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ETHIOPIAN DEVELOPMENT RESEARCH INSTITUTE
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ESSP WORKING PAPER 91

Cities and agricultural transformation in Africa: Evidence from Ethiopia

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June 2016

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ABSTRACT

Due to the rapid growth of cities in Africa, many more farmers are now living in rural hinterlands in relatively close proximity to cities where many provide food to urban residents. However, empirical evidence on how urbanization affects these farmers is scarce. To fill this gap, this paper explores the relationship between proximity to a city and the production behavior of rural staple crop producers. In particular, we analyze data from teff producing farmers in major producing areas around Addis Ababa, the Ethiopian capital. We find that farmers located closer to Addis Ababa face higher wages and land rental prices, and because they receive higher teff prices they have better incentives to intensify production. Moreover, we observe that modern input use, land and labor productivity, and profitability in teff production improve with urban proximity. This urban proximity has a strong and significant effect on these aspects of teff production, possibly related to the use of more formal factor markets, lower transaction costs in crop production and marketing, and better access to information. In contrast, we do not find a strong and positive relationship between rural population density increases and agricultural transformation – increased population density seems to lead to immiserizing effects in these settings. Our results show that urban proximity should be considered as an important determinant of the process of agricultural intensification and transformation in developing countries.

Keywords: agricultural transformation, crop intensification, urbanization, cities, Ethiopia, sub-Saharan Africa

1. INTRODUCTION

Agricultural transformation is crucial for poverty reduction and improved food security in sub-Saharan African (SSA) countries, as the agricultural sector is characterized by mainly small-scale, low productivity, low external input usage, and family labor oriented enterprises (World Bank 2008; FAO 2015). Inducing a transformation towards higher agricultural productivity levels, therefore, is often sought in public investment programs or policies interventions in many of these SSA countries (Wiggins 2014). This is deemed especially important given that 70 percent of the SSA population and the majority of the poor live in rural areas where farming remains the most important economic activity (Wiggins 2000; World Bank 2008; Christiaensen et al. 2011). Moreover, even though there have been recent improvements in absolute numbers, SSA still remains highly food insecure (von Grebmer et al. 2015).

Several drivers of agricultural transformation have been identified in the literature. Boserup (1956) saw growing population densities and the associated increased land pressure as the prime cause of technological change in agriculture. Available evidence indeed shows that population growth leads to a reduction in fallow periods and an intensification of input use, mechanization or other (labor) intensive practices, and land-saving farming systems (Fresco 1986; Binswanger and Pingali 1988; Tsakok 2011). The argument of a positive relationship between population density and intensification of agricultural land is especially relevant in settings of semi-subsistence farming that are prevalent in large areas of SSA (Jayne et al. 2014). Furthermore, the Boserup hypothesis is endorsed following recent empirical work on land constraints and farming systems in Africa (Headey and Jayne 2014; Ricker-Gilbert et al. 2014; Muyanga and Jayne 2014; Headey et al. 2014; Josephson et al. 2014).

Building upon the Boserup-idea of transformation, other authors have focused on relative and absolute changes in factor and output prices, driven by a number of additional determinants, and observed how these changes reshape agricultural systems. The induced innovation theory in agriculture (Hayami and Ruttan 1985) postulates that farmers intensify agricultural production in such a way as to economize on the most costly input factor. Given that farmers are responsive to differences in relative factor price ratios, Pingali and Binswanger (1986) and Pingali et al. (1987) further argue that market access is an additional source of technological change. Finally, agricultural intensification can result from growth in demand for agricultural products in international and domestic food markets (Reardon and Timmer 2005; Keys and McConell 2005; Pingali 2007; Djurfeldt 2015).

Urbanization, in particular, is seen as an important new factor for transformation in Africa (Tschirley et al. 2013; Reardon et al. 2013). The United Nations estimates that the number of people living in cities in SSA grew by 160 percent between 1990 and 2014 and that this number is further expected to triple to 1.3 billion people by 2050 (UN 2014). Urbanization is considered an important driver of economic development and long-term structural transformation, and therefore has the potential to significantly contribute to poverty alleviation in these countries (Ravallion et al. 2007; Dorosh and Thurlow 2014). In particular, urbanization fosters a shift from agricultural activities to more economically rewarding non-farm activities, with the overall agglomeration effects of such activities potentially generating economies of scale and additional employment (Fafchamps and Shilpi 2003, 2005; Deichmann 2009; Christiaensen and Todo 2014). Urbanization also indirectly affects rural poverty through urban-rural spillovers and economic linkages, such as remittances and rural non-farm income opportunities.

Moreover, urbanization fosters economic transformation through food and agricultural markets. For example, increased urban consumption and changing preferences for high-value and higher quality agricultural products increase urban demand and willingness-to-pay for agricultural products (Tschirley et al. 2013; Reardon and Timmer 2014; Djurfeldt 2015). As urban residents rarely produce their own food, this has important implications on rural agricultural production systems (von Thünen 1826; Wiggens 2000; Cali and Menon 2012).[1] There is, however, relatively limited evidence on how increased urbanization and urban demand for goods and services affects agriculture in the surrounding areas supplying these cities.[2]

In this paper we contribute to this literature by analyzing how proximity to a large urban city affects farmers' agricultural production practices in Ethiopia. In particular, we look at the case of staple crops, which are the overwhelming source of income for these farmers. In Ethiopia, important changes are happening in urban-rural settlement patterns. It is estimated that the rural population living less than 3 hours away from a city increased from 15 percent to 47 percent of the population over the 13-year period between 1998 and 2011 (Schmidt et al. 2015). Moreover, while the share of the urban population in the total population of Ethiopia is still relatively low at 17 percent, the urban population is rapidly increasing and it is expected to triple from 15.2 million in 2012 to 42.3 million by 2034 (World Bank 2015). However, although Ethiopia is becoming rapidly more urban, it remains however one of the poorest and most food insecure countries in SSA, with the majority of its people still highly dependent on the agricultural sector for their livelihoods (von Grebmer et al. 2015). Agricultural transformation is therefore high on everybody's agenda.

To study the relationship of agriculture with proximity to cities, we use unique data from Ethiopian farmers located in major producing areas surrounding the capital, Addis Ababa, to test different hypotheses. We focus on the transformation in the production of one specific staple crop – teff. This crop is especially relevant as an example because it is an important staple food for urban consumers and a major source of income for poor farmers in rural areas. We find that farmers located close to Addis Ababa receive higher output prices, but also face increased wage and land rental costs. At the same time, urban proximity is positively related with the use of chemical fertilizer and the adoption of improved seed. The direct effect of urban proximity, combined with the indirect (output) price effect, result in agricultural intensification, as measured by higher land and labor productivity and by profits. Our findings therefore suggest that increasing urbanization in Africa will likely lead to increased agricultural transformation that benefits staple crop producers. In contrast, we do not find a significant and positive relationship between intensification and increasing rural population densities. This confirms findings of Headey et al. (2014) and Josephson et al. (2014) who show immiserizing intensification driven by land pressure increases in rural Ethiopia.

The paper is structured as follows. Section 2 provides background information on Ethiopia. To understand the channels through which urban proximity influences intensification, we develop a conceptual framework, which is described more fully in Appendix 1. In Section 3, we describe the analytical methods adopted, including sampling design and the data obtained, and the empirical strategy used. Section 5 presents the results, and the last section covers the conclusions.

2. BACKGROUND ON CITIES AND TEFF IN ETHIOPIA

Urbanization in Ethiopia is one of the lowest in the world, with only 17 percent of its population estimated to live in cities in 2012 (World Bank 2015). However, rapid growth of cities has occurred in the past and even faster changes are expected in the future. Schmidt and Kedir (2009) estimate that, based on an agglomeration index approach and using the last three national censuses (1984, 1994, 2007), urbanization rates will increase from 3.7 to 14 percent over the period studied, almost quadrupling the urban share of the national population (CSA 2007). Using the latest census information, Addis Ababa is by

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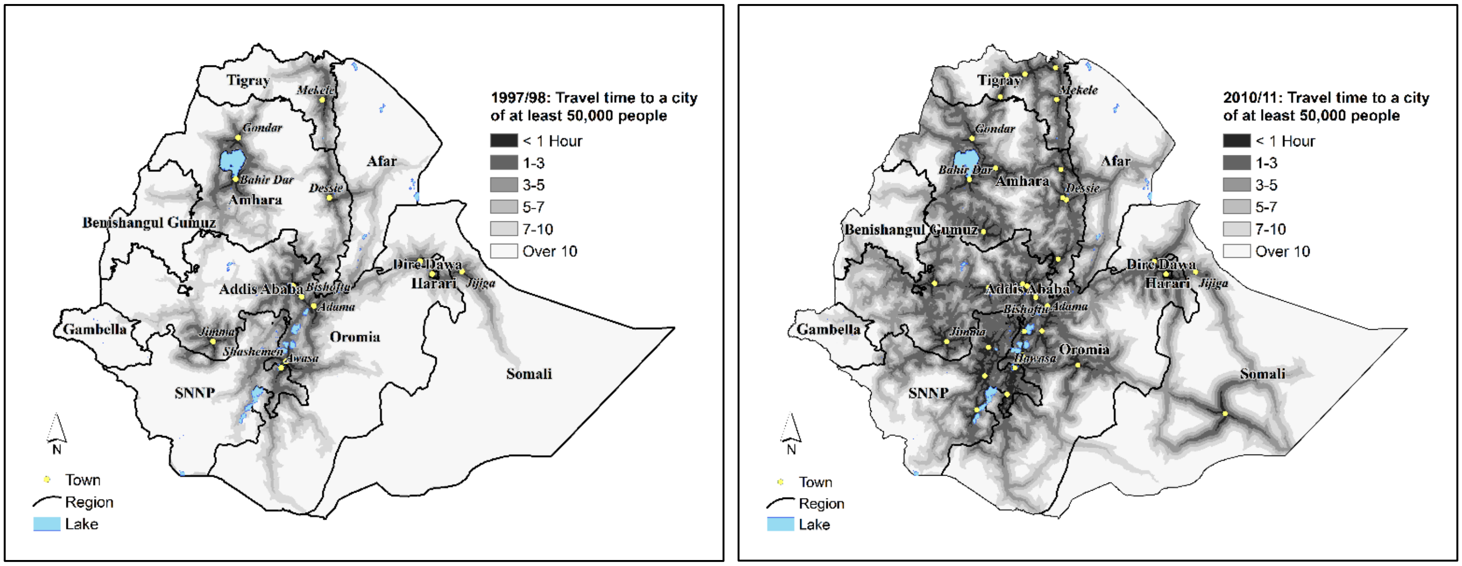
[1] The link between urban demand and specialization in agriculture stems from the seminal work of von Thünen (1826). Because of lower transportation costs, farmers living close to markets receive higher effective market prices for their products, which increases their rented land value. Rural areas close to markets will therefore specialize in high value commodities; and market expansion will result in the development of different spheres of land uses and specialization of different agricultural products centered on the urban market.

[2] Urban proximity has been shown to determine the specialization and organization of economic activities in rural areas (Fafchamps and Shilpi 2003, 2005; Deichmann et al. 2009). Rural resident close to urban centers and markets are more likely to be employed in non-farm wage and self-employment jobs, while more remotely located residents specialize in agricultural production.

far the largest city in Ethiopia – in 2007 about a quarter of the urban population (10.5 million) in Ethiopia lived in Addis (Schmidt and Kedir 2009). Driven by complementary rapid road infrastructure development, Kedir et al. (2015) further estimate that only 15 percent of the population was located within 3 hours of a city with a population of at least 50,000 in 1997/1998, but in 2010/11 this number had changed to 47 percent of the population (Figure 2.1). The World Bank (2015) expects that urban populations will continue to grow rapidly in Ethiopia. They project an annual growth rate of 5.4 percent over the next decades, which would lead to a tripling of the urban population from 15.2 million in 2012 to 42.3 million in 2034. By 2028, 30 percent of the population would live in urban areas.

Figure 2.1: Travel time to a city of at least 50,000 people (1996/97 and 2010/11)



Source: Kedir et al. (2015)

Teff is an important staple crop in Ethiopia. In 2011, teff constituted 23 percent of total grain crop area and 17 percent of total grain production in Ethiopia (CSA 2012). Moreover, production has doubled in the last decade from over 1.5 to 3.5 million metric tons. 29 percent of teff production is sold, which is relatively high compared to other cereals such as wheat and maize (20 and 11 percent, respectively). Hence, teff has a higher commercial surplus and is often considered a cash crop for its producing farmers (Minten et al. 2015, 2016). Further, teff is more commonly eaten by urban households. In urban areas, teff accounts for 23 percent of per capita total food consumption (Berhane et al. 2011). In Addis Ababa, teff accounts for almost half of total cereal expenditure, while in other regions this is much less. Moreover, teff is consumed relatively more by richer and urban households – the income elasticity of demand for teff is high in urban areas, estimated to be 1.1 by Berhane et al. (2011). Addis Ababa is growing in size, and consequently the demand for teff is increasing. Moreover, household incomes (proxied by per adult equivalent consumption) in urban areas of Ethiopia are increasing, have risen an estimated 38 percent between 2005 and 2011. Given that teff is an economically superior commodity in urban areas with high income elasticities, this has led to large increases in demand for the grain. The expected growth in the number and in the average incomes of urban households seems set to increase the urban demand for teff well into the future.

3. METHODOLOGY

3.1. Sampling and Data

For the empirical analysis, we use data from a large-scale survey of teff producers in Ethiopia. Teff producers in five production areas with the largest teff commercial surplus around Addis Ababa were surveyed in 2012. An innovative sampling design was implemented to randomly select farmers from both the smallest and largest teff producing woredas in these zones. To achieve this, all woredas were ranked in terms of cultivated area per zone. Two woredas then were randomly selected from both the group of upper and lower producing woredas. Within each of the 20 selected woredas, all kebeles (villages) were ranked in terms of teff production, and two kebeles were randomly selected from the top 50 percent of teff-producing kebeles and one from the bottom 50 percent. Hence, a total of 60 villages was randomly selected. Within each village, a census was created that listed all farmers based on area cultivated. From this list, 20 farmers were randomly selected to be interviewed. Of these 20, ten farmers were selected from the list of large production farmers (cultivating all together 50 percent of the area) and ten farmers from small production farmers (the other 50 percent of the area). Hence, a total of 1,200 farmers was surveyed. The third column of Table 4.1 provides descriptive statistics on the household head and farm characteristics of these teff producing households. The majority of farmers are males, over 45 years old, and with at least some education.

