except for its impact on crop intensities, has little impact on other intensification indicators.

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Agricultural Intensification: The Status in Six African Countries

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1. Introduction

Since independence in the 1960s, Sub-Saharan African countries (SSA) have undergone exceptionally fast population growth. They also have faced urbanization and some economic growth, which would have tended to increase the demand for agricultural products. The rising population has resulted in farm sizes that in many areas are now close to Asian levels (Headey and Jayne, 2014; Otsuka and Place, 2014). On the other hand, urbanization has created new market opportunities for the farmers. Under the theory of intensification of farming systems of Ester Boserup (1965) and Hans Ruthenberg (1980), both population growth and market access can lead to a virtuous cycle of higher use of organic manure and fertilizers and investments in mechanization, land and irrigation that have the potential to offset the negative impact of population growth on farm sizes, maintaining or increasing per capita food production, and even increase farmer's income (The BR model of intensification). The increase in output, however, comes at the cost of an increase in labor and other inputs per hectare cultivated. The positive outcome has been realized in those tropical areas of the world where technical change has added impetus to productivity growth. However another outcome was observed by Geertz (1963) in Java prior to the Green Revolution, in which the intensification triggered by population growth and market access was insufficient to lead to enough productivity growth to make today's farmers better off than their parents, and that instead they became worse off. Geertz called this process agricultural involution. Since the 1960s, biological technical change in SSA has been lagging behind the rest of the world, and so have fertilizer use, mechanization and investment in irrigation (World Bank 2008).

The literature on agricultural intensification in Africa developed significantly in the 1980s and has resumed over the past decade. It generally finds that in most areas studied intensification has progressed along the lines predicted by Boserup and Ruthenberg, and that agricultural involution is confined to few areas. These studies have been done using samples of locations for intensive studies. Under the Intensive Agricultural Surveys (ISA) that have been imbedded in broader Living Standard Measurement Studies (World Bank, 2009), national household data for six African countries is becoming available that contains the intensification and technology variables as well as income. These panel data will over time present a unique opportunity to test the BR model in different countries and different agroclimate zones, and to see whether there are signs of involution. At the present cross section data are available for six countries, while panel data are or will become available for all countries over the next few years. As we will show, only panel data over a sufficient period of time will be able to rigorously test the BR theory.

In this paper we are setting the stage for such later studies by describing the status of intensification across the six countries (Ethiopia, Malawi, Niger, Nigeria Uganda and Tanzania). Following Binswanger et al. (1993) we also study the impact of the agro-ecological endowment and access to markets of the environments in which the farmers live on population density, infrastructure and agricultural variables including output, and use of modern inputs. We construct a single variable for each of these, the agro-ecological potential derived from the potential yield estimates of Toth et al. (2012), and market access (measured by an urban gravity variable) of the environments in which the farmers live. Since AEG and UG are clearly exogenous to the status of intensification, input use and investment, we can estimate causal effects rather than just correlations. Among other findings we show that population density and infrastructure have evolved over time so that we observe higher densities, and better infrastructure and market access in areas with high agro-ecological potential and a high UG.

In the process we develop a comprehensive and internationally comparable measure of the agro-ecological potential (AEP) based on the modeling of attainable crop yields across all agricultural areas of the globe estimated by IAASA and FAO (Tóth et al, 2012). As a proxy for urban demand we develop a measure of urban gravity (UG) that a particular location experiences with respect to all urban centers in the country with current population of over 500,000 people.² We use an estimate of the light emitted at night of each city that is derived from exiting light intensity measures across all pixels of the city³. The light emitted by each city is assumed to be highly correlated with its overall GDP. We adjust the light intensity of each city using the distance from the enumeration area (EA) in which the farmers live.

Once we show that the agro-ecological potential and UG exercise a significant influence on the observed population density, infrastructure and market access, these three variables become endogenous variables in an analysis of their impact on farming systems variables such as the crop intensity or proportion of land irrigated. That means that we cannot directly test the BR framework in a cross section framework, but we can describe how intensification differs between countries and major agro-ecological zones. We can also estimate the influence of AEZ and UG on the intensification variables via all pathways of causality, including via population density and infrastructure. Direct estimation of the impacts of population density, infrastructure and market access will have to wait for panel data to become available. A limitation of the paper is that the data sets contain no data on land investments and mechanization (other than for Nigeria).

More specifically this paper will

1. Develop internationally comparable measures of overall agro-ecological crop potential (AEP) and of Urban Gravity (UG) in the farmers' location.
2. Describe the degree of agricultural intensification across the countries, and across the agro-ecological zones found in these countries.
3. Estimate the causal impact of agro-ecological potential and UG on population density, infrastructure and market access, and on a range of agricultural intensification variables.

2. Agricultural intensification: Theory and findings

The general model of the evolution of farming systems originates in the work of Ester Boserup (1965) and Hans Ruthenberg (1980) - henceforth the BR theory or framework-. In the 1980s these ideas were summarized, partially formalized, and tested for SSA in books by Prabhu Pingali, John McIntire, Yves Bigot, Daniel Bourzat and Hans Binswanger (Pingali et al 1987), Binswanger and McIntire (1987) and McIntire et al (1992). All these authors consider the evolution of farming systems, the methods of maintaining soil fertility, the technology in use and the labor input per hectare as endogenous, being influenced by the both agro-ecological and the socio-economic characteristics of the environments with which the farmers are confronted. The main driving forces of the evolution of the farming systems towards higher intensification and crop-livestock interaction are population pressures (often measured as population density) and market access, both of which define the opportunities of households in the areas. Additional factors

² We leave out the smaller cities, as their income as measured via light emissions could be affected by the agro-ecological potential of the zone in which they sit, making them endogenous to the system analyzed.

³ As a proxy of light intensity we used sum of nighttime lights in 2009. Input values ranging from 0-63, indicate average intensity of light observations, regardless of frequency of observation. Ephemeral events such as lightning strikes and fires have been discarded. The satellite source is DMSP F16, inter-calibrated for comparison between years. The range of 0-63 refers to the pixel-level value (the source data are gridded at 30 arc seconds). The variable we are using is aggregated at the 5 arc minute block level (resolution of SPAM, GAEZ and other harvest choice variables), which would include many pixels from the lights data.

considered are outside migration and wage opportunities, human capital, as well as human and animal diseases.

In low population density areas (other than the arid zone), cropping is characterized by long forest fallow systems in which the re-growth of the forest after cultivation restores soil fertility in terms of nutrients and soil structure, and suppresses weeds. Land is cleared by fire, with the ashes, further increasing the nutrient content of the soil. Seeding takes place between the stumps, using a digging stick or hand hoe. The stumps make the use of a plough impossible. Weeding is not necessary as weed seeds have decayed during the long fallow period. Farmers hold no cattle. The labor requirements for producing crops are very low. After one or several seasons, soil nutrients and soil organic matter decline, the soil structure deteriorates, weeds start to reemerge. Declining yields and rising labor requirements for weeding and land preparation lead farmers to abandon the land and open new forest areas or re-grown forests for cultivation.

If population growth reduces the availability of forests, and if new market opportunities emerge, farmers have to intensify agricultural production. The BR effects of higher population density and improved market access lead to the following impacts:

1. The progressive reduction in fallow length until the land is permanently cultivated, and from there onwards to multiple cropping per year.
2. Soil fertility must be restored via the incorporation of nearby vegetation into soils, preparation of compost and/or manure, and/or artificial fertilizers.
3. The appearance of grassy weeds makes hand hoe cultivation much more difficult, and as tree stumps disappear in the short fallow stage, the plough is introduced via animal draft or tractors.
4. Cultivation moves from lighter soils on mid-slopes to heavier soils in lower slopes and depressions that have higher water retention capacity, and to more fragile soils on the upper slopes.
5. Cultivation in these new areas requires investment in land for the prevention of soil erosion, or drainage and irrigation.
6. Farmers and herders start to trade crop residues for cattle dung – livestock interaction. Eventually farmers acquire animals and herders sometimes acquire cropland – livestock integration.
7. Labor requirements per unit of land increase for restoring of soil fertility, weeding, land preparation, and for investments in land.
8. Intensification is associated with increases in yields, which is faster where new technology or irrigation is introduced.
9. It often leads to a switch to higher value crops in an effort to maximize the value of output per unit of land.
10. Land rights evolve from general rights to cultivate in an area to rights to specific plots of land. This process radiates from the homesteads to more distant areas, including pastureland under fallows and pastures. Common property resources are progressively privatized.

We already noted that these effects do not necessarily lead to an increase in farmer welfare: The increase in labor demand can be so large that welfare remains constant or declines, for two reasons. First, farm income per capita, $\frac{Y_f}{N}$, is by definition the product of farm income per hectare, $\frac{Y_f}{L}$, and land per capita, $\frac{L}{N}$:

$$(1) \quad \frac{Y_f}{N} = \frac{Y_f}{L} \cdot \frac{L}{N}, \text{ or in percentage change terms:}$$

$$(2) \quad \Delta \ln \frac{Y_f}{N} = \Delta \ln \frac{Y_f}{L} + \Delta \ln \frac{L}{N}$$

If population density is rising, then land per capita is falling, leading to a loss of income, all else equal. Of course, the Boserup argument is that all else is not equal because households intensify production (increase output per hectare, $\frac{Y_f}{L}$). Thus the extent to which gross income per capita declines or rises depends on whether changes in gross income per capita compensate for declines in land per capita. But a second cause of ambiguous welfare effects is that welfare is better represented by net farm income, or gross income less costs. The intensification process involves an increase in a number of costs, including labor, oxen, modern inputs and land preparation (e.g. irrigation).

