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How does population density influence agricultural intensification and productivity? Evidence from Ethiopia

Anna Leigh Josephson [a], Jacob Ricker-Gilbert [a,*], Raymond J.G.M. Florax [a,b]

[a] Department of Agricultural Economics, Purdue University, United States

[b] Department of Spatial Economics, VU University Amsterdam and Tinbergen Institute, The Netherlands

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A B S T R A C T

This study uses household-level panel data on smallholder farmers in Ethiopia to estimate how rural population density (RPD) affects agricultural intensification and productivity. Our results suggest that higher RPD is associated with smaller farm sizes, and has a positive effect on input demand, represented by increased fertilizer use per hectare. Overall, increased input use does not lead to a corresponding increase in staple crop yields, and thus farm income declines as population density increases. This suggests a situation where farmers in areas of high RPD may be stuck in place, unable to sustainably intensify in the face of rising RPD and declining farm sizes.

Introduction

Population growth is a critical challenge facing sub-Saharan Africa (SSA) in the twenty-first century, as the region's population currently stands at 900 million people, and is projected to double by 2050 (Population Reference Bureau, 2012). The majority of people in SSA live in rural areas, which are experiencing rapid population growth and declining per capita farm sizes. Therefore, the influence of population growth on agriculture will have a large impact on the ability of smallholder farmers to feed themselves and their families. Despite its importance, there is little empirical evidence on how rural population density (RPD) affects African agriculture.

Against this backdrop, the objective of this paper is to estimate how RPD impacts agricultural intensification and productivity in the SSA nation of Ethiopia. To do so, we estimate the impact of RPD on: (1) household landholding; (2) factor and output prices including agricultural wage rates, along with maize prices, and teff prices; (3) fertilizer use per hectare; (4) maize and teff yields; and (5) farm income per hectare. With a population of 92 million, that is expected to grow to 160 million by 2050, Ethiopia is an excellent case study to estimate the relationship between RPD and agriculture.

Issues of growing population and land constraints are prominent throughout Africa, as most of the rural population resides in densely populated areas (Jayne et al., 2012). On the surface this may suggest an agricultural development strategy that encourages production increases on the extensive margin, gained through expansion of cultivation into unused areas of land. Yet, there is some debate over the amount of unused land that actually exists in areas where most smallholders reside. The majority of Ethiopia's population resides in the highland regions that have the country's best soils and highest rainfall. As a result, most of the arable land in the highlands is already under cultivation. In addition, land tenure insecurity is known to be a major factor that affects smallholder investment in Ethiopia (Holden and Yohannes, 2002; Deininger and Jin, 2006; Pender and Gebremedhin, 2007; Ali et al., 2011), even although formal registration programs are being implanted to improve land rights (Deininger et al., 2009; Holden et al., 2009). Smallholders may be unwilling to invest in expanding their landholding if they feel that their claim to the land is insecure. Additionally, environmental concerns such as erosion and salination, associated with clearing land, suggest that even if possible, such expansion may not be environmentally desirable for SSA. Further, alternative strategies to deal with RPD, such as encouraging migration from high-density to low-density regions are often difficult due to social and cultural constraints. In Ethiopia, historic tensions resulting from land reallocation and redistribution make such movements even more problematic.

Considering the difficulties associated with increasing production at the extensive margin, increasing agricultural productivity through sustainably intensifying output per unit of land is

* Corresponding author. Address: Department of Agricultural Economics, 403 West State Street, West Lafayette, IN 47907, United States. Tel.: +1 (765) 494 4260; fax: +1 (765) 494 9176.

E-mail address: jrickerg@purdue.edu (J. Ricker-Gilbert).

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essential. Relevant economic theories provide predictions regarding how growing RPD will indirectly influence agricultural productivity and intensification. Boserup (1965) hypothesized that increases in RPD will lead to greater use of labor intensive inputs, causing a shift away from long-fallow periods towards annual and multi-cropping practices.[1] Driven largely by changes in prices of land and labor, Boserup's hypothesis suggests that population pressure will increase demands for modern inputs, ultimately increasing productivity per unit of land. Additional theories extend this argument to the value of labor, including Hayami and Ruttan (1970). Their theory utilizes the underlying idea that prices indirectly encourage behavioral changes in order to adapt and survive under changing conditions. Often referred to as the "induced innovation hypothesis", Hayami and Ruttan's theory suggests that the positive influence RPD has on agricultural productivity occurs because the price of labor declines relative to the price of land. This generates demand for labor and encourages increased use of labor-intensive inputs, such as inorganic fertilizer and modern varieties of seed, which should ultimately increase output per unit of land.

It is also possible that RPD itself is a driver of demand for inputs and staple crop productivity. Increasing RPD can directly affect agricultural intensification through improving the flow of information in an area, encouraging institutions to develop and improve, and by reducing transaction cost. Regions with greater RPD may be characterized by more rapid, and potentially more accurate, diffusion of information regarding market prices, increased availability of inputs and outputs, and lower transportation costs, all of which can lead to increases in productivity (Foster and Rosenzweig, 1995; Baerenklau, 2005; Conley and Udry, 2010; McMillan et al., 2011).

We use data on Ethiopia from three sources to undertake this analysis. First, we use six waves of household-level data from the Ethiopian Rural Household Surveys covering 1293 households across 15 villages. Second, we use population and land estimates, gathered from two Geographic Information System (GIS) databases: (1) the Global Rural–Urban Mapping Project (GRUMP) and (2) GlobCover 2009. Finally, we use qualitative data to complement the quantitative data, with information gathered from focus group discussions conducted in Ethiopia in May of 2012.

In order to analyze the influence of changing RPD on agricultural productivity and intensification and productivity, we first estimate how RPD affects landholding and output prices directly. Subsequently, we estimate the effect of RPD on intensification, measured as fertilizer use per hectare, maize and teff yield, and farm income per hectare in a system of equations. We test RPD's direct effect on these measures of intensification and productivity, along with RPD's joint indirect effect on intensification as measured through its impact on landholding, wage rates and staple crop prices. Because we use a six-round panel dataset, we are able to exploit the panel structure to address some potential endogeneity concerns. All of these equations are estimated as linear models utilizing the correlated random effects (CRE) estimator, which controls for potential correlation between covariates and time-constant unobserved heterogeneity (Wooldridge, 2010).

Our results suggest that RPD has a positive effect on input demand, represented by increased fertilizer use per hectare. However, RPD does not have an overall effect on maize yields or teff yields. Hence, we find that increased RPD has a marginally significant negative effect on farm income per hectare. These results suggest the existence of a Cochrane's treadmill, where despite input intensification, there is no corresponding increase in yields, but instead a decline in farm income (Cochrane, 1958; Levins and Cochrane, 1996). In this process, farmers may apply more fertilizer in an attempt to combat declining soil fertility, and decreased fallow periods that occur as RPD rises, in hopes of maintaining a base level of productivity (Drechsel et al., 2001; Tittonell and Giller, 2013).