Table 3.1: Basic descriptive statistics and comparison with non-teff producers

Descriptive variable	Unit	Surveyed farmers	LSMS teff farmers	LSMS non-teff farmers	Probit coefficient
Age of head	years	45.41	46.62	46.16	-0.02**
Gender of head	male=1	0.95	0.93	0.78	0.52
Educated head	yes=1	0.54	0.31**	0.21	-0.15
Household size	number	6.33	5.78*	5.04	-0.02
Orthodox religion	yes=1	0.87	0.86	0.93	0.38
Head is married	yes=1	0.94	0.92	0.76	-0.38
Land owned	ha	2.00	1.66	1.48	0.11
Altitude	log meter	7.65	7.67	7.66	0.96*
Farm income	log ETB	6.50	8.06	7.57	-0.04
Livestock income	log ETB	7.42	7.38	7.23	-0.05
Herbicide use	yes=1	0.65	0.64	0.43	0.34
Pesticide use	yes=1	0.13	0.11	0.26	0.02
Own Mobile phone	yes=1	0.30	0.30	0.22	-0.02
Own TV	yes=1	0.03	0.04	0.02	1.54*
Received loan	yes=1	0.39	0.44	0.46	0.18
Constant					-7.54*
observations		1,200	441	1,748	

Notes: 'Surveyed farmers' refers to the farmers selected for this survey. 'LSMS farmers' refers to the farmers selected in the Living Standards Measurement Study (LSMS) of the World Bank in the same geographical area of Ethiopia. Column 3 reports the sample average values for surveyed farmers. Column 4 reports the average values for teff farmers from the LSMS survey. Column 5 reports the mean value for non-teff farmers in the LSMS survey. The asterisks in column 4 report the results of a (village-level clustered) t-test with null hypothesis that the difference in mean values between surveyed and LSMS teff farmers is zero (n=1,641). 'Probit coefficient' in column 5 report the coefficients from a Probit estimation of the probability to be active in teff production (n=2,189). The asterisks indicate whether the coefficient is significantly different from zero: *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

This sampling procedure was specifically designed to select a representative sample of commercial farmers who are located in the most productive rural teff-producing areas connected to Addis Ababa. This sample design provides high internal validity and gives us a representative sample of teff farmers in these areas. However, it is not representative for all Ethiopian teff farmers, and we cannot control for potential selection into teff farming. To assess whether teff farmers are significantly different from non-teff producing farmers, we compare our data with the LSMS data in the same five geographical zones in Table 4.1. First, we compare teff producing farmers in our survey (column 3) with teff producing farmers in the LSMS survey (column 4) for characteristics that are included in both surveys. We find that the teff farmers covered in our survey are of similar age and religion and have similar levels of mobile phone ownership and herbicide use; but tend to be more educated and have larger households. Second, within the LSMS data, we compare the teff producing with non-teff producing farmers (column 5) to test whether there is a substantial selection bias into teff production. The last column of Table 3.1 reports the coefficients of the probit estimation that explains being a teff farmer, and we find that farmers' age, altitude and owning a television, are weakly related with the probability of growing teff.

The main independent variable of interest in this paper is our measure of urban proximity. Urban remoteness (i.e. the inverse of urban proximity) is defined as the transportation costs that farmers face when selling teff in the urban center of Addis Ababa. Such an indicator is assumed to be a better measurement of proximity than physical distance or travel time (Chamberlin and Jayne 2013). In practice, we measure urban proximity as the cost of transporting one quintal (0.1 ton) from the farm to the urban wholesale market of Addis Ababa (ETB/quintal).[3] This transportation cost is calculated as the combination of two costs, i.e., the cost of transporting teff (i) from the farm to the market center in the village; and (ii) from the market center in the village to the major wholesale market in Addis Ababa, using common modes of transport.

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[3] ETB = Ethiopian Birr, 1 USD = ETB 18 on January 1, 2013

Agricultural input prices were collected in a community questionnaire. Using monthly observations, village data were aggregated to yearly averages for DAP fertilizer prices (ETB/quintal), urea fertilizer prices (ETB/quintal) and agricultural wages (ETB/day). Land rental rates (ETB/ha) were calculated from the land tenure section in the household survey.[4] For each of the parcels rented-in or share-cropped, farmers reported the price paid to the land owners or the value of output shared with such persons, together with the parcel size, soil quality, walking distance, etc. To obtain rental prices, we pooled fixed land rental rates and sharecropping payments at the plot level for those households involved in these arrangements. Data on teff prices (ETB/quintal) were further collected from the teff transaction section in the household survey, which contains information on quantities sold, prices received, main place of sales, and the buyer in each teff sales transaction during the last production season. However, there might be endogeneity issues when the reported land and output prices are related to household (farming) characteristics, e.g., welfare status. Therefore we estimate a land rental and output price formation model using the parcels and transaction panel data for each household as the unit of observation (results are reported in Appendix 2). The reported land rental rates and teff output prices are regressed on the parcel-level and transaction-level determinants of prices respectively using a fixed effect model. From these panel estimations, the predicted values of the land rental and input price are calculated for each farmer and later are used as an independent variable in our models.[5]

Data on inputs applied and teff output achieved was collected at the teff plot level and averaged over all plots cultivated by the household. The inputs considered are use of DAP (kg/ha), urea (kg/ha), improved teff seed (kg/ha), agrochemicals (ETB/ha), and labor (person-days per hectare). We use these household level data in levels but also report on input ratios and the use of formal factor markets. The input ratios are the use of agrochemicals over labor, the plow equipment index over labor, and the use of fertilizer and improved seed over land.[6] We also look at the share of rented land, hired labor, and purchased seed in the total usage of each input by the household. The intensification outcomes are teff land productivity (kg/ha), labor productivity (kg/person-days), input expenditure (ETB/ha), and profits (ETB/ha). Profits or net income are calculated as the difference between the monetary value of teff output and monetary value of all input expenditures in teff production. The latter covers the cost of fertilizer, agrochemicals and seed usage; and also includes the cost of labor, where we assume the local wage rate as the opportunity cost of (family) labor.

Table 3.2 reports the summary statistics for all outcome variables, i.e., prices (panel 1), inputs (indices) applied (panel 2), and intensification outcomes (panel 3) achieved in teff production. The third column reports the sample average. We see that farmers on average use 91 kg of DAP, 64 kg of urea, and 12 kg of improved seed when cultivating one hectare of teff. Teff output is slightly over one ton per hectare or 10 kg per person-day, resulting in an average net income from teff production (profits) of 7,384 ETB per hectare. We further see that only 13 percent of the labor and 11 percent of the land used in teff production is hired or rented. Purchased seed accounts on average for 16 percent of the seed used in teff production.

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[4] However, the results for land prices should be interpreted carefully as land markets in Ethiopia are thin and underdeveloped, making land prices potentially an unreliable measure of factor scarcity.

[5] The majority of farmers performed more than one teff transaction, implying that we have a transaction panel for each household. On the contrary, land rental rates could only be calculated for those households that rented in or sharecropped teff land. However, the panel price formation models allow us to impute the missing values of land rates using regression based imputation. The value of sharecropping was calculated as the value of the share of output on the plot that had to be paid to the land owner and used as land rental rate if the parcel was sharecropped.

[6] Following Headey et al. (2014), we construct an index on household's ownership of plow equipment. Using a Principal Component Analysis on six different types of plow equipment that might be owned and used in teff production by the household (i.e. axe (*metrebia*), pick-axe (*doma*), sickle, plough, yoke, and hay fork), we transform these different variables into one Principal Component that accounts for most of the variability. Given that teff production requires a thorough preparation of the land before planting, higher levels of intensification in teff production might require the substitution of manual labor by the use of plow equipment.

Table 3.2: Sample means of outcome variables

Variable	Unit	Mean	Median	SD
Prices				
Price of teff	ETB per quintal	1,047	1,043	117
Wage rates	ETB per day	37	37	12
Land rental rate	ETB per ha	4,702	4,716	127
Price of DAP	ETB per quintal	1,390	1,411	131
Price of urea	ETB per quintal	1,133	1,162	110
Agricultural inputs and indices				
Use of DAP	kg per ha	91	82	75
Use of urea	kg per ha	64	50	67
Use of improved seed	kg per ha	12	0	20
Use of agrochemicals	ETB per ha	54	40	63
Use of for labor	day per ha	126	108	75
Ratio agrochemicals over labor	.	0.57	0.39	0.74
Ratio plow index over labor	.	0.03	0.02	0.03
Ratio fertilizer over land	.	445	240	667
Ratio improved seed over land	.	28	0	66
Share of purchased seed in total	%	16	0	33
Share of hired labor in total	%	11	1	18
Share of rented land in total	%	11	0	25
Intensification outcomes				
Teff land productivity	kg per ha	1,071	978	600
Teff labor productivity	kg per day	10	9	6
Teff input cost	ETB per ha	3,277	2,879	1,859
Teff non-labor input cost	ETB per ha	2,514	2,243	1,560
Teff profits	ETB per ha	7,384	6,228	5,880

Number of observations in each model is 1,200. 'SD' is the standard deviation.

3.2. Empirical strategy

Following the conceptual framework presented in detail in Appendix 1, we estimate empirically the effect of urban proximity on prices (b_i), agricultural inputs and indices (q_i) and intensification outcomes (y_i). First, we estimate a reduced form of equations (1), (2), and (3), where the outcome variables are regressed only on transportation cost d_i. Then, we estimate a less parsimonious model where we allow for indirect effects through teff output and input prices b_i (except in the price model) and control for different possible confounding variables. These regressions are estimated using a seemingly unrelated regression (SUR) framework. SUR amounts to a GLS estimation taking into account that errors of the different models might be correlated for an individual, but not across individuals. To overcome the problematic assumption of homoscedastic errors of the SUR estimator, we bootstrap the standard errors to allow for the heteroskedastic structure on the error terms (Cameron and Trivedi 2008).

$$\ln(b_i) = \alpha_w + \beta_w * d_i + \theta_w * \text{Controls} + \varepsilon_w \qquad (1)$$

$$q_i = \alpha_q + \beta_q * d_i + \gamma_q * \ln(b_q) + \theta_q * \text{Controls} + \varepsilon_q \qquad (2)$$

$$y_i = \alpha_y + \beta_y * d_i + \gamma_y * \ln(b_q) + \theta_y * \text{Controls} + \varepsilon_y \qquad (3)$$

In each of these models, we are primarily interested in the direct and indirect effect of urban proximity. The direct effect of urban proximity through the production function corresponds with the β coefficients in the above equations. This direct effect captures changes due to improved information flow, reduced transaction costs, and stronger market-related institutions that may result from closer urban proximity (Stifel and Minten 2008; Josephson et al. 2014). The indirect effect of urban proximity on intensification outcomes is captured by the changing output prices (p_i) and input prices – wages (w_i) and land rental rate (r_i) – over distance. To determine the total effect of urban proximity on the different outcome variables, the direct and indirect effects need to be combined. For example, the total effect of transportation cost on the demand for agricultural inputs (q_i) becomes[7]

$$\frac{\partial \mathrm{q}_i}{\partial \mathrm{d}_i} = \beta_2 + \frac{\partial q_i}{\partial \mathrm{p}_i} * \frac{\partial \mathrm{p}_i}{\partial d_i} + \frac{\partial q_i}{\partial \mathrm{w}_i} * \frac{\partial \mathrm{w}_i}{\partial d_i} + \frac{\partial \mathrm{q}}{\partial \mathrm{r}_i} * \frac{\partial \mathrm{r}_i}{\partial d_i} \qquad (4)$$

To minimize the extent of omitted variable bias in the estimated coefficient of urban proximity in equations (1), (2), and (3), we further control for additional determinants of agricultural intensification. First, we include several farm characteristics: (i) age, gender, ethnicity, and education of the household head; (ii) households' assets and household size; and (iii) agro-ecological conditions – altitude, the share of brown or black soils, and the share of flat land versus sloped land. Second, farmers' market access is generally considered an important determinant of agricultural outcomes in developing countries (Stifel and Minten 2008; Dorosh et al. 2010). Therefore, we control for households' membership in an agricultural cooperative and the distance to the nearest asphalt road. Finally, we include a measure of population pressure as an independent determinant of intensification (Ricker-Gilbert et al. 2014; Muyanga and Jayne 2014; Headey et al. 2014; Josephson et al. 2014). The majority of the literature in this area has used GIS-based estimates of rural population density as a measure for population pressure. These data, however, are not available at the village level in Ethiopia. Headey et al. (2014) instead use average farm size as alternative proxy of land pressure.[8] In line with these authors, average farm sizes were collected from the Bureau of Agriculture in each of the study villages and are included in the regressions as a measure of rural population density.

3.3. Estimation issues

An important confounding effect that might drive the relationship between urban proximity and agricultural intensification outcomes, but is much more difficult to control for than omitted variable bias, is unobserved heterogeneity. Capitals or other large cities in developing countries do not develop randomly over space. Cities are likely to emerge in areas that are characterized by favorable agro-ecological conditions and agricultural potential. For example, Motamed et al. (2014) show that urbanization happens earlier in places with higher agricultural potential. Conversely, rural hinterland areas are often characterized by mountainous geography and arid climatic conditions (Reardon and Timmer 2014). Unobserved agricultural potential poses important estimation problems. Unfortunately, we do not directly observe agricultural potential. However, to some extent we control for this effect through the agro-ecological indicators included in the above models. A related problem is that farmers' settlement in the hinterland might also not be random, even if we control for observed differences between farmers. Agglomeration effects and new geographic economy theories suggest that individuals tend to settle in places that are close to growing urban areas, as they offer better economic opportunities (Fafchamps and Shilpi 2003).[9]

While we are not able to deal with these endogeneity problems directly, we address each issue indirectly by applying the endogeneity tests as outlined by Jacoby and Minten (2009). To apply these tests to our data, we use land productivity as a proxy for agricultural potential. To calculate the former, teff yield at the plot level (y_{ip}) is regressed on a set of plot level determinants (x_{ip}). We use data from the cultivated teff plots of each household as the unit of observation. Given that the large majority of farmers cultivates more than one teff plot, panel data allow us to estimate a fixed effects model of this production function:

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[7] To calculate the different effects in equation (4), we run a post-estimation command (nlcom in Stata) that calculates the nonlinear combination of the estimated coefficients after the SUR regression. $\frac{\partial \mathrm{p}_i}{\partial d_i}$, $\frac{\partial w_i}{\partial d_i}$, and $\frac{\partial r_i}{\partial d_i}$ are obtained from the regression coefficients in equation (1); and β_2, $\frac{\partial \mathrm{q}_i}{\partial \mathrm{p}_i}$, $\frac{\partial q}{\partial \mathrm{w}_i}$, and $\frac{\partial \mathrm{q}_i}{\partial \mathrm{r}_i}$ are obtained from the regression of equation (2).

[8] Boserup predicted that population (density) growth increases land pressure because cropping will become more continuous and plot sizes shrink due to inheritance fragmentation. Headey et al. (2014) argue that farm size is a better measurement of land pressure than GIS population density constructs in Ethiopia because the latter do not take into account geography nor soil quality, are constructed based on strong interpolation assumptions and given the local institutional setting.

