How does Population Density affect Agricultural Productivity? Evidence from Ethiopia

Anna Leigh Josephson Jacob Ricker-Gilbert Jordan Chamberlain Raymond Florax
Purdue University Purdue University Michigan State University Purdue University
josephsa@purdue.edu

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I. Introduction and Motivation

Like other African countries, land resources in Ethiopia are generally considered to be abundant. However, household survey data from Ethiopia suggest that average farm size is around one hectare, and has been shrinking over time (Dessalegn, 1997). Some evidence also suggests that landlessness is an emerging phenomenon in Ethiopia (Gebreselassie, 2006 & 2011). With Ethiopia's population expected to double by 2050 to around 160 million people, farm sizes seem set to shrink even further in the absence of accelerated migration rates. Given Ethiopia's long and tragic history of famine, higher rural population densities and shrinking farm sizes are a major concern for the future food security of the country.

Relevant economic theories give contrasting predictions of how increases in rural population density should affect agricultural productivity. Over 200 years ago, Malthus predicted that unchecked fertility rates over-stretched natural resources, leading to famine and temporary reductions in population growth, before fertility rates started the cycle all over again. This model notably precluded the possibility of technological intensification in agriculture, or of bringing more land under cultivation. Boserup (1965) linked rising population to technological intensification in an endogenous manner, with population pressure inducing rising demands for modern inputs such as chemical fertilizer and improved seed, which in turn boosts production per unit of land. Von Thunen had much earlier presented a related argument that as the value of land increases (because of improved market access, but also population pressure), farmers switch to higher value crops to maximize value per hectare. Hayami and Ruttan (1970) also emphasize population growth induces innovation since it causes the price of labor to decrease relative to the price of land (Hayami & Ruttan, 1970), which increases demand for labor intensive and high yielding inputs like hybrid seeds and chemical fertilizer. More recently, the agglomeration economies literature has identified endogenous technological benefits of population density, such as thicker markets and greater technological spillovers (World Bank, 2009). While this literature is urban biased, its predictions could certainly apply to rural areas. Moreover, population density could increase access to nonfarm income sources and raise demand for agricultural products, both of which could benefit agricultural intensification. Finally, Johnson (2000) discusses a "political Boserup effect", in which governments in population-dense areas or countries actively implement policies to prevalent Malthusian crises. In addition to technological intensification of agriculture, this might include human capital policies, migration policies and family planning policies. Hence a range of endogenous processes provide avenues for population-dense areas to escape the Malthusian trap. Whether these areas fully do so, however, is an empirical question, and clearly one potentially influenced by government policies, agro-ecological conditions and other factors, such as culture.

Therefore, the specific objective of this study is to therefore determine how changes in population density in Ethiopia affect agricultural intensification, measured in terms of 1) chemical fertilizer adoption, and 2) increased staple crop production, in the case of this paper, maize and teff. We use household-level panel data from the Ethiopian Rural Household Survey (ERHS) along with GIS data on population density from Ethiopia to quantify the impact of population density on purchases of (demand for) chemical fertilizer and maize and *teff* production. We complement this with some insights from a focus group questionnaire conducted in a subset of the ERHS villages.

Although there is a literature looking at population density and agricultural intensification (for example, Pender 1998 & 2001, Pingali & Binswagner 1984), our contribution is to use household-level data to estimation the relationship between population density and agricultural intensification. Although this research remains a work in progress, our analysis allows us to isolate the effects of population on input demand and output supply from other factors such as relative prices and household demographics. Bearing that in mind, the main findings of this study are as follows. First, we find that population density has a positive and significant effect on fertilizer demand, indicating that population growth leads to intensification of input use, at least up to a certain level of population density. Second, we find that the production of teff and maize depends on population density, although teff is produced in lower amounts at larger population densities while maize is produced more.

The remainder of the paper is structured as follows. In Section 2 we provide some historical context, giving background on Ethiopia land history, as it relates to agricultural productivity. In Section 3 we provide more overview of theories of induced innovation to explain how increasing land pressures in many parts of Africa are likely to affect the evolution of farming systems and welfare of farmers across Africa. In Section 4 we present our estimates of the impacts of rising population densities on household behavior and welfare, drawing on household panel survey data from Ethiopia. Finally, Section 5 considers the implications of these findings for agricultural and poverty reduction strategies in Ethiopia.

II. The Ethiopian Context

The historical, political, and societal past of Ethiopia makes it an interesting place to study land use. The past three political regimes and their treatment of land as well as migration have tremendously influenced the way in which farming and land use have evolved throughout the past century.

Consideration of the highland to lowland dynamics is necessary to understand the process of resettlement and treatment of land in Ethiopia. Only when bureaucracy became more centralized in the twentieth century did the two parts of the nation form a more cohesive structure. With the development of markets the nation commercialized and the lines between the different geographic regions become more blurred. However, most of Ethiopians still remain concentrated in the highlands, primarily for graphical, societal, and historical reasons (Pankhurst, 2009). These justifications can further be explained in four ways: 1) climate, 2) technology, 3) land tenure, and 4) state formation. These points will be explained in the next two paragraphs, the first discussing the highlands and the second about the lowlands.

The highlands have had many advantages which led to their more rapid development and hence greater population expansion. First, the highlands have benefited from a more steady rainfall and plateaus have been conducive to the development of agriculture, in terms of climatic and environmental terms. Second, the highlands have benefited from century old technological innovations on ox-ploughs, which led to intensification of production and similarly expansion of land under cultivation and denser population (Hammond, 2008). Third, the land-tenure system which developed in the highlands simultaneously with plough agriculture was based on kinship groups that allocated rights to individuals. With increasing population, this had led to the gradual decrease of size of plot managed by household labor. Fourth and finally, the combination of factors discussed above permitted for the development of surplus, early state formation, and clear, central social formations (Pankhurst, 2009). Therefore, due to these four reasons, population has remained most dense in the highland regions of Ethiopia.