The remainder of this paper is structured as follows. The next section presents some background on Ethiopia, considering the nation's institutional history and how present RPD and agricultural practices have been historically influenced. The conceptual framework and methodology are presented in Section 3. Sections 4 through 6 present the data, results, and conclusions, respectively.

Background

Historical, political, cultural, and agro-ecological factors have played an important role in individuals' and families' decisions to locate in certain areas. Highland and lowland dynamics, resettlement programs, and land policy have all helped to shape the present RPD distribution as well as agricultural practices in Ethiopia.

Highland and lowland dynamics

Highland and lowland dynamics have long influenced patterns of settlement and treatment of land in Ethiopia. Throughout its history, most of Ethiopia's population has lived at relatively high elevations, between 1500 and 2300 m. The lowlands have always had comparatively low population densities (Pankhurt, 2009).

The highlands have many advantages that led to their early development and corresponding greater population expansion, including, steady rainfall and plateaus which are conducive to agriculture, as well as technological innovations on ox-ploughs, which led to intensification of production and expansion of land under cultivation (Pankhurt, 2009). Conversely, the lowlands have been characterized by variable and limited rainfall, shallow soils, and disease.[2] These conditions do not encourage settlement or agricultural development, so technological innovations in the lowlands did not move beyond the hoe cultivation, until recently.

Land redistribution

Despite the historical reasons why people have settled in one region or another, the Ethiopian government has practiced land redistribution for decades. Redistribution, often referred to as "resettlement", took place due to overcrowding throughout the Ethiopian highlands. In resettlement programs under the Marxist Derg government, during the 1970s and 1980s, households were moved to seven randomly selected sites.[3] The locations chosen for resettlement were generally ill-suited for agriculture and in the first year of the program, as many as 5.5% of those resettled died of starvation. In addition, as many of these locations were in the western lowlands, many settlers died of diseases that did not exist in the highlands. Cultural factors and ethnic strife generated problems between the resettled and host populations. Ultimately, as many as 14% of resettled families returned to their original homes or moved to cities (Tareke, 2009).

A voluntary version of the resettlement program was implemented under the present federal democratic government.

[1] In this article, based on evidence that farmers in Ethiopia have moved away from fallow periods due to the need to increase yield, we focus on the later part of this transformation, after fallow periods had been eliminated.

[2] For the sake of parsimony, we conflate the Eastern and Western lowlands in this description. These are, however, quite different environments and have different constraints for agricultural production. The constraints in the East are associated with variable and limited rainfall, but not disease. The constraints in the West are disease, particularly tripanosomiasis and malaria, but not rainfall. However, for this discussion, we do refer to the two areas, as a single lowland region.

[3] In this case, random indicates that locations were not vetted for suitability, beyond asking the question: is there space in the region? Further, individuals already residing in the areas were not considered in any regard while planning occurred (Pankhurt, 2009).

However, the program was voluntary only in the sense that those being relocated were given a choice about doing so; the concerns and issues of the host populations were not addressed (Pankhurt, 2009). As a result, the "voluntary" resettlement program was still unsuccessful, primarily due to animosity from host populations. Therefore, many resettlers returned to their original homes or migrated to larger cities.

Land tenure

It is not surprising that the Ethiopian government's resettlement practices generated a sense of tenure insecurity among smallholder farmers. As RPD has increased, tenure rights have become even more tenuous.

All land in Ethiopia is officially owned by the government. Specific land use rights are granted to every Ethiopian who wants to engage in agriculture. When this system was put in place in 1995, it generated increased demand for land, so the federal government undertook a program of land reassignment to ensure that the law was carried out. These new assignments of land were intended to occur through administrative reallocation of land. However, redistribution threatened the federal government's popularity. Therefore, in 1997 the constitution was updated, and the federal government ceded the responsibility of redistribution and land allocation to individual regions (Gebeyehu, 2013).

To this day, land policy remains dictated by the federal government but is carried out by individual regional governments. Current land policy does not allow for the sale of land, although inheritance of land is legal (Ali et al., 2011). This land policy creates a weak rental market (Teklu, 2008), encourages urban migration (de Brauw and Mueller, 2012), and fosters a general feeling of tenure insecurity (Devereux, 2000; Benin and Pender, 2001; Holden and Yohannes, 2002; Gebremedhin et al., 2003; Okumu et al., 2004; Deininger and Jin, 2006; Pender et al., 2006; Pender and Gebremedhin, 2007).

In focus group discussions, participants also revealed that tenure insecurity continues to influence input decisions and thus agricultural productivity. Many farmers felt that insecurity increases the amount of inputs they use in annual crop production, likely to extract what they can from the land while they maintain control over it. Although this is a perception from farmers in our field group surveys, there is also empirical evidence that the reverse may actually be true (Pender, 1998). Previous literature on this issue in Ethiopia is somewhat mixed, and Ali et al. (2011) finds that households who are tenure-insecure do not make long-term investments in coffee and chat production. Other studies suggest that redistribution has improved access to inputs, increasing use of fertilizer and staple crop yields (Benin and Pender, 2001; Holden and Yohannes, 2002; Gebremedhin et al., 2003; Okumu et al., 2004; Deininger and Jin, 2006; Pender et al., 2006; Pender and Gebremedhin, 2007; Deininger et al., 2009).

In an effort to improve smallholders' tenure security and formalize land rights, the government of Ethiopia recently began implementing a nationwide formal registration program of nearly 20 million smallholder plots. Evidence suggests that the program has helped increase land-related investments, and productivity (Deininger et al., 2009; Holden et al., 2009). Although efforts have been made to improve land rights in Ethiopia, tenure insecurity remains an important issue.

Population growth

Exacerbating the issues of redistribution and insecure tenure is the large increase in population throughout Ethiopia. With a United Nations' projected growth rate of 3.2% annually, the population is expected to reach 160 million people by 2050 (Population Reference Bureau, 2012). This growth is largely driven by the nation's young age structure, a fertility rate of 5.1 children per woman, and fewer than 10% of women using contraception.

Ethiopia's economy is dependent on agriculture, with the growing population relying on the land for their livelihoods. Agriculture contributes 41% of gross domestic product (GDP) and over 85% of employment in the country (World Factbook, 2012). Therefore, the way in which Ethiopian farmers respond to increased population pressures will have an impact on millions of smallholder farmers, as well as on the food security of the nation.

Methodology

This section presents the outline for our estimation of the impact of RPD on landholding, factor prices, fertilizer demand per hectare, crop yields, and farm income per hectare. We also discuss the direct and indirect pathways through which RPD influences these measures.

Our conceptual and empirical model is motivated by Boserup (1965). We first discuss the role of RPD on landholding and factor prices. Second, we conceptualize how RPD influences a utility maximizing household's demand for modern inputs per hectare, the yield of staple crops, and farm income per hectare. Table 1 presents a full list of explanatory variables used in our analysis.