[9] An instrumental variable approach could allow us to identify exogenous variation in urban proximity to Addis Ababa. For example, Fafchamps and Shilpi (2003) instrument travel time with foot travel time and physical village level characteristics, while Dorosh et al. (2013) use terrain roughness as an instrument for travel time. However, such approaches do not seem to be very convincing to satisfy – at least conceptually – the exogeneity assumption for a good instrument. An alternative solution is to use physical arc distances like Deichmann et al. (2009), but these measures of urban proximity do not take into account heterogeneity in geography and soil quality.

$$\ln(y_{ip}) = \alpha + X_{ip} * \beta + \eta_i + \varepsilon_{ip} \qquad (5)$$

After estimating this function (results are reported in Appendix 2), we calculate the household fixed effect (η_p) and the plot specific idiosyncratic error term (ε_{ip}). These residuals are combined and added to the mean value of teff land productivity (kg/ha), to construct yield levels adjusted for input use and soil/rain shocks at the plot level ($\overline{y_{\iota p}}$). We will refer to these as 'adjusted teff yields'. As a first test, we assess the heterogeneity in land productivity across space by examining how adjusted teff yields, $\overline{y_{\iota p}}$, vary over location within our sample. The second test involves the assessment of endogenous location of farmers over space. To do so, we use households' fixed effects, η_p, calculated from equation (5) as a proxy for farmers' ability in producing teff. This allows us to test whether the unobserved fixed abilities of farmers differ between households over space.

The results of the two tests are reported in Table 4.3. Both tests involve a pooled regression where transportation cost is included as the sole explanatory factor of observed yield (column 2), adjusted yield (col. 3), and farming ability (col. 4). The regression coefficient reported in the second column indicates that observed land productivity is indeed negatively correlated with transportation cost. However, once we adjust the observed yield levels for the confounding effect of distance on input use and weather shocks, we see that the correlation of transaction costs and adjusted yield levels becomes insignificant (in the third column). Hence, agricultural potential – as proxied by teff yields at the plot level – does not change significantly over space. The last column of Table 3.3 reports the estimated coefficient from the regression of farming ability on transportation cost. The test shows that transportation costs are not significantly related with household fixed farming ability, suggesting that households' unobserved (teff) farming characteristics do not change with urban proximity in our data. [10]

Table 3.3: Endogeneity tests of city and farmer location

	Observed Yield y_{ip} (kg/ha)	Adjusted Yield $\overline{y_{\iota p}}$ (kg/ha)	Farming Ability η_p (.)
Transportation Cost (ETB/quintal)	-2.232***	-0.975	-0.001
	(0.700)	(0.702)	(0.001)
Constant	1,288.8***	1,181.9***	0.067
	(70.27)	(65.60)	(0.110)
Observations	2,791	2,786	2,786
R-squared	0.010	0.002	0.003

Notes: Standard errors are reported in parentheses. The first test involves the pooled regression of observed yield (y_{ip}) and yield adjusted for plot and weather shocks ($\overline{y_{\iota p}}$) on transportation cost. Standard errors are clustered at the household level and estimated by bootstrap for the adjusted yield. The second test involves a pooled regression of household farming ability (η_p) on transportation cost. Standard errors are clustered at the village level and estimated by bootstrap. *** p<0.01, ** p<0.05, * p<0.10.

4. RESULTS

4.1. Non-parametric regressions

We start this empirical section with presentations of non-parametric regressions. These regressions do not require that the functional form of a relationship is specified in advance and, consequently, help to explore relationships in the data without preconditions. In particular, we report the local polynomial smoothing estimates of transportation cost (x-axis) on output and input prices, respectively (Figure 4.1); the application of agricultural inputs (Figure 4.2); input ratios (Figure 4.3); and intensification outcomes (Figure 4.4).[11] Within each figure, different graphs are reported for each outcome variable, and graphs are numbered consecutively starting from the upper left graph. The graphs also report confidence intervals for each relationship, which primarily highlight the less precise estimates at the extreme ends of the transport cost distribution.

Figure 4.1 suggests a negative correlation between the transportation cost to Addis Ababa and the output price of teff. Graph 1 shows that the price of teff decreases from 1,150 ETB per quintal in villages nearby Addis to 950 ETB per quintal in

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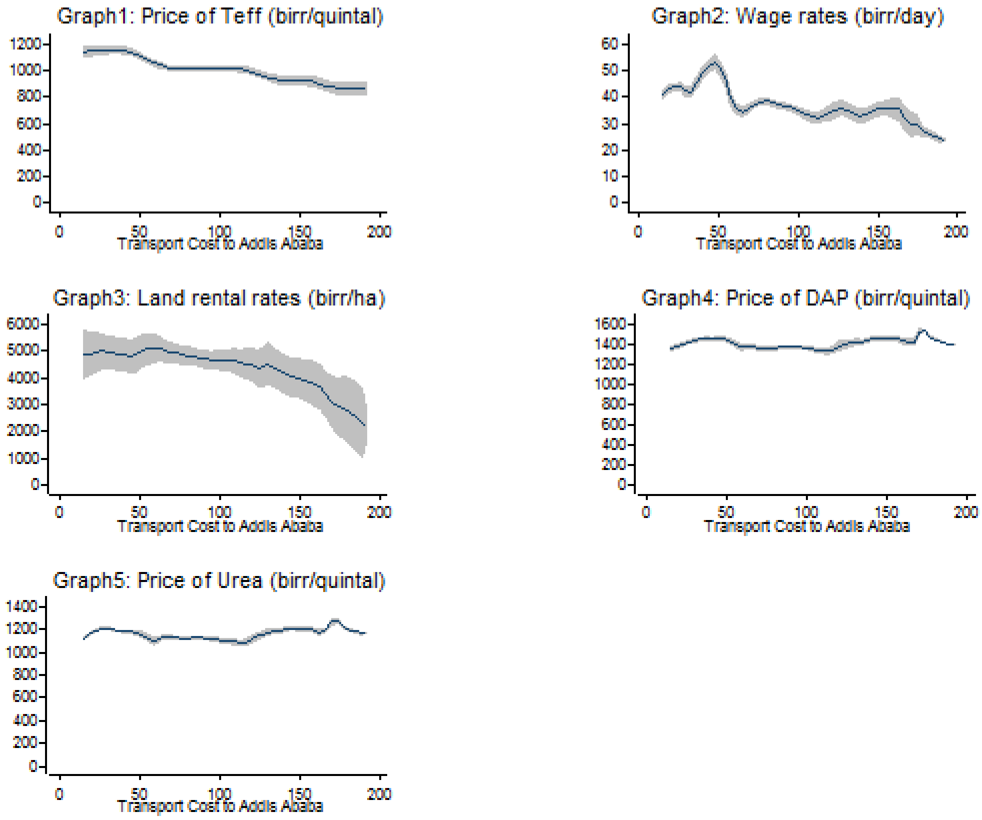
[10] Following Jacoby and Minten (2009), we also implemented a non-parametric LOWESS estimation of the relationship between urban proximity and respectively (i) observed yield and (ii) adjusted yield. While the observed yield levels show a negative trend with respect to the transportation cost, the gradient of the adjusted yield levels becomes less steep. The results of this non-parametric test can be obtained from the authors.

[11] To construct the graphs for teff output price and land rental rates, we make use of the observed and self-reported data. However, in the empirical section we use the imputed values using the regression method described in section 3.

the most remote villages, closely following transportation costs from Addis (Minten et al. 2016). There is also a clear negative relation between the local wage rate paid in the village and urban remoteness. Graph 2 shows that the village wage rate drops from 45 ETB per day to 25 ETB per day from less to more remote villages, a decrease of more than 50 percent. As land cannot be sold in Ethiopia, we can only look at land rental prices as an indicator of implicit land values. Land rental prices also show clear downward patterns over space, as would be expected (Jacoby 2000). Also in this case, prices drop to half for the most remote villages. Finally, prices of DAP (Graph 4) and urea (Graph 5) fertilizer are not correlated with urban proximity. This is not surprising, given that chemical fertilizer distribution is coordinated and regulated by the government and that prices and margins are fixed (Rashid et al. 2013).[12] Hence, these figures suggest that more remote farmers receive significantly lower prices for their teff output, but at the same time also face lower prices for labor and land.

Figure 4.1: Correlation of transportation cost to Addis Ababa with village prices for teff, wages, land rental, DAP, and urea



Source: Authors' estimates.

Note: Solid lines represent local polynomial smoothing estimates of transportation cost (x-axis) on output and input prices (y-axis). The shaded area corresponds with the 95% confidence intervals. Graph 1 shows the results for teff output price; Graph 2 shows the results for wage rates, Graph 3 shows the results for land rental rates; Graph 4 shows the results for DAP price; and Graph 5 shows the results for urea price.

We further look at correlations between urban proximity and input use. We observe increasing application rates of chemical fertilizer and improved varieties by farmers living close to the urban center (Figure 4.2). Farmers close to the capital use more than 120 kg DAP per hectare (Graph 1), while those further away use only half of that amount. The use of urea (kg per hectare) also drops by more than half for the most remote households. The effect of urban proximity is the most pronounced for the use of improved teff seed: Graph 3 shows that the application of improved seed drops to almost zero kg per hectare at the most costly and distant end of the transport cost distribution. Graph 4 suggests that there is no clear relationship between remoteness from an urban center and the use of agrochemicals. We see that the total use of labor (including family, hired and shared labor) on the plot increases over transportation cost in Graph 5. Hence, farmers more closely located to an urban city use less labor per hectare. As indicated in our model (see Appendix 1), with greater distance from an urban center, demand for farm labor is reduced because of lower output prices and productivity (the second and third term), but at the same time demand for labor increases with lower rural wages (first term is positive).

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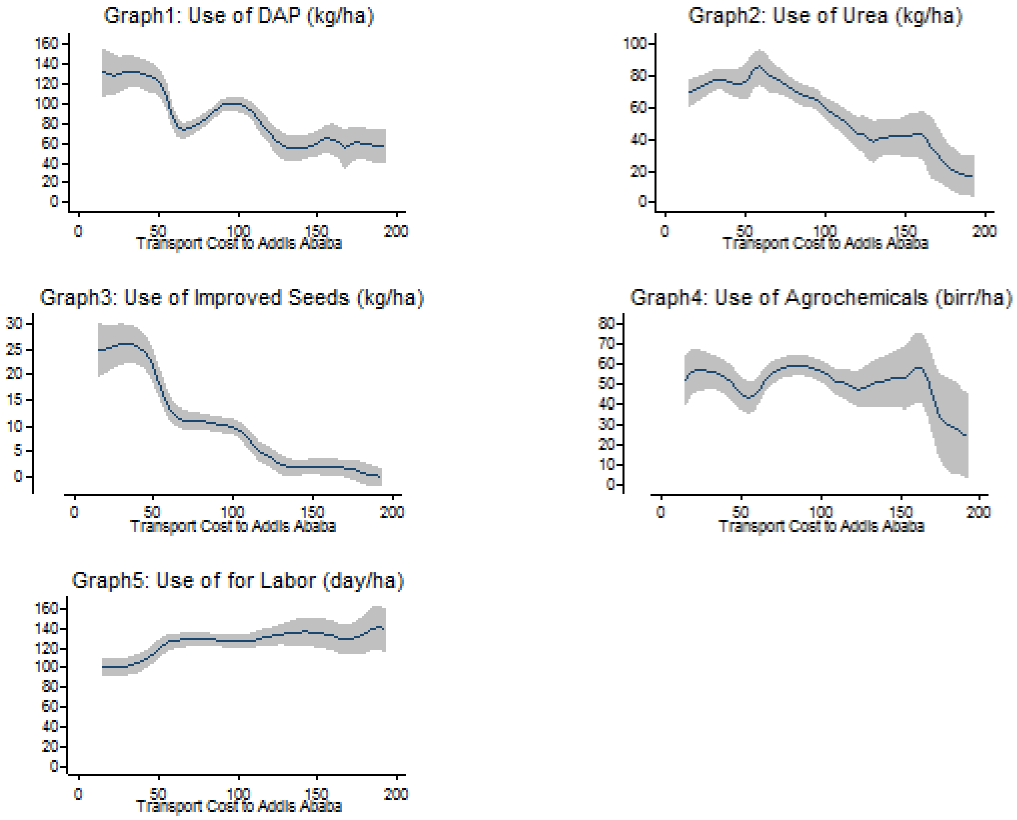
[12] For the same reason, the price of agrochemicals is assumed to be fixed, but we have no data to test this empirically.

Figure 4.2: Correlation of transportation cost with application of agricultural inputs

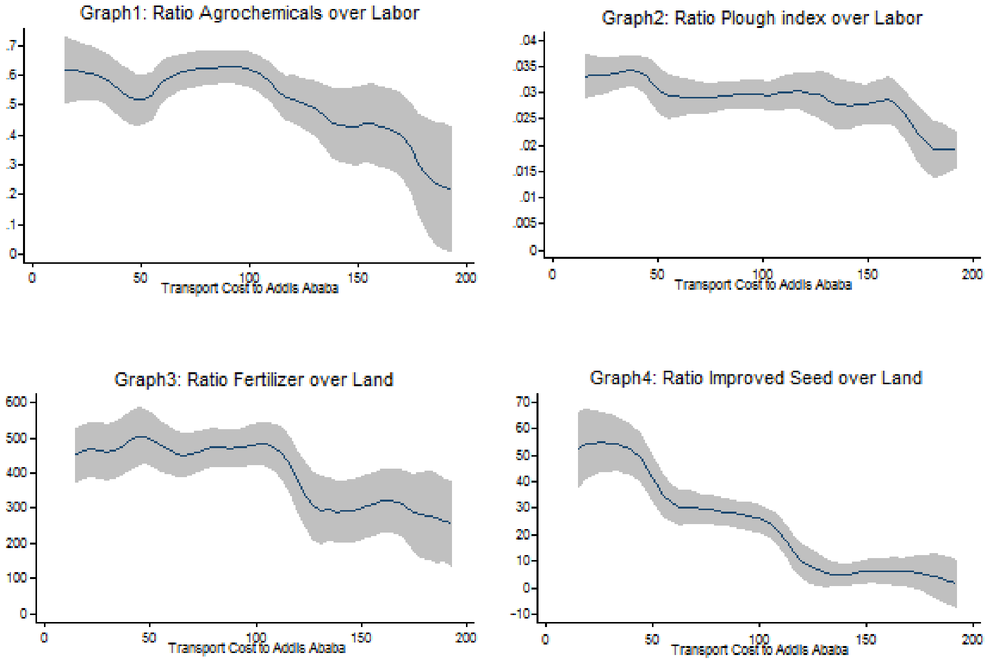


Source: Authors' estimates.

Note: Solid lines represent local polynomial smoothing estimates of transportation cost (x-axis) on the application of agricultural inputs (y-axis). The shaded area corresponds with the 95% confidence intervals. Graph 1 shows the results for the use of DAP; Graph 2 shows the results for the use of urea, Graph 3 shows the results for the use of improved seed; Graph 4 shows the results for the use of agrochemicals; and Graph 5 shows the results for the use of labor. All variables are plot level averages of inputs used by the household.

Figure 4.3 further reports how transportation cost is related to different input ratios in teff production. Graph 1 shows that the ratio of agrochemicals over labor tends to decline when transportation costs increase. Similarly, the ratio of the plow ownership index over labor tends to decline over distance, as shown in Graph 2. These two graphs suggest that labor is substituted for plowing and agrichemicals, especially with herbicides, as these are a substitute for weeding labor. Graph 3 and 4 show that the ratio of fertilizer over land and improved seed over land is negatively correlated with remoteness from an urban center. Hence, farmers who are closely located to an urban center, use their land more intensively.

