Agricultural labor markets and fertilizer demand: Intensification is not a single factor problem for non-separable households

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July 30, 2018

Abstract

Financial constraints and low profitability of use are a focal point of research examining low fertilizer use in sub-Saharan Africa. Yet little is known about whether constraints caused by market imperfections limit households' abilities to intensify production. This paper investigates whether this is the case by testing the effect of labor endowment on farm labor and conditional fertilizer demand. My results demonstrate that labor-constrained households use less of either input and suggest that labor market imperfections affect conditional fertilizer demand. A one standard deviation increase in the share of working-age men in a household with no migrant members would increase total farm labor demand by 18.3% of a standard deviation and conditional fertilizer demand by 41.6% of a standard deviation. With an own-price elasticity of -0.09, I find that fertilizer demand among these households is fairly inelastic with respect to fertilizer prices, while a cross-price elasticity of 0.06 indicates that it weakly increases with market wages. This suggests that policies which solely lower fertilizer prices are unlikely to be as effective as those which also address barriers to participation in labor markets.

Keywords: Agricultural labor markets, agricultural household models, non-separability, labor supply, farm input demand

JEL Codes: J22, J23, J43, J46, Q02, Q12

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†I thank Andrew Dillon, Jake Ricker-Gilbert, Joey Goeb, Hamza Haider, Thom Jayne, Bob Myers, and seminar participants at Michigan State University and the Midwest International Development Conference for their helpful comments. All remaining errors and omissions are my own.

1 Introduction

With a growing population that relies on a fixed quantity of arable land, the only option for most smallholder farmers in sub-Saharan Africa is to increase output through intensification on land they already cultivate (Jayne et al. 2014). In many countries, however, use of yield-increasing inputs such as fertilizer remains low. One common explanation is that fertilizer is too expensive for farmers to obtain or use profitably. Yet binding financial constraints do not sufficiently explain the low fertilizer application rates seen throughout sub-Saharan Africa. As is known from theory and shown by Feder (1985), Singh et al. (1986), and others, if a household is prevented from participating in a single market, it can reallocate resources so it first maximizes expected farm profits, then chooses consumption levels accordingly. If all markets but those for credit are complete and accessible, then households should be able to rent out or sell land or labor for income to purchase other inputs.

Despite this reasoning, national policy aimed at raising fertilizer use often focuses on a single dimension: relaxing financial constraints through large-scale input subsidy programs. Similarly, while there is widespread recognition among researchers that missing or incomplete markets can prevent farmers from adopting a new technology,[1] the literature has neglected examination of their role in limiting input use at the intensive margin. Studies focus on the role of plot and farmer characteristics in variation in profitability of fertilizer use (Marenya & Barrett 2009, Sheahan 2011), difficulties in access and timing of availability (Jayne & Rashid 2013), and time-inconsistent preferences (Duflo et al. 2011). While this work is critical to understanding low fertilizer use in sub-Saharan Africa, it overlooks the possibility that problems in other markets may prevent farmers from scaling up production, even when fertilizer is heavily subsidized.[2]

In this paper, I begin to fill this gap in the literature on intensification by testing whether imperfections in factor markets affect agricultural labor and conditional fertilizer demand. I link recent work which tests for complete markets in Indonesia (LaFave & Thomas 2016) and sub-Saharan Africa (Dillon & Barrett 2017; Dillon et al. 2017) with empirical work on agricultural intensification. Conceptually, it is reasonable to expect that market imperfections would affect input demand at the intensive margin, not just the extensive margin. Yet studies on market imperfections do not discuss the implications for production, while those on intensification typically do not discuss the implications of market imperfections. This paper's primary contribution is to bridge this gap.

There is a large body of historical evidence which shows that imperfections in multiple

[1] See, for example, Sunding & Zilberman (2001) for a review.

[2] One notable exception is Karlan et al (2014), who find that incomplete insurance markets limit agricultural investment in northern Ghana.

markets affect an agricultural household's production decisions. Chayanov (1926) and Sen (1966) noted that the shadow price of labor may be endogenously determined among smallholders, who maximize utility rather than profits. In their canonical work, Singh et al (1986) show that, when multiple markets are missing or incomplete, the agricultural household's endowments of land and labor help determine its production decisions. When this is the case, input demand no longer depends solely on input and output prices, but also on household consumption preferences and endowments. That is, imperfections in multiple markets cause the agricultural household's problem to be non-separable. For example, a farm household's labor demand will depend on the number of family members able to work, or the area of land it cultivates will depend on the quantity it owns.

In addition to theoretical work showing how incomplete markets will change households' production decisions, there is considerable empirical evidence that, in many parts of the developing world, markets are in fact incomplete. This includes work on incomplete credit and insurance markets (e.g., Townsend 1994; Berg 2013; Karlan et al. 2014; Beaman et al. 2015), as well as evidence on thin or imperfect land and labor markets (e.g., Collier 1983; Lopez 1984; de Janvry et al. 1991; Sadoulet et al. 1998).

In line with this evidence, the implicit assumption of incomplete markets is common in the intensification literature, which typically models a household's problem as being non-separable. Yet empirical evidence on the degree to which this assumption holds is ambiguous. For example, several papers in a recent Food Policy Special Issue on intensification include household size and other characteristics in estimating fertilizer demand functions (Ricker-Gilbert et al. 2014; Josephson et al. 2014; Headey et al. 2014; Muyanga & Jayne 2014). In these studies, certain household characteristics, such as the education level of the household head, are significant. Household size and adult equivalents are not. Similarly, Ricker-Gilbert et al. (2011) and Xu et al. (2009) include household composition and characteristics in their models of demand for commercial fertilizer in Malawi and Zambia, respectively, but in neither study is household composition a significant predictor of fertilizer demand. In Alene et al.'s (2008) study of maize supply and fertilizer demand in Kenya, household size positively impacts households' participation in maize markets, while its effect on fertilizer adoption and demand is insignificant. At the same time, evidence from Ricker-Gilbert et al. (2009) in Malawi and Sheahan (2011) in Kenya shows that input subsidies may result in overapplication of inputs, which suggests that input market failures may *not* constrain production. The ambiguity in empirical work highlights the need to examine both the assumption and implications of non-separable models more closely.

This paper's first contribution is thus to test for separability in farm labor and conditional fertilizer demand by building on the approach of Benjamin (1992) and LaFave & Thomas

(2016). This approach is driven by the observation that, if markets are complete, farm input demand should only depend on prices and technical relationships. Household composition, which helps determine household labor supply and consumption preferences, should play no role in production decisions.

Using nationally representative household-level panel data from Ethiopia, I draw on LaFave & Thomas's (2016) method and test whether an exogenous shock to household composition—aging of household members—affects the household's agricultural labor demand. Restricting the sample accordingly ensures that my results are not driven by endogenous household composition changes, such as if household members migrate due to low labor demand. I also extend their approach to test for the effect of household composition on fertilizer demand among fertilizer users. I find that total farm labor and conditional fertilizer demand increase with household labor supply. All else equal, a one standard deviation increase in the share of working-age males in a household with no migrant members would increase total labor demand by 18.3% of its wave 1 standard deviation and total conditional fertilizer demand by 41.6% of its wave 1 standard deviation. Separability is rejected in total agricultural labor demand and total conditional fertilizer demand, though I fail to reject that household composition has no effect on demand per hectare for either input.

While a rejection of separability in itself says nothing about whether markets are failing, or where the problems may be, it does imply that households are not fully participating in markets. As noted by de Janvry et al. (1991), this means there are imperfections in multiple markets. High frictions and other market imperfections, in turn, can cause inefficiencies and misallocation, and, ultimately, lower productivity (Adamopoulos et al. 2017, Jones 2011a). Similarly, due to linkages and complementarities in input use and markets, the additional constraints households face as a result of incomplete markets will spill over into other production decisions (Jones 2011b, Kremer 1993). As such, policy interventions that do not account for these linkages and incompleteness be significantly less effective (Taylor & Adelman 2003).

This paper's second contribution is therefore to examine how households adjust their farm labor and conditional fertilizer demand in response to changing input prices. Doing so builds on the work of de Janvry et al. (1991), who show that imperfections in multiple markets can decrease the degree to which households respond to price changes, or even change the sign of the response. It can also help identify households primary constraints and, thus, where policy changes will have the greatest impact. As Deaton (1989) argues, this type of analysis is a necessary component of any discussion of policy implications.

This approach fills a key gap in the intensification literature, which has recently focused on how rising population density changes relative factor prices, and how these changing prices affect intensification. Fertilizer prices and wage rates enter into this question, but neither they nor local labor markets are the primary focus. For example, several of the previously mentioned papers on intensification showed that wage rates have a negative (though not necessarily statistically significant) impact on fertilizer use (e.g., Muyanga & Jayne 2014; Ricker-Gilbert et al. 2014; Josephson et al. 2014).[3]

In the second portion of this paper, I find low elasticity of agricultural labor demand with respect to market wages, at -0.08, among households with no migrant members. This suggests that households are not participating fully in agricultural labor markets and is consistent with both the separability results as well as ex ante evidence that households rely primarily on their own labor supply for on-farm work (Bachewe et al. 2016). Among the same households, I also find that conditional fertilizer demand is relatively inelastic with respect to fertilizer prices, at -0.09. This suggests that policies which solely lower fertilizer prices will, at best, only marginally increase fertilizer use among these households. Fertilizer demand among all households has a positive elasticity with respect to market wages, at 0.06, though the effect is not statistically different from zero. Together, the elasticity results, coupled with the separability results, highlight the need for policies which focus on interlinkages between input use and markets as part of a strategy to increase fertilizer use.

Identification hinges on delinking choice variables that are endogenous to fertilizer and agricultural labor demand–namely, household composition, area cultivated, and crop choice. In testing for separability, as well as estimating cross-price elasticities, I follow the approach of LaFave & Thomas (2016) and implement a number of sample restrictions to assess the validity of treating these variables as exogenous. For both fertilizer and labor demand, the overall pattern of results is robust to restricting the sample to households in which any composition changes were strictly exogenous. In fact, the separability results are stronger among these households.

The rest of the paper proceeds as follows: the next section presents a conceptual framework of an agricultural household's maximization problem. Section 3 discusses input and output markets in Ethiopia, and section 4 describes the data. Section 5 discusses the empirical and identification strategies. Section 6 presents the results for the tests of separability, section 7 discusses the price elasticity analysis and results, and the final section concludes.

[3]While these studies are important contributions to our understanding of smallholders' responses to rising population density, their focus differs from this paper's, and the implications for intensification from the price results are not discussed.

2 Conceptual framework of an agricultural household

2.1 Utility maximization with a single missing market

This section describes how Benjamins (1992) framework can be extended to test for separability in demand for other inputs. In the model pioneered by Singh et al. (1986), the agricultural household cultivates crops not just for sale, but also for consumption, so that consumption depends directly on how much is produced. When markets are complete and households can obtain or earn income from land, labor, and other inputs as desired, the household will first allocate inputs to maximize profits from production, then make its consumption decisions. Households which have an excess supply of any input are able to rent it out or sell it, while those with excess demand can purchase or rent it in at market prices.