Increases in household welfare, where they occur, are often associated with diversification of agricultural production to a broader range of high value product that can be marketed through improving commercialization channels. Where rising population pressure and market access lead to increased specialization, and where agricultural technology adoption and input use increase, there may be a beneficial diversification into rural nonfarm activities.

In contrast to positive intensification processes, under very high population pressure and poor policy, institutional or agro-ecological environments, intensification could lead to involution and the diminution of economic and social well-being, and environmental degradation. Geertz (1963) characterized involution as a situation in which increasing demand for food is met by highly labor intensive intensification, but at the cost of very small and decreasing marginal and average returns to inputs. Because there still is relatively little landless labor in SSA, the extra work would often fall on family workers, rather than being supplied by landless workers, as in Asia. Of the 10 cases of very high population density in SSA studied by Turner et al. eds. (1993), there are signs of involution in the humid tropical areas of Imo State in Nigeria, and in the Usambara mountains of Tanzania, where special rules inhibit erosion control because it can jeopardize access to land for women.⁴ Based on macro rather than micro data, Lele and Stone (1989) also suggest that a significant share of the intensification observed in SSA was already showing signs of involution by the mid-1980s. This means that the conclusions from aggregate data are more pessimistic than from case studies.

Heady and Stone (2014) find that agricultural intensities in much of African agriculture have reached the stage of permanent cropping. Most of the literature is consistent with the theory of intensification, both in Africa, as well as elsewhere. Baltenwick et al (2003), in an analysis of 48 sites in 15 countries of Africa, Latin America, and Asia, find that the forces of population density and market access transcend national and continental specificities and applied well across the study sites in all three continents. Their reviews, following McIntire et al (1992), focuses especially on crop-livestock integration and confirm the general trends and more detailed findings of these authors.

The papers in Pender et al. eds. (2006) study of strategies for sustainable farming systems in the East African Highlands focused primarily on low to medium potential areas. The selection of areas of lower agro-ecological potential also implies a bias in the results, this time against the BR effects, as in lower potential areas the work and investment incentives are likely to be lower than in higher potential areas. They find similar corroborating evidence for the general impacts, again with variations which will be discussed in subsequent sections of this paper. They emphasize that intensification is progressing especially well where vibrant markets are nearby. Much earlier this had been found to be true in a case study of the agricultural history of Machakos district in Kenya,

⁴ Women had secure access to unimproved land for their subsistence production, but once a parcel was improved via erosion control, would lose such access.

where the output demand from Nairobi played an important role (Tiffen and Mortimore 1992). Moreover the opportunities of earning income in Nairobi provided resources for investment in Machakos district. Clearly urban centers present both market and trade opportunities which is important in interpreting the results in this paper. Finally Turner and Fisher-Kovalski (2010), in a tribute to Boserup's 100th birthday, find that the Boserup framework has held up well.

Heady and Jayne (2014) in a study using FAO data over the past decades from their regular reporting and periodic agricultural censuses elaborated on their findings in the following three points:

1. "Farms sizes are typically declining in countries believed to have had more binding initial land constraints, whereas farm sizes in less land constrained countries have mostly stayed constant."
2. "Per hectare measures of input and output trends are mostly consistent with the Boserup hypothesis. Specifically, we typically observe more intensive production patterns in more land constrained countries. Cattle/oxen, fertilizers, cropping intensity and yields all appear to increase with land constraints, but irrigation, mechanization and other forms of capital appear low and fairly unresponsive to land pressures in the vast majority of African countries." And
3. "Gross output value per hectare appears highly responsive to land constraints. However, since net output per hectare is the more [relevant] welfare indicator, it is difficult to make strong welfare inferences from this fact." (All from Heady and Jayne, forthcoming, p...).

Their findings therefore are consistent with the BR framework, except that capital investments have been lagging behind what population pressure would suggest. Therefore their findings provide only mixed support for the BR framework.

3. Analytical Framework

We model the current status of the farming system within a cross section framework, and show that we will have to analyze the changes in the farming system with panel data over time. This is because population growth has been higher and infrastructure more developed in areas of high AEP and UG. AEP and UG also influence the farming system directly. It is therefore not possible to instrument population density and infrastructure with AEP and UG and then use the predicted value in a second stage to estimate the causal effect of population density and infrastructure on measures of agricultural intensification. Instead we can use only variables that are strictly exogenous to what we want to explain: AEP, UG of the nearest large city. The coefficients of AEP and UG of these reduced form regressions reflect the total impact of the exogenous variables on the endogenous farming systems characteristics, both via their direct impacts on the farming system, as well as via effects that operate via population density and road infrastructure.

Let index i stand for household i , z for the Enumeration Area (EA) and H_{kz} for the k th dependent population density, infrastructure or farming system characteristic. The cross section regression then will take the form

$$H_{ikz} = f(AEP_z, UG_z) \quad (1)$$

H_{ikz} stands for the dependent variable $k = 1, \dots, K$, (see below)

where AEP is the agro-ecological potential of all field crops in US dollars at international prices, and UG_z is the distance-modulated urban gravity of all cities with recent population greater than 500,000.

The dependent variables are as follows:

- Population density of the EA
- Distance to the nearest road and the nearest markets
- Average owned or cropped area per household
- Cropping intensity, defined as gross cropped area per net cropped area
- Proportion or area of land area under fallow
- Proportion of net crop area irrigated
- Proportion of households using different technologies: high yielding varieties, organic manure, fertilizer, or pesticides

Equations are estimated for each of the dependent variable, and in double logarithmic form.

Definition of the variables

Agroecological potential

We calculate the agro-ecological potential from the currently available GAEZ data of the International Institute for Systems Analysis and the Food and Agriculture Organization (Tóth et al, 2012).

For each 5 arc-minute grid cell of agricultural land of the World the data set uses crop models to calculate *agroclimatic yields*, for 280 crops and land-use types. These are progressively aggregated to 49 crops. Agroclimatic yield takes account of all climate related constraints and uses and optimum crop calendar. GAEZ then calculates *Agroecological suitability and productivity* that takes account of the distribution of grid-specific soil and terrain conditions and fallow requirements. We use the data on “*Potential yield*” that does adjust for fallow requirements. GAEZ constrain potential yield for 28 crops, of which we use those for which international prices are available. We end up with potential yield for the following crops: wheat, rice, maize, barley, millet, sorghum, white potatoes, cassava, soybean, coffee, cotton, groundnut, banana, sweet potatoes, and beans.

These potentials are calculated for the past, current and potential future climates; and for low, medium and high input levels, of which the current values at intermediate level is the most appropriate for us: “In the case of intermediate input/improved management assumption, the farming system is partly market oriented. Production for subsistence plus commercial sale is a management objective. Production is based on improved varieties, on manual labor with hand tools and/or animal traction and some mechanization. It is medium labor intensive, uses some fertilizer application and chemical pest, disease and weed control, adequate fallows and some conservation measures.” (Tóth et al. 2012, p 18) In light of the limited irrigation in Africa we are using the data for the rain-fed category. To summarize, we will use the *agro-ecological level for the current climate conditions at intermediate levels of input use under rain-fed conditions*.

The data in the GAEZ system are for each crop. But we want to characterize the aggregate agro-climatic potential in the communities being analyzed. Therefore we need to assign a value to the potential crop productivities across crop. In order for the calculations to be comparable across countries, we did it with respect to average world market prices of for the past three years during which the LSMS studies were carried out. The commodities include the 15 crops mentioned above

for which we have found international price data. We then aggregate the potential production value of each crop per ha by the cropping pattern observed in each of the communities, or close to them. We use the share of each crop in the cropped area of each EAs as weights to aggregate the potential crop values into the overall AEP.

Two limitations need to be considered when using the AEPs. First, they reflect international prices for three very recent years, and therefore are AEPs for today. When we analyze the influence of the AEP on current farming systems variables such as cropping intensity, value of production or input use, current prices are appropriate. However when we analyze the impact of AEP on population density and road investments, the AEP for a prolonged past period should be used, with which the current AEP is only correlated. Second, the AEP calculations for each region in a country are based on the current cropping pattern observed in each EA, rather than a past cropping pattern, for which the data set contains no data. In addition, as cropping patterns respond to prices, technical change and market conditions, the AEP calculated today would not be the same as an AEP calculated at an earlier or later date. Even if the yield potentials do not change, our AEP variable, while comparable across country at each point of time, is not unchanging.

For the aggregation of the potential crop values to AEP we only take account of the value of the main product, not any by-products. Let S_{iz} denoting the cropping pattern in the EAs obtained from the geo variables, namely the share of land under crop i ($i=1 \dots N$) in the EA ($z=1 \dots N$), and if A_{ijz} denotes the corresponding areas, then

$$S_{iz} = \frac{\sum_{j=1}^N A_{ijz}}{\sum_{i=1}^M \sum_{j=1}^N A_{ijz}} \quad (3)$$

Let P_i be the international price of crop i . And Let X_{iz} be the agroecological potential of crop i in the EA j . Then the agro-ecological potential in the EA z is

$$AEP_z = \sum_i S_{iz} P_i X_{iz} \quad (4)$$

From the coordinates of the community to be matched to the geographic units of the GAEZ data, we calculate the central point of each of the EAs. We select the corresponding grid cell from the IASA-FAO data set as well as the adjacent grid cells. We average across such geographic units by weighing the values for the adjacent grid cells by their distance from the central point of the households of the EA for which we calculate the AEP.