Farm size and rural population density

Ex ante we would expect changes in RPD to influence cultivation practices and farm size. As land rental markets in Ethiopia are thin and under-developed, prices for land are an unreliable proxy for factor scarcity. Therefore, we use farm size as a proxy for land price. Boserup (1965) postulates that when RPD increases, farming intensity also increases, as farmers move away from long-fallow towards short-fallow practices, and ultimately to annual and multiple cropping systems. Further, as population increases, and land is passed down from parents to children, it is divided into smaller plots, leaving less land for each household. Hence, over time, cropping will become more frequent and will be done on smaller plots of land. Therefore, we estimate landholding l for household i at time t as:

$$l_{it} = \alpha^l d_t + X_{it}\zeta^l + G_t\gamma^l + \nu^l_{it} \quad (1)$$

where the variable of interest l is the amount of land held by a household, measured in hectares. In Eq. (1), RPD is represented by d_t, and α^l is the corresponding parameter.[4] Household-level factors including value of assets, whether the household lost land during previous government land redistributions, the highest grade attained by the head of the household, whether the household is female-headed, whether the household suffered a recent death, the number of adult equivalents in the household, and the number of oxen which the household owns is denoted by the matrix X, and ζ^l is the corresponding parameter vector. A set of community-level variables including the number of agricultural cooperatives in the region, the distance from the village to the nearest to the agricultural cooperative, the distance of the village to the nearest paved road, a remote-sensing based estimate of net primary productivity[5] (NPP), elevation, and a ten-year rain average are denoted by the matrix G,

[4] We initially tested by population density, as well as its square-term, in order to test for nonlinearities in the data. However, we found that the square-term was insignificant and suggested turning points of RPD which are not observed in Ethiopia. Therefore, we omitted the term from the analysis.

[5] Net primary productivity (NPP), a variable determined through remote sensing, is a measure of the rate at which chemical energy is stored as biomass in a given period. It is a useful proxy for agricultural production potential in a particular area, as it measures the overall productivity for the region. In the dataset we use in this analysis, NPP is measured as the mass in grams of carbon per square meter per year (Zhao et al., 2005).

Table 1
Variables used in the empirical analysis, with definitions.

Dependent variables	
Fertilizer use/cultivated area	Kilograms of fertilizer used per cultivated area (hectares) in a year
Maize yield	Kilograms of maize produced per hectare in a year
Teff yield	Kilograms of teff (white) produced per hectare in a year
Income/cultivated area	Farm income (birr) per cultivated area (ha) in a year
Landholding*	Amount of land owned by a household (ha)
Daily wage*	[Log] Wage rate for agricultural labor per day (birr)
Prices*	[Log] Previous year prices (birr) of maize and teff per kilogram
Regressors	
Rural population density (RPD)*	Total rural population per square kilometer land – constructed using GRUMP estimates for population and GlobCover 2009 population for land. Only the time average of this measure is used, while the time-varying component is omitted
NPP	Net productivity potential of the area
Elevation	Elevation of the area of interest (meters)
Elevation squared	Elevation squared of the area of interest (meters squared)
Value of assets	Sum of value of assets of household (birr)
Agricultural cooperatives	Number of agricultural cooperatives in the respective area
Distance to cooperative	Distance, in kilometers, to the closest agricultural cooperative
Distance from the capital	Distance, in kilometers, from the capital to the village
Distance to a paved road*	Distance, in kilometers, from the village to a paved road
Rainfall 10-year average*	Rainfall average for the ten years prior to the year of interest (mm)
Annual rainfall average*	Rainfall average for the year of interest (mm)
Female headed household*	Dummy variable: if household is female headed = 1
Recent death*	Dummy variable: if household experienced recent death of adult (over 18) in household = 1 (proxy for shock to a household)
Land lost during redistribution	Dummy variable: if household lost land during redistribution in 1995 = 1
Highest grade*	Level of education attained by household head (0 through 14, with 13 indicating some college, 14 indicating college degree)
Adult equivalents*	Number of adult equivalents in household
Oxen*	Number of oxen owned by household

Note: The symbol * denotes that a time average of the variable is also included in regressions.

with a corresponding parameter vector γ^l. The error term is denoted by υ^l, and year dummies are also included.

Prices and rural population density

The effect of RPD on input prices comes from the theory of induced innovation, adapted to the process of agricultural development by Hayami and Ruttan (1970). The theory implies that as population grows, *ceteris paribus*, land becomes scarce relative to labor. The change in the land to labor ratio causes the price of labor to decrease relative to the price of land. This implies that as RPD grows, competition will increase for land, as well as work off-farm. This will cause the price of land to increase, as discussed previously, and the wage for labor to decrease.

We estimate the log of daily agricultural wages w for the household as follows:

$$\log(w_{it}) = \alpha^w d_t + X_{it}\xi^w + G_t\gamma^w + \upsilon^w_{it} \tag{2}$$

where RPD is represented by d_t, and α^w is the corresponding parameter. A matrix X of household-level factors is included, with a corresponding parameter vector, ξ^w. A matrix G of community-level variables is included, with a corresponding parameter vector γ^w. The error term is υ^w, and year dummies are also included.

We estimate the log of maize and teff price received by the household as follows:

$$\log(p^c_{it}) = \alpha^c d_t + G_t\gamma^c + \upsilon^c_{it} \tag{3}$$

where the output price of interest, represented by p^c, is either the price of maize or the price of teff. The superscript c refers to parameters related to the prices of either maize or teff. We use lagged prices, based on the previous rounds' prices,[6] in order to be able to connect this equation to other equations in the system of equations, presented later.

Prices are determined primarily by community factors. As in previous equations, d_t represents RPD, while α^c is the corresponding parameter. A matrix of community-level variables is denoted by G_t with a corresponding parameter vector, γ^c. The error term is υ^c, and year dummies are also included.

Demand for modern inputs and staple crop yield

We next discuss our estimation strategy for fertilizer use per hectare, staple crop yield,[7] and farm income per hectare. If higher RPD is associated with higher price of staple food crops, and small farms, this may induce a supply response where farmers adopt modern inputs like chemical fertilizer in order to increase output per unit of land.[8]

Demand for chemical fertilizer, denoted by y, is denoted as follows:

$$y_{it} = \alpha^y d_t + \omega^y \log(w_{it}) + \pi^y \log(p_{it}) + \lambda^y l_{it} + R_{it}\rho^y + G_t\gamma^y + \epsilon^y_{it} \tag{4}$$

where RPD is represented by d_t, along with its parameter α^y. Prices, denoted by p, include the price of fertilizer and price of staple crops, while l represents landholding, along with π^y and λ^y as the corresponding parameters. Wage rate, w, is also included as an explanatory variable along with its parameter, ω^y. A matrix of community-level variables is denoted by G, while γ^y is the corresponding parameter vector. A matrix of household-level factors is denoted by R, while ρ is the corresponding parameter vector. The error term is ϵ^y, and year dummies are included.

The equations for maize yield, teff yield, and farm income are similar to Eq. (4).