In the case of a failure in a single market, the household can reallocate resources, and its optimization problem will remain recursive (Feder 1985). When there are imperfections in multiple markets, the household is unable to do so, and farm input demand will depend not just input and output prices and technical relationships, but also on consumption preferences and relative endowments of land and labor. That is, the household's problem is no longer separable (Benjamin 1992; Udry 1999). Testing for separability between farm production and household consumption decisions thus amounts to testing for complete markets.

To test whether separability holds in input demand, I begin with a single period agricultural household model, as given by Singh et al. (1986) and Benjamin (1992), and the assumption that all markets are complete, except for a missing credit market. Under these conditions, a household with an endowment of labor $\bar{L}$ and land $\bar{A}$ will seek to maximize its utility in a given period by solving:

$$max U(c, l; \mu, \phi) \text{ subject to} \tag{1}$$

$$\pi = p^y y - wL - rA - p^Z Z \tag{2}$$

$$y = f(L, Z, A; \theta) \tag{3}$$

$$L = L^F + L^H \tag{4}$$

$$A = \bar{A} - A^O + A^i \tag{5}$$

$$\bar{L} = l + L^O + L^F \tag{6}$$

$$p^y c + wl \leq \pi(w, r, p^Z, p^y; \theta) + w\bar{L} + rA^O \tag{7}$$

That is, a household with observed characteristics μ and unobserved characteristics ϕ maximizes its utility from consumption of the agricultural good c and leisure l through profits π obtained through production of the same agricultural good, y, with its corresponding market price p^y. It does so by allocating land A, labor L, and fertilizer Z, with a production technology that depends on these inputs and exogenous shocks θ.

Labor used in production is the amount of time spent working by household members on the farm, L^F, added to that spent by hired laborers L^H. The quantity of land used in production A is assumed to be the household's initial endowment of land $\bar{A}$, less that which is rented out A^O, added to that which is rented in A^i. The household divides its time endowment $\bar{L}$ between time spent in leisure l, on-farm work L^F, and off-farm work L^O.

Finally, the household's budget constraint, as given in equation (7), indicates that, in the absence of credit markets, households are unable to borrow to let their consumption exceed their income. Household income, the right hand side of equation (7), is a combination of farm profits and income earned from the household's labor—its time endowment less the time spent in leisure—and the renting out of land.

Under this recursive problem, the household first maximizes farm profits, then chooses its consumption of leisure and the agricultural good to maximize its utility. First order conditions from the profit maximization problem imply that farmers will use a given farm input up to the point where its marginal product is equal to its price divided by the output price. Hired and family labor are assumed to be perfectly interchangeable. The household values its own labor at the market wage, because the opportunity cost of leisure is simply the wage that could be earned working on or off the farm. That is, the household's shadow wage equals the market wage.

These first order conditions imply that demand for farm labor and fertilizer depend only on input prices, the output price, and weather conditions:

$$L^* = L^*(w, r, p^Z, p^y; \theta) \tag{8}$$

$$Z^* = Z^*(w, r, p^Z, p^y; \theta) \tag{9}$$

2.2 Utility maximization with imperfections in multiple markets

When multiple markets are incomplete, or if there are high transactions costs or other frictions associated with them, the agricultural household's production decisions will not be made independently of its consumption decisions. To demonstrate how labor market imperfections could affect demand for both farm labor and fertilizer, I build on Benjamin's (1992) approach and the model described above and examine a scenario in which differential search or monitoring costs mean that households either face lower returns to off-farm labor, or that hired labor is more costly than on-farm family labor.

Case 1: High costs to obtain off-farm employment

Following standard models of labor supply, the household's supply of labor to both off-farm and on-farm work L^s is given by $L^s = \bar{L} - l(w, M; \mu, \phi)$, where M=$\pi + w\bar{L} + rA^O$, the right hand side of (7), and is the household's full income constraint. Moreover, let the household's off-farm wage be defined as $w^O = w - g(TC)$, where *g(TC)* denotes search and other transactions costs associated with finding off-farm work, and w is the market wage and is also equivalent to the (optimal) marginal product of labor, MP_L*.

In this case, the household will only receive $w^O L^O < wL^O$ from off-farm work. As a result, its members will work on the farm up to the point where $MP_L' = w^O$, where $L' > L^*$. That is, farm labor demand will be increasing in household labor supply, which is increasing in its labor endowment. Labor supplied off the farm will also increase with the household's labor endowment and, as a result, so will its income from off-farm work. If households face limited access to credit or financial markets, this income could relax a liquidity constraint in purchasing fertilizer.

Case 2: High search or monitoring costs associated with hired labor

If instead it is costly for households either to find hired laborers, or if hired laborers will not work hard on the farm unless well-monitored, the total cost of a hired laborer can be given as $w^H = w + h(TC)$, where *h(TC)* denotes the search or monitoring costs and $w^H > w$. Farm profits are now given by:

$$\pi' = p^y y - wL^F - w^H L^H - r^A - p^z Z \tag{2'}$$

In this case, it will be less costly for the household to use its own labor over hired labor, so, as above, farm labor demand will be increasing in household labor supply. Moreover, since fertilizer and labor are complements in production,[4] and since labor costs are decreasing in family labor supply, fertilizer demand will increase with family labor supply. Since labor supply is increasing in labor endowment, so will fertilizer demand.

2.2.1 Input demand with market imperfections

Generalizing the two scenarios described above, demand for farm labor L and fertilizer Z can be given by:

$$L^{**} = L^{**}(w, r, p^Z, p^y, M'; \theta, \mu, \phi) \tag{8'}$$

[4]It takes labor to apply fertilizer, and fertilizer use generally results in more weed growth, which requires more labor to manage (Kamanga et al. 2014)

$$Z^{**} = Z^{**}(w, r, p^Z, p^y, M'; \theta, \mu, \phi) \tag{9'}$$

Where both labor and fertilizer demand now depend on household characteristics and preferences, including the labor endowment, as well as the household's income (denoted by M' to differentiate between the full income constraint under profit maximization with complete markets).

To summarize the models described above, when markets are complete, or in the case of a single missing market, farm households behave as profit-maximizers. When multiple markets are incomplete, households' production decisions change, and they may no longer use inputs at the same rate as if markets were complete. As I described in the preceding sections, this provides a framework for understanding how high transactions costs or other types of failures in labor markets could lower fertilizer use, even if fertilizer markets themselves remain unchanged.

2.3 Demand response to changes in input prices

Another implication of households not fully participating in factor markets is that they may respond to price changes in counterintuitive ways. This is described at length by de Janvry et al. (1991), who show how imperfections in food or labor markets explain low supply response to changes in cash crop prices in sub-Saharan Africa. By extension, it is possible that smallholders' demand responses to changing input prices are different from what is predicted by economic theory.

In a separable model, an increase in any input price will increase production costs, which will decrease input use. The household will also shift away from use of the more expensive input and complementary inputs towards its substitutes, meaning that the demand response of an input, with respect to price changes for its complements, is unambiguously negative. With complete markets, we would expect a strong, negative cross-price elasticity of fertilizer or labor demand with respect to the price of the other. As mentioned above, this is because fertilizer and labor are complements in production.

In a non-separable model, this might not hold. A wage change will affect the agricultural household both as a producer, but also as a group of laborers who can earn income from wages. As shown in equations 8' and 9', this will affect production decisions, including fertilizer demand.

How, exactly, a wage change affects fertilizer demand depends on a number of factors. Two of these factors are the household's binding constraints in fertilizer use and whether the household is a net buyer or seller of labor. For example, if there are limited off-farm employment options, then net sellers of labor would see a (weak) increase in off-farm income from an increase in wage. This increase in income would relax a binding liquidity constraint, and fertilizer demand could increase with off-farm wages. For net buyers of labor (who are, presumably, constrained in labor), an increase in market wages would increase production costs and the opportunity cost of working on the farm. Combined, this would result in reductions in both on-farm labor and fertilizer use.

How households ultimately respond to price changes can help guide policy. Price elasticities indicate the underlying tradeoffs in input use and can point to where farmers may be most constrained.

3 Input markets in Ethiopia

The institutional context of land and fertilizer markets in Ethiopia differs somewhat from those in neighboring countries. The government has undergone a series of drastic regime shifts in the past 50 years, ranging from a hands-off imperial regime from 1960-1974, to a period of heavy intervention by the socialist government (1975-1990), and to subsequent market liberalization. Throughout this time—since the socialist government—land has been controlled by the state, and households currently receive certificates which allow them to use, rent out, or bequeath land, but not sell it (Ambaye 2015). Land leasing is legal and the market active (Teklu & Lemi 2004; Holden & Ghebru 2006; Pender & Fafchamps 2006; Deininger et al. 2008, and others), though frictions and high transactions costs in land lease markets have been found in Tigray (Ghebru & Holden 2008) and Amhara (Deininger et al. 2008). The presence of these frictions and transactions costs suggest barriers to participation in land rental markets, which would be consistent with non-separability.

Fertilizer was introduced to Ethiopia to the four major grain-producing regions—Oromia, SNNP, Tigray, and Amhara—in the late 1960s (Rashid & Negassa 2011; IFDC 2012). Private fertilizer companies never held a large market share, and, even following the end of the socialist regime in 1990, fertilizer has remained a largely state-controlled good, with all fertilizer imports coordinated through the state-run Agricultural Input Supply Enterprise (AISE) (Rashid et al. 2013).

Farmer cooperatives are heavily involved in fertilizer acquisition. Every year, fertilizer acquisition begins at the *kebele* level, where farmers state their estimated demand for the upcoming growing season. These estimates are aggregated up administrative divisions until they reach the AISE, which decides how much fertilizer to import. This quantity is imported and then passed back down the chain (IFDC 2012). A comparison of fertilizer prices in neighboring countries shows that Ethiopia's prices are somewhat lower, suggesting a blanket government subsidy that is enjoyed by all farmers purchasing fertilizer (Rashid et al. 2013).

Cereals account for 90% of fertilizer use, with the bulk of it being applied to three crops: teff, wheat, and maize (IFDC 2012).

It is difficult to say, *ex ante*, whether the structure of fertilizer markets in Ethiopia suggest they may be incomplete. Ethiopia has not been the subject of reports, as in neighboring countries, of input subsidies which benefit a select group of farmers,[5] and fertilizer appears to be available to any farmer who wants to use it. This suggests that any barriers to fertilizer use are not caused by problems in the fertilizer market, but instead by problems in other markets (e.g., credit). On the other hand, fertilizer markets are clearly not competitive, with a single actor—the government—controlling prices and sales.

In contrast with fertilizer and land markets, agricultural labor markets in Ethiopia are relatively neglected, with only a few, mostly dated works (e.g., Holden et al. 2004; Dercon & Krishnan 1996; Block & Webb 2001). An exception is Bachewe et al. 2016, who find that rates of hired in agricultural labor vary systematically with household landholdings and demographic characteristics, particularly the age, gender, and education level of the household head.[6] Although they do not explicitly test for it, their findings are consistent with a rejection of separability. They also find that the share of hired in labor decreases with distance to the capital, Addis Ababa, which suggests spatial differences in agricultural labor markets. More recently, Dillon et al. (2017) reject separability and find that poor households in Ethiopia experience agricultural labor shortages, while wealthier households have an excess supply.