In the analysis that follows we assume that today's agro-ecological potential is highly correlated with the agro-ecological potential over the past. Because the crop yield estimates that have been used in computing AEP include the known impacts of soil degradation, today's estimates are possible a slight underestimation of past AEPs. However, much of the AEP is explained by innate characteristics of the soils that have not changed and a relatively stable climate over the past. We conclude that past AEP would be highly correlated with current AEP and that the current AEP variable captures the impact of past AEP as well. This is an important assumption, as migration, fertility, infrastructure investment decisions were made over a long historical period, and we therefore should capture the impacts of AEP in the past. This also applies to the intensification variables, although they can change much more rapidly than population density and infrastructure. Therefore for the intensification variables the errors in variables possibly associated with small changes in AEP over the past are less severe.

Population pressure

In this paper we measure population pressure in two ways, starting with the traditional measure of population pressure (persons/sqkm). However, the raw population density is not a true measure of rural population pressure, as it does not account for the vast differences in agro-

ecological potential across EAs, regions and countries. To integrate population density with AEP, for each EA we therefore also compute an agro-ecological population pressure that takes account of the AEP, namely the AEP per sqkm divided by the population density, which gives us the AEP per person in the EA. Unlike for raw population density, the lower this number, the higher is the population pressure.

Rural population for each EA has not been collected in the LSMS-ISA surveys. We therefore use the data for rural population density collected by Harvest Choice⁵. These data are disaggregated to the level of communities which contain the EA.

The EAs in the surveys have been chosen with probability proportional to their population at the last census. Our measure of rural population density will differ significantly from rural population density data derived from census data. The reason is that the sample gives preference to EAs with higher population, and low population density areas will be presented less. What we are measuring is the rural population density of the areas in which most of the rural people actually live.

Urban Gravity

We follow Henderson et al. (2009) Gallup et al. (1999), Kiszewski et al. (2004) in using the correlation between the intensity of light emitted by a particular pixel of space. While light intensity is not a direct measure of economic activity, it is highly correlated with it. If GDP data are flawed, they may be a superior measure of economic activity at the national level.⁶ A great advantage of light intensity is that they can be used as proxies for GDP for sub-units of countries for which GDP data are not available, as is the case for most cities in Africa. The data for light intensity come from the Defense Meteorological Satellite Program (DMSP) of the National Geophysical Data Center.⁷

To measure the aggregate emission of light at night from a city, we aggregate the light intensity of each pixel over all pixels of the city. The resulting light emission should be correlated to the economic output and income of the city, and therefore be a proxy for the food demand emanating from it.

To take account of the distance decay of economic pull of cities over space, we weigh the light intensity of each city with respect to EA_z by travel time in hours to each of these cities, using a negative exponential function. (Deichman 1997). We then aggregate the resulting UG by summing it over all cities in the country or across the border of neighboring countries with population above 500,000.⁸ We adjust the light intensity of cross-border cities by the composite index of the difficulty of movement of people, goods and information across the respective borders, using the higher difficulty of cross-border movement of the two respective countries. The result is the aggregate UG to which each EA is exposed.

⁵ We use of Rural population density (pers./sq. km) in 2005. Calculations based on data from: Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); The World Bank; and Centro Internacional de Agricultura Tropical (CIAT). 2004.

⁶ The authors present estimates across countries and over time of reported GDP and light intensity, and also present an estimator of GDP which optimally combines the two.

⁷ The data source is the DMSP F16 the U.S. Air Force's research project called the Defense Meteorological Satellite Program (DMSP) established in 1960. Since 1994 DSMP produce a time series of annual cloud-free composites of DMSP nighttime lights. Together with the NGDC –EOG (the National Geographic Data Center – Earth Observation Group).

⁸We choose cities over 500,000 population at the current time, because smaller cities often are centers of agricultural services and markets, and therefore their population is influenced by the AEP of the surrounding area, which makes it endogenous

As in the case of AEP, we assume that today's urban gravity is correlated with UG over the past, during which migration, fertility, infrastructure investment decision were made, and therefore the coefficients of today's urban gravity capture both current and past impacts of UG. Since urban populations and incomes have changed very rapidly over the past decades, the errors in variable problem associated with past UG being imperfectly correlated with current UG is more severe than in the case of AEP. Again, for the intensification problem that change more quickly over time the problem will be less.

Public infrastructure

We used two variables as proxy of public infrastructure: distance to the main road, and distance to key market center. Both variables are included in the set of GEO variables collected under the LSMS-ISA project by means of households' GEO coordinates. The former is the distance in Kms to the nearest trunk road while the latter is the Household's distance to nearest major market.

Owned and operated land

In the data we have the farmer's self-reported area of each plot⁹. Areas measured by GPS are available for a significant share of the plots, however, in each country regression analysis was used to relate self-reported area to area measured by GPS. The estimated regression coefficients were then used to estimate a predicted GPS area for those plots where that area is not reported.

We distinguish between owned and operated area. Operated area is defined as owned area plus rented in area minus rented out area.

Land use intensity

The primary variable we use for land use the cropping intensity (CI) of cropped land, rather than Boserup's and Ruthenberg's R-value. This is because, as we shall see, in most countries fallow rates are now very low, and we are no longer looking at the transition from long or short fallow systems to permanent agriculture, for which the R-value is best suited.¹⁰ Cropping intensity takes account of multiple cropping, the use of the land for more than one crop a year, which is observed in several countries. We define

$$CI = \frac{G*100}{N} \quad (5)$$

Where G is gross cropped, the sum of the areas cropped in the main season plus the areas cropped in the second season, and N is net cropped area, the area cropped in the main cropping season. If there is only single cropping, CI is 100%. It rises to 200 % when all cropland is used in both seasons, and can go higher when some land is used more than 2 times in a year. The cropping intensity is calculated as the mean over households in an EA, while the population density is the mean over communities as defined in the Harvest Choice data sets.

Irrigation and technology variables

For irrigation we use the share of cropped land that is irrigated. Data on inputs and outputs is collected at the plot level, which is a subdivision of the parcel. The data does not contain the area of each plot. Because different plots may use different inputs and techniques, this means that we cannot estimate area under a particular technique in this data set. Instead we have to focus on whether a farmer does use, or does not use a particular technique. We estimate the proportion of

⁹ In some countries the GPS is available for parcel, in order for plots

¹⁰ Ruthenberg's (1980) R-value $RV = N*100 / (N+F)$, where N is net cropped area (also called cultivated area) and F is fallow area.

households in each EA that are using improved seeds, chemical fertilizers, organic manure or pesticides.

4. Results

Descriptive statistics

The descriptive statistics are presented in tables 1 to 4, both by country and by AEZ.

The agricultural endowments

In table 1 b, row 1, we see that the average AEP per ha across all the countries is 740 dollars per ha, evaluated at international commodity prices prevailing between 2005 and 2008. This appears to be low, as most of the farmers in the countries analyzed are far from intermediate input levels used to calculate the AEP. When we calculate the AEP per person living in the EAs the average is only 394 dollars, which shows that effective population pressure relative the AEP is also high. We have argued in the last section that AEP per person is a superior measure of population pressure than AEP/ha. Map 1 shows the AEPs/ha for the EAs in our sample across our six countries.

Table 1 a and 1 b here

It is immediately apparent that areas of high potential areas are most prevalent in pervasive in Uganda and Central and Southern Malawi. In other countries it is mostly light green areas with potential between 478 and 786 dollars per ha that are scattered across the countries, rather than the darker green areas with higher potential. In Ethiopia and Nigeria there are also many are many brown areas that have low potential, mainly in the dry northern parts of each of these countries. In Niger of course low potential areas dominate in the entire country.

Insert map 1 here.

Consistent with the insights from map 4, Uganda shows the highest AEP per ha at \$1,878, followed by Malawi (\$999), Tanzania (786), Ethiopia (\$691), Nigeria (\$657), and finally Niger (\$478), which is not surprising given the aridity of the country. It is striking that Uganda has almost twice the AEP/ha as the next country, Malawi. Note that the AEP only takes account of the first season, and that Uganda has by far the highest cropping intensity (table 6). Therefore the real advantage of Uganda is even more striking.

The rural population densities over the sample AEZs are the highest in Uganda and the lowest in Tanzania. Nigeria follows at 218 people/sqkm, Malawi at 182 and Ethiopia at 174. Very low population densities are observed in Tanzania (59) and Niger (60). Our sample estimates of rural population density, the rural population densities across the entire countries. The extreme case is Uganda with a rural population density for the AEZs of 266, while the overall population density across rural and urban areas, according the WDI (World Development Indicators), is only 176 persons/sqkm. The reason is that the EAs in the surveys have been selected with probability proportional to their population, which means that the highly populated rural areas are represented more strongly in the sample than the low density ones.