Conversely, the lowlands have suffered from developmental stagnation and decreased population density, as a result. First, lowlands have been characterized by variable and limited rainfall, shallow soils, and constraints on human settlements due to water availability and disease. Second, the lowlands technological innovations have not progressed beyond hoe and shifting cultivation techniques, or in some cases pastoralism, associated with seasonal migration. While this limits outputs from agriculture, it allows livelihoods to be sustained within the existing environmental constraints; though this does lead to sparse development. Third, unlike the highland's individual plot allocation, people in the lowland use communal tenure over large areas of land, with some collective regulation of access and limited individual rights. Finally, unlike the social development of the highlands, the lowlands remained largely egalitarian with autonomous local groups until the late nineteenth century, though local leaders still retain power based on control of labor and religion (Pankhurst, 2009). Therefore, contrary to the highlands, the lowlands have remained least dense over time.

The two geographic regions of Ethiopia long remained physically, politically, and culturally separated. Only with the development of more centralized government and clear market structure did the two begin to unite in a more definite way, although the highland to lowland dynamics still remain important to determine differences in resettlement trends through the country (Rahmato, 2007).

Due to trends of resettlement between the highland and lowland regions of Ethiopia, the topic of land tenure is quite relevant. Land tenure in Ethiopia has long been fraught with conflict and insecure rights. As land tenure and security of rights is important to rural farms and as agriculture is a main source of income and livelihood for between 85 percent and 90 percent of the country's population (Helland, 1999), these rights have become even more tenuous as population density has increased.

The present tenure system is determined by the constitution drafted in 1995. This document formed a bicameral legislature and a judicial system and attempted to establish specific rights to Ethiopian citizens. One of these rights was vested land ownership in the state to every Ethiopian who wanted to engage in agriculture, to receive inheritable use rights to a piece of land, without cost. This was intended to occur through administrative reallocation of land; but this itself created conflict as it undermined any still existing security of tenure. Therefore in 1997, a new proclamation devolved this responsibility away from the state to the individual regions (Jemma, 2004). This transition has led to a series of common issues, discussed by Deininger (2008), including: 1) random and unanticipated administrative redistribution of land; 2) decreased opportunities for rental circumstances; 3) decreased investment in land; and 4) prohibition of mortgaging and sale of land. Many individuals in focus groups conducted in May 2012 discussed their concerns about the present system of land tenure, as well as their overall feelings of security. In fact, most more than 60 percent of those surveyed, indicated that they had insecure feelings of tenure.

Exacerbating the issues of redistribution and insecure tenure is the large and persistent increase in population throughout Ethiopia. With an UN-projected growth rate of 3.2 percent annually, the population is expected to reach 2.7 billion people by 2050. With a young age structure, fertility at 5.1 children per woman, and under 10 percent contraceptive use among women, population is expected to continue to increase dramatically through the next few decades. Furthermore, all focus group participants in May 2012 expressed concern over the growing population and the constraints on farming associated with more people and an increased demand for land. Many cited farm sizes decreasing due to large family size and extended life spans among the population. The issue of land security and land use are likely to increase in importance in Ethiopia over the next years with the continued growth of the population.

In addition to concerns about growing population and decreasing land availability, survey participants indicated general trepidation over increasing fertilizer prices. Many cited increasing prices, combined with mandatory bundling of fertilizer and improved seed, which make access to fertilizer more difficult. Many villages, particularly those in high population density areas, said that such bundles were too expensive to purchase, and therefore were going without both fertilizer and improved seed. Beyond these issues, field group participants expressed that access to markets tremendously influenced their choices to grow crops, due to their ability to attain certain prices at market. Therefore, variables representing these factors are included in later price regressions. Overall, the field group surveys indicated an apprehension among rural famers regarding their future ability to profitability grow crops, expressed most clearly in many farmers stating that they did not feel their children would be as well off in their same profession. These field group results assisted in the formation of our hypotheses, and the development of our conceptual and empirical models which now follow.

III. Conceptual and Empirical Model

Our conceptual and empirical models are motivated by Boserup, Hayami and Ruttan, as well as work by Pender, and Pingali and Binswanger. Therefore, we conceptually present that growth in population should cause demand for an agricultural good Y to shift outward from D to D', raising the price of Y from P to P' *ceteris paribus* (see Figure 1). The increase in price should induce a supply response where farmers adopt technology, such as chemical fertilizer or hybrid seed, to increase production of Y. Therefore, for household *i* in village *j* at time *t*, demand for modern inputs such as chemical fertilizer and hybrid seed should be a function of:

1) $X_{ijt} = \beta P_{jt} + Z_{ijt}\delta + c_{ij} + \varepsilon_{ijt}$

where *X* represents the level of input used by household *i* in village *j* at time *t*. In this study we consider kilograms of chemical fertilizer purchased by the household as the modern input of interest. Population density, measured in people per square kilometer of arable land is denoted by *P*, and *β* represents the corresponding parameter. Other factors that influence demand for modern inputs are denoted by Z, and δ represents the related vector of parameters. Factors such as input and output prices are considered in Z as changes in relative prices drive demand for intensive inputs such as fertilizer, according to the induced innovation hypothesis (Hyami & Ruttan, 1970). Other factors included in Z are credit and market access, family demographics, as well as weather and other agronomic conditions (see Table 1 for a full list of explanatory variables). The error term in equation 1) consists of two parts; the time-constant unobservable household-level factors that impact input demand are denoted by c, while ε represents time-varying unobserved shocks that influence demand for inputs.

Just as population growth may induce farmers to adopt modern inputs, it may also cause staple crop production to increase per hectare. Therefore for household i in village j at time t, output supply of staple crops can be modeled as a function of:

2) $Y_{ijt} = \varrho P_{jt} + Z_{ijt}\alpha + b_{ij} + v_{ijt}$

where Y represents production in kilograms per hectare of staple crops (maize and teff). Just as in equation 1) population density is denoted by P, and here ϱ represents the corresponding parameter. In addition, other factors that impact output supply are denoted by Z, and a represents the related vector of parameters. The error term in equation 2) consists of two parts just as in equation 1). The time-constant unobservable household-level factors that influence output supply are denoted by b, while v represents time-varying unobserved shocks that influence output supply.

We estimate equations 1) and 2) as a system of seemingly unrelated regressions (SUR) in Stata.

Identification Strategy

The objective of this study is to estimate how population density impacts demand for modern inputs and staple crop production. In order to argue that population density has a causal effect on these measures of agricultural intensification, our estimation strategy has to deal with the possibility that population density is endogenous in equations 1) and 2) causing biased coefficient estimates as the error terms in these equations may be correlated with P. Potential endogeneity of population density stems from possible reverse causality because while Boserup's hypothesis maintains that population density influences agricultural intensification; it is also possible that agricultural intensification still influences population growth. The latter relationship was first promoted by Malthus in the 19th century, and has been supported by (neo)-Malthusians since that time.