4 Data

To test whether separability holds in agricultural labor and fertilizer demand, I use data from the three waves of the World Bank's Ethiopia Socioeconomic Survey (ESS). A nationally representative panel survey, the first wave (2011/12) included only rural households, while those in small towns and urban areas were added in subsequent years (2013/14 and 2015/16). The survey covered 290 rural and 43 small town enumeration areas (EAs) in all regional states except for the capital, Addis Ababa, with an additional 100 major urban area EAs added in the second and third waves. While attrition was low—of the 3,969 households interviewed in the first wave, 95% were tracked through the second and third waves—I restrict the sample to rural households which were interviewed and cultivated land in all three waves to mitigate

[5]For example, wealthier and better-connected farmers have been found to be more likely to receive input subsidy vouchers in Malawi (Dorward & Chirwa 2011)

[6]Though rates of hiring in are low, with 76% of households in their survey of the four major grain-producing regions relying solely on family labor.

attrition bias and to focus on households for which farming is a primary livelihood. I also drop households in regions where fertilizer use and accessibility are low—Afar, Somalie, Gambela, Harari, Benishangul-Gumuz, and Dire Dawa—as this provides a different set of constraints than those faced by a farmer in an area where fertilizer is widespread, relatively easily obtainable, and has been used for decades. This leaves a total of 1,732 rural households which cultivated land and have had access to fertilizer since the 1960s.

Demographic data, including household composition, was obtained directly from the surveys and was cross-checked across years to ensure accuracy. So as to avoid skewing of results by outliers, I drop households in the top 99th percentile of landholdings, which is 7 hectares.

I model fertilizer demand as the quantity of fertilizer actually applied, as measured at the plot level, and pooled across fertilizer types (DAP, urea, and NPS). While this aggregation masks differences in fertilizer nutrient content—such as varying levels of nitrogen by fertilizer type—further disaggregation is not feasible for two reasons. First, farmers were asked not just about the quantities of DAP and urea applied separately, but also about the quantity of a mixture of the two that was applied. Since the relative ratio of the two fertilizers in the mixture was not reported, it is impossible to accurately calculate how much DAP and urea were applied individually. Second, NPS fertilizer was brought to Ethiopia between the second and third survey waves. This means that farmers in the first two waves were unable to use it, while those in the third wave likely substituted use of the other two fertilizer types with NPS. Disaggregating fertilizer demand by type would require accounting for these substitution effects.

Agricultural labor demand was also measured at the plot level, which I then aggregate up to the household level. This aggregation includes all types of laborers—household men, women, and children, as well as hired laborers—and all activities (planting, weeding, fertilizing) except for harvesting, as harvest labor is generally proportional to production and occurs when production is complete. I adjust the time spent working by children under the age of 12 by one half to account for child labor being less productive than adult labor. The time spent working by each household member is recorded in hours per day, days per week, and number of weeks, while hired labor is measured in days. As such, I calculate the total number of hours provided by household members and divide it by 6, the median hours per day worked over all three waves, so that all labor inputs are measured in days.

In addition to demographic and agricultural information, price data can be obtained from the surveys. Price data for market goods—agricultural output and inorganic fertilizer—was collected at the community level, while wage and land rental data were collected from farmers who participated in those markets. In both instances, households were not asked about a going rate for either input, but what they paid (or received). Due to data restrictions, I calculate land rental rates from households which rented in land for a season and from that calculate zone-level medians (moving to the region level when data was either missing or implausibly high or low). For fertilizer, cereal, and labor prices, I begin with an EA-level median and moved to the next highest administrative division in cases of missing or implausible data.

Finally, the LSMS team matched household GPS coordinates with geoclimatic and other geo-referenced data, which contain temperature and rainfall data.

5 Estimation and identification strategies

5.1 Demand functions

5.1.1 Labor demand

As described in section 2 above, a key restriction implied by separability and the hypothesis of complete markets is that input demand only depends on observed market prices and technical relationships. Household characteristics, preferences, and composition, which affect the household's shadow wage, should not impact input demand. To test this restriction, I follow the approach of Benjamin (1992) and LaFave & Thomas (2016) and include variables for household composition and other characteristics in estimating linear approximations of the input demand functions given in (8') and (9'). First, I estimate labor demand L of household i in community j and time t as:

$$\ln L_{ijt} = \beta_0 + \sum_{n=1}^{4} \beta_1^n M_{ijt}^n + \sum_{n=1}^{4} \beta_2^n F_{ijt}^n + \beta_3 \ln X_{ijt} + \beta_4 \ln \bar{A}_{ijt} + \eta_i + \vartheta_{jt} + \tau_t + \varepsilon_{ijt} \quad (10)$$

Household composition is the restriction of interest and is included as the share of males (M) and females (F) in specific age groups which I discuss in greater detail below. In a recursive model, where markets are complete, the household's shadow wage should equal the market wage, so household composition would have no effect on input demand, and neither β_1 nor β_2 would be statistically different from zero. Conversely, finding that either one or both are significantly different from zero suggests there is a differential between the shadow and market wages and amounts to a rejection of the null hypothesis of separability and complete markets. Moreover, as described in section 2.2, we would expect that, in certain circumstances that lead to the shadow wage differing from the market wage, input demand would be increasing in household labor endowment—as given by β_1 and β_2. That is, $\beta_1 > 0$ and, depending on whether female household members supply labor, it is possible that $\beta_2 > 0$.

Identification of β_1 and β_2, however, requires controlling for other household characteristics that are likely correlated with household composition and that can affect input demand. Larger households are generally wealthier, and wealthier households tend to be better educated, which can affect the ways in which information is obtained and processed (Schultz 1975). Both household wealth and education levels can affect demand for fertilizer, an inherently risky input, as well as other cultivation decisions, which ultimately affect input demand in general. Larger households also generally own more land, and the land they own is typically of better quality—which affects profitability of input use and, thus, total input demand. Identification of the effect of household labor endowment on input demand, as distinct from its effect through a positive correlation between household wealth and landholdings, thus requires controlling for these factors.

For this reason, I include landholdings directly, as $\bar{A}$, and household size, X. Given that landholdings comprise the bulk of smallholders' assets, I assume that including landholdings also controls for household wealth. I also follow the approach of LaFave & Thomas (2016) and estimate the input demand functions using household-level fixed effects, included in equation 10 as η. Doing so differences out the time-invariant household characteristics which may be correlated with household size and composition, like the household head's gender, education level, and religion, as well unobservable characteristics, such as farmer experience and risk aversion. This is a slight departure from other work on non-separable household models, which has typically relied on inclusion of observable characteristics for identification of the household composition term, but fail to account for unobservable characteristics.

Given that households, for the most part, cultivate the same plots year after year, aggregating at the household level absorbs time-invariant plot characteristics, such as land quality, that are likely to affect input demand and also be correlated with household size, thus providing another potential source of bias. While aggregation at the household level does not allow for identification of differences between plots, it ensures that results are not driven by substitution of inputs between plots over time—for example, if farmers practice crop rotation.

Input demand also likely depends on area-specific shocks, such as rainfall and temperature, and this is accounted for with a community-time fixed effect, ϑ, which also absorbs input prices, expected output prices,[7] and other time-varying community-level characteristics. Including a community-time fixed effect also accounts for characteristics of labor, land,

[7]This approach makes the simplifying assumption that all households form expectations about output prices in the same way.

credit, fertilizer, and crop markets that could change over time. Similarly, the year fixed effect, τ, controls for secular trends.

With household fixed effects, household composition is identified by changes in the share of members within a given gender-age group. Given the relatively short panel length—five years—age groupings that are coarse may not have sufficient variation for identification. Conversely, age groupings that are too narrow may have too few non-zero observations. My preferred configuration is based on life cycle effects and the distribution of ages of landholders. It has a total of 8 groups: males (or females) under age 12, those ages 12-19, those ages 20-64, and those ages 65 and up. That is, I group together young children who are unlikely to provide any meaningful labor, then adolescents who may be working on the family farm but are not providing the bulk of the labor, then working-age adults, then the elderly. With an average life expectancy of 64.5 in Ethiopia in 2015, it seems safe to assume that the majority of people in the final age group are unable to work at the same intensity as those in the younger groups.

As robustness checks, I modify the configuration used by LaFave & Thomas (2016) and use the following age groups: under 12, 12-19, 20-34, 35-49, 50-64, and 65 and up. This somewhat more flexible specification also separates young adults (20-34) who are more likely working on someone else's land than their own[8] from adults (35-49 and 50-64) who are likely working in their own land, and from the elderly (age 65 and up). Finally, I pool adults (ages 20 and up), again disaggregating by gender.

While the configuration used by LaFave & Thomas (2016) has the benefit of not imposing the assumption that, say, a 20 year old man has the same effect on input demand as a 50 year old man, my preferred specification, which pools males (or females) age 20-64, has two distinct advantages. First, there is an average of just one male age 20-64 in the households in the sample. This means that a given household is more likely than not to have no male members in the 20-34 category, the 35-49 category, or the 50-64 category.[9] This lack of variation is potentially problematic for identification. The second advantage of my preferred specification is that it returns a single point estimate for the share of working-age males—the household's labor supply. The single point estimate makes it easier to interpret the results in a wider context of how changes in labor supply can affect input demand.

[8]The earliest age at which anyone in the survey owned land is 20, and the median age of a landholder is 35.

[9]The average number of men in each of those categories is 0.48 (20-34), 0.32 (35-49), and 0.18 (50-64).

5.1.2 Fertilizer demand

I next extend the model from equation (10) to estimate the effect of household composition on fertilizer demand but impose additional restrictions to deal with potential selection bias. Having already restricted the sample to the four regions of Ethiopia where fertilizer has been available and widely used since its introduction in the late 1960s (Rashid & Negassa 2011; IFDC 2012), I am left with 1,732 households in the sample, of which 22% did not use fertilizer at all in any given year, while only 44% used fertilizer in all 3 waves. The most common reasons for not using fertilizer were its high price and lack of money, with only 4% of households reporting ignorance of its use by the third wave. This implies that households which did not use fertilizer chose not to (as opposed to being unaware of it) and are likely to be systematically different from those which did. In particular, households not using fertilizer are likely to do so either because they cannot use it profitably, or because they lack the means to purchase it. Both of these could be correlated with household composition.

To mitigate this potential selection bias, I estimate fertilizer demand conditional on it being used in a given growing season.[10] Restricting the sample accordingly allows me to isolate households for which fertilizer is profitable from those for which fertilizer is either unprofitable or too risky to use, as the latter group faces a different set of constraints. It should be noted, however, that including households which went from zero use to non-zero use in one year to the next means that the overall effect will be a combination of intensive and extensive margin effects. This will likely result in point estimates that are higher than if I were just looking at households which used fertilizer in all three survey waves, but doing so reduces the sample size too much.