In the second row the AEP /ha (multiplied by 100) has been divided by the rural population density to arrive at the AEP per person. Across all the countries it is only \$394 per rural person. Map 2 shows the AEP per rural person across all of the countries. The concentration of AEPs in red suggests that Tanzania has low agro-ecological population pressure. It is also surprisingly suggest that Niger has among the highest AEP per person, and therefore low agro-ecological potential across the sample countries. Uganda, despite its high population density also has relatively low

agro-ecological population densities over vast areas. The highest agro-ecological rural population pressure (in blue) is found in Southern Malawi and south-eastern Nigeria.

Map 2 here

Because of its relatively high AEP/ha and low population density, Tanzania has by far the lowest agri-ecological population pressure, i.e. the highest AEP/person at \$ 1313 per person. This is followed by Niger, because its AEP/ha is not that far from the next ranking country Ethiopia, but its rural population density is comparatively very low. Only then comes Uganda at \$703, a little more than half the value for Tanzania. This is followed by Malawi and Ethiopia, while the lowest AEP/person is found in Nigeria 301). Our measure of agro-ecological population pressure throws a very different light on population pressure across countries than could have been expected from the raw population densities.

The cool humid tropics have always been considered to be very fertile. It is therefore not surprising that the AEP/ha is by far the highest (\$1161). But because these areas also have high population densities, the AEP per person is down to \$489, less than half the AEP/ha, and only about 100 dollars above the average across countries. While the warm arid tropics have by far the lowest AEP/ha, their AEP/person is the highest among all the AEZs, at \$1109, primarily on account of its very low rural population density of 14 persons/sqkm. These findings suggest that migration and population growth over the past have far more than equalized the chances of people living in the most challenging climate environments the better ones, so that they actually face lower agro-ecological pressure than better endowed climate zones. The warm arid areas are followed by the warm semi-arid areas, another challenging climate zone, at \$627 per person. The warm sub-humid areas and the cool semi-arid areas have the lowest AEP/person at only \$304.

When we look at the large differences of agro-ecological population pressure across countries and AEZs, it is clear that that migration and population growth, while important determinants of population pressure, have failed to equalize AEZ/person. This may well be because colonial, and then national boundaries have made cross-country migration difficult.

Map 3 shows the Urban Gravities for the six countries, and their country and AEZ averages are shown in row 5 of tables 1a and 1b. The concentration of red dots suggests that UG is high near major urban centers such as Blantyre or Lilongwe in Malawi, or Kampala in Uganda. But it then tapers off quickly and vast stretches of our countries have extremely low urban gravity (in blue). However, in Nigeria there are few EAs with dark blue color, and indeed urban gravity is the highest in Malawi at a value of 169, and the lowest in Ethiopia at only 7. Tanzania and Uganda come in lower than Malawi, but have higher UG than Ethiopia and Malawi. Urban gravities vary even more across AEZs than countries, with the lowest on found in the warm arid areas at only 0.1, and the highest in the warm humid areas at 299.

Except for Niger and Nigeria that have low average elevation, the elevations in the remaining four countries are between 913 meters for Malawi and 2054 meters for Ethiopia. Average growing periods vary between 81 days in Niger and 303 days in Uganda. This means that in Uganda, unlike the other countries, farmers typically grow crops in both seasons. As discussed previously, our measure of AEP takes account of only one season, which means that the advantage of Uganda in terms of AEPs is much larger than the AEPs discussed above. Nigeria and Malawi also benefit from long rainy seasons. Except for Niger and Malawi, growing periods in the other three countries is around 200 days.

Map 3 here.

Average distance of households to the nearest tarred road across all countries is 15 km, while to the nearest market it is much higher at 66 km. Distances to roads are the lowest in Uganda

at 8 km, followed by Malawi, that has also the lowest distance to markets. The farthest distances to markets occur in Nigeria and Tanzania at 70 km. That Nigeria, among highest per capita income country should do so poorly in markets suggests that they may have used larger markets as reference, while Malawi may have chosen very small markets. In the regression analysis we use the log of the variables and also include a country dummy, so that only the within country variation is used to estimate the relationships to the dependent variables. Among the AEZs the distances to roads and markets vary little, suggesting that most of the variation is associated with the countries rather than the Agro-ecological potential.

Poverty, income, and household characteristics are summarized in Table 2a and b.

The poverty rate is the highest in Tanzania (92%) and the lowest in Niger (41%). The high AEP/person of Tanzania has not at all resulted in a low poverty. Nor has the low AEP per ha resulted in high poverty in Niger. In the other countries the poverty rates vary between 52 and 75%. Except for the low poverty rate in the warm arid area (of which Niger has the largest population) they vary far less across AEZs than the poverty rates by country.

Table 2 a and b here

Age of household heads varies between 41 years in the warm tropics and 44 years in the cool humid areas, which are free of Malaria and perhaps some other diseases. The percentage of female farmers is low in the West African countries Niger (7.6%) and Nigeria (13%), which have an a large share of Muslims in the population. In the four East African countries the female farmer shares vary between 21 and 27 percent.

Land and land use intensity

Area operated is owned area plus rented in area, and closely correlated with area owned. Area operated is on average 1.57 ha per farm. It varies from the lowest in Malawi at 0.74 ha to the highest in Niger at 5.1 ha. Malawi's AEP per ha is twice the one in Niger, which makes the difference less stark. What is surprising is that Uganda, one of the high population density, has an operated area slightly equal to Tanzania's 2.4 ha. Since Tanzania has a very much lower population pressure, we would expect farm sizes there to be significantly larger. It appears that Tanzanian farmers are unable to make use of the larger land endowment per person, perhaps because they are labor constrained and unable or unwilling to make the investments required for animal draft or tractor plowing that would allow them to operate larger areas.

Table 3 a and b here

Cropping intensity is gross cropped area divided by net cropped area. It is greater than one in all countries, therefore the stage of permanent cropping has been reached everywhere. Cropping intensity is especially low in Malawi (1.01) and Tanzania (1.07): Land pressure in Tanzania is very low, consistent with its cropping intensities, while it is very high in Malawi: The AEP per person in Tanzania exceeds the one in Malawi by 129 percent. Theory suggests that Malawi's high population pressure would have led to high land and irrigation investment, allowing for high cropping intensities. We therefore find another inconsistency with the predictions of the BR framework. Crop intensity is by far the highest in Uganda at 1.89, which is on account of the bimodal rainy season. The other countries have cropping intensities between 1.19 and 1.23.

In light of permanent cropping, on average the rate of fallow in the six countries is only 1.2 percent, and therefore fallow can no longer contribute to soil fertility maintenance and restoration. It is clear that the high population growth rates and growth in urban demand have virtually eliminated fallows in the countries. The highest proportion of land under current fallow is found in Tanzania, at 7.5 percent. While that is consistent with Tanzania's low population density and AEP

per person, one would have thought that Tanzanian farmers could make more use of fallow to restore soil fertility. The lowest rate of fallow is in Nigeria at only 0.1%.

Past fallow rates are derived from the data on whether a plot had been fallowed in the past or the year it was last fallowed. We have these data only for four countries, for which, as a whole, current and past fallow rates are very similar.

Irrigation and Technology

Across the six countries average area irrigated per farm is only 0.03 hectares and the share of irrigated area in total area is only 4.4 percent. Surprisingly the area under irrigation is the highest in Tanzania at 0.45 ha, while it is by far the lowest in Malawi at 0.03 ha. Given the previous discussions, this is again inconsistent with the BR hypotheses. Across agro-ecological zones the warm arid zone has the largest area at 0.11 ha, but because of the large farm sizes the share irrigated is only 2.4 percent. The warm semi-arid areas come next in irrigated area cool semi-arid and warm sub-humid areas.

Table 4 a and b here

The area of land irrigated is by far the highest in the warm arid areas (0.11ha). This is not surprising because the payoff to irrigation is higher the dryer the climate. In all other climate zones it is around 0.01-0.05 ha. This is not surprising in the cool or warm humid and sub-humid areas, because the payoff to irrigation is much lower in such areas than in more arid zones. What is surprising is that the cool and the warm semi-arid tropics have such low irrigation levels, as here the payoffs to irrigation are higher than in more humid areas. Both the semi-arid areas have extremely low fallow rates, therefore the scope, and farmers can no longer increase the area cultivated in their farm. Irrigation, with the promise of a secure crop in the first season and a crop in the second season should long have been a favored investment for farmers. Even if groundwater resources in Africa are less than in South and East Asia, for many farmers they are not poor. Many of these could have used bore-wells.

That even in the semi-arid and arid zones irrigation where payoffs to irrigation are very high irrigation is so low despite growth in population and urban demand suggests that farmers have not responded to these trends by increasing irrigation as the BR framework would predict. Is it possible that this lack of response is caused by exceptionally poor availability of groundwater, which farmers could have tapped via borewells?

The proportion of households using improved seeds across all countries (except Nigeria) is only 9 percent. Malawi is doing by far the best at 61 percent of households. It also has the highest proportion of households using inorganic fertilizers at 76%, but the lowest proportion using pesticides (3%). Only 16 percent of its households use organic manure, which according to BR should have become an important technology for soil fertility maintenance in this country. Malawi is doing far better with respect to seeds and fertilizers than with respect to crop intensity, irrigation, organic fertilizer and pesticides. Malawi appears to be a major puzzle for the BR framework, according to which we should have seen higher levels of all intensification levels, rather than the very uneven pattern of the intensification variables .