Figure 4.3: Correlation of transportation costs with Input ratios of production factors

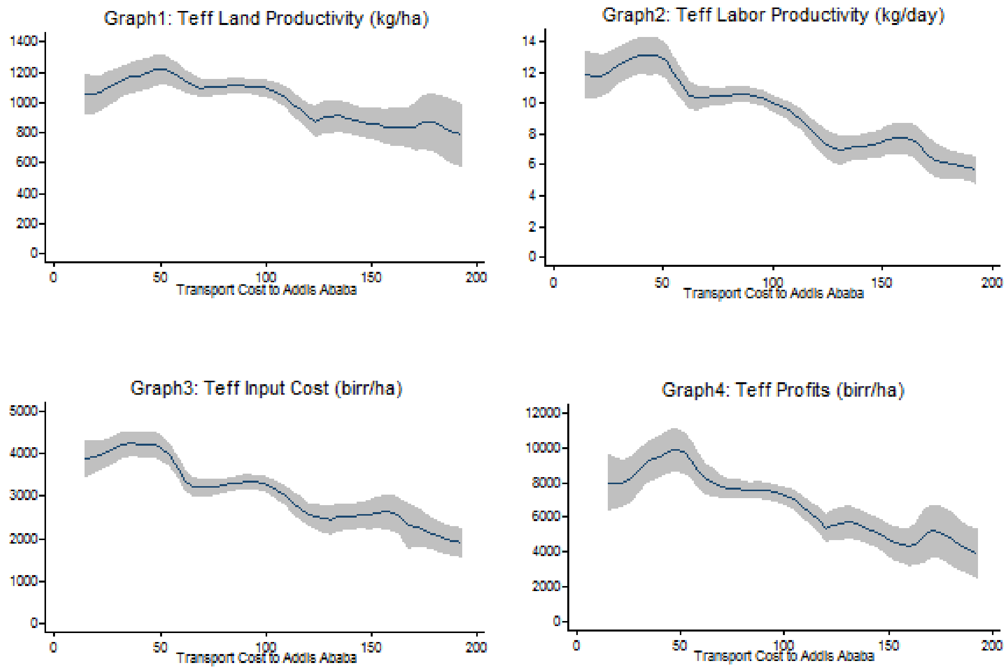


Source: Authors' estimates.

Note: Solid lines represent local polynomial smoothing estimates of transportation cost (x-axis) on different indices and rations of agricultural inputs (y-axis). The shaded area corresponds with the 95% confidence intervals. Graph 1 shows the results for the ratio of agrichemicals over labor usage; Graph 2 shows the results for the ratio of the plow equipment index over labor, Graph 3 shows the results for the ratio of fertilizer usage over land; Graph 4 shows the results for the ratio of improved seed usage over land.

Finally, Figure 4.4 shows how intensification varies with transportation cost. Graph 1 shows that land productivity drops from 1,100 kg per hectare to 800 kg per hectare over the sample. Similarly, teff labor productivity (kg per day) drops with greater transportation cost in Graph 2. Close to Addis Ababa, farmers are able to achieve more than 12 kg of teff per person-day of labor supplied in teff production, which decreases to 6 kg for farmers at the far right of the distribution. Graph 3 reports the cost of agricultural inputs in teff production, showing a clear reduction in expenditures in teff production when households are located further away from Addis Ababa. Graph 4 further shows that the profits (in ETB per hectare) from teff production also decrease with remoteness from Addis Ababa. Profits from teff production close to Addis Ababa are above 8,000 ETB per hectare, and this drops to half that level (almost 4,000 ETB per hectare) at the far end of the transport gradient.

Figure 4.4: Correlation of transportation cost with intensification outcomes



Source: Authors' estimates.

Note: Solid lines represent local polynomial smoothing estimates of transportation cost (x-axis) on teff intensification outcomes (y-axis). The shaded area corresponds with the 95% confidence intervals. Graph 1 shows the results for the teff land productivity; Graph 2 shows the results for the teff labor productivity, Graph 3 shows the results for the teff input costs; (Graph 4 shows the results for the teff profits.

These non-parametric graphs on the three outcome vectors overall show a striking relationship with urban proximity. In the next section, we will explore these relationships in depth, relying on a multi-variate regression approach.

4.2. Multivariate regression analysis

We estimate equations (1) to (3) following the two empirical strategies described in the methodology section.[13] The upper panel of each regression output table in the remainder of the paper reports the reduced form estimation in which urban proximity is the only independent variable. However, this reduced form (just as for the graphs in the previous section) does not take into account other factors that might explain intensification outcomes. To control for these confounding effects, the lower panel in each table reports the results of a less parsimonious model in which other drivers of agricultural intensification, as well as control variables, are included. To help read the results, we only report the regression coefficients of urban proximity, average farm sizes, and distance to an asphalt road (as a measure of market access).[14] For the effect of urban proximity, we distinguish between the direct, indirect (through input and output prices), and total effect, as calculated from equation (4).

The upper panel of Table 4.1 reports the regression results for teff output price (column 2), wage rate (column 3), land rental rate (column 4), and DAP and urea prices (columns 5 and 6). All prices have been transformed into natural logarithms, and coefficients are multiplied by a thousand to ease interpretation. For each price variable, we see that the results of the non-parametric regressions are confirmed in the reduced forms (presented in panel one). We find evidence of a significant negative relationship between teff prices, wages, and land rental prices with increasing transportation costs to Addis Ababa. In contrast, urban remoteness has no significant effect on prices of DAP and urea. The conclusions of the reduced form regression remain valid if we include other determinants and control variables in the less parsimonious model in the lower panel. The effective price that farmers receive for one quintal teff is significantly lower for more remote farmers. An increase in the transportation cost by 50 ETB per quintal, directly reduces the price of teff received for one quintal by 4 percent. Moreover, farmers close to Addis Ababa face higher labor costs and land rental costs. The results also show that farm size at the village level, as a measure of land pressure, is significantly and positively related with village level prices of rental

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[13] In the working paper version, we also look at different welfare indicators. The results show that wage income, non-farm income, total crop income and household income per capita decrease over transportation costs.

[14] The detailed results are available in Appendix 3.

rates and fertilizer, but not with teff output prices and wages. The distance to an asphalt road seems to be an important determinant for fertilizer prices, but not for the other prices described above.

Table 4.1: Estimation results of teff output prices, wages, land rents, DAP price, and urea price

Prices	log of teff prices (ETB/quintal)	log of wage (ETB/day)	log of land rent (ETB/ha)	log of DAP price (ETB/quintal)	log of urea price (ETB/quintal)
REDUCED FORM MODEL					
Transportation Cost (ETB/quintal)	-0.86***	-3.06***	-0.18***	-0.02	-0.01
	(0.22)	(0.89)	(0.03)	(0.26)	(0.30)
Constant	7,021.88***	3,839.17***	8,471.07***	7,233.32***	7,028.78***
	(18.49)	(86.08)	(2.89)	(23.77)	(26.88)
R-squared	0.066	0.106	0.050	0.000	0.000
LESS PARSIMONIOUS MODEL					
Transportation Cost (ETB/quintal)	-0.55***	-2.48**	-0.13***	0.31	0.46
	(0.20)	(1.14)	(0.04)	(0.29)	(0.35)
Farm Size at village level (ha)	2.55	52.54	1.78	39.41***	40.43***
	(7.95)	(47.64)	(1.52)	(14.36)	(14.93)
Distance to asphalt road (minutes)	-0.04	0.16	0.00	0.13***	0.10***
	(0.03)	(0.15)	(0.01)	(0.04)	(0.04)
Constant	6,875.39***	3,955.94***	8,480.41***	7,144.66***	6,936.68***
	(65.38)	(401.56)	(10.94)	(113.26)	(99.33)
R-squared	0.126	0.161	0.282	0.202	0.180

Source: Authors' estimates.

Note: Number of observations in each model is 1,200. The reduced form model (upper panel) includes transportation cost as the only determinant in the regression. The less parsimonious model (lower panel) includes additional intensification drivers and control variables in the regression. The full regression output is reported in Appendix 3. Both models are estimated using a Seemingly Unrelated Regression (SUR). Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1. The coefficients are multiplied by 1,000 to ease presentation.

The regression results of equation (2) for different inputs used are reported in Table 5.2. All variables are measured as the average plot level usage in per hectare terms. The reduced form estimation in the upper panel shows that the use of DAP (column 2), urea (column 3) and improved seed (column 4) is negatively related with transportation costs. On the other hand, the use of agro-chemicals (column 5) does not seem to be related to transportation cost, while a positive correlation between labor use (column 6) and remoteness is found. In the less parsimonious model, the direct effect of transportation costs remains significant and negatively related to the application of urea and improved seed. However, we see that the estimated direct effect on DAP usage becomes insignificant, and that labor use is now weakly and negatively related to transportation costs. Moreover, we also observe a significant negative indirect effect of transportation costs through output, wage and land rental prices on DAP and urea application. As a consequence, we find a significant negative total effect of transportation cost on the use of agricultural inputs, except for agrochemicals, which is estimated to be unrelated to urban proximity. For example, an increase of 50 ETB per quintal in transportation costs decreases (on average) the use of urea by 19 kg per hectare, and the use of improved seed by 6 kg per hectare – all things equal. Table 4.2 further shows that the average farm size in the village is not a significant driver of increased usage of modern inputs, but only (weakly) significantly related to the use of urea. Population pressure is however significantly related to plot level use of labor (found also by Headey et al. 2014). Increasing distance from an asphalt road has a further negative effect on DAP usage and the use of improved seed.

Table 4.2: Estimation results of agricultural input use – DAP, urea, improved seed, agrochemicals, and labor

Teff outcome	DAP (kg/ha)	Urea (kg/ha)	Improved Seed (kg/ha)	Agrochemicals (ETB/ha)	Labor (person-days/ha)
REDUCED FORM MODEL					
Transportation Cost (ETB/quintal)	-0.47***	-0.37***	-0.19***	-0.06	0.23**
	(0.13)	(0.08)	(0.04)	(0.14)	(0.09)
Constant	132.27***	96.32***	28.19***	58.74***	106.01***
	(13.70)	(10.33)	(4.20)	(12.80)	(9.09)
R-squared	0.045	0.036	0.106	0.001	0.011
LESS PARSIMONIOUS MODEL					
Transportation Cost (ETB/quintal)					
Direct effect	-0.21	-0.35***	-0.10***	0.04	-0.20*
	(0.13)	(0.12)	(0.04)	(0.14)	(0.12)
Indirect effect	-0.11**	-0.13**	-0.02	0.04	0.01
	(0.06)	(0.05)	(0.01)	(0.04)	(0.03)
Total effect	-0.32**	-0.47***	-0.12***	0.08	-0.18*
	(0.14)	(0.13)	(0.03)	(0.12)	(0.11)
Farm Size at village level (ha)	10.93	-2.15	3.02*	-6.14	-8.83**
	(7.28)	(4.47)	(1.68)	(4.59)	(4.08)
Distance to asphalt road (minutes)	-0.06***	0.01	-0.01**	-0.02	0.02
	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)
Constant	-653.83	-1,886.64*	-331.21	-415.01	1,195.41
	(1,166.76)	(1,088.00)	(239.87)	(926.91)	(917.03)
R-squared	0.167	0.291	0.210	0.167	0.169

Source: Authors' estimates.

Note: Number of observations in each model is 1,200. The reduced form model (upper panel) includes transportation cost as the only determinant in the regression. The less parsimonious model (lower panel) includes additional intensification drivers and control variables in the regression. The full regression output is reported in Appendix 3. Both models are estimated using a Seemingly Unrelated Regression (SUR). The less parsimonious model reports three effects of transportation cost: (i) 'direct effect' is the coefficient of transportation cost in the regression; (ii) 'indirect effect' is the non-linear combination of the product of the coefficients of teff output price, wage and land rental rate in the parsimonious model with respectively the coefficient of transportation cost on each of these outcomes in the price regressions of Table 4.1; and (iii) 'total effect' is the non-linear combination of the direct and indirect effect. Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses below the coefficient: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

We further analyze how input ratios in teff production change with increasing transportation costs in Table 4.3. The reduced form regression coefficients suggest that the ratio of the plow equipment index over land (column 3), the ratio of fertilizer over land (column 4), and ratio of improved seed over land (column 5) is significant negatively correlated with transportation costs. No significant relation is observed for the ratio of agrochemicals over labor (column 1), probably because agrochemicals usage does not change over distance (Table 4.2). Once we control for other determinants in the less parsimonious model, the ratios of fertilizer over land and improved seed over land remain negatively related to transportation cost. There is also a significant indirect price effect of distance on the ratio of fertilizer over land. Hence, Table 4.3 suggests that farmers close to an urban city substitute the use of land by improved inputs, compared to more remote farmers. Population pressure is not related to any of these indices, but the distance to an asphalt road is negatively correlated with the ratio of agrochemicals and the ratio of the plow equipment index over labor.

Table 4.3: Input ratios and monetization of input factor use

Teff outcome	Ratio Agrochemicals over Labor	Ratio Plow index over Labor	Ratio Fertilizer over Land	Ratio Improved seed over Land
REDUCED FORM MODEL				
Transportation Cost (ETB/quintal)	-1.46	-0.05**	-1.31*	-0.39***
	(1.33)	(0.03)	(0.77)	(0.10)
Constant	699.94***	34.27***	558.15***	61.26***
	(134.60)	(2.46)	(80.92)	(11.46)
R-squared	0.004	0.003	0.004	0.039
LESS PARSIMONIOUS MODEL				
Transportation Cost (ETB/quintal)				
Direct effect	0.80	0.03	-2.30**	-0.32***
	(1.29)	(0.03)	(1.02)	(0.12)
Indirect effect	0.74	0.00	-0.73*	-0.04
	(0.51)	(0.01)	(0.38)	(0.04)
Total effect	1.55	0.03	-3.00***	-0.37***
	(1.22)	(0.03)	(1.01)	(0.11)
Farm Size at village level (ha)	-19.92	2.71	2.53	3.41
	(51.64)	(1.89)	(45.17)	(5.61)
Distance to asphalt road (minutes)	-0.32**	0.01*	-0.02	-0.03
	(0.14)	(0.01)	(0.17)	(0.02)
Constant	-1,638.09	228.39	438.77	-1,156.07*
	(9,543.94)	(360.69)	(9,494.65)	(697.91)
R-squared	0.224	0.089	0.164	0.103

Source: Authors' estimates.

Note: Number of observations in each model is 1,200. The reduced form model (upper panel) includes transportation cost as the only determinant in the regression. The less parsimonious model (lower panel) includes additional intensification drivers and control variables in the regression. The full regression output is reported in Appendix 3. Both models are estimated using a Seemingly Unrelated Regression (SUR). The less parsimonious model reports three effects of transportation cost: (i) 'direct effect' is the coefficient of transportation cost in the regression; (ii) 'indirect effect' is the non-linear combination of the product of the coefficients of teff output price, wage and land rental rate in the parsimonious model with respectively the coefficient of transportation cost on each of these outcomes in the price regressions of Table 4.1; and (iii) 'total effect' is the non-linear combination of the direct and indirect effect. Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1. The coefficients in column 2 and 3 are multiplied by 1,000 to ease presentation.