With this caveat, the conditional fertilizer demand equation is similar to that for labor demand, with household composition included in the same way, and controls for household landholdings, wealth, and other observable characteristics. I again include a community-time fixed effect, which absorbs input and expected output prices, as well as other shocks which would affect fertilizer profitability. Given the nature of fertilizer acquisition—through requests made to local agricultural cooperatives, which relay these requests up the chain of government until the AISE determines how much fertilizer to import—fertilizer access may

[10] I choose this approach rather than that typically taken in the literature on fertilizer demand—a double hurdle model—because estimating conditional demand allows me to account for time-invariant household-level heterogeneity through household fixed effects. The probit estimator in the first stage of the double hurdle model requires a correlated random effects approach and the assumption that, conditional on the included covariates, household composition is uncorrelated with unobserved, time-invariant household characteristics, such as farmer skill. Using household-level fixed effects allows me to avoid making this strong assumption. Although estimating conditional fertilizer demand restricts the sample significantly and gives no insight into the participation decision, it brings with it more confidence in the consistency of the household composition coefficients.

significantly between communities and potentially over time, and this is also controlled for with the community-time fixed effect. As with labor demand, I also include a year fixed effect to control for country-level trends and household fixed effects to control for time-invariant household-level characteristics such as farmer skill. That is, I estimate:

$$\ln Z_{ijt} = \delta_0 + \sum_{n=1}^{4} \delta_1^n M_{ijt}^n + \sum_{n=1}^{4} \delta_2^n F_{ijt}^n + \delta_3 \ln X_{ijt} + \delta_4 \ln \bar{A}_{ijt} + \eta_i + \vartheta_{jt} + \tau_t + \varepsilon_{ijt} \tag{11}$$

With the same covariates as in the labor demand equation, and where Z is the (log) quantity of fertilizer applied in growing season t. The test for the null hypothesis of separability is, again, that $\delta_1 = \delta_2 = 0$. As discussed in 2.2, there are certain scenarios in which we would expect the household's labor endowment to have a positive effect on fertilizer demand: if the household is labor-constrained and cannot hire in sufficient outside labor, its fertilizer use will increase with household labor supply. Alternatively, if households are cash-constrained and unable to access credit markets, fertilizer use will increase with income from off-farm work[11]—which is increasing in labor supply. In either of these cases, if imperfections in labor markets spill over into fertilizer demand, we would expect $\delta_1 > 0$. Depending on whether female family members supply labor, we might also expect $\delta_2 > 0$.

Due to life cycle effects and gender dynamics, households with a higher share of older males are likely wealthier than those which are younger or predominantly female. Given that fertilizer is an expensive input, it is possible that any effect of household composition and, particularly, labor endowment on fertilizer demand is due primarily to a wealth effect. Controlling for household wealth through landholdings thus helps with identification of δ_1 and δ_2 and provides insight as to the mechanism behind any effect.

5.2 Identification

Despite the extensive controls provided by the inclusion of observable household characteristics, household, community-time, and year fixed effects, there remain threats to identification. Over a long enough time-frame, household composition is likely to be endogenous. For example, if local labor markets are thin, households with large landholdings may be unable to hire in sufficient labor and will instead choose to have more children to increase their labor supply. Within the five-year panel, this is unlikely to be a source of bias, as children born after the first wave will be too young to provide any meaningful labor, so that household labor supply is quasi-fixed. Shorter-term changes, particularly migration decisions, pose a bigger problem. If households send members away, either for school, to find work, or for

[11] Or from renting out land.

early marriage to relieve financial pressures (e.g., the additional labor the household member could provide on the farm does not cover their consumption needs), then household composition will be partially determined by labor demand. LaFave & Thomas (2016) deal with this problem by restricting the sample to households in which changes in composition were solely due to aging, an approach I follow here through two sets of restrictions.

I first exclude households which experienced births, deaths, and migration over the course of the sample, unless that migration was due to marriage of a household member over the national median age for marriage (16.5 years old for women and 23 years old for men (Central Statistical Agency Ethiopia 2012)) or the member who died was older than the average life expectancy of 64.5 years (World Bank 2015), which leaves 881 households. Although children born after the first survey wave will be at most age 4 by the third wave, if their birth is related to a productivity shock that could affect the household longer term, there is a potential for simultaneity bias between household size and labor demand. While it would take a rare, catastrophic event for this to be the case, the same could also be true for the death of a household member. I include households with members who married because it is plausible that societal pressures to marry by a certain age are strong enough that, for household members over that age, migration for marriage is unrelated to household labor demand.

The second sample restriction is that used by LaFave & Thomas (2016) and excludes households with any births, deaths, or migration at all over the three survey waves. That is, any changes in household composition are solely due to aging. While this approach has the advantage of identifying household composition through a strictly exogenous process, its stringency comes with a cost in sample size: of the 715 households remaining, only 472 used fertilizer in either the first or second survey waves. Small sample size aside, this is the preferred specification because of the strictly exogenous nature of the composition changes.

These sample restrictions also serve to delink changes in household composition with changes in landholdings. Under current government policy, households do not own land, *per se*, but are given certificates of use by the state. These certificates are *de facto* land rights and remain relatively constant over the course of the survey.[12] While there is a potential for simultaneity bias between landholdings and input demand, I assume that the transactions costs associated with acquiring or relinquishing a land certificate are such that landholdings are quasi-fixed over the course of the survey. This assumption is backed up by the relative stability of landholdings by survey wave, as shown in table 2.

[12] Simultaneity bias between landholdings and input demand is also possible, though not likely, given the quasi-fixed nature of landholdings. More problematic for identification is if both landholdings and household composition variables changed as a result of a productivity shock. If household composition changes are due solely to aging, however, then changes in landholdings are uncorrelated, conditional on the inclusion of life cycle variables (age of household head and household wealth).

A larger concern of simultaneity bias is that caused by including area cultivated. Alternatively, excluding cultivated area could cause omitted variable bias. The bias could arise because larger areas of land generally require greater input use, while the quantity of land cultivated may reflect other input constraints. One option in dealing with this potential source of bias is to look at intensity of input demand, so that the choice variable—area cultivated—is moved to the left-hand side of the equation. Udry (1999) and Carter & Yao (2002) take this approach. Other studies look at demand for total labor rather than intensity and simply include cultivated area as a control, under the justification that it is a relatively fixed input once the growing season begins (LaFave & Thomas 2016; Dillon & Barrett 2017). Benjamin (1992) includes harvested area in his study, while Bowlus & Sicular (2003) include it directly and then run a series of robustness checks using land endowment and grain quotas as instruments, and Dillon et al. (2017) also use landholdings as an instrument.

While neither landholdings nor cultivated area change greatly over time, as shown in table 2, there is a clear upward trend in the survey data. As a robustness check, I also estimate input demand per hectare of land cultivated in addition to estimating total input demand. Estimating total input demand allows me to isolate the impact of household composition on a single input—labor or fertilizer—as opposed to a ratio of inputs (labor or fertilizer per hectare cultivated. Estimating intensity of input demand, on the other hand, provides a robustness check and is in keeping with the primary focus of the intensification literature.

Another, related source of simultaneity (or omitted variable) bias is crop choice. This is an issue primarily related to fertilizer demand: although different crops have different fertilizer and labor requirements (Franke 2014), many labor activities occur regardless of crop choice (e.g., land preparation, planting, and weeding), while recommendations for fertilizer application vary widely between crops. Of the six major staple crops grown in Ethiopia, the majority of fertilizer is applied to only three: teff, wheat, and maize (IFDC 2012). It is thus plausible that substitution between staple crops occurs and that fertilizer prices affect farmers' decisions of which cereals to plant.

The literature on fertilizer generally deals with this potential simultaneity bias by restricting the sample to crops on which fertilizer is typically applied. Doing so comes at the cost of estimating farm-level fertilizer demand. Moreover, I find little evidence of substitution between staple crops, with the share of cultivated land planted to maize, wheat, or teff relatively unchanged throughout the survey waves, at 0.38 in wave 1, 0.40 in wave 2, and 0.39 in wave 3, as shown in table 2. As an additional robustness check, however, I take the same approach as with cultivated area and estimate fertilizer demand per hectare of maize, wheat, or teff cultivated.

6 Separability results

In this section, I first present results for the tests of separability in agricultural labor and fertilizer demand. I then discuss in greater detail how these results change when restricting the sample to exclude households with endogenous composition changes and what can be inferred from the fact that the point estimates do, in fact change.

6.1 Testing for separability in labor demand

6.1.1 Total labor demand

Regression results for total labor demand are shown in columns (1)-(3) of table 4. Column (1) shows results for the full sample, column (2) shows those for the sample which excludes households with births, early deaths, or migration that was not due to marriage, and column (3) shows those for the aging-only sample, the preferred specification. Under the null hypothesis of separability, the household composition variables, the β_1 and β_2 in equation 10 should not be statistically different from zero. This is not the case for total labor demand: the p-values of the tests of joint significance at the bottom of the table show that the male composition point estimates—β_1—are jointly different from zero at $p<0.1$ for all sample restrictions, and the null hypothesis of separability is rejected.[13] The female composition coefficients—the β_2—are jointly different from zero for all but the most restricted sample, in column (3).[14]

It is clear that the results are not driven solely by endogenous composition changes, because they hold even among the aging-only households. In fact, the point estimates on the individual composition variables show a consistent pattern. For the share of working-age males, the point estimates increase from 0.326 to 0.640, as I first restrict the sample to exclude households with any births, early deaths, or migration not due to marriage over the average age. When I restrict the sample further to exclude households with any changes not due to aging, the point estimate increases again to 0.830.

Putting this in perspective, and using the distribution of total labor demand and household composition in the first survey wave, a one standard deviation increase in the share of

[13] This also holds for the finer categorization of household composition categories (see table 8 in the appendix).

[14] This is probably not driven only by endogeneity of household composition because I find that they are jointly different from zero using the finer categorization of household composition categories (see table 8 in the appendix). In these results, the share of females aged 20-34 has a negative effect on farm labor demand, while the other female composition groups all have a positive effect. Women aged 20-34 are of prime child-bearing age, so an increase in the share of women in this group may also reflect an increase in the number of dependents. Women of this age are also usually the ones in charge of cooking, cleaning, and caring for their children, so it is possible that they are not considered part of household farm labor supply.

working-age males in a household with no migrant members would result in an increase in total labor demand equivalent to roughly 18.3% of its wave 1 standard deviation. For the full sample, which includes aging-only households as well as those with migrant members, a one standard deviation increase in the share of working-age males would only increase total labor demand by 5.4% of a standard deviation.

One way of looking at this is that the share of working-age males—the household's labor supply—appears to have an increasingly large effect on farm labor demand as the sample becomes increasingly restricted. A similar trend holds for every other adult composition group but with the opposite sign: they have a more negative effect on labor demand in the aging-only sample than in the full sample. Put together, it appears that adult household composition matters more (though with opposite effects) for households with no migrant members. This general pattern holds for labor demand per hectare cultivated and both sets of fertilizer results, and I discuss it further in section 6.3.

6.1.2 Demand for labor per hectare cultivated

One key threat to identification of the household composition variables was omitted variable bias caused by either excluding cultivated area from the demand equation, or simultaneity bias caused by improperly including it. Columns 4-6 of table 4 show the results for demand for labor per hectare cultivated, with results for the full sample in column 4, those for the sample which excludes households with births, early deaths, or migration not due to marriage in column 5, and the aging-only households in column 6. The general pattern of results is consistent with those for total labor demand, but the point estimates are not precisely estimated, and separability is not rejected.[15]

These results suggest that the total labor demand results were not driven primarily by omitted variable bias, though it is possible that omitting cultivated area from the first set of regressions biased the composition coefficients upwards. For example, as column 6 shows, the point estimate for the share of working-age males in an aging-only household on demand for labor per hectare is 0.604, compared to 0.830 for total labor demand, as shown in column 3. Put differently, a one standard deviation increase in the share of working-age males in a household with no migrant members would increase labor demand per hectare by roughly 11.6% of a standard deviation. A corresponding composition change would increase total labor demand by 18.3% of a standard deviation, as noted above.