In terms of inputs, on balance Ethiopia appears to have a more even performance than Malawi. 53 % of its farmers use organic fertilizer, 41 percent use inorganic fertilizer, and 18% and 23% use improved seeds and agrochemicals. In terms of the BR intensification variables, Ethiopia conforms fairly well to BR.

Niger does very well in terms of use of organic fertilizer at 48 %. However its use of chemical fertilizers is 18 percent, and use of improved seeds and agrochemicals are very low. That Ethiopia and Niger do well with respect to organic fertilizer in Niger may be caused by the high

numbers of cattle, while in Ethiopia it may be caused by the widespread use of animal draft. The low use of improved seeds in Niger is likely to be associated with the unavailability of significantly improved varieties of sorghum and millet.

Forty-one percent of households in Nigeria use inorganic fertilizer and 34% use agro-chemicals. However the use of organic fertilizer is the lowest among the countries at only 3%. This low use in the country with the highest agro-ecological population pressure is again a problem for BR.

Tanzania's use of the four inputs varies between 12 percent for agro-chemicals and 18% for improved seeds. That the use of these inputs is low but even in the country with the lowest agro-ecological population density is consistent with BR.

In Uganda the use of improved seeds is at 18% while that of inorganic fertilizer is only 3 percent of households. Organic fertilizer and agro-chemicals fall in between at around 12 percent. Even though its agro-ecological population density is far lower than for Tanzania, it is doing worse than Tanzania, again a challenge for BR.

Improved seed use is significantly higher in the cool areas than in the warm areas (11-25% versus 1.2-6.9%). A similar difference arises for organic fertilizer, where the cool areas have use varying between 56% and 61%, while for the warm areas they vary between 3% and 13%. In warm areas it is very difficult to accumulate soil organic matter, which decays rapidly when exposed to heat, while in cool or cold areas it is far easier to do so. The poor returns to organic fertilizer may therefore be a major barrier to intensification in the warm areas, compared to the cool area. There are hints in the literature that this may indeed be the case, with consistency of intensification with BR better in the cooler areas than in warm areas.

The use of chemical fertilizers across the cool zone and the warm semi-arid zone is much higher than in the remaining three warm zones (40% to 53% versus 6% to 26%). This may be related to the higher use of improved seeds in the cool areas already discussed, although high fertilizer use and low seed use go together in the warm semi-arid zones. The warm areas, other than the semi-arid and arid ones) have soils that are low in cation-exchange capacity which limits the payoff to chemical fertilizer. We will discuss the implications of these findings in the conclusion section.

5. Regression results

In the regressions we explore the impact of AEP and UG on population density, public investment, farming systems characteristics and technology use. The coefficients of AEP do not help us test the BR framework, but provide causal relationships with respect to AEP. However, the coefficients of urban gravity, in addition to explaining what it does, do test the BR framework. They have to be consistent with the predictions of the BR framework with respect to the impact of market access on intensification.

We estimate the regressions aggregating all the variables at the EAs level. We focus on 1993 EA located in 7 AEZ. The regressions are estimated in double log form, and apart from the two variables of interest, AEP, UG and their interaction include only country dummies.¹¹ By doing so we only use the within country variations to estimate the equations and differences in policies and other country-specific factors are therefore left out.

¹¹ Square terms were all insignificant, except for crop profits and therefore dropped.

In table 5 we see that the R-squares for the three equations are between 0.12 and 0.14. We see that population density and road investments have responded over the past to AEP, but not the distance to markets. The coefficient for distance to road is much larger than that of population density. While road investment has been responsive to AEP, market distance has not, suggesting that other factors than AEP determine investments in or emergence of markets.

Urban gravity on the other hand does not affect population density. But instead has a strong impact on distance to road with an elasticity of 0.31, more than twice as high as that of AEP. Market distance is also reduced for EAs subject to more urban gravity, presumably because the density of markets is higher close to major cities.

It is therefore clear that both population and public investment in the past have responded significantly to AEP and UG, which is as we expected. Therefore, cross section regressions explaining any intensification variable (or any other agricultural variable that stems from a public or private decisions), with population density and infrastructure variables will lead to upwardly biased coefficients of the independent variables. To the extent that AEP and UG are constant or evolving at constant rates, the problem can be overcome using panel data with fixed effects as done in Binswanger et al. (1993).

In table 6 we look at the five farming systems indicators. The R-squares or Pseudo R-squares vary between 0.16 for crop and perennial area to 0.77 for area under fallow. We see that AEP does not affect any of the five variables, while UG affects four of the five: Own area, cropped area and crop and perennial area with elasticities from -0.05 to -0.09 . UG also increases crop intensity with a smaller absolute elasticity of 0.03. This is the only variable for which the interaction term of UG and AEP is statistically significant, and the elasticity of UG with respect to crop intensity at the mean of AEP is only 0.003 but highly statistically significant.

In table 7 we see that the share of land irrigated is unresponsive to either AEP or UG and seems to be determined by other factors. However AEP has a significant impact on all four technology variables, with the larger elasticity of 0.07 for inorganic fertilizer and the lowest one at 0.03 for organic fertilizer. The interpretation of these findings is that higher input use has significantly higher payoffs in areas of high AEP than low AEP. This, of course, is well known, but it is interesting to see that our AEP variable and the household data can capture this effect. On the other hand, urban gravity has very little to do with use of inputs, except for use of modern varieties. We will discuss the implications of these findings in the conclusion section.

In table 8 we see that for profits per ha the linear term of AEP is positive, while the square term is negative, indicating diminishing returns to improvements of AEP at higher levels. At the mean of AEP the elasticity of profits per ha with respect to AEP is a respectable 0.37. What this means is that higher input use at higher AEPs does not fully equalize profits with those in areas of lower AEP, and in such areas households will need larger areas to reach similar incomes. That this may actually be the pattern across areas is consistent with the total lack of response of household income to either AEP or UG. On the other hand urban gravity has no impact on profits per ha or profits per household, suggesting that differential population growth and migration equalize these measures.

Summary and Conclusions

New measures of agro-ecological population pressure and of urban gravity

This paper first developed internationally comparable measures of agro-ecological potential and urban gravity. These measures impact positively on population densities, public investments in road and markets, and on some indicators of agricultural intensification.

We used the AEP/ha variable to calculate AEP per person, a new measure of agro-ecological population pressure. We find that this measure ranks countries quite differently with respect to rural population pressure than rural population density. The AEP/ha of Uganda is by far the highest in among the countries the lowest in Niger, with Tanzania close to the average across countries. However, in terms of AEP per rural person it is the highest in Tanzania followed by Niger, and then only Uganda. Agro-ecological population pressure is therefore the highest in Uganda, followed by Niger and the Tanzania. In terms of rural population density on the other hand, the rank with Uganda the first, and both Niger and Tanzania last. We therefore conclude that agro-ecological population pressure is so poorly related to population density that rural population density is a poor measure of population pressure on the natural resources.

Descriptive results

Given the rise in population pressure in all these African countries, the improvements in infrastructure and growing urban demand, Africa's land use intensity has reached permanent cropping in all the countries. Fallow areas have virtually disappeared. Under permanent agriculture high doses of organic and inorganic fertilizers are required to maintain or restore the soil nutrients taken out by the plants. Except for Malawi and Ethiopia the proportion of households using chemical fertilizers is clearly too low to do so. Nor is this compensated by high proportion of households using organic fertilizer, which is high only in the warm semi-arid and the three cool areas. The BR theory also predicts that under pressure from population growth and market access irrigation investment, and other modern technologies would be used more intensively to increase yields. However, these factors also not triggered significant irrigation investments even in semi-arid areas where the payoff to irrigation is high. Unfortunately we do not have data on other land investments, or on mechanization to judge whether expected intensification responses have occurred with respect to these important investments. However, the descriptive analysis suggests that the BR impacts of population pressure and market access have triggered an inadequate response of the farming systems with respect to irrigation and technology use.

An additional inconsistency arises when comparing Tanzania to Malawi, with Tanzania having about 2.4 times the AEP/person as Malawi, i.e., much lower population pressure. Yet cropping intensity is about the same and so is the intensity of use of manure. Use of agro-chemicals is more prevalent in Tanzania than Malawi. The only area where Malawi has greater intensity of input use than Tanzania is in the use of inorganic fertilizers and improved seeds. In addition to being triggered by the forces of intensification, these higher uses are consistent with the long-standing effort of Malawi to increase the use of these two factors, including the significant subsidies that have been provided in recent years.

Of course, our descriptive analysis is in now ways a rigorous test of the BR hypotheses. First of all, there are enormous variations in soils, crops and other biological variables that are likely to have a significant impact on the degree of intensification and its pattern among the different intensification variables. These have been completely ignored in this paper. In addition, there are sharp differences in policies and infrastructure investments that have not been taken into account. It is therefore important that the theory be tested with panel data, where these variations can be aggregated into fixed environment effects.