[6] For the first round in our data we use data collected in 1989. The year 1989 was the first round of the ERHS, but we have chosen not to use it in our study. This round had fewer households than later rounds, and was also limited in scope in terms of crop production questions. For 1995, we use 1994 prices, for 1997, we use 1995 prices, and so on.

[7] While we estimate the two crops separately, we define their respective equations simultaneously, due to their similarities.

[8] However, this assumes that farmers have adequate resources to access such inputs as their farms become smaller.

Direct and indirect pathways of rural population density

We hypothesize that population density affects input demand, yields and farm income through direct and indirect pathways. For example, in Eq. (4) the direct pathways represent factors such as information flow, transaction costs, and institutions that may result from rising population density. The indirect pathways through which population density impacts fertilizer demand are measured through landholding, daily wages, and prices of maize and teff, which are estimated in Eqs. (1)–(3).[9] When the direct and indirect pathways are summed, the total effect of RPD on fertilizer demand is determined.

In order to derive the effect of RPD d on input demand, y, we rewrite Eq. (4) as:

$$y_{it} = \alpha^y d_t + \omega^y \log(w_{it}(d_t)) + \pi^y \log(p_{cit}(d_t)) + \lambda^y l_{it}(d_t) + R_{it}\rho^y + G_t\gamma^y + \epsilon^y_{it} \quad (5)$$

The total derivative of y with respect to d is defined as:

$$\frac{\partial y_{it}}{\partial d_t} = \alpha^y + \frac{\partial y_{it}}{\partial w_{it}} \times \frac{\partial w_{it}}{\partial d_t} + \frac{\partial y_{it}}{\partial p_{cit}} \times \frac{\partial p_{cit}}{\partial d_t} + \frac{\partial y_{it}}{\partial l_{it}} \times \frac{\partial l_{it}}{\partial d_t} \quad (6)$$

where α^y is the direct effect of RPD on fertilizer demand in this equation. The indirect effect of RPD on fertilizer demand through wage rates is equal to $\frac{\partial y_{it}}{\partial w_{it}} \times \frac{\partial w_{it}}{\partial d_t}$. The indirect effect of RPD on fertilizer demand through maize and teff prices is $\frac{\partial y_{it}}{\partial p_{cit}} \times \frac{\partial p_{cit}}{\partial d_t}$, while the indirect effect of RPD on fertilizer demand through landholding is $\frac{\partial y_{it}}{\partial l_{it}} \times \frac{\partial l_{it}}{\partial d_t}$. The indirect effect plus the direct effect give us the total effect of RPD on fertilizer demand.

The effect of RPD on maize and teff yields and farm income are derived in an analogous manner.

Estimation strategy

Each model is first estimated on an equation-by-equation basis, utilizing the correlated random effects (CRE) estimator. In order to use the CRE estimator we decompose the error ϵ, as $\epsilon = b_i + u_{it}$, where b_i represents the time constant unobserved heterogeneity and u_{it} represents the time-varying unobserved shocks.[10] The CRE estimator is based on the assumption that the unobserved heterogeneity takes on the form of $b_i = \psi + \mu\overline{M}_i + u_{it}$, where $u_{ij}|M_{it} \sim N(0, \sigma^2_{it})$ and $\overline{M}_i$ is the time average of household level characteristics in all of the equations (Mundlak, 1978; Wooldridge, 2010). To functionalize the CRE estimator it is necessary to include $\overline{M}_i$ in the specification of the different equations. Adding $\overline{M}_i$ addresses potential correlation between the entire history of the explanatory variables and the random household effects, and should control for possible correlation between covariates in the model and time constant unobserved heterogeneity that could bias our coefficient estimates. In addition, we include a rich set of control variables that should relieve concern about RPD being correlated with omitted variables, so we argue that this variable is conditionally exogenous in our equations. That being said, just as with the case with any study using observational data, care should be taken when inferring direct causality from our results.

In a linear model context, the CRE estimator produces coefficient estimates for the original (non-averaged) variables that are identical to those generated by a household-level fixed effects estimator (Wooldridge, 2010). The additional benefit from the use of the CRE estimator is that it does not remove time-constant covariates from the model, unlike a fixed-effects specification. As some variables considered in our models do not vary over time, using the CRE estimator allows us to keep them during the estimation process. RPD is measured as the time average of population density between waves of the survey because it is difficult to accurately measure population growth at the community level. Therefore RPD is treated as time-constant in this study but its partial effects can be estimated by using CRE. The CRE estimator is implemented by running a simple pooled regression on the expanded model specifications. In order to correct for heteroskedasticity and correlation across time we use robust standard errors with non-zero covariances at the household level ("clustered" standard errors).

Based on this foundation, we next run the CRE-specification as a seemingly unrelated regression (SUR) model. As our system is non-recursive, it is worth noting that this estimation is the same as three-stage-least-squares (3SLS). Further, it allows for a relationship between unobserved factors and observed variables. We control for heteroskedasticity and correlation within households in our equations with a clustered bootstrap procedure at the household level (see Stata (2013) for details), running 500 repetitions. The SUR setup assumes that equations are related, with the errors correlated across the system. As expected, the estimation results for the equation-by-equation approach and the SUR approach are very similar. Therefore, in our discussion of estimation results, we concentrate on the more efficient SUR results.

Data

The data used in this article come from three different sources. First, we use household-level data on smallholder farms in Ethiopia. Second, we use GIS data, collected from the GRUMP and GlobCover 2009 databases. Finally, we use qualitative data collected in Ethiopia in May of 2012 during field group discussions conducted by the authors. All three sources are briefly discussed below.

Household-level data used in this study come from survey data sets collected in Ethiopia by the International Food Policy Research Institute (IFPRI). The Ethiopia Rural Household Survey (ERHS) is a panel dataset tracking approximately 1500 households in eight survey waves over the twenty-year period from 1989 to 2009. We use the center six waves of the survey which follows 1293 households.

The households are located across 15 villages, which were selected to cover diversity in the farming systems in the country, including grain-plough areas in the highlands as well as the enset-growing areas in the lowlands (Dercon and Hoddinott, 2011). Efforts were also made to include a span of population densities, however, as the data only considers rural, and non-pastoral households, it is not considered to be nationally representative.

Estimates of rural RPD are derived from the Global Rural–Urban Mapping Project (GRUMP) database. The dataset provides gridded estimates of local population densities, beginning with sub-national census data, separating the urban and rural components, and then allocating the resulting population numbers equally across urban and rural space which has been divided into regular grid cells of approximately one square kilometer.

Information on land resources was obtained from the global land cover dataset, GlobCover 2009. This dataset has two definitions of arable land. First, land that is classified explicitly as mainly or partially under crops is denoted as (actual) arable land. Second, potential arable land is classified as all land cover classes which are likely to support conversion to agricultural usage. We use the latter, broader definition in our analysis, as this broader definition of land allows for the capture of all potential uses of land by rural Ethiopian farmers.