Table 4.4 shows the estimation results for different intensification outcomes in teff production. Results are reported for teff yields (kg per hectare) in the second column and for labor productivity (kg per person-days) in the third column. In the reduced form setting, transportation cost is (weakly) negatively related to teff yields and (strongly) to labor productivity. Once we control for other determinants and controls in the less parsimonious model (lower panel), we see that the direct effect of urban proximity remains significant for teff yield, but this does not hold for labor productivity. The indirect price effect is significant for both outcomes, and as a consequence, the total effect of transportation cost on teff land and labor productivity is significantly negative. The last two columns of Table 5.4 report the estimation results for agricultural input expenditures (including labor) and profits (net revenues) from teff production, both measured in ETB per hectare. In both the reduced form and the less parsimonious model estimation, the direct effect of transportation cost is negative and highly significant. Moreover, the indirect effect of transportation costs that runs through prices is significant, resulting in a negative total effect. An additional transportation cost of 50 ETB per quintal leads to a drop in teff profits of 2,000 ETB on average. Surprisingly, neither the average farm size at village level, nor distance to an asphalt road, have a significant effect on expenditures or profits in teff production. Population pressure is therefore not a significant driver of increasing intensification in these settings.

Table 4.4: Estimation results of intensification outcomes

Teff outcome	Yield (kg/ha)	Labor Productivity (kg/day)	Input Costs (ETB/ha)	Teff Profits (ETB/ha)
REDUCED FORM MODEL				
Transportation Cost (ETB/quintal)	-2.30*	-0.04***	-13.51***	-33.41**
	(1.30)	(0.01)	(3.14)	(14.19)
Constant	1,270.57***	14.05***	4,450.10***	10,284.90***
	(132.71)	(1.21)	(337.21)	(1,476.53)
R-squared	0.017	0.060	0.061	0.037
LESS PARSIMONIOUS MODEL				
Transportation Cost (ETB/quintal)				
Direct effect	-2.07*	-0.01	-8.12**	-26.41**
	(1.23)	(0.01)	(3.22)	(12.95)
Indirect effect	-1.57***	-0.01***	-4.53**	-11.85**
	(0.55)	(0.00)	(1.78)	(5.20)
Total effect	-3.65***	-0.03**	-12.63***	-38.43***
	(1.36)	(0.01)	(3.59)	(13.90)
Farm Size at village level (ha)	-32.89	0.27	128.06	191.81
	(53.28)	(0.50)	(138.36)	(531.68)
Market access	0.17	-0.00	-0.72*	2.13
	(0.16)	(0.00)	(0.42)	(1.77)
Constant	-36,885.13***	-348.29***	-31,673.99	-330,800.21***
	(5,902.61)	(61.75)	(24,580.35)	(68,549.27)
R-squared	0.209	0.190	0.217	0.171

Source: Authors' estimates.

Note: Number of observations in each model is 1,200. The reduced form model (upper panel) includes transportation cost as the only determinant in the regression. The less parsimonious model (lower panel) includes additional intensification drivers and control variables in the regression. The full regression output is reported in Appendix 3. Both models are estimated using a Seemingly Unrelated Regression (SUR). The less parsimonious model reports three effects of transportation cost: (i) 'direct effect' is the coefficient of transportation cost in the regression; (ii) 'indirect effect' is the non-linear combination of the product of the coefficients of teff output price, wage and land rental rate in the parsimonious model with respectively the coefficient of transportation cost on each of these outcomes in the price regressions of Table 4.3; and (iii) 'total effect' is the non-linear combination of the direct and indirect effect. Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses below the coefficient: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Finally, Table 4.5 reports the estimation results from an additional set of regression analyses where different welfare indicators are used as outcomes variables. Columns 2 to 5 of Table 4.5 report the results of the reduced form and less parsimonious model for wage employment (ETB), non-farm income (ETB), crop income (ETB), and household income per capita (ETB/capita). All welfare variables enter the regressions after being transformed into logs. Transportation cost is negatively correlated with all welfare outcomes of the household in the reduced form specification (panel 1). The results in the less parsimonious model in lower panel of Table 4.5 show that wage earnings are not significantly related to transportation costs. The income that teff producers earn from non-farm income is directly (but not indirectly) affected by transportation costs. This confirms results found in other countries on the impact of urban proximity on these sectors (Fafchamps and Shilpi 2003; Deichmann et al. 2009). Finally, transportation costs are significantly related to both (gross) total farm income from all crops and per capita total household income. Transportation costs are negatively related to these welfare outcomes because of a significant direct and indirect effect of urban proximity. Finally, average farm size is positively related to wage and non-farm income, while distance to an asphalt road is negatively related to wage income.

Table 4.5: Estimation results of welfare outcomes

Teff outcome	Wage Income (ETB)	Non-farm Income (ETB)	Total Farm income (ETB)	Household Income per capita (ETB/capita)
REDUCED FORM MODEL				
Transportation Cost (ETB/quintal)	-5.76**	-14.27***	-8.67***	-7.57***
	(2.86)	(2.97)	(1.69)	(1.68)
Constant	1,187.76***	7,518.66***	10,521.80***	9,809.34***
	(297.63)	(297.71)	(155.30)	(154.18)
R-squared	0.008	0.022	0.109	0.099
LESS PARSIMONIOUS MODEL				
Transportation Cost (ETB/quintal)				
Direct effect	-3.48	-10.26***	-2.60*	-2.57*
	(2.56)	(3.53)	(1.44)	(1.41)
Indirect effect	-0.20	2.31	-2.03***	-1.76***
	(1.04)	(1.42)	(0.64)	(0.58)
Total effect	-3.67	-7.95**	-4.63***	-4.33***
	(2.58)	(3.36)	(1.51)	(1.48)
Farm Size at village level (ha)	187.35*	320.49**	17.30	19.41
	(104.61)	(154.10)	(50.34)	(44.93)
Market access	-0.61**	-0.68	0.03	0.04
	(0.29)	(0.79)	(0.24)	(0.21)
Constant	-16,334.38	38,470.24	-25,645.75**	-17,581.75
	(22,242.48)	(46,011.79)	(12,960.35)	(11,783.36)
R-squared	0.044	0.090	0.458	0.377

Source: Authors' estimates.

Note: Number of observations in each model is 1,200. The reduced form model (upper panel) includes transportation cost as the only determinant in the regression. The less parsimonious model (lower panel) includes additional intensification drivers and control variables in the regression. The full regression output is reported in Appendix 3. Both models are estimated using a Seemingly Unrelated Regression (SUR). The less parsimonious model reports three effects of transportation cost: (i) 'direct effect' is the coefficient of transportation cost in the regression; (ii) 'indirect effect' is the non-linear combination of the product of the coefficients of teff output price, wage and land rental rate in the parsimonious model with respectively the coefficient of transportation cost on each of these outcomes in the price regressions of Table 4.3; and (iii) 'total effect' is the non-linear combination of the direct and indirect effect. Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1. The coefficients are multiplied by 1,000 for easier presentation.

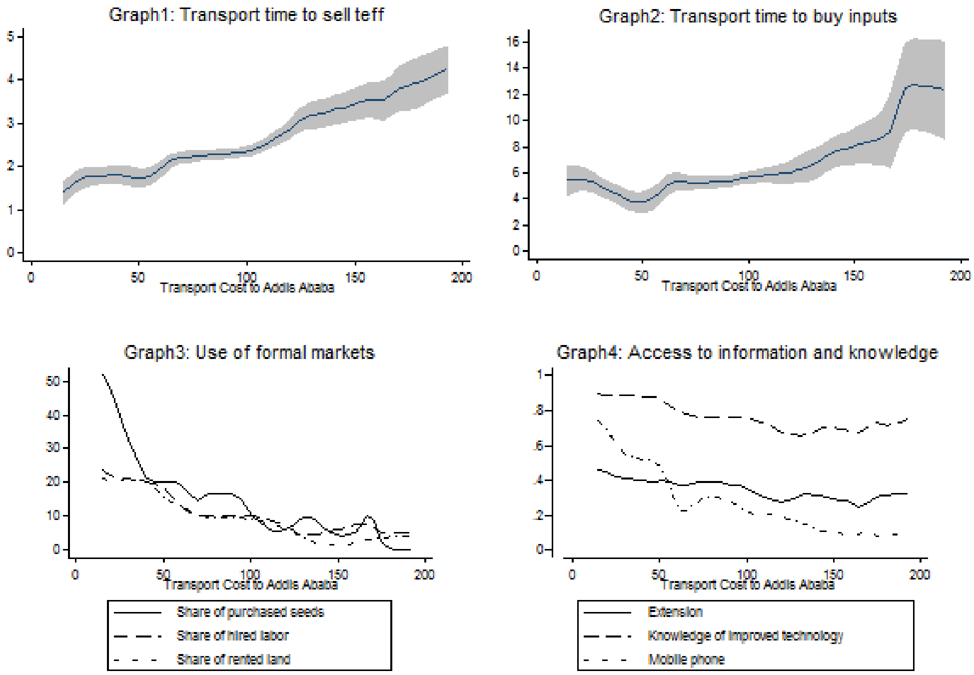
Hence, the results in this section show a strong relationship between urban proximity and different indicators of agricultural intensification and profitability (and other welfare outcomes) in teff production. We find that that farmers located closer to Addis Ababa tend to apply significant more fertilizer and improved seed in teff production. Moreover, both because of a direct effect and changing prices, farmers located closer to Addis Ababa achieve significantly higher productivity and profitability levels than those farmers who are more remote from Addis Ababa. However, we find little effect of rural population pressure on agricultural practices. Consequently, the smaller sizes of farms in more densely populated areas seem to lead to lower overall incomes.

4.3. Explaining the direct effect

The multivariate analysis shows that even when controlling for the indirect price effects and other drivers of intensification, urban remoteness has a significantly negative direct effect on most intensification outcomes. In this section, we explore three potential channels related to differential institutions, transaction costs, and information over space that might drive this effect. Less remote farmers might: (i) face lower transaction costs when they sell output at local teff markets or when they acquire inputs from distribution centers, (ii) rely more on formal input markets, which may improve allocation of resources because of better use of price signals, or (iii) have better access to agricultural information and knowledge.

Figure 4.5 shows the results of the different hypotheses using non-parametric regressions. First, we plot the correlation between urban remoteness and the transport time to sell teff (Graph 1) and to buy fertilizer (Graph 2). Graph 1 shows that the time spent by farmers to travel to the output market (and to find a buyer) increases from 1 hour to over 4 hours, indicating less dense market and trader presence in more remote areas. Similarly, Graph 2 shows that the transport time to buy fertilizer increases over urban remoteness. This cost does not only include the travel time to buy fertilizers at agricultural cooperatives, but also the time spent on trips in which farmers were unsuccessful in buying fertilizer. As shown by Minten et al. (2013), farmers in remote areas in Ethiopia often need to make additional trips to buy fertilizer because of a lack of supply by distributing cooperatives and administrative hurdles.

Figure 4.5: Correlation of transportation cost with channels behind direct effect



Source: Authors' estimates.

Note: Solid lines represent local polynomial smoothing estimates of transportation cost (x-axis) on different variables (y-axis). Graph 1 shows the results for the travel time to buy teff. Graph 2 shows the results for the travel time to by fertilizer. The shaded area in Graph 1 and 2 corresponds with the 95% confidence intervals. Graph 3 shows the results for the different shares of teff inputs. The solid line reports the share of improved seed in total seed usage; the dashed line reports the share of hired labor in total labor; and the dotted line reports the share of land rented land in total land. Graph 4 shows the results for access to information. The solid line reports the access to extension services, the dashed line reports the ownership of a mobile phone and the dotted line reports the knowledge of improved technologies.

Graph 3 illustrates the monetization of production factors, plotting the share of inputs bought in formal markets by urban remoteness. There is a substantial drop in the share of purchased seed, hired labor, and rented land with increasing transportation costs. The share of purchased seed close to Addis Ababa is almost 50 percent, which declines to almost zero for the most remotely located farmers. We also observe a drop in the use of hired labor and rented land from above 20 percent for farmers close to Addis Ababa to less than 10 percent for the more remote farmers. The drop in these shares is compensated by a higher use of exchange labor and sharecropped land respectively for the more remote farms (results not reported).

Finally, Graph 4 shows how access to information and knowledge change over urban remoteness. The share of households that received a visit from an extension agent and that own a mobile phone decreases over distance. Moreover, farmers' awareness of the existence of improved technologies, i.e., conservation agriculture and improved sowing technologies, and their benefits in teff production drops with increased urban remoteness.

4.4. Sensitivity analysis

To assess the robustness of the findings reported in the previous section, we estimate several alternative specifications of the prices, agricultural inputs, and intensification models in Table 4.6. In each of these sensitivity analyses, we either include additional control variables or use alternative measurements of urban proximity, and estimate this model using the less parsimonious SUR regression. To present the results in a simple manner, Table 4.6 only reports the direct effect of transportation costs for the price outcomes, and the total effect for the agricultural input and intensification outcome.[15] The

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[15] Full results can be obtained from the authors upon request. We also performed an additional robustness test where we estimate the input demand equations with a SUR Tobit model that takes into account the truncated nature of input usage (using Stata's cmp command). The results are in line with the original coefficients.

second column reports the original coefficients as reported in Tables 4.1 to 4.4. The other columns report the coefficients for each robustness test separately.

Table 4.6: Sensitivity tests on analytical model results

	Original Coefficients		Unobserved heterogeneity		Transportation costs with opportunity time		Transportation costs squared		Farmers selling to other markets	
Direct effect of Transportation Costs										
Teff prices (ETB/quintal)	-0.55***	(0.20)	-0.50**	(0.20)	-0.47**	(0.19)	-0.21**	(0.10)	-0.53***	(0.20)
Wage (ETB/day)	-2.48**	(1.14)	-2.25**	(1.10)	-1.64	(1.02)	-1.15**	(0.53)	-2.50**	(1.14)
Land rent (ETB/ha)	-0.13***	(0.04)	-0.11***	(0.04)	-0.11***	(0.04)	-0.07***	(0.02)	-0.12***	(0.04)
DAP price (ETB/quintal)	0.31	(0.29)	0.35	(0.29)	0.23	(0.28)	0.20*	(0.12)	0.30	(0.30)
Urea price (ETB/quintal)	0.46	(0.35)	0.52	(0.37)	0.33	(0.33)	0.29*	(0.15)	0.51	(0.35)
Total effect of Transportation Costs										
DAP (kg/ha)	-0.32**	(0.14)	-0.20	(0.13)	-0.28**	(0.13)	-0.14**	(0.07)	-0.34**	(0.14)
Urea (kg/ha)	-0.47***	(0.13)	-0.41***	(0.11)	-0.41***	(0.12)	-0.25***	(0.06)	-0.45***	(0.12)
Improved Seed (kg/ha)	-0.12***	(0.03)	-0.11***	(0.03)	-0.11***	(0.03)	-0.05***	(0.02)	-0.12***	(0.04)
Agrochemicals (ETB/ha)	0.08	(0.12)	0.09	(0.13)	0.07	(0.11)	0.02	(0.06)	0.07	(0.13)
Labor (person-days/ha)	-0.18*	(0.11)	-0.08	(0.10)	-0.18*	(0.10)	-0.09	(0.06)	-0.18*	(0.11)
Ratio agrochemicals over Labor	1.55	(1.22)	1.21	(1.27)	1.36	(1.07)	0.39	(0.51)	1.58	(1.28)
Ratio plow index over Labor	0.03	(0.03)	0.01	(0.03)	0.04	(0.03)	0.01	(0.01)	0.03	(0.03)
Ratio fertilizer over Land	-3.00***	(1.01)	-2.03**	(0.88)	-2.74***	(0.91)	-1.55***	(0.49)	-3.19***	(1.04)
Ratio improved seed over Land	-0.37***	(0.11)	-0.30***	(0.09)	-0.34***	(0.10)	-0.17***	(0.05)	-0.39***	(0.12)
Yield (kg/ha)	-3.65***	(1.36)	-0.74*	(0.41)	-3.18***	(1.20)	-1.95***	(0.60)	-3.49**	(1.36)
Labor Productivity (kg/hour)	-0.03**	(0.01)	-0.01	(0.01)	-0.02**	(0.01)	-0.01***	(0.00)	-0.02**	(0.01)
Input Costs (ETB/ha)	-12.63***	(3.59)	-9.20***	(3.06)	-10.87***	(3.28)	-6.16***	(1.63)	-12.76***	(3.66)
Teff Profits (ETB/ha)	-38.43***	(13.90)	-12.28*	(7.26)	-33.24***	(12.23)	-19.99***	(6.02)	-36.93***	(13.86)

Source: Authors' estimates.