Therefore, we deal with potential endogeneity of population density caused by reverse causality in two ways. First, we use a correlated random effects estimator (CRE) to control for potential correlation between population density *P* and the unobserved time-constant factors that affect input prices and landholding. These factors denoted as c_{ij} in equation 1 and b_{ij} in equation 2 are unobservable to us as researchers but could include farmer motivation, risk aversion, and ability. The CRE estimator operates under the assumption that the unobserved heterogeneity takes on the form in equation 1) of $c_{ij} = \varphi_{ij} + \bar{X}_{ij}\xi + r_{ij}$ and that $r_{ij} \mid Z_{ij} \sim Normal\ (0, \sigma^2_{rij})$; where $\bar{X}_{ij}$ is the household time average of Z_{ijt} in equations (1) and (2). To operationalize the CRE estimator $\bar{Z}_{ij}$ needs to be included in these equations. When implemented as a linear model the CRE estimator controls for unobserved heterogeneity, and produces coefficient estimates that are identical to those generated by household-level fixed effects (Wooldridge 2010). The added benefit of the CRE estimator over fixed effects is that the CRE does not remove time-constant covariates from the models.

The second component of endogeneity that must be addressed is potential correlation between population density and unobserved time-varying shocks that affect equations 1 and 2. These could include weather shocks or income shocks at the household or community-level. In order to deal with this issue, we estimate a reduced from model of population density *D* in community j at time t as a function of the following factors:

$$P_{jt} = M_{jt-k}\gamma + \varepsilon_{ijt}$$

where M denotes physical factors that affect population density, such as elevation, at time t. When k>0, M represents historical factors that affect population density, such as historical population levels in 1950 and long run annual rainfall. These factors serve as instrumental variables (IV) to identify population density coefficients in equations (1) and (2). Factors such as elevation are good instruments because they likely affect historical patterns of settlement, without directly affecting the error terms in the input price and land holding models presented in equations (1) and (2), respectively. This is particularly the case after using the CRE to remove time-constant unobserved heterogeneity, along with conditioning on other covariates, such as household characteristics and observable shocks, like death of family members. In order to make time-constant IV's such as elevation vary over time we follow McMillen et al. (2011) and interact them with the year dummy variables.

In order to operationalizes our IV estimation we use the control function (CF) approach. The CF approach entails taking the residuals from equation (3) and adding them as an additional covariate in equations (1) and (2). This method controls for endogeneity and has the additional benefit over two stage least squares because it supplies a direct test of endogeneity (Wooldridge 2011). If the residuals are statistically significant in (1) and or (2) then population density is endogenous in those equations, but it is controlled for by the presence of the residual. Bootstrapping must be used to obtain valid standard errors that account for the two-step estimation process.

IV. Data

As population grows through Ethiopia, farming practices change, correspondingly intensifying agricultural techniques. In particular, the amount of fertilizer and previously uncultivated land used increase in order to increase output. As in times of pressure, people find ways to increase food production through these intensified techniques; it is overall driven by changes in relative prices. When population grows, the price of labor relative to the price of land decreases and other methods are used (Hayami & Ruttan, 1970). This study quantifies how population density affects input use and output per hectare of staple crops. In doing so, we empirically test Boserup's hypothesis that increasing population density leads to agricultural intensification, as measured by 1) demand for chemical fertilizer and 2) increased staple crop yields.

This study draws from three types of data and associated analyses. First, we draw on regional databases describing spatial distributions of rural population and arable land. Estimates of rural population density are derived from the Global Rural-Urban Mapping Project (GRUMP). The dataset provide gridded estimates of local population densities, starting with sub-national census data and allocating the population across a set of grid cells corresponding to that particular area. GRUMP separates the urban and rural components of local population with the rural portion being equally allocated between all rural grid cells in the area. Information on the arable land within each pixel was obtained from the Global Agro-Ecological Zones (GAEZ) 3.0 database. This data consists of gridded estimates of local land and agro-climatic resources, including soils, terrain, land cover, and other climate indicators, as well as derived estimates of agricultural suitability and potential yields for a multitude of commodities under given management levels. Using the land cover components of the GAEZ database, we created three definitions of "arable land"; areas classified as 1) under cultivation; 2) under cultivation or grassland; 3) under cultivation or grassland or forest/woodland. The reasoning behind the adoption of multiple definitions was to evaluate the robustness of the analysis to alternative definition, with classification of 1) reflecting currently available farmland, but 2) and 3) indicating potential available farmland if adequate costs are incurred to alter grassland and forest land to farming.

Within a Global-Information System (GIS), we combined the data on arable land and rural population at the level of one square kilometer grid cells, covering all of sub-Saharan Africa. We omitted all pixels categorized as rural that contained less than 10 percent arable land or exceeded 2,000 persons per square kilometers, based on the assumption that populations over this level were approaching peri-urban status or were mis-categorized. Use of this data permits for a greater localized variation in rural population densities than were possible if estimated at multiple aggregated spatial units.

Second, we consider farm level conditions in greater detail by drawing on household survey data sets collected in Ethiopia by International Food Policy Research Institute (IFPRI). The nationwide Ethiopia Rural Household Survey (ERHS) is a panel dataset tracking approximately 1,500 households in seven survey waves over the fifteen year period from 1993 to 2009. We use the first six waves of the survey. The dataset is broadly representative of non-pastoral households in the nation, in regard to population densities, incomes, and agronomic factors. For further information, please see Table 2, which includes some basic characteristics on the survey sites. A variation in population density is desirable to study the hypotheses which are provided through the selected sample in the EHRS. This is necessary as a reasonably wide population density range will be necessary to obtain meaningful research answers. This is partly to examine the differing roles that agricultural practices play at different levels of population density and to see how agricultural output varies with these changes. The set includes consumption, asset, and income data, as well as household characteristics, agriculture, and livestock information, food consumption, health, women's activities, as well as community level data on electricity, water, sewage and toilet infrastructure, health services, education, NGO activities, migration, wages, production, and market.