Regression analysis

We found significant responses of population density and infrastructure, farming systems characteristics, farm technology and profits per ha to our measures of AEP and UG, and the signs are all according to expectations. However there is a sharp divide between the nature of impact of AEP and UG across the variables:

- AEP increases population density and road investment, but not distance to markets, while UG does not affect population density but reduces both the distance to roads and to markets.
- AEP has no impact at all on key characteristics of the farming system such as areas farmed, crop intensity and fallow areas, while UG reduces all area measures and increases cropping intensity.
- While neither AEP nor UG have an impact on irrigation investment, AEP affects the use of all four inputs, while UG only increases the use of improved seeds.

We have provided a few hints as of why the response patterns with respect to AEP and UG differ so significantly, but a full understanding will undoubtedly require more sophisticated research approaches.

In terms of testing BR with respect to UG we see that it increases crop intensity and improved seeds, but not any of the technology variables, which does not provide much support for the operation of BR in Africa.

Implications

We are still missing panel data and several intensification variables to test the BR framework rigorously, or test whether there is agricultural involution in parts of Africa. However, the facts that we have described in this paper are only partially consistent with the BR framework. Except for Uganda, intensity of land use still appears low, especially in Malawi where agro-ecological population pressure is very high. In particular, and in line with other findings in the literature, the use of organic and chemical fertilizers, except perhaps in Malawi and Niger, appears far too low to maintain soil fertility, a fact that is quite well known. In addition investments in irrigation also seem to fall far short of what the high agro-ecological population pressures imply. This last finding is consistent with Heady et al (forthcoming), who stress that other investments also appear to have responded inadequately to rising population pressure. The implication of these results, and observations of many other observers of African agriculture, is that the process of intensification over much of these African countries appears to have been far less beneficial to farmers than what could have been expected according to the BR hypothesis.

The question is why are we not seeing the same or similar responses, especially in investments that appear to have occurred in tropical areas of Asia or Latin America? This is an old question in agricultural economics. But discrimination among different potential explanations persists. We conclude by spelling out some of the implications for research on this topic.

Since irrigation in Africa is so small and such a high proportion of agricultural areas in Asia, aggregate comparisons with tropical Asian countries, or comparisons focused on rice, provide a distorted picture of the differences. What should be compared are un-irrigated areas also called upland areas. A step towards a proper comparison among continents would be to single out both similar tropical AEZs and focus on upland areas, which is possible with the growth of relevant geo variables and national panel data on rural households.

The differences in agricultural incentives has been analyzed across the globe and suggest that in 2005 Africa, while benefiting from improved incentives, still lags the other developing regions that have improved them more (Anderson and Masters, 2009). While African countries may have further improved incentives since then, the growth of farm subsidies and in China and India suggests that Africa may still lag behind. The analysis of non-tariff barriers has also improved so that these should be taken into account.

Aspects of government policy other than price incentives and subsidies also have an impact on agricultural profitability, such as infrastructure and marketing investments. As shown in this

paper, the Harvest Choice data now allow for comparison across countries and continents. The World Bank has started to study the business environment for agriculture and agro-industry across a number of countries around the world that includes comparisons of credit provision, so that these factors could also be taken into account. In addition comparable data sets on macro-economic environment and corruption are now also available.

But the different intensification outcomes across continents could also have behavioral sources such as poor response to price and investment incentives. The supply and investment analysis requires panel data over more than two periods. Such data will become available for the African LSMS-ISA countries, and are already available for Asia, so that similar analysis can be performed across the different countries and continents and response elasticities compared.

The final issue is an assessment of public and private research expenditures and available technologies across countries. The former can be done based on the ASTI data, although it will be challenging to isolate expenditures for upland crops from expenditures for irrigated crops. Measuring differences in available technology across countries and environments remains a major challenge, however.

It is clear that the research agenda is vast, and that data from LSMS, IASA and FAO, Harvest Choice, ASTI and other sources will provide much opportunity for this research. By developing new measures of agro-climatic potential and urban gravity that are comparable across environments and countries, we hope to have made a small contribution to the research methods needed to tackle this large research agenda.

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Table 1a: Endowments by country

	ETH	MWI	NER	NGA	TZA	UGA	Total
1. Value of agroecological potential (US\$/ha)	691.171	999.128	478.692	657.011	786.351	1877.932	739.567
2. AEP per person (US\$/person)	396.702	547.569	792.365	301.022	1313.54	703.672	393.780
3. Rural population density (pers./sq. km) (2005)	174.229	182.466	60.413	218.26	59.865	266.876	187.812
4. Average growing period (days)	205.105	183.168	81.99	204.063	213.164	303.752	208.597
5. Elevation (meters)	2054.972	912.972	344.613	307.75	1068.343	1252.377	923.735
6. UG	7.398	169.324	22.836	134.625	30.083	63.565	82.928
7. HH Distance in (KMs) to Nearest Major Road	14.439	10.596	11.511	15.979	17.757	7.949	15.301
8. HH Distance in (KMs) to Nearest Market	64.483	7.747	56.29	70.066	70.372	31.56	66.256

(*) UG travel time in hours to cities with 500K population .

Source: Authors' computation from LSMS-ISA surveys

Table 1b: Endowments by AEZ

	Tropic - warm arid	Tropic - warm semiarid	Tropic - warm subhumid	Tropic - warm humid	Tropic - cool semiarid	Tropic - cool subhumid	Tropic - cool humid	TOTAL
1. Value of agroecological potential (US\$/ha)	152.374	584.988	732.644	936.005	350.338	867.052	1161.476	739.567
2. AEP per person (US\$/person)	1109.466	626.970	303.627	325.910	304.425	508.648	489.290	393.780
3. Rural population density (pers./sq. km) (2005)	13.734	93.304	241.297	287.197	115.082	170.462	237.38	187.812
4. Average growing period (days)	48.332	124.34	234.108	298.932	141.948	224.778	277.151	208.597
5. Elevation (meters)	382.215	480.378	326.829	496.783	1949.865	1951.339	1845.837	923.735
6. UG	0.108	62.801	126.824	224.241	2.195	26.627	5.717	82.928
7. HH Distance in (KMs) to Nearest Major Road	30.655	21.324	14.54	7.709	16.515	12.588	15.285	15.301
8. HH Distance in (KMs) to Nearest Market	54.215	64.272	75.497	48.204	55.861	61.871	70.817	66.256

(*) UG travel time in hours to cities with 500K population .

Source: Authors' computation from LSMS-ISA surveys

Table 2a: Households' characteristics by country

	ETH	MWI	NER	NGA	TZA	UGA	Total
1. Age head of hh		43.041	44.491	51.186	48.493	45.772	48.801
2. Female headed hh		0.243	0.076	0.129	0.248	0.273	0.172
3. Poverty headcount ratio at below '05 PPP \$1.25/day (percent) (2005)		75.174	40.803	65.477	91.548	52.538	66.624
4. Gross household income		622.235	1235.743	1413.874	1072.848	1164.357	1333.648
5. Net income=Ag wage+Non-ag. wage+Crop+Livestock+Self employment+Transfer		438.864	806.135	1310.067	871.488	956.875	6786.6
6. Total HH annual consumpt. (in US\$)		1372.651	2384.103	2616.445	1826.523	1227.902	21881.65
7. Gross income per capita		149.706	214.196	262.795	222.641	282.51	256.003
8. Per capita annual consumpt. (US\$)		335.396	845.347	514.034	370.4	249.122	4643.549
9. Gross income from crop per ha		500.547	179.634	1144.569	519.947	495.334	983.407
10. Net income from crop (no food cons section) per ha		156.112	158.131	820.223	268.066	334.78	686.718
Share in total net income							
<i>wage</i>		0.311	0.103	0.122	0.161	0.198	0.179
<i>crop</i>		0.376	0.248	0.601	0.433	0.429	0.4174
<i>livestock</i>		0.134	0.167	0.121	0.131	0.15	0.1406
<i>employment</i>		0.078	0.351	0.151	0.197	0.145	0.1844
<i>transfer</i>		0.101	0.131	0.005	0.078	0.078	0.0786

Source: Authors' computation from LSMS-ISA surveys

Data on income and consumption for ETH not available

Table 2b: Households' characteristics by AEZ

AEZ_CODE	Tropic - warm arid	Tropic - warm semiarid	Tropic - warm subhumid	Tropic - warm humid	Tropic - cool semiarid	Tropic - cool subhumid	Tropic - cool humid	TOTAL
1. Age head of hh	41.293	46.515	52.791	50.781	46.63	45.61	44.729	48.801
2. Female headed hh	0.091	0.04	0.195	0.236	0.209	0.211	0.246	0.172
3. Poverty headcount ratio at below '05 PPP \$1.25/day (percent) (2005)	38.433	81.641	61.765	53.377	63.364	67.5	60.724	66.624
4. Gross household income	1203.237	1390.376	1324.827	1300.825	935.295	1313	1190.442	1333.648
5. Net income=Ag wage+Non-ag. wage+Crop+Livestock+Self employment+Transfer	5367.056	1700.608	1326.037	1070.129	23037.2	16950.01	9722.914	6786.6
6. Total HH annual consumpt. (in US\$)	49634.71	5690.232	2779.43	2487.984	60519.14	57145.1	48010.29	21881.65
7. Gross income per capita	213.977	229.117	271.974	262.68	155.904	245.188	308.121	256.003
8. Per capita annual consumpt. (US\$)	9851.17	1191.895	604.078	469.667	13226.38	11964.73	10318.21	4643.549
9. Gross income from crop per ha	314.499	761.16	1135.457	1245.516	332.121	683.4	721.178	983.407
10. Net income from crop (no food cons section) per ha	263.538	744.52	793.691	375.971	133.823	341.697	458.291	686.718
Share in total net income								
<i>wage</i>	0.071	0.081	0.128	0.229	0.06	0.092	0.088	0.179
<i>crop</i>	0.216	0.529	0.623	0.490	0.727	0.641	0.61	0.4174
<i>livestock</i>	0.486	0.174	0.089	0.121	0.136	0.164	0.184	0.1406
<i>employment</i>	0.167	0.199	0.141	0.116	0.032	0.069	0.073	0.1844
<i>transfer</i>	0.06	0.017	0.019	0.044	0.045	0.034	0.045	0.0786

AEZ do not include information on ETH therefore the total number of HH per AEZ is different compared to the other tables.