To generate the RPD term, we took the estimates of population from GRUMP and divided those numbers by the estimates of land

[9] Both the within and the time-average effects are included for all indirect factors. We will discuss this and provide more information in the next section.

[10] Unobservable factors include motivation, risk aversion, and inherent ability of farmers.

from GlobCover 2009. In doing so, we determine the number of persons per square kilometer, or RPD. Our RPD term is observed at the community-level, and does not vary over local groups of households. Therefore, although we have six rounds of data, as there are only 15 villages in the survey, we have 90 different RPD observations.[11]

Finally, we utilize field group surveys conducted in 12 of the 15 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 their answers to extend our quantitative analysis and support the resulting conclusions. The primary concerns of focus group participants were the rapid population growth across the country and the limited creation of new area suitable for agriculture, which in the past has generally been done by the government. These discussions made clear the challenges facing different communities, as well as measures being undertaken to address these problems in various villages.

Empirical results

This section presents the quantitative and qualitative results of our study including descriptive statistics and regression results, as well as insights from our field group discussions, which are woven into our discussion throughout the text. We first present descriptive statistics on the relationship between RPD and agricultural intensification. Subsequently, we discuss our regression results and the total effects of RPD on agricultural productivity.

Descriptive statistics

Based on agricultural data from the ERHS and RPD data derived from GRUMP and GlobCover 2009, we construct six lowess smoothing graphs where RPD is on the *x*-axis and the measures of agricultural intensification are on the *y*-axis.[12] In order to put these graphs in context, we include Table 2 that shows different points in the RPD distribution.

Table 2
RPD: percentiles and mean.

Percentile	10th	25th	50th	75th	90th	Mean
RPD (persons/km^2)	80	107	158	279	394	210

The descriptive figures illustrate the unconditional effects of RPD on the factors of interest, as they do not hold all other factors constant as in a regression context. As such, Fig. 1 provides, describes and illustrates general trends for agriculture in Ethiopia, which are instructive for informing the overall results of our analysis and conclusions.

In Fig. 1(a), the amount of land held by each adult equivalent decreases almost continuously as RPD increases, up to a very high level of RPD, at which point there is a slight increase. In Fig. 1(b) there is a similar result, as the number of adult equivalents per area cultivated increases as population grows, although there is a slight decline just below 400 people per square kilometer. These measures, although they are similar, are not perfect inverses, as Fig. 1(a) considers landholding (land owned by a household), while Fig. 1(b) considers the area cultivated (land cultivated by a household). As the quantity of land in an area is ultimately fixed, less land is available for each individual as population grows, causing the landholding per adult equivalent to decrease. It is worth noting that in Fig. 1(b), the fall is not as dramatic as in Fig. 1(a). While land owned decreases, land cultivated may not decrease by as much, as some households may still be able to participate in rental or sharecropping activities, hence allowing cultivated area for each family to remain relatively high. However, this suggests that the land is used more intensively as RPD rises, perhaps through declining fallow periods or transfer of land to those who use it most efficiently. Together, these graphs are both generally consistent with Boserup's theory of population and intensification.

With rising population, and declining farm size, we also observe decreasing farm income per adult equivalent Fig. 1(c), and declining asset value per adult equivalent Fig. 1(d). This is likely a result of more people in an area, as even if a household has more assets or is earning more income, there are more family members between whom the money must be divided.

These figures also suggest that coping strategies to combat increasing difficulties may be problematic. First, fertilizer use per hectare increases as RPD rises Fig. 1(e), but the figure shows that there may be a RPD threshold beyond which fertilizer intensification is not possible. This is shown with a plateau around 200 people per square kilometer, after which little to no change in fertilizer use occurs. There could be many reasons for this, including limited marginal response from staple crops to fertilizer after a certain level of application, credit constraints, and diversification to crops which do not require fertilizer. Frequently in our field group discussions from May 2012, participants discussed lack of available credit as being a significant barrier that prevented them from purchasing more fertilizer. This is likely worse in areas of high RPD, where small farm sizes greatly limit credit availability. Additionally, our focus group discussions revealed that some farmers in densely populated areas have diversified into to tree crops, such as coffee and chat, as they generally require very little fertilizer.[13]

Additionally, daily agricultural wage rate Fig. 1(f) shows an inverted-U relationship over the population density distribution. The initial increase of wage rates at low and medium levels of population density may suggest that there could be some competition to attract labor with higher wages in places where labor is scarce relative to land. Around the 250 people per square kilometer, wage rates move downwards, as labor becomes abundant relative to land. This is consistent with both Boserup and the induced innovation hypothesis. Based on discussions in our field group surveys, we found that although many farmers say they would like to work off-farm, the opportunities are often sparse and wage rates are low.

Together these figures suggest a story of declining farm sizes, coupled with decreasing farm income and asset values at higher population densities. Coping strategies may not be successful due to limits of fertilizer use and low daily wages. Overall, this series

[11] One limitation of this measure of population density is that estimated population values at different points in time are based on highly aggregated growth rates. This is major reason to prefer a CRE formulation over a household fixed effect or other differencing strategy to control for unobservables. The CRE formulation keeps time-averages of all variables in the model so the estimates are likely more reliable in this context.

[12] Lowess graphs provide a locally weighted, smoothed scatterplot. The function generates a new variable which, for every *y*-variable, contains the corresponding smoothed value. The smoothed values are obtained by running a regression of the *y*-variable on the *x*-variable. The regression is weighted so that the central point (x_t, y_t) gets the highest weight and points that are further away receive less weight. Estimated regression lines are used to predict the smoothed value for the *y*-variable only. This is repeated for all remaining values. Lowess is considered to be a desirable smoother due to its locality – it tends to follow the data. Polynomial smoothing methods, for example, are global in what happens on the left of a scatterplot, and can therefore influence fitted values on the right. The same is not true for a lowess smoothing method due to its central focus (see Stata (2013), for details).

[13] Many farmers have also diversified into other cash crops, including vegetables, such as green beans and other legumes, as well as livestock production. For this discussion, we only mention tree crops, as they are the most popular cash crop in Ethiopia, vegetable crops still require fertilizer, and livestock production is outside the scope of this article.