Finally, we utilize field group surveys conducted in twelve of the ERHS villages in May of 2012. Using questions designed to gain qualitative information about farmers' perceptions regarding population growth, land use, farming practices, children, and the future, we use this information to extend our quantitative analysis and support the resulting conclusions.

V. Results

This section addresses how rising population density influences farmer behavior, in regard to using chemical fertilizer and staple crop production. Table 3 shows some summary statistics of the relationship between some of the variables of interest for our study. Further, Figure 2 through Figure 7 present the lowess smoothing relationship between dependent variables of interest in this study graphed against population per arable land, for the densities of 2005. It is important to note that these are unconditional bi-variate relationships between the variables of interest and population density, so other factors are not held constant. The population per square kilometer arable land is created using the GRUMP population estimates, which are then divided by the arable land estimates, which were generated by the GAEZ spatial database estimates. Figures 2 and 3 show fertilizer variables, respectively fertilizer use per hectare and fertilizer expenditure per hectare, against population per arable land; these figures indicate that fertilizer use increases from low population densities but sharply decreasing just below 500 people per square kilometer. At this same point, fertilizer expenditure shows a similar decrease, as would be expected from lowered use overall. Figure 4 shows area owned by a household against square kilometer of arable land. Interestingly, contrary to what would be expected, land owned by a household increases around 500 people per square kilometer. The reasoning for this cannot simply be explained by past work as conceptually, one would expect a decrease in land owned as population becomes denser. However, likely due to redistribution practices in population dense regions of Ethiopia, there are likely more people holding land in these population dense regions, due to government efforts to expand production and arable land in those regions. Figures 5 and 6 show yield for teff and maize against square kilometers of arable land, and both indicate decreasing production with increasing population density. However, while teff decreases constantly, with each population density lower than the last, maize increases and then sharply decreases. Both production observations are likely due to ability to cultivate more intensive crops at higher population densities, or greater ability to purchase crops due to off-farm activities or sales of cash crops. These results are interesting, though, as they question where people in dense population regions are obtaining their staple crops, including teff and maize.

Table 4 gives more information on population per arable land. This variable is constructed from the extracted GRUMP population estimates, divided by the square kilometers of arable land in the region. The table gives the mean and various percentiles for each of the survey sample years, and all indicate that population is becoming steadily more dense, by all measures.

To analyze this data, we preformed two stages of the regression. First, we estimated two regressions using population density and its square as dependent variables. Both estimating equations were identical with rural populations (in 1920, 1970, and 1990), a ten year rain average, net productivity potential, elevation and its square, as well as dummy terms for years as independent variables. The results of these regressions can be found in Table 5. Both equations have significant values for the ten year rain average, net productivity potential, and year dummy variables, and the population density equation also has a significant value for the rural population density in 1920. From these equations, we estimated the residuals, which were then incorporated into the seemingly unrelated regression estimating equations for price equations (wages, land rental rate, maize price and teff price), as well as for our variables of interest, fertilizer demand and output supply of maize and teff. The results of these regressions are given below.

Price Variables

The price variables of interest in this regression are wages for agricultural work, rental rate for land, as well as maize and teff prices, at the woreda level. In column (1) the results for the log of wages are provided. These results indicate that population density per arable land, as well as its residual are significant. Furthermore, household variables including value of assets, off-farm income, the highest grade completed by the household head, whether the household is below the poverty line, and whether a recent death occurred in the household are also significant. Community variables such as agricultural cooperatives and number of dealers in the region are significant, as is the ten year rain average for the area. This indicates overall that population density has a positive impact on wage rate, which is reflected in evidence from field group surveys that show a growing interest in off-farm labor due to population growth. However, these results also show that household and community factors are also important to actual wages. The next column, column (2) gives results for a regression of the log of land rental rates. These results indicate the all population variables are significant, showing a turning point for population density at -0.310. Therefore, rental rates decrease to a point, then increase, and then begin to decrease again. Field group participants indicated that rental rates are highly uncommon, and even illegal, in Ethiopia, which may give the results a questionable nature. In addition to population variables, though, agricultural cooperatives and dealers, as well as the rain average were significant. All of the household variables were also significant. When considering the price regression, both the log of teff prices and the log of maize prices were considered, in columns (3) and (4), respectively. In the former, all population variables, as well as household, income, and rain variables were significant. In fact, all variables included, save for asset value, were significant. The population variables again indicated a turning point, this time at 0.40. In the latter, only population and its residual were significant. Off-farm income, whether the family lost land during redistribution, and the number of adult equivalents in the household were significant, along with the community variables for agriculture cooperatives, dealers, and historic rain fall. These results follow field group surveys which indicated better prices, and better production incentives, if agricultural cooperatives or dealers were available in the area. Overall, the price results indicate an importance of population density for wage rates, rental rates, and prices for maize and teff.

Fertilizer Demand

Fertilizer demand is estimated to model the effect of population growth on input intensification. The intensity of purchased inputs per hectare, as described in Figure 1 and Figure 2 indicates that fertilizer use and fertilizer expenditure per hectare is found to increase as population becomes denser. The econometric results are presented in Table 7. The results of the regression indicate, that, in terms of fertilizer demand by a household, the most important factors are the value of assets owned by the household, the off-farm income earned annually by the household, the number of dealers and agricultural cooperatives in the area, as well as several climate factors including nutrient availability, workability, and the five and ten year rain averages. Several dummy variables for years and peasant associations are also significant. Furthermore, as we would anticipate from the conceptual model, both population per arable land and its square term, as well as their respective residuals, are significant to fertilizer use. The former term is positive, while the latter is negative. These results indicate a turning point in the data, around 445 people per square kilometer. Therefore, use of fertilizer increases until this point, at which it decreases again. Overall, these results indicate that several factors, most including population, wealth,, and quality of soil and rain are important to the amount of fertilizer used in an area. This does not altogether align with what would expect from Boserup, as fertilizer use would therefore simply increase; however, it does agree with the results of our field group surveys, which indicated that many participants were unable to afford fertilizer, due to its growing expense.