Source: Authors' computation from LSMS-ISA surveys

Table 3a: Land and fallow by country

		ETH	MWI	NER	NGA	TZA	UGA	Total
Land								
1.	Area owned (ha)	1.16	0.68	4.53	1.119	2.405	1.833	1.341
2.	Total area rented in (ha)	0.199	0.063	0.683	0.294	0.08	0.435	0.256
3.	Area rented out (ha)	0.025	0.004	0.037	0.002	0.038	0.021	0.014
4.	Area Operated (ha)	1.334	0.74	5.096	1.411	2.446	2.028	1.571
Land use								
5.	Gross cropped area (ha)	0.582	0.739	5.825	1.63	2.031	2.385	1.474
6.	Net crop area (ha)	0.295	0.67	4.932	1.291	1.952	1.007	1.124
7.	Crop intensity	1.205	1.015	1.189	1.228	1.068	1.888	1.227
Fallow								
8.	Area under current crop and fallow (ha)	0.295	0.679	5.006	1.293	2.212	1.1	1.161
9.	Current crop area (ha)	0.295	0.67	4.932	1.291	1.952	1.007	1.124
10.	Current fallow area (ha)	NA	0.009	0.074	0.002	0.259	0.094	0.037
11.	Past fallow area (ha)	NA	0.017	0.183	NA	0.121	0.392	0.035
12.	Prop. of current fallow area in current crop and fallow area	NA	0.006	0.007	0.001	0.075	0.053	0.012
13.	Prop. of past fallow in current crop and fallow land	NA	0.015	0.03	NA	0.043	0.148	0.013

Source: Authors' computation from LSMS-ISA surveys

Table 3b: Land and fallow by AEZ

		Tropic -warm arid	Tropic - warm semiarid	Tropic - warm subhumid	Tropic - warm humid	Tropic - cool semiarid	Tropic - cool subhumid	Tropic - cool humid	TOTAL
Land									
1.	Area owned (ha)	3.08	1.843	1.101	0.957	1.157	1.474	1.177	1.341
2.	Total area rented in (ha)	0.457	0.272	0.297	0.294	0.211	0.191	0.173	0.256
3.	Area rented out (ha)	0.02	0.013	0.005	0.011	0.019	0.024	0.027	0.014
4.	Area Operated (ha)	3.414	2.098	1.392	1.152	1.349	1.635	1.288	1.571
Land use									
5.	Gross cropped area (ha)	3.881	2.194	1.567	1.614	0.73	0.972	0.716	1.474
6.	Net crop area (ha)	2.95	1.878	1.244	0.836	0.444	0.693	0.35	1.124
7.	Crop intensity	1.228	1.134	1.217	1.585	1.152	1.216	1.308	1.227
Fallow									
8.	Area under current crop and fallow (ha)	2.984	1.891	1.293	0.873	0.449	0.752	0.369	1.161
9.	Current crop area (ha)	2.95	1.878	1.244	0.836	0.444	0.693	0.35	1.124
10.	Current fallow area (ha)	0.034	0.013	0.049	0.037	0.005	0.059	0.02	0.037
11.	Past fallow area (ha)	0.072	0.012	0.022	0.164	0.005	0.033	0.077	0.035
12.	Prop. of current fallow area in current crop and fallow area	0.003	0.004	0.013	0.022	0.003	0.019	0.011	0.012
13.	Prop. of past fallow in current crop and fallow land	0.013	0.003	0.008	0.062	0.002	0.012	0.026	0.013
14.	Lenght of current fallow	NA	0.001	NA	NA	0.001	NA	NA	0.001

Source: Authors' computation from LSMS-ISA surveys

Table 4a Irrigation and Technology by country

		ETH	MWI	NER	NGA	TZA	UGA	Total
1.	Irrigated area (ha)	0.016	0.003	0.036	0.033	0.045	0.02	0.029
2.	Dummy using organic fertilizers	0.53	0.16	0.48	0.03	0.17	0.12	0.25
3.	Dummy using improved seeds	0.18	0.61	0.03	NA	0.18	0.18	0.09
4.	Dummy using inorganic fertilizer	0.41	0.76	0.18	0.41	0.16	0.03	0.38
5.	Dummy using agro-chemicals	0.23	0.03	0.07	0.34	0.12	0.11	0.27

Source: Authors' computation from LSMS-ISA surveys

Table 4b Irrigation and Technology by AEZ

		Tropic -warm arid	Tropic - warm semiarid	Tropic - warm subhumid	Tropic - warm humid	Tropic - cool semiarid	Tropic - cool subhumid	Tropic - cool humid	TOTAL
1.	Irrigated area (ha)	0.113	0.051	0.03	0.007	0.031	0.016	0.012	0.029
2.	Dummy using organic fertilizers	0.114	0.132	0.027	0.03	0.614	0.563	0.583	0.239
3.	Dummy using improved seeds	0.012	0.02	0.03	0.069	0.108	0.25	0.181	0.091
4.	Dummy using inorganic fertilizer	0.072	0.5	0.262	0.058	0.399	0.532	0.462	0.375
5.	Dummy using agro-chemicals	0.135	0.376	0.267	0.063	0.15	0.272	0.308	0.269

Source: Authors' computation from LSMS-ISA surveys

Table 5: Population density and infrastructure

	(1) Log Pop. Dens.	(2) Log Dist. To Road	(3) Log Distance to Mrkt
Log Value of AEP \$/ha	0.056*	-0.146***	0.001
UG ¹	0.066	-0.309***	-0.061*
Interaction Log UG and Log AEP	-0.001	0.024***	-0.006
Country dummy ETH	0.393***	-0.274**	-0.325***
Country dummy MWI	0.289**	-0.069	-1.960***
Country dummy NER	-0.947***	-0.670***	-0.705***
Country dummy TZA	-0.971***	-0.219*	-0.376***
Country dummy UGA	0.508***	-0.472***	-0.935***
Constant	4.092***	3.453***	4.292***
Observations	1,993	1,993	1,993
R-squared	0.118	0.136	0.122

¹UG: travel time negative exponential, with borders restriction to cities with 50
Nigeria is the baseline for the country dummy

Table 6: Land areas and intensification

	OLS				Tobit
	Log Own Area	Log Crop Area	Log Crop and Perennial Area	Crop intensity	Proportion of land under current fallow ²
Log Value of AEP \$/ha	0.016	0.006	-0.002	0.001	-0.002
UG ¹	-0.086***	-0.054**	-0.062***	0.029***	0.0005
Interaction Log UG and Log AEP	0.003	-0.001	0.000	-0.004***	-0.001
Country dummy ETH	-0.067	-0.602***	-0.161***	-0.086***	
Country dummy MWI	-0.094***	-0.185***	-0.229***	-0.102***	0.122***
Country dummy NER	0.761***	0.801***	0.761***	-0.019	0.131***
Country dummy TZA	0.291***	0.166***	0.128***	-0.090***	0.295***
Country dummy UGA	0.238***	0.121***	0.197***	0.205***	0.248***
Constant	0.694***	0.848***	0.934***	0.796***	-0.250***
Observations	1,993	1,993	1,993	1,993	1,750
R-squared	0.256	0.320	0.159	0.158	0.771
Elasticity of AEP taking account of both the linear and the interaction term				-0.0032	
P-value				0.543	
Elasticity of UG taking account of both the linear and the interaction term				0.0241	
P-value				0.001	

¹UG: travel time negative exponential, with borders restriction to cities with 50 Nigeria is the baseline for the country dummy

²Information on Proportion of land under current fallow is NA in ETH.