Note: Number of observations in each model is 1,200. The 'original coefficients' in column 2 are the estimation coefficients of the direct effect (prices) and total effect (inputs and intensification outcomes) of transportation cost on each of the outcome variables as reported in the parsimonious models of Tables 4.1, 4.2 and 4.3 (standard errors not reported). The third column reports the coefficients results when farming ability (see notes Table 3.3) are included as additional variable in the parsimonious model to control for unobserved heterogeneity. In the fourth and fifth column we use as main independent variable transportation cost including opportunity cost of the farmer and the squared value of transportation cost in the parsimonious model. In the last column we control for a dummy whether Addis Ababa is the final destination of the retailer who bought the teff from the farmer. All models are estimated using a Seemingly Unrelated Regression (SUR). Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses to the right of the coefficient: *** p<0.01, ** p<0.05, * p<0.1. All of the direct coefficients of transaction costs on prices are multiplied by 1,000. The direct and total coefficients in the last column are respectively multiplied by 10,000 and 100 to ease interpretation.

First, the cross-sectional data do not allow us to control for unobserved household effects when estimating the different models. Even though we argued in Section 4 that unobserved heterogeneity is of less concern in our sample, there remain concerns that many decisions in teff production are related to inherent household ability, e.g., social networks, farming skills, etc., which might also affect settlement and location patterns. Therefore, we include the proxy of unobserved farming ability, i.e., the households fixed effects obtained from estimating the production function in equation (10) at the plot level, as an additional control variable in the empirical models. The third column of Table 4.6 reports the results. Comparing the coefficients in the second and third column confirms our previous findings on the effect of urban proximity on the different outcomes. Transportation costs have a significant negative (direct) effect on teff prices, wages, and land rent. The estimated sign of the coefficients of the total effect of urban proximity, is the same for the application of urea, improved seed, the ratio of improved seed over land, yield, input costs and profits. However, we find no significant correlation between transportation costs and use of labor use and labor productivity. Hence, based on our measure of farming ability, the majority of the results of the previous sections are robust to unobserved heterogeneity.

Second, we measured transportation cost as a combination of the cost to ship teff to the village market and to ship it further to Addis Ababa. Farmers however also face opportunity costs when transporting the teff from the farm to the market place (in or outside the village). Therefore, we calculate the cost of travelling by multiplying the travel time to get to the village market center (hours) with the local wage rate in the village (ETB/hour). This proxy of farmers' opportunity cost is added to the measurement of transportation cost used in the previous analysis. The results reported in the fourth column of

Table 4.6 show that the coefficients of transportation cost have the same sign and order of magnitude as the original coefficients reported in column 2, except for the wage rate coefficient.

Third, the non-parametric figures suggested a negative correlation between transportation cost and most of the agricultural inputs and intensification outcomes, but the effect was most pronounced at the end of the transportation cost distribution seen in Figure 4.4. Therefore, in the fourth column of Table 4.6 we use squared transportation costs instead of the transportation cost in levels. Because the unit of measurement is different between the level and quadratic term, comparison in magnitude are not sensible, but the signs of the estimated effects of transaction costs on the different outcomes is the same as before.

Finally, not all farmers sell their teff to markets in Addis Ababa directly or some farmers might sell their teff to other urban (or local) teff markets. This is especially relevant for farmers living close to secondary cities such as Bahir Dar or Adama (Nazareth). These cities have large teff markets and teff demand also affects their surrounding rural areas. Unfortunately, we only have information in our dataset on whether the teff that is sold is shipped to Addis Ababa or ‘elsewhere’, and for the latter we do not know the final destination. However, we can construct a dummy that is equal to one if the buyer of the teff was a trader selling teff to Addis Ababa. This proxy of the destination of the teff sales is included in the last robustness regression, and is reported in the fifth column of Table 4.6 to show whether selling to Addis Ababa has a stronger effect on agricultural intensification. The destination dummy does not show up as a significant determinant of agricultural input or intensification outcomes (results not reported), and furthermore, the fifth column shows that the results of transport costs to Addis Ababa are nearly identical to the original results reported in the tables of Section 4.2.

5. CONCLUSIONS

While the empirical literature has looked at the link between urban proximity and agricultural production choices, the relationship between urban proximity and agricultural intensification is less well understood. This is especially so for staple crops on which most farmers in Africa depend for a living. To fill this gap, we analyze the spatial patterns of teff production in major teff producing areas around Addis Ababa, the Ethiopian capital. Teff is an important staple crop in Ethiopia and, as population and incomes are continually growing in Addis Ababa, urban demand for teff is rapidly increasing. Because of this and with recent improvements in roads in the country, a significantly larger share of the rural population is ‘connected’ to the city. We analyze how proximity to an urban center, Addis Ababa, for teff producing farmers is linked to teff intensification outcomes. We show that farmers more closely located to Addis Ababa – as measured by transportation costs – receive higher output prices, but also face increased wage and land rental rates. Moreover, farmers in the near vicinity of Addis Ababa are more likely to increase input and factor use and rely more on formal factor markets. The total effect of urban proximity on teff intensification (including the indirect (output) price effects) includes higher yields, improved labor productivity, and greater profits in teff production.

We provide evidence of strong heterogeneity in staple food production practices, modern input application, factor market development, profitability, and output market use between those villages that supply Addis Ababa and those that are more remote from the city. We show that urban proximity should be considered as a main determinant of the process of agricultural intensification and transformation in developing countries. A large number of countries in SSA rapidly are becoming urban. Our results show that cities are an important new engine for agricultural intensification in SSA countries. Moreover, we show the importance of urban market demand as a driver for agricultural transformation in the staple food sector. These findings have important implications on programs aiming to stimulate agricultural transformation, as the location of these efforts is crucial to ensure the likelihood of success.

Our results further show the importance of increasing investments in roads and other physical infrastructure to reduce farmers’ transportation costs and provide greater access to markets. Investments in better road and port infrastructure and the takeoff of containerization have been shown to decrease transaction costs in domestic and international trade, thereby stimulating farmers’ to participate actively in markets (Poulton et al. 2006; Barrett 2008; Iimi et al. 2015). Similarly, new communication systems make information exchange, cost searching, and communication in general less costly (Pingali 2007). Reduced transportation and transaction costs lead to higher agricultural production, consumption, and income; and eventually to lower poverty rates (Jacoby 2000; Khandker et al. 2006; Stifel and Minten 2008; Gollin and Rogerson 2010; Dercon et al. 2009; Stifel et al. 2015). Our results show that once farmers are better connected with urban cities, they will likely become incentivized to intensify their agricultural production.

Finally, despite substantial investments in urban services and infrastructure, land tenure policy has been a restrictive factor in rural-urban migration in the Ethiopian hinterland (Headey et al. 2014). Land is owned by the government. Rural farmers can only obtain land on the condition that they live within the village. Moreover, transfer of land rights through sales and exchange are not allowed, which limits transferability of land between migrants and non-migrants (Zewdu and Malek 2013; World Bank 2015).[16] Land tenure insecurity and fear of losing any allocated land further discourages rural outmigration, which has undermined farmers' incentives to make land investments that are crucial to increase productivity levels. This has also slowed down the reallocation of labor to non-farm and other remunerative activities in the urban sector (Deininger et al. 2011; Chamberlain and Schmidt 2012; De Brauw and Mueller 2012). Moreover, this land tenure system has slowed down the rate of urbanization and thus the growth of cities in Ethiopia. Our results show that such policies might unintentionally restrain farmers from reaping the benefits of increased urban demand for food and the positive urban consumption – rural production linkage.

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[16] It has even been argued that the government's refusal to privatize land has been motivated by the social and economic problems which arise when rural residents decide to sell the land and migrate to urban areas (Solomon and Mansberger 2003).

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APPENDICES

Appendix 1: Conceptual framework

THE GENERAL MODEL

Consider an agricultural commodity which is produced by a representative farmer in a rural area and sold in “the city” where the consumers live. Define *d* as the distance from the farm to sell the agricultural commodity to the city.[17] The farmer uses input L to produce agricultural output Y. The production function is

$$Y = A(d) * f(L) \tag{A1}$$

where $f(L)$ has standard concave properties of $f_L > 0$ and $f_{LL} < 0$. A(d) is a factor neutral productivity shifter – which is assumed to capture the direct productivity effect of being close to the city – with $\frac{\partial A(d)}{\partial d} < 0$. The productivity effect comes from better access to infrastructure and services, extension and information, improved technologies and better networks for farmers closer to cities (Stifel and Minten 2008; Josephson et al. 2014).

The effective prices the farmer receives for his output is a function of the price in the city and the distance to the city (De Janvry et al. 1991; Minten and Kyle 1999). The price of the agricultural commodity in the urban market is p^u. Define $\mu(d)$ as the per unit cost of transportation to the city with $\frac{\partial \mu(d)}{\partial d} > 0$. The effective output price for the farmer p is then

$$p(d) = p^u - \mu(d). \tag{A2}$$

Hence, a farmer that is closer to the city receives higher output prices with lower transportation costs.

Closeness to the city may also affect the farmer’s input costs, but this effect is likely to depend on the nature of the production factor. For example, if the farmer buys his fertilizer and seed in the city and has to transport this to the farm, his input costs will increase with distance to the city. However, if the city competes with the farm as a potential alternative use for the input, the cost effect will be opposite. This is particularly relevant for labor input. If the alternative employment for labor is employment in the city, the price of labor will be lower the further away from the city. As a general specification, we can write that $\mathrm{r}_L(d) = \mathrm{r}_L(\mathrm{r}_L{}^u, d)$, but the impact of d on r_L $(\frac{\partial \mathrm{r}_L}{\partial d})$ is uncertain ex-ante. In the next section we will discuss the likely impact for different types of inputs.

The farmer maximizes the following profit function

$$\max_L \Pi = max(\, p * Y - r_L * L) \tag{A3}$$

which yields the input demand function:

$$\Pi_L\colon p(d) * [A(d) * f_L(L^*)] - \mathrm{r}_L(d) = 0 \tag{A4}$$

These first order conditions (FOC) define the optimal demand for input L^* as a function of distance to the city (*d*). Using the implicit function theorem one can derive that (see mathematical derivations for details):

$$\frac{\partial L^*}{\partial d} = -\frac{\partial \mathrm{r}_L}{\partial d} + A * f_L * \theta^L * \frac{\partial p}{\partial d} + p * f_L * \theta^L * \frac{\partial A}{\partial d} \tag{A5}$$

where $\theta^L = 1/\,[\,1 - p * A * f_{LL}\,]$. Equation (A5) shows that there are three effects of distance from the city on the input used on a farm. The first term captures the input price effect, the second term the output price effect, and the third term captures the impact of declining productivity with distance. With θ^L positive, the output price effect (second term) and the productivity effect (third term) are definitely negative: a fall in the output price and in productivity both reduce the demand for inputs. The

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[17] The farmer’s decision to sell output at a market may also depend on market distance (Key et al. 2000, Poulton et al. 2006, Barrett 2008). We do not explicitly model the market participation decision, and instead assume that the farmer sells output at the market.

own price effect of the input (first term) depends on the nature of the input and how its cost relates to distance. In the last section of this appendix we derive the effect of urban proximity on input use in a two-input model, and show that there may be additional substitution or complementarity effects among different inputs.

INPUT USE AND HYPOTHESES

In our empirical analysis we will consider four types of inputs: labor, land, fertilizer, and improved seed. The impact of distance on the cost of these inputs is likely to differ significantly.

Teff farmers compete on the *labor* market for hiring unskilled labor with employment opportunities in the city (Addis Ababa). This means that rural wage rates likely decline with distance to the city. Formally, the city wage rate is w^u and the rural wage rate $w(d) = w^u - x(d)$, with $x(d)$ the travel costs to the city for rural workers. This implies that $\frac{\partial \mathrm{r}_L}{\partial d} < 0$ for rural labor, and that there is a trade-off in the overall impact of distance on farm labor use in equation (A5). With growing distance from the urban center, demand for farm labor is reduced because of lower output prices and productivity (the second and third term), but at the same time demand for labor increases with lower rural wages (first term is positive).

The prices of *fertilizer and improved seed* are unlikely to change over distance in Ethiopia, as they are sold by state-controlled cooperatives at fixed prices in each village (Rashid et al. 2013). This implies that $\frac{\partial \mathrm{r}_L}{\partial d} = 0$ for fertilizer and seed, and that the overall effect of distance on the use of fertilizer and improved seed is negative, as only the (negative) second and third effects remain in equation (A5). However, while the official prices may be the same in all cooperatives, Minten et al. (2013) find that the transaction costs of obtaining the fertilizers are much higher in remote areas. One factor is the uncertainty of suppliers, so farmers have to go multiple times to the cooperative to acquire their inputs. Minten et al. (2013) show a significant increase of distance to Addis Ababa in the time it takes to acquire inputs. If we interpret r_L as the opportunity cost of acquiring fertilizer and seed, i.e., price plus time, then $\frac{\partial \mathrm{r}_L}{\partial d} > 0$. This effect would then reinforce the other two negative impacts on input use with distance.

The *land market* is again quite different. It is a local market where prices for farm land are not determined in the city. In fact, prices for land will be endogenous, as they are determined by the farmer’s output price (which declines with distance from the city), the productivity of the land (which also declines with distance from the city), and the demand for alternative uses of the land. The alternative uses of the land may also be influenced by distance to the city. If these uses are also less attractive or if there is no impact, land rents will decline with distance to the city. Hence, as in the labor market, there will be a compensating effect through which the impacts of lower output prices and lower productivity are offset by falling land rents. However, since the decline in land rent is driven by the decline in prices and productivity, the total effect on land use for teff will be negative, except when the land supply relative to the production of teff is fixed, i.e., an inelastic supply function.