White Teff Production

White teff is a staple component of the diets of most rural Ethiopians and is used, often mixed with other grain flour, to produce injera, the staple food of most diets. It is frequently preferred to the similar, but much darker, black teff. The econometric results can be found in Table 7. The results of the regression indicate that white teff production is influenced by a large number of variables including whether or not the household lost land during the 1995 redistribution, the number of agricultural cooperatives and dealers in the area, whether the head of household is female, whether the household is poor, whether there was a death in the household within the past year, the number of adult equivalents in the household, the price of white teff in the nearest woreda, as well as a number of other agronomic conditions including past rain, nutrient availability, rooting conditions, and workability. Furthermore, several year dummies and location dummies are also significant. Additionally, population per arable land, its square term, and the respective residuals are all significant. However, interestingly, population per arable land has a negative coefficient, indicating that larger population leads to less white teff production. This could be the result of a number of changed behaviors including transition to other, more stable and reliable crops, transition to cash crops, or from moving away from agricultural altogether; all of these activities were suggested by field group discussions which occurred in large areas. Additionally, these results also indicate a turning point at 711 people per square kilometer. As population densities in our survey set are not yet this dense, this point is not observed. However, this result does indicate that at some point, teff production would increase again, even though it would not be produced at middle population densities. Ultimately, these results are quite interesting, and are even more so when compared with maize production.

Maize Production

Maize is a tremendously important crop in Ethiopian agriculture. In 2011 production of all cereal crops, at approximately 5 million tons, maize composed one quarter of the overall production (Access Capital, 2012). The econometric results can be found in Table 7. The results indicate that fewer variables than maize are significant to maize production, and most interestingly, population per arable land and its square have the opposite sign, indicating that maize production increases with population density. This would seem to suggest that maize is such a staple crop that regardless of population density, people are determined to grow it. There is, however, again a turning point, this time occurring at 326 people per square kilometer. This result indicates that until this point people increase their maize production, at which point it begins to decrease. This is quite interesting as it occurs in the opposite direction, and far earlier, than the turning point for teff. However, beyond the population results, several other factors including whether the household lost land during the 1995 redistribution, off-farm income, whether the household is female-headed, whether there was a death in the household in the past year, and several agronomic factors including past rain, nutrient availability, and workability were significant. Several year and location dummies were also significant. Ultimately, the results for maize suggest that it is quite a different crop than teff. While qualitative and quantitative evidence suggests teff has become scarce throughout Ethiopia in the past decade, it seems that maize has remained an important and staple crop for rural households, despite growth in population density.

VI. Conclusions

Despite that sub-Saharan African has much of the world's unused and underused arable land, a significant and growing share of Africa's farm households are living in densely populated areas. These areas are characterized by small and declining farm sizes for most people in these regions (Gebreselassie, 2006). Interestingly, inadequate access to land and inability to utilize available underused land are topics that are important, but under-evaluated, in national development plans and poverty reduction strategies. To our knowledge there has been limited investigation of the challenges associated with increasingly densely populated and land-constrained areas of rural Ethiopia, despite the fact there is a sizeable and increasing share of its rural population of its rural population living in such regions.

The main findings of this study are as follows: 1) population density has a positive and significant effect on fertilizer demand, indicating that population growth leads to intensification of input use, at least up to a certain level of population density; 2) production of teff and maize depends on population density, although teff is produced in lower amounts at larger population densities while maize is produced more. Both results for the demand and supply equations indicate a turning point, so that these results are true up until at point, at which, they reverse directions.

It is not clear if increasing fertilizer use, redistributing land, and other intensification strategies will be enough to overcome Ethiopia's hunger and poverty issues on their own. Field discussion groups in May of 2012 indicate that climate change and related soil degradation is a major issue facing smallholders. Despite government efforts to improve these areas, concerns continue to grow in other aspects. Those surveyed also indicated trepidation about education opportunities, health care, and birth control access in the future, all of which could hurt future productivity. Therefore, it is clear that to the farmers of Ethiopia, problems of production cannot be solved with land management practices alone.

VII. References

Access Capital: Investing in Ethiopia. "Sector Review: Agriculture". January 13, 2012.

Benin, S. and J. Pender, (2001). "Impacts of Land Redistribution on Land Management and Productivity in the Ethiopian Highlands, *AAEA Meeting Selected Paper*, August 2001.

Boserup, E. (1965). The Conditions of Agricultural Growth: the Economics of Agrarian Change Under Population Pressure. Chicago: Aldine Publishing Company.

Dercon S. and J. Hoddinott, 2011. "The Ethiopian Rural Household Surveys 1989-2009: Introduction". *International Food Policy Research Institute*.

Dessalegn, R. 1997. *Manufacturing poverty: rural policy and micro-agriculture*. Paper presented at the Workshop of the Land Tenure Project of the Institute of Development Research, Addis Ababa.

Devereux, S., 2000. "Food Insecurity in Ethiopia". Discussion paper for DFID.

Gebreselassie, S. (2006), "Land, Land Policy, and Smallholder Agriculture in Ethiopia: Options and Scenarios," *Futures Agricultures Consortium*, Institute for Development Studies.

Gebreselassie, S., (2011). "Land, Land Policy, and Smallholder Agriculture in Ethiopia," *Future Agricultures Briefing*. Future Agricultures Consortium. <www.future-agricultures.org>

Hammond, L., 2008. "Strategies of Invisibilization: How Ethiopia's Resettlement Programme Hides the Poorest of the Poor". *Journal of Refugee Studies* 21 (4): 517 – 536.

Hayami Y., and V. Ruttan (1970). "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960." Journal of Political Economy. 78(5):115-41.

Johnson, D. Gale. 2000. "Population, food and knowledge," American Economic Review 90(1): 1–14.

McMillan M.S., W.A. Masters, and H. Kazianga (2011). "Rural Demography, Public Services, and Land Rights in Africa: A Village-Level Analysis in Burkina Faso." NBER Working Paper Series.

Muyanga, M., and T.S. Jayne (2011). "Land Constraints in Kenya's Densely Populated Rural Areas: Implications for Food Policy and Institutional Reform." Department of Agricultural, Food & Resource Economics, Michigan State University.

Pankhurt, A., 2009. *Moving People in Ethiopia: Development, Displacement, and the State.* Rochester, New York: Bodell and Brewer Ltd.

Pender, J. (1998). "Population Growth, Agricultural Intensification, Induced Innovation and Natural Resource Sustainability: An Application of Neoclassical Growth Theory." Agricultural Economics 19: 99-112.

Pingali P. and H. Binswanger. (1984). "Induced Innovation Model of Agricultural Development." International Agricultural Development. John's Hopkins University Press, 163-178.