[15] One set of coefficients is consistently significant across columns (4)-(6): landholdings. Labor is used less intensively on large farms—with an elasticity of demand with respect to landholdings around -0.07. Put differently, there is a strong relationship between household landholdings and the area cultivated, which is suggestive of land market failures as well.

With no (composition) coefficients which are statistically different from zero, it is impossible to say whether household composition affects demand for labor per hectare. I cannot conclude that it does, but I cannot rule out that it does not.[16]

6.2 Testing for separability in conditional fertilizer demand

6.2.1 Total fertilizer demand

Conditional fertilizer demand results are shown in table 5, with total fertilizer demand in columns 1-3 and fertilizer demand per hectare cultivated in columns 4-6. As with labor demand, results for the full sample are in columns 1 and 4, those for the sample which excludes households with births, early deaths, or migration not due to marriage in columns 2 and 5, and those for the aging-only households in columns 3 and 6. Unlike labor demand, I fail to reject separability in the first two columns: the p-values of the joint tests of significance at the bottom of the table show that none of the household composition coefficients are jointly significant. For the aging-only households, however, the male composition coefficients are jointly different from zero at p=0.1, and separability in total fertilizer demand for these households is rejected at the 10% level. Neither the female composition coefficients, nor the household composition coefficients combined have a joint effect that is statistically different from zero.

Although the composition coefficients are very noisy and not individually significant, there is again a consistent increase in the point estimates for the share of working-age men as I restrict the sample. In the full sample (column 1), this coefficient is nearly zero, at 0.046. In the sample which excludes households with births, early deaths, or migration not due to marriage over the average age, shown in column 2, this coefficient is 0.819. In the aging-only sample, in column 3, the coefficient rises to 1.09. Translating these point estimates into units of fertilizer, a one standard deviation increase in the share of working-age males in a household in the full sample would, all else equal, increase total conditional fertilizer use by roughly 0.9% of its wave 1 standard deviation. By comparison, total conditional fertilizer use would increase by 41.6% in the aging-only sample. As with labor demand, the share of working-age men appears to matter more in households with no migrant members.

[16] The results using the finer composition categories, as well as other robustness checks using the number of household members in each category (as opposed to the share) suggest that there is an effect (albeit a smaller one). When using the number of members in each category, the household composition variables have a joint effect that is significant at the 10% level. Both sets of results and other robustness checks are in the appendix.

6.2.2 Demand for fertilizer per hectare cultivated

Columns (4)-(6) of table 5 show the results for demand for fertilizer per hectare cultivated. As with labor demand, I am unable to reject separability: none of the household composition coefficients have a joint effect different from zero.[17] The same potential issue of omitted variable bias appears to hold here: the composition point estimates are smaller for fertilizer intensity demand compared to those for total fertilizer demand.[18] For example, the share of working-age males in an aging-only household has a point estimate of 0.768—compared to 1.09 for total fertilizer demand. That is, a one standard deviation increase in the share of working-age males in an aging-only household would only increase demand for fertilizer per hectare by 13.3% of a standard deviation—compared with the 41.6% of a standard deviation increase in total fertilizer demand from above.[19] This suggests, again, that the total demand coefficients also include, to some extent, the effect of household composition on cultivated area.

Despite the failure to reject the null hypothesis of separability—which means I cannot say anything conclusively about the effect of household composition on fertilizer demand intensity—it should be noted that, again, household composition appears to matter more in households which have no migrant members than those which do.[20] As column (4) of the same table shows, the share of working-age males has a small (and noisy) effect on fertilizer demand per hectare, with a point estimate of -0.11. For the aging-only sample, the point estimate is much higher (though imprecisely estimated), at 0.768.

This pattern holds across all the results presented in tables 4 and 5, and I discuss its implications next.

6.3 Differences by sample restriction

Breaking down the changes in results by sample restriction, two key patterns emerge. First, there is a general trend that the share of working-age males in the household has a larger

[17]The share of females age 12-19 does, for households with no migrant members, but it is not entirely clear why. These results should be interpreted relative to the omitted categories—the share of males (or females) under age 12, and it is not clear why, relative to these groups, females ages 12-19 would negatively affect fertilizer demand.

[18]This is also the case when estimating fertilizer demand per hectare of maize, wheat, or teff—the crops which receive the bulk of fertilizer in Ethiopia (IFDC 2012).

[19]This is in part because of the significantly larger standard deviation of fertilizer applied/ha (86.6 compared to total fertilizer demand at 44.7)

[20]Across sample restrictions, fertilizer is also applied less intensively on large farms: the elasticity of fertilizer demand per hectare with respect to landholdings is around -0.09 across sample restrictions. As with demand for labor per hectare, this is consistent with there being frictions in land markets that prevent households from reallocating land, as would be expected from the government's policy regarding land certificates.

(and positive) effect on input demand in the restricted samples than in the full sample. That is, the share of working-age males in the household has a larger and positive effect on input demand per hectare among households which had no migrant members over the course of the survey, compared to households which did. This is especially pronounced in the fertilizer demand functions. Conversely, the female composition coefficients *decrease* steadily with the sample restrictions, especially in the input intensity demand regressions. The share of females of any age has either a smaller or a more negative effect on input demand in the aging-only households, compared with the rest of the sample.

What is driving the differences in results between the full sample and restricted samples? One possibility is that household composition is endogenous and biases the estimates downwards. A related but slightly different interpretation is that households in which there was no migration, births, or deaths are systematically different from those in which there were—and the two groups are indeed different on observable characteristics and input choices, as shown in table 3. For example, the most restricted sample had less land and fewer household members but a higher share of female family members than households in which there were births, deaths or migration. It is plausible that whichever mechanisms prevent the aging-only households from sending a member away for work or marriage[21] also affect their input demand decisions.

Another possibility is differences in transactions costs. de Janvry et al. (1991) suggest the presence of transactions costs which limit households' participation in markets, even if those markets are otherwise complete, and Foster & Rosenzweig (2017) show how these transactions costs could vary with farm size. Another set of literature shows how high transport costs and other market frictions can lead to misallocation of inputs, including the share of labor devoted to agriculture (Gollin & Rogerson 2013). More relevant to these households is that having a migrant member could reduce the transactions costs associated with obtaining inputs or credit or income with which to purchase inputs.

This idea is supported by work showing that there are differences in households' abilities to fully participate in markets. For example, Bowlus & Sicular (2003) reject separability in villages where there are limited employment opportunities within and immediately outside rural Chinese townships but fail to do so when there is an active labor market nearby. In a similar vein, Carter & Yao (2002) argue that not all households are prevented from participating in markets in the same way, and that this implies a need for both global and local tests of non-separability.

If households in the restricted sample face higher transactions costs, it is also likely that they participate in a narrower geographic range of markets. For example, households with

[21] For example, low liquidity or lack of information about off-farm employment and labor markets.

a migrant member living in a nearby city may travel regularly to that city, or the migrant member may send back information about fertilizer prices or people looking for temporary work. If it is the case that households in the aging-only sample participate in a narrower range of markets, they are also likely to be most affected by markets at the most localized level (i.e., in and around the village), where the households with migrant members may have the means and network connections to access markets further away. Unfortunately, it is difficult to disentangle the potential effects of statistical bias, systematic differences in households, different transactions costs, and geographic spread of market access, and I leave the question for further research.

6.4 Implications from separability results

While the rejection of separability in itself is insufficient to determine the cause of rejection (de Janvry et al. 1991; Carter & Yao 2002), it is clear that the household's labor endowment has a positive impact on input demand for certain types of households. As discussed in section 2.2, this could be due to a discrepancy between the costs households face to use their own on-farm labor compared with off-farm labor and hired labor. Alternatively, finding that labor-constrained households use less labor would also be consistent with limited off-farm employment opportunities or low availability of hired labor. Identifying which constraints households face requires estimating the shadow wage relative to the market wage, as Dillon et al. (2017) do. As described earlier, labor market imperfections could spill over into fertilizer demand: given that labor is needed to apply fertilizer, then to weed plots sufficiently later in the season, it is possible that labor is a binding constraint in fertilizer application.

Binding financial constraints would also explain the fertilizer results, assuming local labor markets function relatively well. If this is the case, a household which lacks the means to purchase fertilizer could earn income from working off the farm. The potential of a household to earn off-farm income will also increase with the number of members available to work off the farm, so we would expect households with a larger labor supply to be more likely to have the means to purchase fertilizer. This is consistent with reports that fertilizer is too expensive for Ethiopian farmers to use (Croppenstedt et al. 2003) but does not explain the wedge between households' valuation of their own labor compared to that of hired laborers implied by the labor demand results.

Which—if either—of these explanations holds determines what kind of policy will be most effective in increasing input use. I explore these implications further in the next section, where I estimate labor and fertilizer demand price elasticities.

7 Price elasticities

My results in the preceding sections showed that separability does not hold in conditional fertilizer and agricultural labor demand. They demonstrated that problems in multiple markets limit input use and intensification. In this section, I investigate further the implications for intensification by estimating the elasticities of labor and conditional fertilizer demand with respect to the price of the other. As discussed in section 2, price elasticities are useful because they indicate underlying relationships and trade-offs between different inputs. I first discuss estimation of the price elasticities, then discuss the results and implications for intensification.

7.1 Price elasticity estimation

To estimate the price elasticities, I modify equations 10 and 11 to include a vector of input and (expected) output prices. Since output prices are unknown at the time of planting, I assume households form expectations about future prices through a naïve expectations model, so that expected output prices simplify to those realized in the previous year.

As discussed in section 4, price data in the survey was measured at a combination of the farm level and market level, with land rental rates and wages reported by farms who participated in those markets, and fertilizer prices collected separately in community markets. While fertilizer and cereal prices are unlikely to be affected by any individual household, it is possible that certain farmers are better at negotiating than others. If this is the case, wages and land rental rates may depend on household preferences and labor supply, or be simultaneously determined with the farm's input demand.

To mitigate this potential endogeneity, and to avoid skewing of results by outliers, I take enumeration area-level medians of all prices and move up in levels of aggregation if the values are either implausible or missing. Doing so makes the price data collinear with the community-time fixed effect initially included in equations 10 and 11. As such, I drop the community-time fixed effect and include just a year fixed effect, while recognizing that doing so is at the cost of controlling for community-level trends which could bias or reduce the precision of the estimates.[22]

While certain community-level characteristics—such as elevation and distance to an urban center—are time-invariant and are thus absorbed in the household fixed effect, rainfall,

[22]The results on the household characteristics variables are similar across specifications but less precise when dropping the community-time fixed effect, suggesting that bias is not a major concern. The estimates were also less precisely estimated when I included a community-time fixed effect at a higher level of aggregation, compared to dropping it altogether.

which is likely to influence planting decisions, is not. Under the assumption that farmers form expectations about rainfall according to the same naïve expectations model as assumed for expected output prices, I include the previous year's rainfall in the modified demand equation.