Given these different effects on input prices, one may have cross-input effects, depending on the cross-elasticities. In the next section, we have derived the demand functions with two inputs to show how the demand for one input is affected by changes in the demand for the other input with distance. However, the sign and the size of these effects is essentially an empirical issue; and in the empirical part of the paper, we look at input use ratios and how they change with distance to the city.

MATHEMATICAL DERIVATION

One-input case

The farmer maximizes the profit function (A6) which yields the input demand function (A7):

$$\max_L \Pi = max(p * Y - r_L * L) \tag{A6}$$

$$\Pi_L \colon p(d) * [A(d) * f_L(L^*)] - \mathrm{r}_L(d) = 0 \tag{A7}$$

This first order conditions (FOC) defines the optimal demand for input L^* as a function of the distance to the city (*d*). Using the implicit function theorem one can derive that:

$$\frac{\partial L^*}{\partial d} = A * f_L * \frac{\partial p}{\partial d} + p * f_L * \frac{\partial A}{\partial d} + p * A * f_{LL} * \frac{\partial L^*}{\partial d} - \frac{\partial \mathrm{r}_L}{\partial d} \tag{A8}$$

Rearranging equation (A8) and defining $\theta^L = 1/\,[\,1 - p * A * f_{LL}\,]$, we get

$$\frac{\partial L^*}{\partial d} = A * f_L * \theta^L * \frac{\partial p}{\partial d} + p * f_L * \theta^L * \frac{\partial A}{\partial d} - \frac{\partial \mathrm{r}_L}{\partial d} \tag{A9}$$

Two-input case

Farmers face the following profit maximization problem

$$\max_{L,T} \Pi = max(\, p * Y - \mathrm{r}_L * L - \mathrm{r}_Z * Z) \tag{A10}$$

Solving the maximization problem results in the associated system of demand equation:

$$\Pi_L\colon p(d) * [A(d) * f_L(L^*, Z^*)] - \mathrm{r}_L(d) = 0 \tag{A11}$$

$$\Pi_Z\colon p(d) * [A(d) * f_Z(L^*, Z^*)] - \mathrm{r}_Z(d) = 0 \tag{A12}$$

These two first order conditions (A11) and (A12) determine the optimal solution (L^*, Z^*) and can be used to analyze how input usage change with the distance from the urban center (*d*). To calculate the comparative statics with respect to distance ***d***, we substitute the optimal solution (L^*, Z^*) in the FOC and calculate the derivative with respect to ***d*** (implicit function theorem):

$$\frac{\partial \Pi_L}{\partial d} = \frac{\partial p}{\partial d} * A * f_L + p * \frac{\partial A}{\partial d} * f_L + p * A * \left[f_{LL} * \frac{\partial L^*}{\partial d} + f_{LZ} * \frac{\partial Z^*}{\partial d} \right] - \frac{\partial \mathrm{r}_L}{\partial d} = 0 \tag{A13}$$

$$\frac{\partial \Pi_Z}{\partial d} = \frac{\partial p}{\partial d} * A * f_Z + p * \frac{\partial A}{\partial d} * f_Z + p * A * \left[f_{ZL} * \frac{\partial L^*}{\partial d} + f_{ZZ} * \frac{\partial Z^*}{\partial d} \right] - \frac{\partial \mathrm{r}_Z}{\partial d} = 0 \tag{A14}$$

We can write these two equations (A13) and (A14) with two unknown parameters $\frac{\partial L^*}{\partial d}$ and $\frac{\partial Z^*}{\partial d}$ in matrix notation, and solve this system using Cramer's rule:

$$\begin{bmatrix} p * A * f_{LL} & p * A * f_{LZ} \\ p * A * f_{ZL} & p * A * f_{ZZ} \end{bmatrix} * \begin{bmatrix} \frac{\partial L^*}{\partial d} \\ \frac{\partial Z^*}{\partial d} \end{bmatrix} = \begin{bmatrix} \frac{\partial \mathrm{r}_L}{\partial d} - \frac{\partial p}{\partial d} * A * f_L - p * \frac{\partial A}{\partial d} * f_L \\ \frac{\partial \mathrm{r}_Z}{\partial d} - \frac{\partial p}{\partial d} * A * f_Z - p * \frac{\partial A}{\partial d} * f_Z \end{bmatrix}$$

$$\frac{\partial L^*}{\partial d} = \begin{vmatrix} \frac{\partial \mathrm{r}_L}{\partial d} - \frac{\partial p}{\partial d} * A * f_L - p * \frac{\partial A}{\partial d} * f_L & p * A * f_{LZ} \\ \frac{\partial \mathrm{r}_Z}{\partial d} - \frac{\partial p}{\partial d} * A * f_Z - p * \frac{\partial A}{\partial d} * f_Z & p * A * f_{ZZ} \end{vmatrix} \Big/ D$$

$$\frac{\partial Z^*}{\partial d} = \begin{vmatrix} p * A * f_{LL} & \frac{\partial \mathrm{r}_L}{\partial d} - \frac{\partial p}{\partial d} * A * f_L - p * \frac{\partial A}{\partial d} * f_L \\ p * A * f_{ZL} & \frac{\partial \mathrm{r}_Z}{\partial d} - \frac{\partial p}{\partial d} * A * f_Z - p * \frac{\partial A}{\partial d} * f_Z \end{vmatrix} \Big/ D$$

The sign of the derivatives $(\frac{\partial L^*}{\partial d})$ and $(\frac{\partial Z^*}{\partial d})$ depends only on the sign of the determinant in the denominator. This is because under the profit maximization assumption, the Hessian matrix of second order conditions (D) is negative semidefinite and, hence, its determinant is positive:

$$\frac{\partial L^*}{\partial d} = p * A * \left\{ f_{ZZ} * \frac{\partial \mathrm{r}_L}{\partial d} - \frac{\partial p}{\partial d} * A * [f_L * f_{ZZ} - f_Z * f_{LZ}] - \frac{\partial A}{\partial d} * p * [f_L * f_{ZZ} - f_Z * f_{LZ}] - f_{LZ} * \frac{\partial \mathrm{r}_Z}{\partial d} \right\}$$

$$\frac{\partial Z^*}{\partial d} = p * A * \left\{ f_{LL} * \frac{\partial \mathrm{r}_Z}{\partial d} - \frac{\partial p}{\partial d} * A * [f_Z * f_{LL} - f_L * f_{ZL}] - \frac{\partial A}{\partial d} * p * [f_Z * f_{LL} - f_L * f_{ZL}] - f_{ZL} * \frac{\partial \mathrm{r}_L}{\partial d} \right\}$$

If we define $\theta^L = f_L * f_{ZZ} - f_Z * f_{LZ}$ and $\theta^Z = f_Z * f_{LL} - f_L * f_{ZL}$. Profit maximizing behavior implies positive first-order derivatives and negative second-order derivatives of the production function $f(L, Z)$: f_L, f_Z > 0, f_{LL}, f_{ZZ} < 0. Hence

$$\frac{\partial L^*}{\partial d} = p * A * \left\{ f_{ZZ} * \frac{\partial \mathrm{r}_L}{\partial d} - f_{LZ} * \frac{\partial \mathrm{r}_Z}{\partial d} - \frac{\partial p}{\partial d} * A * \theta^L - \frac{\partial A}{\partial d} * p * \theta^L \right\} \quad \text{(A15)}$$

$$\frac{\partial Z^*}{\partial d} = p * A * \left\{ f_{LL} * \frac{\partial \mathrm{r}_Z}{\partial d} - f_{ZL} * \frac{\partial \mathrm{r}_L}{\partial d} - \frac{\partial p}{\partial d} * A * \theta^Z - \frac{\partial A}{\partial d} * p * \theta^Z \right\} \quad \text{(A16)}$$

Equations (A15) and (A16) allow us to identify four effects of the distance from an urban center on the optimal input demand in the two-input model. The first term captures the own-price effect of the first input, and, because f_{ZZ}<0, this effect depends on the sign of $\frac{\partial \mathrm{r}_L}{\partial d}$. The second term captures the cross-input price effect of the second input, and the sign depends on $\frac{\partial \mathrm{r}_Z}{\partial d}$. The third term is the output price effect, and the final term is the productivity effect of distance. Given that output prices and the productivity shifter are negatively related with distance, the sign of both terms depends on the sign of the cross-marginal productivities f_{LZ} and f_{ZL} in θ^L and θ^Z. Hence, to determine the overall sign of the comparative statistics $(\frac{\partial L^*}{\partial d})$ and $\left(\frac{\partial Z^*}{\partial d}\right)$, we need to know how input prices change over distance, and how the demand for input *L* affects the demand for input *Z* (and vice versa). We will elaborate on the sign of $\frac{\partial L^*}{\partial d}$ in equation (A15), but the reasoning for $\frac{\partial Z^*}{\partial d}$ in equation (A16) is similar.

We first illustrate the case of technical complements, which implies that the marginal productivity of *L* is positive in *Z* (f_{LZ} > 0). Take the example of labor (*L*) and land (*Z*). Because wages decrease over distance, the first term in equation (A15) is always positive. As labor becomes less costly for farmers more remotely located from the urban market, they will use more labor. Given that land rental rates are assumed to decline over distance (see Section 3), more land will be used and – because f_{LZ}>0 – more labor will be used. In the case of technical complements, θ^L is always negative, resulting in a negative output price effect and productivity effect. Given that output prices and the productivity shifter are negatively related to distance, more remotely located farmers will use less labor. However, as a consequence of the opposing (positive) cross-price effects, the overall effect of urban proximity on optimal input demand of technical complements remains unclear.

We now assume technical substitutes, e.g. fertilizer (*L*) and land (*Z*). As a consequence, the marginal productivity of *L* decreases with increased use of *Z* (f_{LZ} < 0). For simplicity, we assume fertilizer prices to be fixed, and hence the own-price effect becomes zero. Because the price of land decreases over distance, land will be used more and remote farmers will use less fertilizer. Hence, the cross-price effect becomes negative. The direction of the output price and productivity effect depends on the sign of θ^L. However, the latter cannot be determined, because the sign of the first part $f_L * f_{ZZ}$ is always negative, and the sign of the second part $-f_Z * f_{LZ}$ is positive. However, we follow the assumption of Debertin (2012) that in most cases of agricultural inputs, the absolute value of f_{LZ} is small (near zero). As a consequence, the absolute value of the first term will be larger than that of the second term, and θ^L becomes negative. Similar to the case of technical complements, the negative output price and productivity effect of distance causes remotely located farmers to use less fertilizer. Moreover, as the cross-price effect is positive, the overall effect of urban proximity on optimal input demand for these technical substitutes is negative.

Appendix 2: Estimation of teff production function and price formation for teff and land

Appendix Table 1: Panel estimation of teff production function and teff and land price formation

Determinants	Teff output (kg/ha)		Teff price (ETB/quintal)		Land rent (ETB/ha)	
Use of DAP (ln of kg/ha)	0.03**	(0.01)				
Use of urea (ln of kg/ha)	0.02	(0.02)				
Use of herbicides (ln of ETB/ha)	0.03*	(0.02)				
Use of labor (ln of days)	0.01	(0.03)				
Improved teff seed (yes=1)	0.05	(0.04)				
Teff variety is Manga (yes=1)	0.05	(0.04)				
Teff variety is white (yes=1)	0.01	(0.03)				
Teff variety is mixed (yes=1)	-0.02	(0.05)				
Plowing of the plot (number)	0.02	(0.03)				
Manure applied on plot (yes=1)	-0.05	(0.07)				
Organic fertilizer applied on plot (yes=1)	0.07	(0.09)				
Less rain on plot than normal (yes=1)	-0.05	(0.11)				
More rain on plot than normal (yes=1)	0.05	(0.12)				
Rains earlier on plot than normal (yes=1)	-0.25	(0.20)				
Rains later on plot than normal (yes=1)	-0.43**	(0.16)				
Plot suffered from lodging (yes=1)	-0.04	(0.04)				
Soil is fertile (yes=1)	0.10***	(0.02)				
Soil has brown color (yes=1)	0.00	(0.04)				
Soil has black color (yes=1)	0.01	(0.03)				
Soil has mixed color (yes=1)	0.07*	(0.04)				
Slope of plot is flat (yes=1)	-0.03	(0.10)				
Slope of plot is gentle (yes=1)	-0.08	(0.09)				
Soil is easy to plow (yes=1)	0.03	(0.04)				
Teff quantity sold (ln of quintal)			17.6	(11.5)		
Teff variety is manga (yes=1)			289***	(27.0)		
Teff variety is white (yes=1)			215***	(20.0)		
Teff variety is mixed (yes=1)			130***	(33.2)		
Teff sold at farm or village (yes=1)			49.1	(49.6)		
Teff sold to wholesale buyer (yes=1)			15.8	(29.8)		
Teff was weighted before sale (yes=1)			40.8	(47.9)		
Contract before sale (yes=1)			-10.1	(45.0)		
Soil is of high quality (yes=1)					306**	(134)
Soil is of medium quality (yes=1)					174	(139)
Plot size (ha)					-37.6	(131)
Walking distance to parcel (min)					-2.53	(2.02)
Parcel has own water source (yes=1)					723*	(406)
Years since acquiring the parcel (number)					-6.01	(10.7)
Constant	6.55***	(0.19)	1.02***	(59.2)	3,981***	(414)
F-test of insignificant effect of regressors	5.80	p>0.00***	37.45	p>0.00***	1.95	p>0.07*
Observations	2,786		2,046		1,655	

Source: Authors' estimates.

Note: Regression coefficients are reported for the fixed effect estimation of teff production function at the plot level (columns 2 and 3); teff output price formation at the teff transaction level (columns 4 and 5); and land rental formation at the parcel level. For each model, standard errors (clustered at the household or parcel level) are reported next to the coefficients in parentheses. The price model includes monthly dummies (results not reported).