Rahmato, D., 2007. "Resettlement in Ethiopia: The Tragedy of Population Relocation in the 1980s". Forum for Social Studies: A Center for Policy Research and Dialogue.

United States Census Bureau: International Data Base. January 6, 2012. Accessed Online: <http://www.census.gov/population/international/data/idb/informationGateway.php>

Woldemeskel, G., 1989. "The Consequences of Resettlement in Ethiopia". *African Affairs* 88 (352): 359 – 374.

World-Bank. 2009. *World Development Report 2009: Reshaping Economic Geography*. Washington DC: The World Bank.

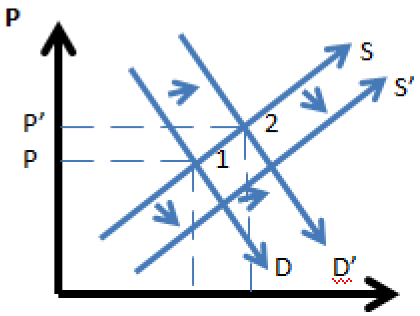

Figure 1: Induced Response to Supply and Demand of an Agricultural Good Due to Population Growth

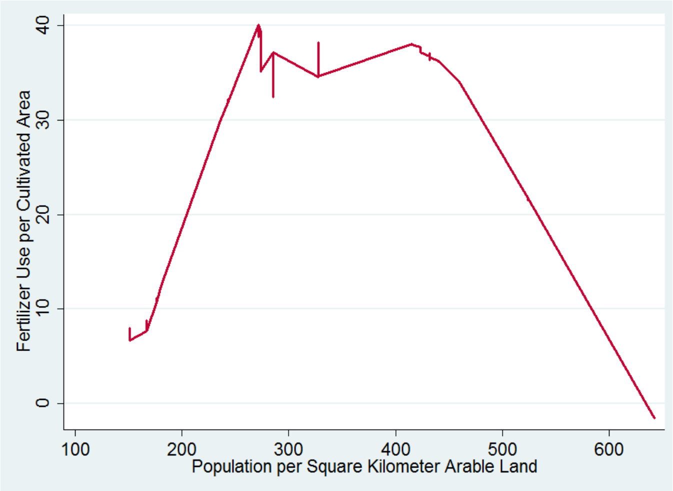

Figure 2: Fertilizer Use per Cultivated Hectare by Population per Square Kilometer of Arable Land

Figure 3: Fertilizer Expenditure per Hectare by Population per Square Kilometer of Arable Land

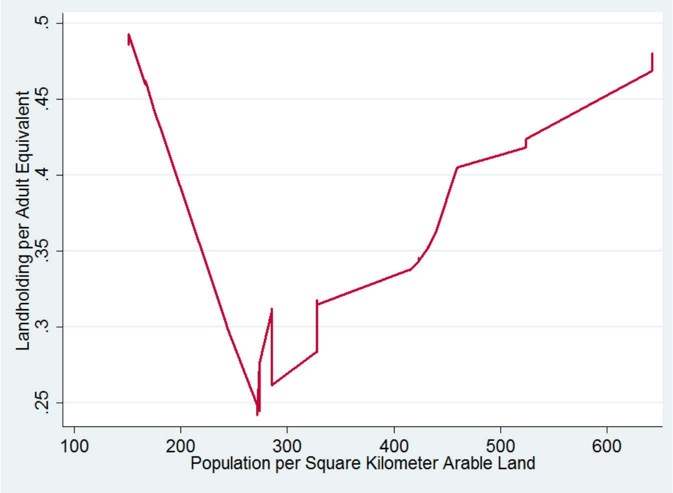

Figure 4: Hectares Held per Adult Equivalent by Population per Square Kilometer of Arable Land

Figure 5: White Teff Yield by Population per Arable Land

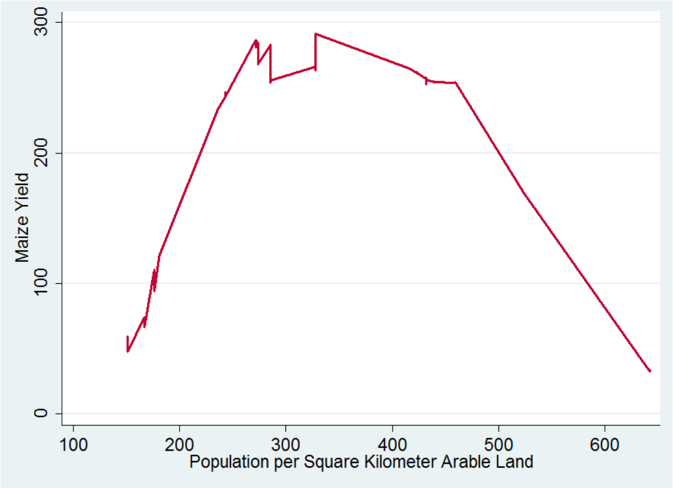

Figure 6: Maize Yield by Population per Arable Land

Table 1: Description of Variables Used in the Analysis

Variable	Definition
Dependent variables:	
Fertilizer	Kilograms of fertilizer purchased in a year
Maize production	Kilograms of maize produced per hectare in a year
Teff production	Kilograms of teff (white) produced per hectare in a year
Landholding	Amount of land held by a household, not necessarily cultivated
(Log) Wage	Wage rate for agricultural labor per day (presented as a log)
(Log) Rental rate	Rate for the single year rental of a hectare of land (presented as a log)
(Log) Prices	Prices (birr) of maize and teff, at the woreda level (presented as a log)
Covariates:	
Population / arable land	Total population per arable land – defined by GRUMP, using GAEZ data for able land (residuals are also considered)
Population squared / arable land	Total population per arable land squared – defined by GRUMP, using GAEZ data for able land (residuals are also considered)
Rural Population	Rural population densities for 1920, 1970, and 1990
NPP	Net productivity potential of soil in the area
Nutrient availability	Availability rating of soils in the area, measurement of soil quality
Rooting conditions	Rating rooting ability in soil, measurement of soil quality
Workability	Rating of soil workability, measurement of soil quality
Elevation	Elevation of the area of interest
Elevation Squared	Elevation squared of the area of interest
Value of assets	Sum of value of assets of a household
Off-Farm income	Amount of money (birr) earned by household in activities off their farm, in a year
Dealers – seed and fertilizer	Number of dealers of seed and fertilizer in respective area
Agricultural coop	Number of agricultural cooperatives in area
Rainfall 10-year average	Rainfall average for the ten years to the year of interest
Wage rate	Wage rate for a day of labor
Poor	Dummy variable: living below the poverty line = 1
Female headed household	Dummy variable: female headed = 1
Recent death	Dummy variable: recent death of adult (over 18) in household = 1
Land lost during redistribution	Dummy variable: land lost during redistribution of 1995 = 1
Highest Grade	Level of education attained by household head
Adult Equivalents	Number of adult equivalents in household
Year	Dummy for each year
Village	Dummy for each village