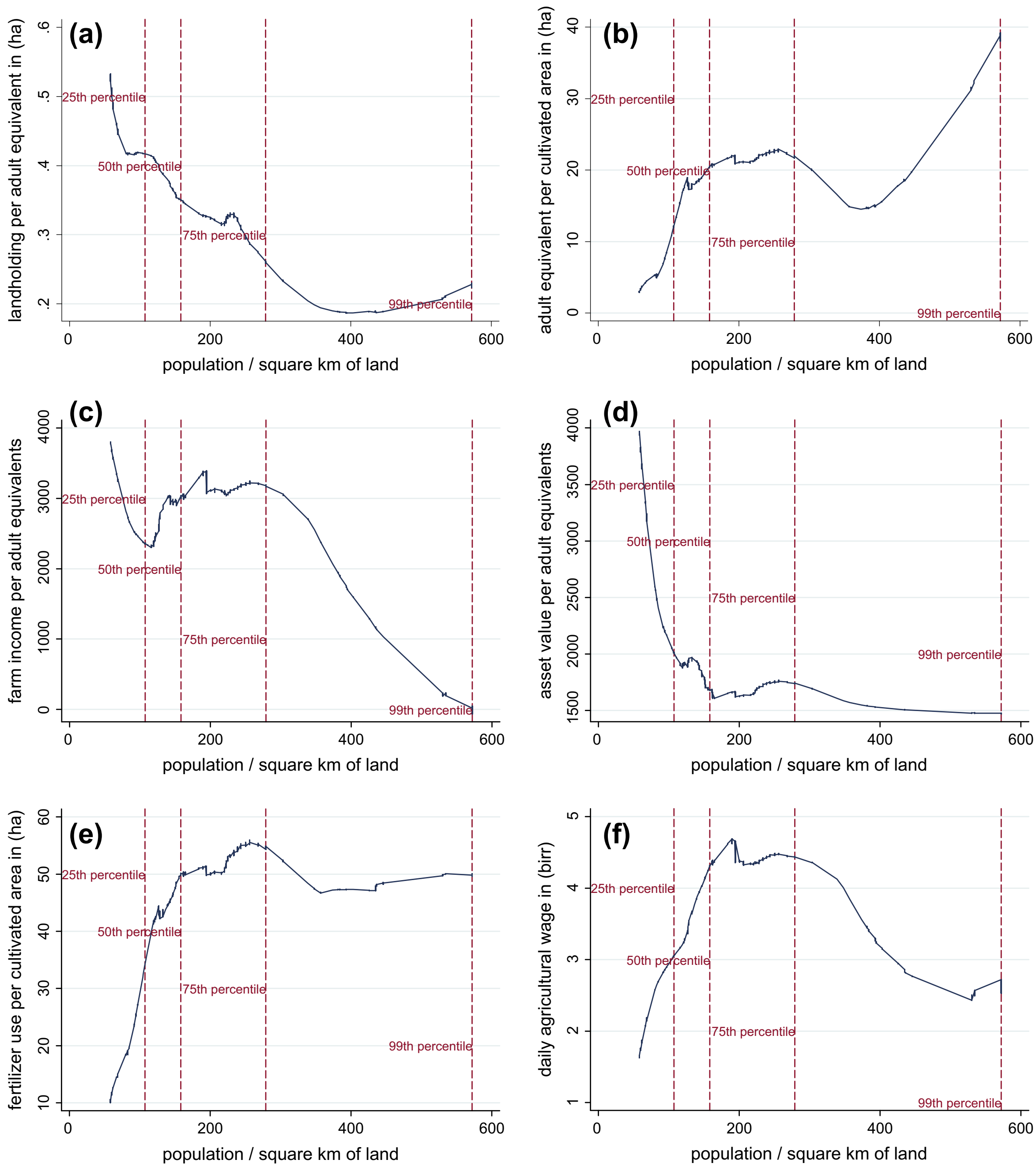

Fig. 1. Landholding per adult equivalent (a), adult equivalents per cultivated area (b), farm income per adult equivalent (c), (d) asset value per adult equivalent, (e), fertilizer use per cultivated area and (f) daily agricultural wages.

of figures suggest that rising RPD has the potential to severely constrain agricultural productivity and household income.

Estimation results

In this section, we present results for factors influencing fertilizer demand per hectare, maize and teff yields, and income per hectare, using the linear correlated random effects specification estimated with a seemingly unrelated regression (SUR) estimator.

Landholding and prices

We first consider factors that influence household landholding, the results of which can be found in Table 3, column (1). The coefficient on RPD, located in column (a) indicates that higher RPD is associated with significantly smaller landholding. This effect suggests that, on average, a 10 person increase in RPD is associated with a 0.37 ha decrease in landholding. The magnitude of this effect is quite large considering that the median landholding of households in our sample is 1 ha. This finding points to serious land constraints for smallholders in areas of high RPD.

Of the other explanatory variables, the highest grade attained by the head of household and the distance to an agricultural cooperative are both associated with increased landholdings. Conversely, if a household is female-headed or if there are a large number of agricultural cooperatives in the area, their landholding is lower on average. Furthermore, the dummy variable for whether or not the household lost land during the 1995 redistribution is statistically significant. As discussed in the background section, massive land redistributions have taken place for decades in Ethiopia. The results suggest that if a family lost land, they now

Table 3
Factors affecting landholding, wage rates, maize prices, and teff prices.

Covariates	(1) Landholding		(2) Log of daily wage		(3) Log of maize price		(4) Log of teff price	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
RPD[b,a]	−0.37***	(0.004)	−0.07*	(0.0002)	0.06***	(0.0001)	−0.007***	(0.0001)
Value of assets[b,a]	0.0002	(0.0003)						
Land lost during redistribution[a]	−0.19**	(0.07)						
Highest grade completed by head of household	0.02**	(0.01)	−0.01**	(0.004)				
Female headed household	−0.11**	(0.05)	0.02	(0.02)				
Recent death in household	0.04	(0.03)						
Number of adult equivalents	0.003	(0.01)						
Number of oxen	−0.02	(0.06)						
Number of agricultural cooperatives[a]	−0.20***	(0.05)	0.03	(0.03)	−0.38***	(0.009)	−0.002	(0.007)
Distance to capital					−0.002***	(0.0001)	−0.0004***	(0.0001)
Distance to agricultural cooperatives[a]	0.06***	(0.01)	0.04***	(0.04)	−0.015***	(0.002)	−0.01***	(0.001)
Distance to paved road	−0.002	(0.01)	0.004	(0.003)	−0.01***	(0.001)	−0.01***	(0.001)
Ten year rain average	−0.001***	(0.0004)	−0.003	(0.0002)	−0.0004***	(6.2e−06)	1.44e−05	(3.5e−05)
Net primary productivity[a]	−1.8e−04***	(2.46e−05)			0.001***	(7.39e−06)	5.3e−05***	(4.9e−06)
Elevation[a]	−0.002***	(0.001)	−0.003***	(0.0004)	−0.001***	(0.0003)	0.002***	(0.0001)
Elevation^2[a]	4.18e−07	(1.75e−07)	8.75e−07***	(8.84e−08)	3.4e−07***	(7.68e−08)	−5.55e−07***	(3.69e−08)
No. of observations	7758		7758		7758		7758	
R^2	0.35		0.63		0.74		0.53	

Note: The model also includes the time average of time-varying covariates and year dummies.
Statistical significance is indicated by ***, ** and * for the 1, 5 and 10% level, respectively.
[a] Time-invariant factor.
[b] A variable has been scaled by 10.

hold 0.19 fewer hectares, on average, than a family who lost no land. Once again, with a median farm size in our sample of 1 ha, 0.19 ha composes about a fifth of the average holding, and therefore comprises a substantial part of an average household's land.