Appendix 3: Full estimation results

Appendix Table 2: Full regression outcome of price model (Table 4.1)

	log of teff prices (Birr/quintal)	log of wage (Birr/day)	log of land rent (Birr/ha)	log of DAP price (Birr/quintal)	log of urea price (Birr/quintal)
Transportation Cost (birr/quintal)	-0.55***	-2.48**	-0.13***	0.30	0.45
	(0.20)	(1.14)	(0.04)	(0.29)	(0.35)
Size of the farm (ha)	2.54	52.67	1.80	39.39***	40.35***
	(7.96)	(47.61)	(1.52)	(14.36)	(14.93)
Distance to asphalt road (min)	-0.04	0.16	0.00	0.13***	0.10***
	(0.03)	(0.15)	(0.01)	(0.04)	(0.04)
Household is member of agricultural cooperative (yes=1)	10.57	13.85	0.96	3.69	0.46
	(8.09)	(24.54)	(1.51)	(8.21)	(9.42)
Age of head (years)	-0.14	0.06	-0.81***	-0.40*	-0.30
	(0.22)	(0.76)	(0.06)	(0.22)	(0.24)
Gender of head (male=1)	2.81	22.94	3.25	8.76	2.31
	(14.91)	(42.28)	(4.17)	(14.30)	(15.06)
Educated head (years=1)	3.29	14.09	1.74	-8.27	-5.90
	(7.00)	(20.49)	(1.69)	(5.41)	(5.07)
Head is from Oromia (yes=1)	17.60	3.40	3.10	6.11	8.72
	(13.51)	(78.86)	(2.60)	(23.43)	(23.69)
Farm assets (ln of birr)	5.93***	7.53*	0.52**	3.42**	3.57*
	(1.51)	(4.16)	(0.25)	(1.35)	(1.88)
Size of the household (number)	-1.92	-9.41**	-1.20***	0.20	1.35
	(1.46)	(4.57)	(0.29)	(1.31)	(1.42)
Altitude (m)	0.04	-0.13	0.00	-0.02	-0.04
	(0.03)	(0.17)	(0.00)	(0.04)	(0.04)
Share of black and brown soils (%)	25.89***	-22.95	4.10**	-6.81	9.75
	(9.20)	(38.19)	(2.06)	(10.29)	(8.40)
Share of flat soils (%)	-3.58	-44.29	9.16***	-8.90	6.29
	(11.64)	(55.19)	(2.41)	(11.39)	(11.30)
Constant	6,875.01***	3,949.12***	8,479.26***	7,147.66***	6,944.74***
	(66.16)	(400.82)	(10.85)	(114.66)	(99.80)
R-squared	0.126	0.161	0.283	0.202	0.180

Source: Authors' estimates.

Note: Full estimation results of the less parsimonious SUR estimation of the price model in Table 4.1. Standard errors are calculated using bootstrap estimation and are clustered at the village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1. The coefficients of the price model are multiplied by 1,000 to ease presentation

Appendix Table 3: Full regression outcome of the input model (Table 4.2)

	DAP (kg/ha)	Urea (kg/ha)	Improved seed (kg/ha)	Agrochem-icals (birr/ha)	Labor (person-days/ha)
Transportation Cost (birr/quintal)	-0.21	-0.35***	-0.10***	0.04	-0.20*
	(0.13)	(0.12)	(0.04)	(0.14)	(0.12)
Size of the farm (ha)	10.95	-2.16	3.02*	-6.15	-8.83**
	(7.28)	(4.47)	(1.68)	(4.59)	(4.09)
Distance to asphalt road (min)	-0.06***	0.01	-0.01**	-0.02	0.02
	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)
Household is member of agricultural cooperative (yes=1)	5.33	5.05	1.90	4.09	-7.11
	(5.27)	(4.23)	(1.39)	(4.22)	(4.77)
Age of head (years)	0.02	0.06	0.05	0.07	-0.12
	(0.14)	(0.16)	(0.06)	(0.15)	(0.15)
Gender of head (male=1)	-2.26	-1.59	0.36	-1.44	17.50
	(10.00)	(8.97)	(3.05)	(8.47)	(10.67)
Educated head (years=1)	2.27	-4.09	1.44	5.11	1.50
	(4.95)	(3.52)	(1.13)	(4.09)	(4.64)
Head is from Oromia (yes=1)	-26.78**	-26.15***	-3.51	49.50***	-45.28***
	(10.48)	(9.21)	(2.35)	(7.02)	(8.86)
Farm assets (ln of birr)	-0.02	0.15	-0.02	0.10	-1.82**
	(0.92)	(0.65)	(0.21)	(0.59)	(0.82)
Size of the household (number)	-2.28***	-1.49**	-0.33*	1.18*	1.50*
	(0.71)	(0.71)	(0.19)	(0.69)	(0.80)
Altitude (m)	0.03	0.07***	-0.00	0.01	0.01
	(0.02)	(0.01)	(0.00)	(0.01)	(0.01)
Share of black and brown soils (%)	3.82	23.33***	0.97	-0.79	0.87
	(5.49)	(5.89)	(1.61)	(5.25)	(5.91)
Share of flat soils (%)	4.59	19.69***	2.93*	-9.61*	-20.97***
	(7.69)	(5.76)	(1.66)	(5.21)	(7.16)
Teff Price (birr/quintal)	73.93***	67.45***	28.23***	-11.69	16.84
	(22.56)	(20.64)	(6.21)	(20.70)	(20.07)
Wage rate (birr/day)	28.35	32.53***	0.34	-14.82	-1.01
	(17.37)	(12.53)	(4.56)	(13.51)	(11.69)
Land rent (Birr/ha)	27.10	88.56	15.29	40.90	-132.65
	(101.86)	(105.45)	(24.47)	(81.70)	(96.58)
DAP price (birr/quintal)	7.90	-84.31	-20.30	69.57	13.50
	(91.29)	(70.86)	(22.23)	(62.44)	(68.65)
Urea price (birr/quintal)	-27.07	155.68**	24.72	-43.06	-18.99
	(96.03)	(76.76)	(21.08)	(65.10)	(71.34)
Constant	-650.57	-1,887.32*	-332.74	-389.68	1,211.11
	(1,167.28)	(1,089.14)	(238.94)	(925.76)	(914.46)
R-squared	0.167	0.292	0.210	0.167	0.169

Source: Authors' estimates.

Note: Full estimation results of the less parsimonious SUR estimation of input model in Table 4.2. Standard errors are calculated using bootstrap estimation and are clustered at the village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 4: Full regression outcome of the input ratios and monetization of input factor use model (Table 4.3)

	Ratio Agrochemicals over Labor	Ratio Plow index over Labor	Ratio Fertilizer over Land	Ratio Improved seed over Land
Transportation Cost (birr/quintal)	0.80	0.03	-2.30**	-0.32***
	(1.29)	(0.03)	(1.02)	(0.12)
Size of the farm (ha)	-19.85	2.69	2.67	3.38
	(51.63)	(1.89)	(45.18)	(5.61)
Distance to asphalt road (min)	-0.32**	0.01*	-0.02	-0.03
	(0.14)	(0.01)	(0.17)	(0.02)
Household is member of agricultural cooperative (yes=1)	29.74	2.30	66.31	-0.48
	(47.47)	(1.42)	(45.37)	(4.78)
Age of head (years)	0.84	0.20**	-3.54***	-0.03
	(1.72)	(0.09)	(1.18)	(0.20)
Gender of head (male=1)	7.73	0.12	-16.75	12.33*
	(63.79)	(1.91)	(91.42)	(6.75)
Educated head (years=1)	54.52	3.04	-2.57	3.52
	(37.42)	(2.01)	(29.48)	(3.10)
Head is from Oromia (yes=1)	698.55***	5.07**	-339.47***	-19.11**
	(80.42)	(2.46)	(78.40)	(7.67)
Farm assets (ln of birr)	7.41	1.25***	-20.36***	-1.16
	(7.15)	(0.24)	(6.80)	(0.80)
Size of the household (number)	-4.16	1.01***	-19.74***	-1.22**
	(9.47)	(0.30)	(6.51)	(0.62)
Altitude (m)	0.09	-0.01***	0.36***	0.00
	(0.13)	(0.00)	(0.12)	(0.01)
Share of black and brown soils (%)	-1.11	-1.61	89.88	-1.53
	(51.54)	(1.76)	(58.90)	(6.19)
Share of flat soils (%)	22.61	0.81	26.72	6.35
	(59.76)	(2.30)	(45.17)	(5.48)
Teff Price (birr/quintal)	-169.03	1.46	448.40**	70.51***
	(178.65)	(11.05)	(178.49)	(16.92)
Wage rate (birr/day)	-289.71**	-0.09	214.59**	-2.19
	(140.58)	(3.95)	(105.97)	(15.31)
Land rent (Birr/ha)	508.50	-5.65	-440.46	66.48
	(926.46)	(29.99)	(849.05)	(69.35)
DAP price (birr/quintal)	-102.57	-8.74	-313.26	-62.15
	(764.65)	(21.88)	(781.94)	(84.25)
Urea price (birr/quintal)	12.16	-16.62	285.05	88.27
	(601.52)	(21.49)	(840.12)	(88.52)
Constant	-1,498.45	234.99	458.38	-1,161.69*
	(9,540.71)	(361.84)	(9,483.25)	(696.70)
R-squared	0.224	0.088	0.164	0.103

Source: Authors' estimates.

Note: Full estimation results of the less parsimonious SUR estimation of the agricultural indices model in Table 4.3. Only the direct effect of transportation cost is reported. Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table 5: Full regression outcome of the intensification outcomes model (Table 4.4)

	Yield (kg/ha)	**Labor Productivity (kg/hour)**	**Input Costs (birr/ha)**	**Teff Profits (birr/ha)**
Transportation Cost (birr/quintal)	-2.09*	-0.01	-8.14**	-26.55**
	(1.23)	(0.01)	(3.22)	(12.98)
Size of the farm (ha)	-33.06	0.27	128.05	190.66
	(53.35)	(0.50)	(138.52)	(531.73)
Distance to asphalt road (min)	0.17	-0.00	-0.72*	2.12
	(0.16)	(0.00)	(0.42)	(1.76)
Household is member of agricultural cooperative (yes=1)	-68.09	-0.13	88.38	-806.88*
	(48.02)	(0.37)	(125.61)	(421.94)
Age of head (years)	0.69	0.00	3.73	3.58
	(1.63)	(0.02)	(3.76)	(16.95)
Gender of head (male=1)	119.94	0.25	124.83	1,093.13
	(78.88)	(0.69)	(267.92)	(689.50)
Educated head (years=1)	78.94**	0.80*	31.66	755.03**
	(33.74)	(0.42)	(109.32)	(327.59)
Head is from Oromia (yes=1)	-380.86***	0.32	-709.14***	-2,995.51***
	(74.67)	(0.66)	(222.81)	(778.81)
Farm assets (ln of birr)	9.58	0.18***	-7.97	100.38*
	(6.25)	(0.05)	(21.72)	(60.46)
Size of the household (number)	-10.24	-0.17**	-40.26**	-51.72
	(7.20)	(0.08)	(18.98)	(76.70)
Altitude (m)	0.11	-0.00	1.12***	-0.31
	(0.18)	(0.00)	(0.37)	(1.90)
Share of black and brown soils (%)	-16.23	-0.39	312.52**	-179.61
	(50.17)	(0.47)	(141.90)	(517.26)
Share of flat soils (%)	67.78	1.96***	192.65	806.39
	(47.78)	(0.54)	(173.47)	(520.53)
Teff Price (birr/quintal)	737.09***	7.36***	1,686.00***	5,552.33**
	(285.03)	(1.88)	(562.78)	(2,647.70)
Wage rate (birr/day)	306.99**	2.24*	1,418.16***	2,026.68
	(122.57)	(1.18)	(335.54)	(1,398.45)
Land rent (Birr/ha)	3,116.32***	33.06***	675.35	29,429.18***
	(644.15)	(7.04)	(2,411.58)	(7,350.77)
DAP price (birr/quintal)	-91.92	-3.19	936.32	-3,272.00
	(638.44)	(6.53)	(1,975.18)	(7,866.92)
Urea price (birr/quintal)	851.58	6.23	514.25	9,743.63
	(643.42)	(5.30)	(2,086.48)	(7,505.35)
Constant	-36,786.37***	-348.73***	-31,396.07	-330,100.66***
	(5,929.58)	(61.87)	(24,588.64)	(68,737.90)
R-squared	0.209	0.190	0.217	0.171

Source: Authors' estimates.

Note: Full estimation results of the less parsimonious SUR estimation of the intensification outcomes model in Table 4.4. Only the direct effect of transportation cost is reported. Standard errors are calculated using bootstrap estimation and are clustered at village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1.

Appendix Table 6: Full estimation of the welfare outcome model (Table 4.5)

	Wage income (ETB)	Non-farm income (ETB)	Total farm income (ETB)	Household income per capita (ETB/capita)
Transportation Cost (ETB/quintal)	-3.48	-10.26***	-2.60*	-2.57*
	(2.56)	(3.53)	(1.44)	(1.41)
Size of the farm (ha)	187.35*	320.49**	17.30	19.41
	(104.61)	(154.10)	(50.34)	(44.93)
Distance to asphalt road (min)	-0.61**	-0.68	0.03	0.04
	(0.29)	(0.79)	(0.24)	(0.21)
Household is member of agricultural cooperative (yes=1)	-234.19	208.70	186.94***	140.57***
	(160.89)	(205.24)	(57.68)	(51.03)
Age of head (years)	-13.31***	-14.86*	1.13	-4.04**
	(3.91)	(8.92)	(1.92)	(1.79)
Gender of head (male=1)	-11.93	203.83	283.44***	102.33
	(289.14)	(332.64)	(78.13)	(102.11)
Educated head (years=1)	-172.97	577.18***	126.94***	125.88***
	(130.97)	(184.56)	(39.44)	(41.33)
Head is from Oromia (yes=1)	52.50	-620.45**	-14.70	-2.22
	(153.26)	(251.77)	(78.78)	(65.71)
Farm assets (ln of ETB)	-36.60	149.79***	76.01***	62.93***
	(22.92)	(36.30)	(7.52)	(7.42)
Size of the household (number)	-38.54	82.98*	57.13***	24.81***
	(28.87)	(49.96)	(10.22)	(9.57)
Altitude (m)	-0.05	0.06	-0.48***	-0.36**
	(0.31)	(0.54)	(0.18)	(0.16)
Share of black and brown soils (%)	31.99	-77.43	-33.11	-36.54
	(138.95)	(268.81)	(63.71)	(53.23)
Share of flat soils (%)	-24.75	318.84	280.01***	193.19***
	(233.59)	(252.77)	(76.16)	(58.90)
Teff Price (ETB/quintal)	-1,164.33**	291.82	1,605.28***	1,382.04***
	(550.42)	(909.07)	(253.99)	(228.06)
Wage rate (ETB/day)	160.18	-899.18**	371.78**	350.04***
	(339.81)	(388.54)	(159.49)	(124.25)
Land rent (ETB/ha)	3,439.19	-1,873.97	1,781.24	1,034.37
	(2,444.07)	(5,474.07)	(1,297.31)	(1,249.06)
DAP price (ETB/quintal)	225.37	-1,461.11	-402.08	-214.55
	(1,018.63)	(1,746.61)	(682.38)	(636.93)
Urea price (ETB/quintal)	-681.49	-764.27	1,504.96	1,278.26
	(1,053.02)	(1,871.40)	(927.88)	(784.63)
Constant	-16,334.38	38,470.24	-25,645.75**	-17,581.75
	(22,242.48)	(46,011.79)	(12,960.35)	(11,783.36)
R-squared	0.044	0.090	0.458	0.377

Source: Authors' estimates.

Note: Full estimation results of the less parsimonious SUR estimation of welfare outcome model in Table 4.5. Standard errors are calculated using bootstrap estimation and are clustered at the village level. Standard errors are reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1

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The Ethiopia Strategy Support Program (ESSP) is financially supported by the United States Agency for International Development (USAID) and the Department for International Development (DFID) of the government of the United Kingdom and is undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM) led by the International Food Policy Research Institute (IFPRI). This publication has been prepared as an output of ESSP and has not been independently peer reviewed. Any opinions expressed here belong to the author(s) and do not necessarily reflect those of IFPRI, the Ethiopian Development Research Institute, USAID, DFID, PIM, or CGIAR.