Table 2: Characteristics of Survey Sites

Survey Site	Location	Background	Main Crops	Perennial Crops	Annual Rainfall (mm)
Hareshaw	Tigray	Poor and vulnerable area.	Cereals	No	558
Geblen	Tigray	Poor and vunerable area, was previously quite wealthy.	Cereals	No	504
*Dinki**	N. Shoa	Badly affected by 1984 famine; very isolated	Millet, teff	No	1664
*Debre Berhan**	N. Shoa	Highland site. Near town.	Teff, barley, beans	No	919
Yetmen	Gojjam	Near Bichena. Ox-plough cereal farming system of highlands.	Teff, wheat, beans	No	1241
Shumsha	S. Wollo	Poor area in neighborhood of airport near Lalibela.	Cereals	No	654
*Sirbana Godeti**	Shoa	Near Debre Zeit. Rich area. Much targeted by agricultural policy. Cereal, ox-plough system.	Teff	No	672
*Adele Keke**	Hararghe	Highland site. Experienced drought in late 1980s.	Millet, maize, coffee, chat	Ye	748
*Korodegaga**	Arssi	Poor cropping area in neighborhood of rich valley.	Cereals	No	874
*Turfe Kechemane**	S. Shoa	Near Shashemene. Ox-plough, rich cereal area. Highlands.	Wheat, barley, teff, potatoes	Yes	812
*Imdibir**	Shoa (Gurage)	Densely population enset area.	Enset, chat, coffee, maize	Yes	2205
*Aze Deboa**	Shoa (Kembata)	Densely populated. Long tradition of substantial seasonal and temporary migration.	Enset, coffee, maize, teff, sorghum	Yes	1509
*Addado**	Sidamo (Dilla)	Rich coffee producing area, densely populated.	Coffee, enset	Yes	1417
*Gara Godo**	Shidamo (Wolayta)	Densely packed enset producing area. Famine in 1983-1984, 2003.	Barley, enset	Yes	1245
*Doma**	Gama Gofa	Resettlement area in 1985. Droughts in 1985, 1988-1990. Semi-arid.	Enset, maize	Yes, some	1150

Source: Dercon and Hoddinott, 2011
*Indicates a village surveyed in the May 2012 qualitative surveys

Table 3: Averages by Population Density Quintile

	Pop. Density quintile	Survey year						
		1994a	**1994b**	**1995**	**1997**	**1999**	**2004**	**Average**
Fertilizer use per cultivated hectare (in kilograms)	5 [highest]	28	28	19	14	33	30	29
	4	55	74	26	30	76	24	47
	3	24	21	16	15	16	4	16
	2	62	60	54	51	63	52	69
	1 [lowest]	13	12	19	19	19	13	19
	Total	**36**	**39**	**23**	**24**	**39**	**17**	**28**
Fertilizer cost per cultivated hectare (in Ethiopian birr)	5 [highest]	15	15	22	28	14	23	20
	4	64	44	37	39	36	50	45
	3	34	30	23	22	23	38	28
	2	36	34	28	39	30	42	35
	1 [lowest]	41	40	36	36	36	43	39
	Total	**38**	**33**	**30**	**33**	**28**	**39**	**34**
Landholding (land owned) per adult equivalent (in hectares)	5 [highest]	0.44	0.49	0.43	0.45	0.46	0.39	0.43
	4	0.51	0.56	0.63	0.32	0.35	0.08	0.42
	3	0.20	0.21	0.21	0.13	0.16	0.21	0.20
	2	0.23	0.31	0.27	0.26	0.26	0.39	0.27
	1 [lowest]	0.47	0.59	0.43	0.44	0.42	0.45	0.47
	Total	**0.34**	**0.41**	**0.37**	**0.34**	**0.34**	**0.34**	**0.36**
White teff yield [white teff produced per hectare] (in kilograms)	5 [highest]	142	121	149	113	129	154	181
	4	129	128	162	158	126	165	191
	3	110	104	100	181	143	122	132
	2	125	122	150	202	289	328	186
	1 [lowest]	104	133	258	313	283	249	235
	Total	**115**	**127**	**148**	**163**	**172**	**184**	**123**
Maize yield [maize produced per hectare] (in kilograms)	5 [highest]	233	133	123	227	211	278	194
	4	223	105	186	488	659	630	382
	3	225	211	210	122	215	154	239
	2	205	251	540	399	408	796	433
	1 [lowest]	173	100	153	153	101	222	184
	Total	**150**	**172**	**160**	**218**	**281**	**399**	**213**

1 USD = 17.5 Ethiopian birr
Values are in real terms

Table 4: Population Statistics

Year	Mean	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
1994a *Population per Square Km of Arable Land*	326	152	215	296	405	642
1994 *Population per Square Km of Arable Land*	326	152	215	296	405	642
1995 *Population per Square Km of Arable Land*	326	152	215	296	405	642
1997 *Population per Square Km of Arable Land*	357	172	241	336	447	642
1999 *Population per Square Km of Arable Land*	357	172	241	336	447	642
2004 *Population per Square Km of Arable Land*	425	203	286	406	566	642
Total *Population per Arable Land*	353	163	221	336	432	642

Table 5: Factors Affecting Population Density and Population Density Squared

Estimated via Linear Correlated Random Effects	**(1) Population Density**	**(2) Population Density Squared**
Covariates:		
Population Density 1920	-0.082***	-52.99***
	(0.00)	(0.00)
Population Density 1970	0.009	7.25
	(0.53)	(0.42)
Population Density 1990	0.005	2.54
	(.12)	(0.16)
Ten Year Average Rainfall	-0.002	23.22
	(0.66)	(0.50)
Elevation (meters)	-0.813**	-583.41**
	(0.03)	(0.06)
Elevation Squared (thousand meters)	0.179**	0.115
	(0.06)	(0.10)
Constant	1,232***	726,247***
	(0.00)	(0.01)
Observations	8,446	8,446
R-squared	0.65	0.62

Note: ***, **, * denotes that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively; p-values in parentheses; model includes time average of time varying covariates (average rainfall).