Next we consider the results for factors influencing the log of daily agricultural wage, shown in column (2) of Table 3. The direct effect of RPD, which can be found in column (a), indicates that a 10 person increase in RPD is associated with a decrease in daily wage rates of about 7.0%, on average.[14] This is as expected based on expectations from Hayami and Ruttan (1970). As there are more people willing to work in a region, wages are likely to decline, as demand for jobs is larger than their supply. Several household and community variables are also significant in influencing daily wage rates. First, the coefficient for highest grade attained by the household head is negative and significant, and suggests that more education does not lead to higher wages. The results suggest that an extra grade of schooling decreases wage rates by 1.0%, on average. This may seem surprising at first but it follows some of our focus group discussions where many participants noted that more education does not necessarily lead to a better jobs, due to variable quality in education and limited job opportunities that require a high level of education.

Next, the results for factors influencing the log of maize and teff prices are presented in Table 3, columns (3) and (4) respectively. The results of RPD on these prices, shown in column (a) of each indicate that overall, RPD have a positive effect on maize price and a negative effect on teff price. As population increases, a 10 person increase in RPD increases maize price 6% and decreases teff price by approximately 0.7%, on average. This finding about teff may seem counter-intuitive, as we expect prices to increase with the rising demand of higher RPD areas, but the magnitude of the coefficient for RPD in the teff equation is relatively small. Location, represented by distances to paved roads, the capital, and agricultural cooperatives also play an important role in determining these prices, suggesting that prices have a great deal of variation by location and, ultimately, that proximity to amenities is important for both crops.

Fertilizer use per hectare

We estimate factors influencing fertilizer use per hectare in order to understand drivers of fertilizer demand and input intensification in Ethiopia. The results for this can be found in Table 4, column (1). We focus on the direct effect, found at the top of the column, as well as the joint indirect and total effects, found at the bottom of the table. The results indicate that RPD has a positive effect on fertilizer intensification. The joint direct effect of RPD suggests that a 10 person increase in RPD is associated with a modest increase in fertilizer use per hectare of approximately 1.82 kg. The effect is statistically significant at the 1% level. The total effect (direct + indirect effect) suggests that a 10 person increase in RPD is associated with a 2.69 kg increase in fertilizer use per hectare, on average. This finding suggests that fertilizer demand is mainly driven directly by RPD, rather than indirectly through landholding, wage rates and food prices. Market and institutional development occurring in areas of high RPD could be helping farm intensify, allowing for this increase. For example, in some regions, the government may make fertilizer available to farmers in highly populated areas, in order to help them intensify.

Additionally, several household characteristics have significant effects on fertilizer demand per hectare. Households with greater landholding tend to use less fertilizer per hectare, as they likely farm less intensively than do farmers with less land. We find evidence that market access impacts fertilizer demand, as households in areas with more cooperatives demand significantly more fertilizer. In addition, households further from a paved road demand significantly more fertilizer. This may seem surprising, but it could be that households further from paved roads are more dependent upon agriculture as opposed to non-farm activities. Rainfall, elevation, and elevation-squared are also statistically significant. This indicates the importance of location and agronomic conditions in determining the demand for and the use of inputs.

[14] This coefficient estimate is a semi-elasticity.

Table 4
Factors affecting fertilizer demand, maize supply, teff supply, and farm income.

Covariates	(1) Fertilizer demand per hect.		(2) Maize yield		(3) Teff yield		(4) Farm income per hect.	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
RPD: direct effect[b,a]	1.82***	(0.04)	7.17***	(0.34)	−2.11	(26.5)	2.70	(184.55)
Value of assets[b,a]	0.0002	(0.0002)	0.01***	(0.004)	6.0e−04	(0.002)	−1.54	(1.26)
Land lost during redistribution[a]	1.11	(3.52)	3.57	(43.24)	246.83***	(50.04)	−57,045	(41,143)
Highest grade completed by head of household	0.12	(0.24)	25.16**	(10.41)	−12.13**	(5.27)	28,537	(33,618)
Female headed household	−3.69	(2.23)	183.32*	(81.25)	−29.34	(35.28)	−5388	(15,740)
Recent death in household	−0.82	(1.35)	105.43*	(48.43)	−46.91*	(26.11)	−83,088	(84,743)
Number of adult equivalents	0.40	(0.43)	2.44	(16.28)	0.37	(10.40)	64,276	(81,170)
Number of oxen	0.90	(0.61)	21.70	(18.06)	41.76**	(17.33)	141,630	(118,261)
Landholding	−8.08***	(1.42)	−15.12	(22.09)	−109.47***	(20.00)	−63,315**	(27,505)
Fertilizer price	−3.53	(4.19)	−253.49	(279.78)	28.45	(96.06)	−90,618***	(39,793)
Daily wage	−1.86	(1.37)	166.71**	(57.60)	−18.72	(37.84)	2953	(42,071)
Teff price	−5.28	(4.48)			360.48***	(133.01)	−128,695	(186,208)
Maize price	0.92	(8.06)	530.55***	(182.93)				(46,017)
Distance to cooperative[a]	−0.50	(0.59)						
Number of cooperatives[a]	50.97***	(3.74)						
Distance to paved road	1.12***	(0.20)						
Net primary productivity[a]	0.003	(0.002)	0.10***	(0.02)	−0.08***	(0.016)	29.59	(20.21)
Ten year rain average	0.08***	(0.03)						
Annual rainfall			−0.07	(0.08)	0.06**	(0.04)	38.82	(50.91)
Elevation[a]	0.14*	(0.07)	6.30***	(0.62)	2.87***	(0.71)	−263.07	(577.48)
Elevation^2[a]	3.66e−05*	(1.89e−06)	−0.002***	(1.59e−04)	−0.001**	(0.0002)	0.05	(0.13)
RPD: indirect effect	0.87***		−12.54		1.47		−259*	
RPD: total effect	2.69***		−5.37		−0.64		−257*	
No. of observations	7758		7758		7758		7758	
R^2	0.31		0.16		0.31		0.01	

Note: The model also includes the time average of time-varying covariates and year dummies.
Statistical significance is indicated by ***, ** and * for the 1, 5 and 10% level, respectively.
[a] Time-invariant factor.
[b] A variable has been scaled by 10.

Maize yield

The results of the maize yield equation can be found in Table 4, column (2). The direct effect, found at the top of the column suggests that a 10 person increase in RPD is associated with an additional 7.17 kg of maize per hectare on average. The effect is statistically significant at the 1% level. However, the joint indirect and total effects are not statistically significant. It seems that RPD may increase yields directly through improvements in markets and information flow, but the joint indirect effects of smaller landholdings, and lower wage rates even in the face of higher maize prices, offset the direct effects and make the total effect statistically insignificant.