Putting this together, I estimate:

$$\ln I_{ijt} = \gamma_0 + \sum_{n=1}^{4} \gamma_1^n M_{ijt}^n + \sum_{n=1}^{4} \gamma_2^n F_{ijt}^n + \gamma_3 \ln X_{ijt} + \gamma_4 \ln \bar{A}_{ijt} + \sum_{n=1}^{3} \gamma_5^n p_{jt}^n + \gamma_6 p_{j,t-1}^a + \theta_{j,t-1} + \eta_i + \tau_t + \varepsilon_{ijt} \quad (12)$$

Where demand for input I, either labor or fertilizer, depends on the same variables as above but also a vector of input prices, p_{jt}—the price of land, labor, and fertilizer[23]—lagged output prices, $p_{j,t-1}^a$, lagged weather shocks, θ_{jt}, and a year fixed effect τ. Here, the coefficients of interest are those in the γ_5 vector. If markets are complete, we would expect negative own- and cross-price elasticities of both labor and fertilizer. A negative cross-price elasticity of fertilizer with respect to wages would also be consistent with a binding labor constraint. This is because an increase in the market wage would increase the cost of hiring in laborers and would also increase the opportunity cost of family labor on the farm. On the other hand, if financial constraints are binding, then an increase in the market wage would increase the income of households selling their labor off the farm. This, in turn, could relax the binding financial constraints, and fertilizer demand would increase.

As with the tests for separability, I estimate input demand for three samples: the full sample, the sample which excludes households with migration not due to marriage, births, or early deaths, and the aging-only sample. While the coefficients of interest here are no longer the household composition variables, the results in tables 4 and 5 indicate that there are systematic differences between households with migrant members and those without. This means that the two types of households may also face different binding constraints in input use. Understanding whether they respond differently to input price changes will shed some light on this.

7.2 Cross-price elasticity results

7.2.1 Elasticity of farm labor demand

Key price elasticity results for agricultural labor and conditional fertilizer demand are given in tables 6 and 7, respectively.[24] As before, columns 1-3 show results for total input demand,

[23] Where the price of hybrid maize seed is excluded due to its low use

[24] Full results available by request.

while columns 4-6 are for demand per hectare. Across all specifications, labor demand is fairly inelastic with respect to fertilizer prices, with very noisy point estimates ranging from -0.023 to 0.081, which translates into a decrease of 3 days, or 1.9% of the wave 1 standard deviation, up to an increase of 12 days, or 7.4% of the wave 1 standard deviation. As discussed above, we would expect, if markets were complete, that labor demand would decrease with fertilizer prices, as the two are complements in production. Alternatively, as fertilizer prices increase, households could be substituting towards more labor-intensive inputs, such as manure or compost application. If this were the case, we would expect labor demand to increase with fertilizer prices. Given the size of the standard errors, which range from 0.16 to 0.27, relative to the point estimates, it seems more likely that these insignificant results are not due to low power, but rather to farm labor demand not depending on fertilizer prices, an inference I discuss in greater detail below.

Farm labor demand also has a negative elasticity with respect to market wages, as expected. The own-price elasticity appears to be somewhat smaller for the restricted sample than the full sample: column 1 of table 6 shows the elasticity of total labor demand with respect to wages is -0.12 for the full sample, while column 2 shows it is -0.05 for households with no births, early deaths, or migration not due to marriage, and column 3 of the same table shows it is -0.08 for households with no migrants. This translates into a decline of roughly 18 days, or 11% of a standard deviation in labor for the full sample, and roughly 11 days, or 7% of a standard deviation for the aging-only sample. In column 4, the elasticity of labor demand per hectare cultivated with respect to wages is -0.11 for the full sample, but only -0.06 for the aging-only sample (in column 6). Likewise, the elasticities are significant for the full sample—for both total labor demand and demand for labor per hectare—but not for the aging-only sample.

While these differences between samples are small, they are robust to alternative specifications and are consistent with the separability results, which suggested that households with no migrant members rely more heavily on their own labor supply. That finding indicated that aging-only households may be further constrained in labor market participation than households with migrant members—who, as suggested by the rejection of separability in total labor demand, are also not participating fully in labor markets.[25]

[25] Also consistent with most households being autarkic with respect to labor is that local labor market participation rates are low: in the first survey wave only 15% of households in the full sample worked off the farm, while 20% hired in farm labor. The hired in rate is comparable to Bachewe et al.'s (2016) findings using other Ethiopian datasets.

7.2.2 Elasticity of conditional fertilizer demand

Elasticity results for fertilizer demand are presented in table 7. As in previous tables, columns 1-3 show the results for total fertilizer demand, and demand for fertilizer per hectare cultivated is in columns 4-6. As with labor demand, the own-price elasticity is significantly lower for the restricted samples than the full sample. The magnitude of the effect drops from a statistically significant -0.42 (for total fertilizer demand, in column 1) or -0.34 (for fertilizer demand per hectare, in column 4) to less than one-fourth of its size when the sample is restricted to exclude households with migrant members.[26] That is, if the price of fertilizer doubled, households in the full sample would decrease their fertilizer by roughly 25 kilograms, or 55% of the wave 1 standard deviation, while households in the aging-only sample would only do so by one-fifth of that—5 kgs, or 10.5% of the wave 1 standard deviation. For all of the restricted samples, in columns 2, 3, 5, and 6, the effects are small and very imprecisely estimated.

This suggests that, for a given decrease in fertilizer prices, certain types of households will only respond with a marginal increase in fertilizer use. This finding is somewhat at odds with that of Dercon & Christiansen (2011), who conclude that high fertilizer prices are a primary constraint to its use in Ethiopia. On the other hand, there is evidence that fertilizer prices in Ethiopia are lower than those in neighboring countries (Jayne & Rashid 2013), and it is possible that fertilizer demand is fairly inelastic at current prices. Also consistent with my results are those of Josephson et al. (2014), who found a negative but not statistically significant effect of fertilizer prices on fertilizer use in Ethiopia.

Interestingly, the elasticity of fertilizer demand with respect to the market wage is of roughly the same magnitude as the own-price elasticity of fertilizer demand among the restricted samples, though the effect (for all samples) is not statistically different from zero. Across all samples, the elasticity is in the 0.06-0.08 range, meaning that a doubling of the market wage would, all else equal, increase fertilizer demand by roughly 5 kilograms, or 10.5% of the wave 1 standard deviation. With insignificant point estimates, it is impossible to draw any definitive conclusions, but a positive relationship between market wages and fertilizer demand would suggest liquidity problems that could be relaxed by household members earning income off of the farm. Although the effect is small and is not precisely

[26] It is unclear what is driving these results. It does not appear to be differences in fertilizer application rates, as shown in table 3. While there is slightly more variation in fertilizer prices among households with migrant members, the difference does not seem large enough to drive these results. One possibility is that households with no migrant members rely more heavily on farm production for consumption and are thus less sensitive to changes in input prices than are households with alternate sources of income, namely, that from migrant members. As with the differences in separability results by sample restriction, I leave this question for further research.

estimated, it is consistent across alternative specifications, suggesting the issue may be one of power and that further disaggregation may reveal interesting patterns, a question I leave for further research.

7.3 Implications for intensification

Taken together, these results rule out certain explanations. First, the low own-price elasticity of farm labor demand suggests that households are not participating fully in agricultural labor markets. An increase in the market wage should increase the price of hired laborers, as well as the opportunity cost to a household of working on the farm, thereby lowering total farm labor demand. Instead, as discussed in section 2, there may be high search costs—both in finding off-farm employment and in hiring laborers, high monitoring costs, or other reasons that farm labor demand is relatively inelastic with respect to the market wage. These costs may be mitigated somewhat for households with members living elsewhere; though the difference in elasticities between the full sample and the restricted samples is small, further disaggregation may be needed to explore whether this is the case.

Given the low own-price elasticity of fertilizer demand for households in either of the two restricted samples, the low elasticity of labor demand with respect to fertilizer prices is not surprising: the primary mechanism through which households adjust their labor use in response to fertilizer prices is most likely through fertilizer use. If fertilizer use does not change much with fertilizer prices, neither should labor.

Relatedly, the low own-price elasticity of fertilizer demand with respect to wages is consistent with the labor own-price elasticity results, as well as with households not participating fully in agricultural labor markets. As mentioned previously, the complementarity of fertilizer and labor means that, if markets were complete, fertilizer demand would decrease with wages. The insignificant but consistently positive relationship between fertilizer use and market wages warrants further exploration to determine whether certain types of households would increase their fertilizer use as a result of market wage increases. That is, it could be that households with a relatively high labor endowment but which are liquidity-constrained increase their fertilizer use if their off-farm income increases. Examining whether this is the case is challenging, as larger households also tend to be wealthier, but is an area for further work.

Finally, for households with no migrant members, fertilizer demand is relatively inelastic with respect to fertilizer prices. As such, solely lowering the cost of fertilizer is unlikely to significantly increase its use among these households, suggesting they face other constraints. This is potentially contradictory with the finding that fertilizer demand (weakly and noisily) increases with market wages but again highlights the need for further disaggregation and examination of whether different types of households are constrained in fertilizer use in different ways.

8 Conclusion

As the primary asset of the rural poor, the degree to which households can sell or substitute their own labor with that of others can directly affect their abilities to allocate resources efficiently. This is especially true for smallholders, who lack collateral or are otherwise unable to obtain credit with which to purchase inputs. In this paper, I suggest that one under-explored constraint to fertilizer use results from problems in agricultural labor markets. I build on the classic test of separability pioneered by Benjamin (1992) and use household-level panel data to test whether household composition affects both agricultural labor and conditional fertilizer demand among smallholders in Ethiopia.

In both instances, separability is rejected, and the share of working-age men in a household has a positive impact on total farm labor and total conditional fertilizer demand. In particular, a one standard deviation increase in the share of working-age males in a household with no migrant members would, all else equal, increase total labor demand by 18.3% of its wave 1 standard deviation and total conditional fertilizer demand by 41.6% of its wave 1 standard deviation. My results are robust to controlling for community-level prices and shocks, as well as the endogeneity of household composition, cultivated area, and crop choice, though I am unable to reject the null hypothesis that household composition has no effect on demand per hectare of either input.

I also estimated the price elasticities of both inputs and found that agricultural labor is relatively inelastic with respect to market wages, with an elasticity of -0.08 among households with no migrant members. This is consistent with households not participating fully in labor markets. Similarly, fertilizer demand among households with no migrant members is only weakly elastic with respect to fertilizer prices, with an elasticity of -0.09, suggesting that lowering fertilizer prices is unlikely to significantly increase fertilizer application rates among certain types of households. Taken together, these results indicate that policies which focus on increasing the functioning of agricultural and other local labor markets may indirectly increase fertilizer use, though the degree to which this would hold is difficult to determine, given that the estimated effect of wages on fertilizer demand is not statistically different from zero.

In focusing on conditional fertilizer demand, this paper examined whether problems in local labor markets affect fertilizer demand at the intensive margin. A natural follow-up question is whether this is true for the decision to use fertilizer at all. Also, while this paper noted differences in input demand separability and elasticities for households with no migrant members, compared to the pooled sample, it remains agnostic as to what drives these differences. Whether they are due to statistical bias, systematic differences between households, or because having a migrant member lowers barriers to participation in markets is a question left to further research.