Year Dummies are also included, all of which are significant at the 1% level.

Table 6: Factors Affecting Prices at the Household Level

Estimated via Linear Correlated Random Effects	(1) Log of Wage Rates	(2) Log of Land Rental Rates	(3) Log of Teff Prices	(4) Log of Maize Prices
Population density / Arable land, in km^2	˜0.238***	-0.013***	-0.004***	-0.001***
	(0.00)	(0.00)	(0.00)	(0.00)
Population density^2 / Arable land		˜-0.021***	˜0.005***	
		(0.00)	(0.00)	
Population density residual	0.000***	0.013***	0.003***	0.004***
	(0.00)	(0.00)	(0.00)	(0.00)
Population density residual		0.000***	0.000***	
		(0.00)	(0.00)	
Value of assets, thousand birr	-0.002***	0.001***	0.000	0.000
	(0.00)	(0.00)	(0.38)	(0.19)
Off-farm income, thousand birr	0.475***	-0.002	-0.021***	-0.119***
	(0.00)	(0.53)	(0.00)	(0.00)
Land lost during redistribution	-0.016	0.008	0.118***	-0.091***
	(0.26)	(0.52)	(0.00)	(0.00)
Agricultural cooperative	0.271***	0.307***	-0.061***	-0.195***
	(0.00)	(0.00)	(0.00)	(0.00)
Dealers	0.054***	0.163***	0.012***	-0.103***
	(0.00)	(0.00)	(0.00)	(0.00)
Highest grade	-0.010***	0.013***	-0.003***	-0.001
	(0.00)	(0.00)	(0.00)	(0.52)
Female-headed household	-0.020	0.031**	-0.025***	-0.017
	(0.23)	(0.03)	(0.00)	(0.33)
Below the poverty line	-0.059***	-0.178***	0.015***	0.021
	(0.00)	(0.00)	(0.00)	(0.12)
Adult equivalents	-0.040***	0.013***	-0.006***	-0.016***
	(0.00)	(0.00)	(0.00)	(0.00)
Recent death	-0.074***	0.189***	-0.020**	0.018
	(0.00)	(0.00)	(0.02)	(0.44)
Rain average (10 years), thousand cm	-0.422***	0.008***	0.082***	0.739***
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	0.000	0.000	0.000	0.000
	(0.99)	(0.99)	(0.99)	(0.99)
Observations	9,312	9,312	9,312	9,312
R-squared	0.68	0.39	0.26	0.33

Note: ***, **, * denotes that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively; p-values in parentheses; model includes time average of time varying covariates and district dummies; † denotes time-constant covariate.

Year and PA Dummies are also included, all of which are significant at the 1% and 5% levels, respectively.

˜values are given in 1000 kilometers

Table 8: Factors Affecting Input Demand and Output Supply

Estimated via Linear Correlated Random Effects	(1) Fertilizer Demand	(2) White Teff Production	(3) Maize Production
Population density / Arable land, in km^2	0.890***	-6.402***	0.652*
	(0.00)	(0.00)	(0.10)
Population density^2 / Arable land, in km^2	-0.001***	0.009***	˜0.001***
	(0.00)	(0.00)	(0.99)
Population density residual	-0.885***	8.190***	-1.777****
	(0.00)	(0.00)	(0.00)
Population density^2 residual	0.001***	-0.011***	0.001
	(0.00)	(0.00)	(0.14)
Value of assets, thousand birr	0.085***	-1.971***	1.652***
	(0.00)	(0.00)	(0.00)
Off-farm income, thousand birr	-4.675*	-165.440	-87.279***
	(0.10)	(0.62)	(0.00)
Land lost during redistribution	3.138***	71.569***	24.748***
	(0.00)	(0.00)	(0.00)
Agricultural cooperative	-12.084***	56.314***	-56.620***
	(0.00)	(0.00)	(0.00)
Dealers	-2.839***	36.064***	-4.317
	(0.00)	(0.00)	(0.99)
Highest grade	0.464***	8.475***	2.523*
	(0.00)	(0.00)	(0.07)
Female-headed household	-0.469	8.075**	-16.137**
	(0.62)	(0.02)	(0.02)
Below the poverty line	0.405	-26.582***	-2.530
	(0.56)	(0.00)	(0.66)
Adult equivalents	0.314**	2.379*	11.608***
	(0.05)	(0.10)	(0.00)
Recent death	1.270	28.774***	33.295***
	(0.31)	(0.01)	(0.00)
Rain average (10 years)	0.027***	-0.100***	-0.094***
	(0.00)	(0.00)	(0.00)
Rooting Conditions	-2.597***	-72.534***	40.885***
	(0.00)	(0.00)	(0.00)
Workability	-4.917***	183.03***	-101.31***
	(0.00)	(0.00)	(0.00)
Price of fertilizer at woreda	0.210***	0.931***	0.159
	(0.00)	(0.01)	(0.57)
Price of maize at woreda	-9.928***	-103.67***	8.275
	(0.00)	(0.00)	(0.17)
Price of teff at woreda	4.525***	-54.400***	18.370***
	(0.00)	(0.00)	(0.00)
Rental rate for hectare of land	0.021*	-0.206*	0.310***
	(0.08)	(0.06)	(0.00)
Daily wage for agricultural labor	1.840*	56.311***	32.430***

	(0.08)	(0.00)	(0.00)
Landholding	0.720***	5.579***	3.383***
	(0.00)	(0.00)	(0.00)
Constant	0.000	0.000	0.000
	(0.99)	(0.99)	(0.99)
Observations	9,312	9,312	9,312
R-squared	0.14	0.18	0.28

Note: ***, **, * denotes that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively; p-values in parentheses.

Year and PA Dummies are also included, all of which are significant at the 1% and 5% levels, respectively.

~values are given in 1000 kilometers