TOBIT REGRESSIONS

Table 7. Irrigation and technology variables

VARIABLES	Tobit Regressions				Probit Regression
	Share of Land irrigated	Share organic fertilizer	Share inorganic fertilizer	Share agro-chemicals	Share of Improved seeds (2)
Log Value of AEP \$/ha	-0.054	0.030***	0.071***	0.048**	0.059***
UG ¹	-0.169	-0.021	-0.027	-0.038	0.122**
Interaction Log UG and Log AEP	0.021	0.000	0.001	-0.003	-0.019***
Country dummy ETH	0.457*	0.946***	0.182***	-0.237***	-0.720***
Country dummy MWI	-0.302*	0.450***	0.455***	-0.731***	
Country dummy NER	-0.325	0.848***	-0.245***	-0.533***	-0.626***
Country dummy TZA	-0.022	0.312***	-0.484***	-0.590***	-0.750***
Country dummy UGA	-0.444**	0.264***	-0.818***	-0.448***	-0.675***
Constant	-0.879*	-0.465***	-0.081	0.070	
Observations	1,993	1,993	1,993	1,993	1,633
R-squared	0.0356	0.486	0.185	0.0917	0.0256

¹UG: travel time negative exponential, with borders restriction to cities with 50

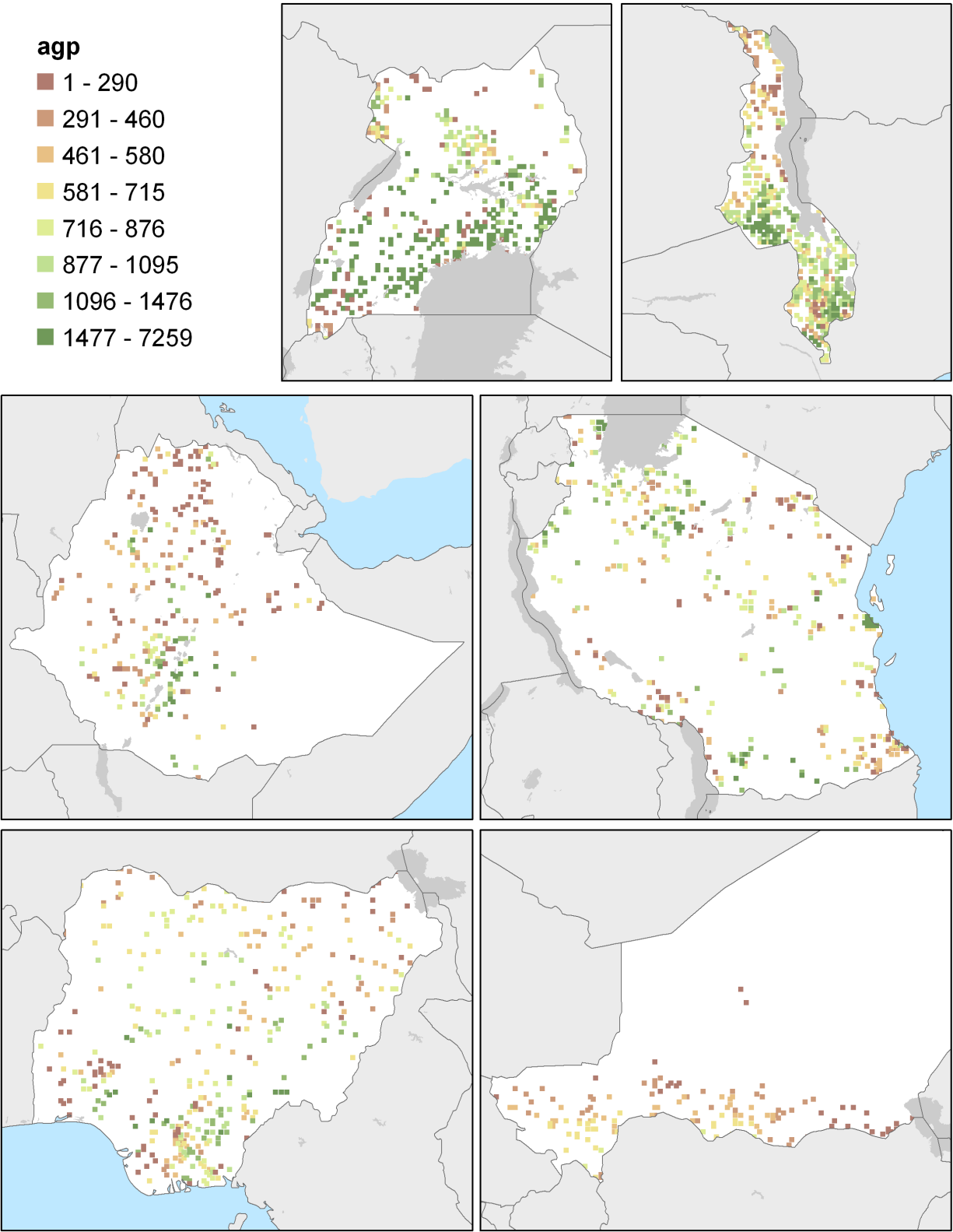
²Regressions on Improved seeds does not include NGA as the variable is not available. MWI is the baseline in this case.
Nigeria is the baseline for the country dummy in all other regressions

Table 8: Regressions on Crop Profit and Income

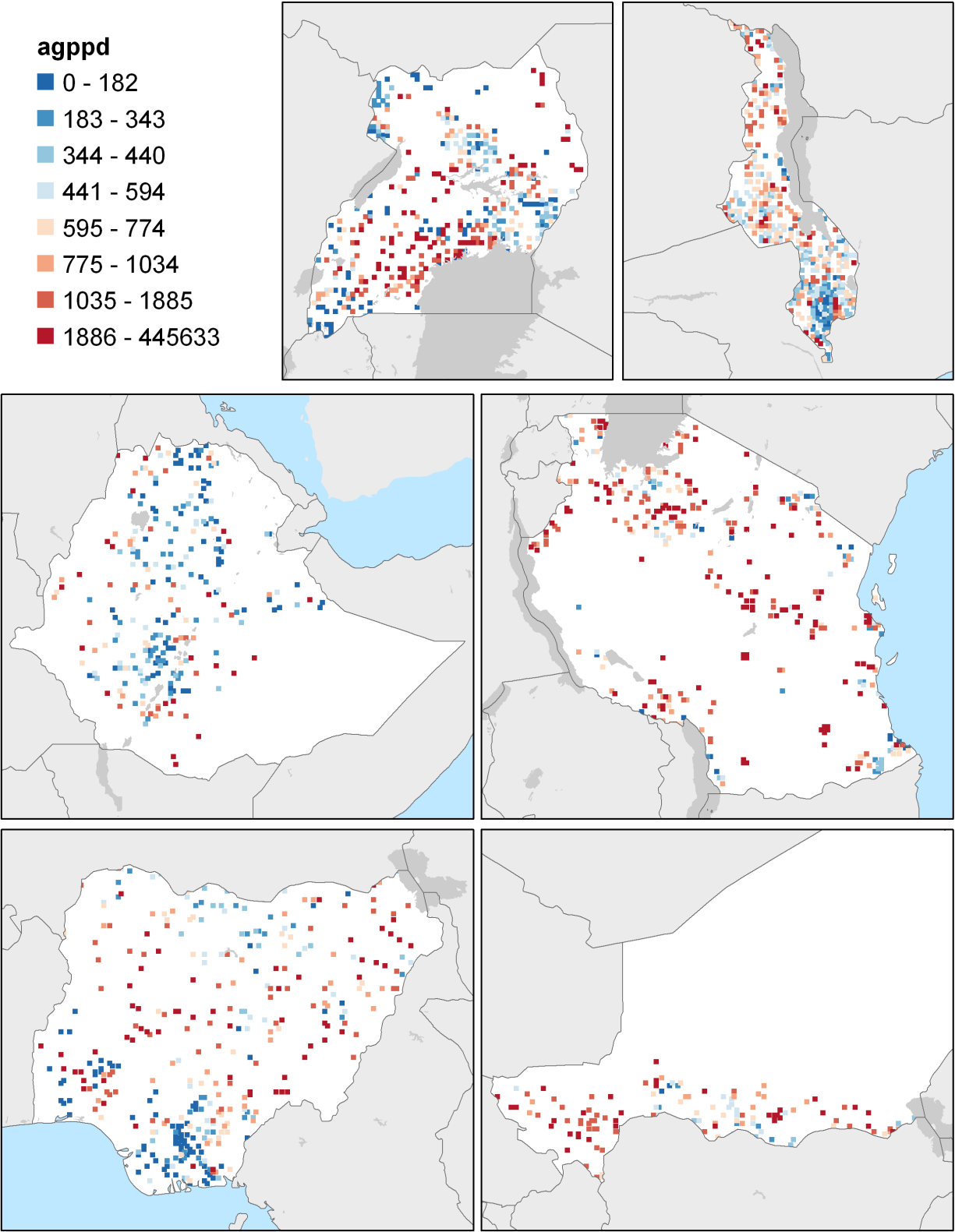
VARIABLES	(1) Log Crop profit/ha.	(2) Log HH pc income
Log AEP (US\$/ha)	0.328***	-0.147***
Log AEP Square (US\$/ha)	-0.037**	0.013**
UG	-0.203***	-0.140***
Interaction Log UG and Log AEP	0.008	0.019***
Country dummy NER	-2.739***	0.013
Country dummy TZA	-1.059***	-0.059
Country dummy UGA	-0.423*	0.036
Constant	5.404***	5.767***
Observations	1,750	1,750
R-squared	0.078	0.030
Elasticity Log AEP and Log AEP square	0.254	-0.119
P-value	0.002	0.000
Elasticity Log AEP and Log AEP square and Log UG	0.0509	-0.259
P-value	0.662	0.000

¹UG: travel time negative exponential, with borders restriction to cities with 50
For ETH: Income not available, MWI is the baseline

Map 1: AEP/ha (agp) for the enumeration areas in of each of the six study countries



Map 2 AEP per rural person (agppd) across all of the countries



Map 3: Urban Gravities for the six countries