Encouraging use of yield-increasing inputs such as fertilizer remains a pressing challenge to policymakers, especially in the face of rising population density. Previous work has shown that policies aimed at increasing input use must address the multifaceted constraints of smallholders. This paper suggests that improving the functioning of agricultural labor markets is a good place to start.

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Descriptive tables

Table 1: Wave 1 summary statistics of variables used in analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
Inputs					
Total labor demand (person days)	1,732	151.4	163.6	9	1135
Labor demand (person days)/ha	1,678	188.6	217.0	6.2	1538
Hired labor demand (person days)	1,732	7.0	31.8	0	580
Conditional fertilizer demand (kgs)	890	59.7	45.7	5	217
Cond. Fertilizer demand (kg/ha)	890	62.3	86.6	0.8	1114
Area cultivated (ha)	1,729	1.1	1.0	0.05	6.37
Household characteristics					
Number of male HH members ages...					
Under 12	1,732	1.1	1.1	0	6
12-19	1,732	0.6	0.8	0	4
20-64	1,732	1.0	0.7	0	7
65+	1,732	0.1	0.3	0	1
Number of female HH members ages...					
Under 12	1,732	1.0	1.1	0	6
12-19	1,732	0.5	0.7	0	4
20-64	1,732	1.1	0.5	0	5
65+	1,732	0.1	0.2	0	1
Household size	1,732	5.4	2.1	1	14
Landholdings (ha)	1,732	1.1	1.0	0	6.4
Prices and rainfall					
Wages (nominal ETB/day)	1,732	22.3	8.2	8.3	50
Fertilizer prices (nominal ETB/kg)	1,732	11.1	1.9	6	18
Land rental rates (nominal ETB/ha/season)	1,732	2536.5	1217.8	954.3	5956.9
Annual rainfall (mm)	1,732	753.1	237.5	332	1295

Note: Conditional fertilizer demand is conditional on non-zero value. Differences in sample size due to trimming cultivated area.

Table 2: Mean area cultivated, landholdings, and share of land planted to maize, wheat, or teff by survey wave

	Wave 1	Wave 2	Wave 3
Area cultivated (ha)	1.12^{++}	1.13^{+}	1.16
	(0.95)	(0.92)	(1.02)
Landholdings (ha)	1.07^{++}	1.22	1.19
	(1.05)	(1.10)	(1.10)
Fraction of cultivated land planted to maize,	0.38**	0.40	0.39
wheat, or teff	(0.28)	(0.30)	(0.30)

Standard deviations in parentheses below. $^{+}$ Wave 2 different from wave 3 at p<0.1, $^{++}$Wave 1 different from wave 3 at p<0.05,$^{+++}$ Wave 1 different from waves 2 and 3 at p<0.1, *** Wave 1 different from waves 2 and 3 at p<0.01; waves 2 and 3 different at p<0.19.

Table 3: Wave 1 summary statistics for input use and household characteristics by status in restricted sample

	Subsample=0	Subsample=1		Subsample=0	Subsample=1
Inputs			**Household characteristics**		
Labor demand (person days)	165.0	131.9	Landholdings (ha)	1.19	0.92
	(171.6)	(149.5)		(1.10)	0.94)
Labor days/ha cultivated	194.0	180.9	Share of males in HH	0.51	0.49
	(224.4)	(205.9)		(0.18)	(0.20)
Used fert. in first survey wave	0.52	0.51	Share of females in HH	0.49	0.51
	(0.50)	(0.50)		(0.18)	(0.20)
Hectares cultivated	1.22	1.0	Share of prime-age males	0.19	0.21
	(1.02)	0.84)		(0.14)	(0.16)
Ha of maize, wheat, or teff	0.49	0.41	Share of prime-age females	0.21	0.23
	(0.56)	(0.51)		(0.12)	(0.15)
kg fertilizer applied	60.0	59.2	Household size	5.92	4.54
	(46.3)	(44.7)		(2.10)	(1.83)
kg fertilizer applied/ha cultivated	72.7	88.3	Asset index score	-0.25	-0.40
	(99.4)	(125.4)		(0.90)	(0.65)
kg of fertilizer applied/ha cultivated	423.2	821.3	Age of HH head	47.7	40.1
of maize, wheat, or teff	(2542.3)	(5877.5)		(14.3)	(14.2)
			Male headed HH	0.84	0.84
				(0.37)	(0.37)

Standard deviations in parentheses below. Fertilizer application rates are conditional on non-zero use.

Main results

Table 4: Household-level fixed effects determinants of labor demand by sample restriction

	(log) Total labor demand (person days)			(log) Labor days/ha cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Share of males age 12-19	0.501***	0.468*	0.430	0.299*	0.262	0.254
	(0.179)	(0.282)	(0.349)	(0.180)	(0.285)	(0.349)
Share of males age 20-64	0.326	0.640	0.830	0.211	0.456	0.604
	(0.273)	(0.486)	(0.683)	(0.269)	(0.466)	(0.635)
Share of males age 65+	0.021	-0.608	-0.507	0.086	-0.378	-0.485
	(0.404)	(0.619)	(0.856)	(0.405)	(0.666)	(0.905)
Share of females age 12-19	0.379**	0.471*	0.380	0.088	0.035	-0.234
	(0.182)	(0.273)	(0.337)	(0.182)	(0.287)	(0.342)
Share of females age 20-64	0.103	-0.165	-0.244	-0.039	-0.287	-0.606
	(0.267)	(0.448)	(0.578)	(0.266)	(0.426)	(0.535)
Share of females age 65+	0.053	-0.036	-0.263	-0.007	-0.332	-0.773
	(0.409)	(0.548)	(0.698)	(0.449)	(0.580)	(0.765)
HH size (log)	-0.125	-0.637		-0.255	-0.192	
	(0.263)	(0.424)		(0.245)	(0.434)	
Landholdings (log)	0.096***	0.072***	0.072***	-0.070***	-0.067***	-0.067***
	(0.013)	(0.016)	(0.019)	(0.013)	(0.019)	(0.022)
Number of observations	5,196	2,643	2,145	5,034	2,565	2,076
Adjusted R2	0.503	0.517	0.531	0.493	0.483	0.490
p-values for F-tests of joint significance						
All male comp. variables	0.021	0.044	0.078	0.365	0.336	0.353
All female comp. variables	0.102	0.102	0.340	0.869	0.779	0.715
Prime age adults	0.480	0.402	0.476	0.698	0.456	0.349
All HH comp. variables (excl. HH size)	0.039	0.044	0.149	0.701	0.642	0.602
All covariates	0.000	0.000	0.005	0.000	0.023	0.026

Notes: Differences in numbers of observations due to trimming cultivated area. Share variables all refer to share of household members in that gender-age group. Share of males and females under the age of 12 dropped due to multicollinearity. Standard errors clustered at the EA level and in parentheses below. Community-time fixed effects included in all specifications. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5: Household-level fixed effects determinants of conditional fertilizer demand by sample restriction

	(log) Total fertilizer demand (kgs)			(log) kg fertilizer/ha		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Share of males age 12-19	-0.199	0.268	-0.052	-0.240	0.387	-0.076
	(0.247)	(0.365)	(0.415)	(0.256)	(0.390)	(0.456)
Share of males age 20-64	0.046	0.819	1.087	-0.107	0.727	0.768
	(0.319)	(0.514)	(0.668)	(0.321)	(0.513)	(0.681)
Share of males age 65+	0.364	0.590	0.637	0.387	0.860	0.843
	(0.510)	(0.772)	(0.982)	(0.489)	(0.721)	(1.298)
Share of females age 12-19	0.055	0.171	-0.101	-0.308	-0.316	-0.746*
	(0.236)	(0.344)	(0.377)	(0.248)	(0.370)	(0.409)
Share of females age 20-64	-0.108	0.151	-0.290	-0.239	0.071	-0.687
	(0.348)	(0.621)	(0.716)	(0.377)	(0.651)	(0.744)
Share of females age 65+	-0.368	-0.276	-0.229	-0.325	-0.248	-1.187
	(0.629)	(0.957)	(1.709)	(0.594)	(0.856)	(1.416)
HH size (log)	-0.456	0.012		-0.649**	-0.046	
	(0.300)	(0.568)		(0.269)	(0.580)	
Landholdings (log)	0.057***	0.059**	0.063**	-0.103***	-0.094***	-0.086**
	(0.020)	(0.027)	(0.027)	(0.022)	(0.032)	(0.034)
Number of observations	2,890	1,451	1,185	2,890	1,451	1,185
Adjusted R2	0.314	0.424	0.454	0.365	0.440	0.446
p-values for F-tests of joint significance						
All male comp. variables	0.522	0.429	0.087	0.437	0.537	0.470
All female comp. variables	0.877	0.907	0.981	0.666	0.741	0.319
Prime age adults	0.917	0.257	0.208	0.817	0.314	0.250
All HH comp variables (excl. HH size)	0.709	0.635	0.289	0.693	0.355	0.415
All covariates	0.050	0.370	0.137	0.000	0.053	0.041

Notes: Differences in numbers of observations due to trimming cultivated area. All specifications restricted to households with non-zero fertilizer application. Standard errors clustered at the EA level and in parentheses below. Share variables all refer to share of household members in that gender-age group. Share of males and females under the age of 12 dropped due to multicollinearity. Community-time fixed effects included in all specifications. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Key labor demand elasticity results

	(log) Total labor demand (person days)			(log) Labor days/ha cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Fertilizer price (ETB/kg)	0.046	0.044	0.019	-0.024	0.078	-0.010
	(0.172)	(0.240)	(0.276)	(0.162)	(0.234)	(0.273)
Wages (ETB/day)	-0.119***	-0.047	-0.077	-0.109**	-0.038	-0.061
	(0.046)	(0.062)	(0.069)	(0.043)	(0.063)	(0.072)
Land rental rate (ETB/ha/season)	0.020	-0.036	-0.007	0.029	-0.002	0.005
	(0.059)	(0.081)	(0.092)	(0.059)	(0.079)	(0.092)
Lagged cereal prices (ETB/kg)	0.430***	0.320*	0.175	0.075	-0.020	-0.156
	(0.130)	(0.179)	(0.200)	(0.125)	(0.171)	(0.198)
Lagged rainfall (mm)	-0.040	-0.293*	-0.276*	-0.180*	-0.332**	-0.290*
	(0.106)	(0.151)	(0.165)	(0.102)	(0.142)	(0.157)
Number of observations	3,464	1,762	1,430	3,356	1,710	1,384
Adjusted R2	0.037	0.039	0.033	0.008	0.007	0.001

Notes: Differences in numbers of observations due to trimming cultivated area. Standard errors clustered at the EA level and in parentheses below. All regressions estimated with household-level fixed effects and include year fixed effects. All prices are in nominal birr. All prices and rainfall are in logs. All covariates from the main specifications are also included. Labor demand for wave 1 is not included, due to the lagged variables. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Key conditional fertilizer demand elasticity results