The results from column (1) also indicate that daily wage rates and maize price have a positive impact on maize yield directly. This makes sense, as areas with higher wage rates may be more productive, and if farmers believe that they are able to get a high price for maize produced, they are likely to attempt to increase yields. In addition, several other community and household-level factors influence maize yield. The value of assets, the education of the head of household, a recent death in the household, and being a female headed household increases maize yield. Several community variables are also significant, including net primary productivity, elevation, and elevation-squared. These suggest that maize yield is dependent on agro-ecological factors, and that location is deterministic of maize yield.

Teff yield

Teff is the second crop in our study used to examine the impact of RPD on staple crop yield. The results for the teff supply equation can be found in Table 4, column (3). Table 4 includes the direct and total effects of RPD on teff yield. These results can be found at the top and bottom of column (3) respectively. They indicate that the direct and total effects of RPD on teff yield are individually and jointly insignificant, suggesting that RPD does not influence teff yield. Unlike the case of maize where direct effects of RPD seems to help increase yields, we do not find any evidence that direct or indirect effects are causing farmers to increase teff productivity.

Several community and household level factors influence teff yield. An additional ox per household increases teff yield, while a recent death in the household, and an additional year of schooling decreases teff yield. Several price factors also drive teff yield. Teff price positively drives teff yield, while landholding negatively influences teff yield. Several community variables are also statistically significant, including net primary productivity, rainfall, elevation, and its square term. Together, these suggest that teff yield is dependent on agro-ecological factors, and location is crucial in determining yields.

Additionally, if a household lost land during redistribution influences teff yields, increasing it by 246.83 kg, on average. This suggests that households which lost land are now incentivized, at least for teff, to produce more than if they did not lose land. As mentioned in the background section, previous literature on this issue in Ethiopia is somewhat mixed, and includes Ali et al. (2011) who find that households who are tenure insecure do not make long-term investments in coffee and chat production.[15] However, teff is an annual crop, and our finding is supported by other studies including Benin and Pender (2001), Holden and Yohannes (2002), Gebremedhin et al. (2003), Okumu et al. (2004), Deininger

[15] As mentioned previously, in this case we are considering short-term investments, which may explain some of the differences between these results and those found in the Ali et al. (2011) study.

and Jin (2006), Pender et al., (2006), Pender and Gebremedhin (2007), and Deininger et al. (2009), which suggests that redistribution has improved access to inputs, increasing use of fertilizer and staple crop yields.

Farm income per hectare

Finally, farm income per hectare is used in our analysis to measure the effect of RPD on overall farm productivity. The results for the farm income equation can be found in Table 4, column (4). The direct effect can be found at the top of the column and suggests that there is no statistically significant effect on farm income from an increase in RPD. However, the overall effect at the bottom of column (4) is marginally statistically significant as a 10 person increase in RPD reduces farm income per hectare by 257 Birr (about US $ 13.50) on average. The effect of RPD on farm income per hectare operates through the indirect pathways of landholding and factor prices. This finding is consistent with other results from Table 4, as farmers use more fertilizer in areas of higher RPD, but do not achieve higher yields. Therefore, they spend more money on inputs while achieving no significant increase in productivity, thus lowering their income. This supports the idea of a Cochrane's treadmill, in which farmers increase input use in order to stay where they are rather than experiencing a decline in productivity.

In addition, column (4) of Table 4 shows that higher landholding is associated with lower farm income per hectare. Households with more land may farm less intensively and obtain lower income per hectare, even if they have higher income overall. Higher fertilizer prices are also associated with lower farm income per hectare. This is what we would expect as higher fertilizer prices increase the cost of production.[16]

Conclusions

The objective of this study is to estimate the impacts of rural population density on agricultural intensification, productivity, and farm income in Ethiopia. We evaluate the direct channels through which RPD impacts intensification and productivity, in terms of fertilizer demand per hectare, maize and teff yields, as well as through farm income per hectare. In addition, we estimate the indirect effects that RPD has on agricultural productivity and intensification and income through its effect on landholding, wage rates, fertilizer price, and maize and teff price. Dramatic increases in RPD and corresponding difficulties in access to land suitable for agricultural activities are prevalent throughout Ethiopia and are likely to persist as rural population densities continue to increase in the country.

The overall picture which emerges from this study is that high rural population density creates a situation where farmers are unable to sustainably intensify staple crop production. We find that increases in population density are associated with declining farm sizes. In addition, we find that fertilizer use increases for higher levels of population density, but higher RPD is not associated with higher maize and teff yields. Correspondingly, higher RPD is associated with a decline in farm income on a per hectare basis.

These results suggest the existence of a Cochrane's treadmill where farmers are simply running in place, intensifying input use, but not increasing staple crop yields, resulting in a decline in farm income per hectare. Farmers may use more fertilizer as a response to negative conditions, such as declining soil fertility, resulting from continuous cultivation and declining fallow periods caused by higher RPD. Additional fertilizer may enable farmers to maintain a base level of productivity, at the expense of lower per hectare income due to the added cost of purchasing fertilizer with little yield response.

The results of this study lead to the following policy recommendations. First, the Ethiopian government needs to develop a functioning land market, to combat the problem of declining farm sizes in the face of rising RPD. Enabling households to legally buy, sell and rent land enables factor mobility, and would encourage households who would rather leave agriculture to receive compensation should they choose to transfer their land to those who will use it more productively.

Second, results from our study find that agro-ecological factors such as net primary productivity impact maize yields. Therefore, the government of Ethiopia needs to continue investing in extension services that will train farmers in better soil management practices. This can help improve soil organic matter and help improve staple crop response rates to inorganic fertilizer.

Third, tenure insecurity and past land redistribution practices influence present farming patterns in Ethiopia, and must continue to be addressed. We find that, at least in the short term, people obtain higher teff yields if they previously lost land during redistribution compared to other households. While other studies have found that tenure insecurity leads to lower long term investments (Ali et al., 2011), since teff is an annual crop, less secure households may mine the soil in order to extract what they can from the land while they have it.

The effects of population density and tenure insecurity are intertwined, because areas with higher RPD may have better market access, but having better market access may create more tenure insecurity as the land becomes more valuable to others. For example, focus group participants in the village of Sibrana, near a main road to Addis Ababa, reported that access to input markets, and output markets are good, and they are able to be productive today. However, the fact that they are living in an area with good infrastructure makes them feel insecure about their tenure situation in the future. While the government's formal land titling program has shown some evidence of being successful (Deininger et al., 2009; Holden et al., 2009), this program should be scaled up and the laws behind it strengthened to ensure smallholders' land rights. This will incentivize them to make long term investments that improve soil fertility, make inorganic fertilizer more effective, and boost staple crop yields and income. These changes will help smallholders in Ethiopia and elsewhere in SSA combat the threat that rising population density poses to their livelihoods.

[16] It is worth noting that tree crops form an important source of income for many households with limited land. In our data, area allocated to coffee and chat is nearly constant over the waves of the survey. However, in many cases coffee area is being replaced with chat, likely a result of increasing prices for chat, due to increased exports and demand throughout North Africa. This translates to an increase in share of household income from tree crops over time in our survey.

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