	(log) Total fertilizer demand (kgs)			(log) Kgs fertilizer/ha cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Fertilizer price (ETB/kg)	-0.417**	-0.087	-0.085	-0.341	-0.002	0.130
	(0.202)	(0.240)	(0.264)	(0.209)	(0.260)	(0.274)
Wages (ETB/day)	0.063	0.078	0.055	0.040	0.062	0.052
	(0.047)	(0.061)	(0.067)	(0.054)	(0.073)	(0.078)
Land rental rate (ETB/ha/season)	0.150***	0.231***	0.154*	0.189***	0.319***	0.215**
	(0.056)	(0.082)	(0.089)	(0.066)	(0.097)	(0.103)
Lagged cereal prices (ETB/kg)	0.360**	0.310	0.210	0.168	0.026	0.134
	(0.161)	(0.228)	(0.260)	(0.166)	(0.227)	(0.248)
Lagged rainfall (mm)	0.168	0.192	0.092	0.083	0.151	0.103
	(0.118)	(0.158)	(0.173)	(0.132)	(0.175)	(0.191)
Number of observations	2,000	1,007	822	2,000	1,007	822
Adjusted R2	0.033	0.062	0.039	0.071	0.082	0.073

Notes: Differences in numbers of observations due to trimming cultivated area. Standard errors clustered at the EA level and in parentheses below. All regressions estimated with household-level fixed effects and include year fixed effects. All specifications restricted to households with non-zero fertilizer application. All prices are in nominal birr. All prices and rainfall are in logs. All covariates from the main specifications are also included. Fertilizer demand for wave 1 is not included, due to the lagged variables. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix

Table 8: Household-level fixed effects determinants of labor demand by sample restriction using disaggregated gender-age groups

	(log) Total labor demand (days)			(log) Labor days/ha cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Share of males 12-19	0.502***	0.449	0.350	0.302*	0.242	0.193
	(0.179)	(0.278)	(0.346)	(0.180)	(0.284)	(0.349)
Share of males 20-34	0.411	0.649	0.738	0.329	0.502	0.570
	(0.276)	(0.493)	(0.685)	(0.271)	(0.469)	(0.627)
Share of males 35-49	0.616*	0.404	0.522	0.646*	0.504	0.574
	(0.347)	(0.577)	(0.766)	(0.344)	(0.540)	(0.689)
Share of males 50-64	0.683	1.254*	2.259**	0.446	1.123	2.007*
	(0.497)	(0.714)	(1.115)	(0.484)	(0.763)	(1.072)
Share of males 65+	0.424	-0.042	0.847	0.393	0.286	0.955
	(0.554)	(0.739)	(1.275)	(0.551)	(0.828)	(1.250)
Share of females 12-19	0.349*	0.396	0.279	0.066	-0.023	-0.308
	(0.183)	(0.272)	(0.331)	(0.185)	(0.289)	(0.336)
Share of females 20-34	0.080	-0.303	-0.381	-0.028	-0.360	-0.684
	(0.270)	(0.452)	(0.574)	(0.270)	(0.432)	(0.533)
Share of females 35-49	0.853**	0.576	0.599	0.836**	0.610	0.201
	(0.360)	(0.558)	(0.734)	(0.354)	(0.547)	(0.704)
Share of females 50-64	0.989**	1.180*	1.122	0.730*	0.802	0.275
	(0.437)	(0.624)	(0.830)	(0.439)	(0.700)	(0.941)
Share of females 65+	0.936*	1.273*	1.150	0.762	0.741	0.132
	(0.537)	(0.684)	(0.921)	(0.561)	(0.788)	(1.100)
HH size (log)	0.061	-0.523		-0.078	-0.041	
	(0.245)	(0.437)		(0.235)	(0.438)	
Landholdings (log)	0.097***	0.075***	0.075***	-0.070***	-0.064***	-0.064***
	(0.013)	(0.016)	(0.020)	(0.013)	(0.019)	(0.022)
Number of observations	5,196	2,643	2,145	5,034	2,565	2,076
Adjusted R2	0.505	0.520	0.535	0.494	0.485	0.492
p-values for F-tests of joint significance						
All male comp. vars	0.073	0.066	0.030	0.360	0.536	0.312
Prime-age males	0.351	0.119	0.083	0.261	0.489	0.257
All female comp. vars	0.011	0.013	0.073	0.046	0.189	0.384
Prime-age females	0.027	0.027	0.091	0.013	0.073	0.158
Prime-age adults	0.107	0.057	0.053	0.042	0.198	0.165
All HH comp (excl. HH size)	0.018	0.015	0.027	0.096	0.372	0.344
All covariates	0.000	0.000	0.001	0.000	0.028	0.042

Notes: Differences in numbers of observations due to trimming cultivated area. Share variables all refer to share of household members in that gender-age group. Share of males and females under the age of 12 dropped due to multicollinearity. Standard errors clustered at the EA level and in parentheses below. Community-time fixed effects included in all specifications. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Household-level fixed effects determinants of conditional fertilizer demand by sample restriction using disaggregated gender-age groups

	(log) Conditional fertilizer demand (kgs)			(log) kgs fertilizer/ha cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Share of males 12-19	-0.210	0.256	-0.056	-0.253	0.362	-0.072
	(0.250)	(0.368)	(0.416)	(0.258)	(0.392)	(0.453)
Share of males 20-34	-0.019	0.710	1.047	-0.179	0.552	0.742
	(0.325)	(0.528)	(0.681)	(0.332)	(0.529)	(0.672)
Share of males 35-49	-0.254	0.563	1.093	-0.576	0.102	0.481
	(0.439)	(0.655)	(0.784)	(0.453)	(0.700)	(0.803)
Share of males 50-64	0.389	1.259	3.031**	-0.369	0.674	1.299
	(0.628)	(0.920)	(1.242)	(0.633)	(0.987)	(1.312)
Share of males 65+	0.638	0.837	2.628*	0.110	0.629	1.433
	(0.684)	(0.940)	(1.494)	(0.674)	(0.979)	(1.740)
Share of females 12-19	0.047	0.171	-0.123	-0.311	-0.305	-0.746*
	(0.239)	(0.347)	(0.384)	(0.250)	(0.371)	(0.411)
Share of females 20-34	-0.159	0.164	-0.296	-0.283	0.072	-0.718
	(0.354)	(0.630)	(0.721)	(0.385)	(0.663)	(0.749)
Share of females 35-49	-0.319	-0.039	0.025	-0.684	-0.542	-0.821
	(0.462)	(0.775)	(0.885)	(0.488)	(0.817)	(0.944)
Share of females 50-64	0.123	-0.127	0.196	-0.442	-0.720	-1.215
	(0.531)	(0.845)	(1.062)	(0.564)	(0.905)	(1.149)
Share of females 65+	-0.119	-0.442	0.203	-0.558	-0.959	-1.766
	(0.721)	(1.065)	(1.928)	(0.732)	(1.060)	(1.740)
HH size (log)	-0.396	-0.042		-0.727**	-0.230	
	(0.301)	(0.585)		(0.298)	(0.593)	
Landholdings (log)	0.057***	0.058**	0.068**	-0.103***	-0.096***	-0.085**
	(0.020)	(0.027)	(0.027)	(0.022)	(0.032)	(0.034)
Number of observations	2,890	1,451	1,185	2,890	1,451	1,185
Adjusted R2	0.315	0.423	0.455	0.366	0.440	0.445
p-values for F-tests of joint significance						
All male comp. vars	0.537	0.643	0.053	0.518	0.705	0.547
Prime-age males	0.491	0.363	0.085	0.514	0.406	0.462
All female comp. vars	0.794	0.986	0.990	0.636	0.764	0.526
Prime-age females	0.587	0.971	0.911	0.511	0.704	0.708
Prime-age adults	0.675	0.626	0.300	0.706	0.451	0.551
All HH comp (excl. HH size)	0.669	0.624	0.248	0.728	0.227	0.570
All covariates	0.070	0.424	0.122	0.000	0.024	0.061

Notes: Differences in numbers of observations due to trimming cultivated area. Excludes households with zero fertilizer use. Share variables all refer to share of household members in that gender-age group. Share of males and females under the age of 12 dropped due to multicollinearity. Standard errors clustered at the EA level and in parentheses below. Community-time fixed effects included in all specifications. *** p<0.01, ** p<0.05, * p<0.1

Table 10: Household-level fixed effects determinants of labor demand by sample restriction using pooled gender-age groups

	(log) Total labor demand (days)			(log) Labor days/ha cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Share of males 20+	-0.153	0.094	0.368	-0.049	0.178	0.362
	(0.208)	(0.386)	(0.530)	(0.200)	(0.370)	(0.515)
Share of females 20+	-0.335*	-0.622*	-0.651	-0.178	-0.339	-0.426
	(0.202)	(0.362)	(0.468)	(0.190)	(0.319)	(0.399)
HH size (log)	-0.160	-0.674		-0.260	-0.179	
	(0.260)	(0.430)		(0.240)	(0.428)	
Landholdings (log)	0.096***	0.071***	0.070***	-0.070***	-0.067***	-0.067***
	(0.013)	(0.016)	(0.019)	(0.013)	(0.019)	(0.022)
Number of observations	5,196	2,643	2,145	5,034	2,565	2,076
Adjusted R2	0.502	0.514	0.529	0.493	0.483	0.490
p-values for F-tests of joint significance						
All HH comp (excl. HH size)	0.180	0.229	0.370	0.617	0.539	0.504
All covariates	0.000	0.000	0.004	0.000	0.004	0.005

Notes: Differences in numbers of observations due to trimming cultivated area. Share variables all refer to share of household members in that gender-age group. Share of males and females under the age of 12 dropped due to multicollinearity. Standard errors clustered at the EA level and in parentheses below. Community-time fixed effects included in all specifications. *** p<0.01, ** p<0.05, * p<0.1

Table 11: Household-level fixed effects determinants of conditional fertilizer demand by sample restriction using disaggregated gender-age groups

	(log) Conditional fertilizer demand (kgs)			(log) kgs fertilizer/ha cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample	Inc. migration for marriage, deaths over 65	Aging only	Full sample	Inc. migration for marriage, deaths over 65	Aging only
Share of males 20+	0.218	0.585	1.146**	0.158	0.563	0.948*
	(0.232)	(0.364)	(0.478)	(0.243)	(0.384)	(0.540)
Share of females 20+	-0.128	-0.061	-0.186	0.062	0.252	0.006
	(0.264)	(0.516)	(0.648)	(0.299)	(0.557)	(0.709)
HH size (log)	-0.503*	-0.004		-0.618**	0.014	
	(0.298)	(0.518)		(0.258)	(0.539)	
Landholdings (log)	0.056***	0.060**	0.063**	-0.103***	-0.090***	-0.082**
	(0.020)	(0.027)	(0.028)	(0.022)	(0.032)	(0.035)
Number of observations	2,890	1,451	1,185	2,890	1,451	1,185
Adjusted R2	0.314	0.424	0.456	0.365	0.439	0.444
p-values for F-tests of joint significance						
All HH comp (excl. HH size)	0.523	0.218	0.044	0.808	0.341	0.195
All covariates	0.014	0.121	0.022	0.000	0.034	0.019

Notes: Differences in numbers of observations due to trimming cultivated area. Excludes households with zero fertilizer use. Share variables all refer to share of household members in that gender-age group. Share of males and females under the age of 12 dropped due to multicollinearity. Standard errors clustered at the EA level and in parentheses below. Community-time fixed effects included in all specifications. *** p<0.01, ** p<0.05, * p<0.1