Dynamic supply response of farm households in Ethiopia

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ABSTRACT

We study the dynamics of the supply response of smallholder grain producers to changes in crop prices and costs of production in Ethiopia. We develop an intertemporal acreage demand allocation model of a representative household under a rational expectations hypothesis. An estimable acreage demand equation is derived and estimated for teff, an important staple grain in Ethiopia. We apply systems and linear dynamic panel data models to a data set covering a time period marked with remarkable agricultural and macroeconomic growth and smallholder-focused economic policies. The results indicate that teff acreage demand increases faster than permanent increases in real teff prices, and it rises by a third of temporary price increases. Moreover, teff acreage demand declines with increases in the opportunity cost of producing teff.

Keywords: dynamic supply response, acreage demand, rational expectations hypothesis, dynamic panel data analyses, smallholder farmers, teff, Ethiopia

I. INTRODUCTION

A large proportion of the poor in sub-Saharan Africa reside in rural areas where smallholder agriculture is the dominant economic activity. Over 80 percent of Ethiopians, including a majority of the poor, are engaged in agriculture. Smallholder farm households in Ethiopia account for over 90 percent of the country’s cultivated area and agricultural output. Agricultural Development Led Industrialization (ADLI) has been the major policy framework in Ethiopia since the early 1990’s. Smallholder farmer focused policies that are derived from the ADLI framework were implemented during the last two decades, including the current Growth and Transformation Plan (GTP). These policies were aimed mainly at eradicating poverty, ensuring food security, and stimulating agricultural growth. Considerable resources are currently directed towards national and multilateral supported agricultural development programs in Ethiopia. Notable amongst the multilateral supported initiatives is the Comprehensive Africa Agriculture Development Program (CAADP), whose objectives in Ethiopia are aligned with the objectives of the GTP (Ministry of Agriculture 2014). One of the objectives of the GTP is increasing smallholders’ productivity and marketed supply (MoARD 2010b). The success of such efforts crucially depends, among others, on how smallholders respond to changes in prices and to policy interventions.

Despite the use of different methodologies and factors to account for supply responses, a number of studies find that farmers in sub-Saharan Africa (SSA) respond inelastically to changes in market incentives, such as prices, and to market liberalization policies.1 That the majority of smallholders in SSA produce little marketed surplus is cited as the most important factor contributing to low supply elasticities. However, Schiff and Montenegro (1997) indicate methodological issues that may have led to misleading conclusions. Moreover, Binswanger (1989) points to the natural gestation period and the resulting fixity of inputs as an explanation for the low short-run agricultural supply responses obtained in a number of studies. He highlights the crucial distinction between short- and long-run agricultural supply responses. Added to this is the fact that the most important input in crop production, land, cannot be made available inelastically, making the distinction between crop-specific and aggregate output supply responses particularly important in agriculture, even in the long-run. This is particularly important in SSA where the application of modern inputs is relatively low and output increases largely derive from cultivation of more land (Binswanger and Pingali 1988; Headey and Jayne 2014).

Few studies have investigated agricultural supply responses in Ethiopia. Unlike the findings on supply response in other SSA countries, studies on Ethiopia find moderately elastic supply responses. Using an aggregate dataset for the 1966 to 1994 period, Alemu et al (2003) find elastic long-run grain supply responses for both price and market liberalization. However, the same study finds that short-run supply was unresponsive for most types of grain. Similarly, Suleiman (2004) finds elastic cereals supply responses using a household level dataset covering the 1994 to 2000 period. Taffesse (2003) investigates the impact of government policy on the dynamics of agricultural supply in Ethiopia during the 1980s. In particular, the study indicates that teff acreage responded negatively to the level of forced grain procurement and positively to teff prices. The period covered in these studies was notable for the command economic system, which was replaced in early 1990s by policies that liberalized markets. The effect on supply responses of policies aimed at increasing smallholder farmers’ productivity, which have been prominent in Ethiopia since the mid-1990s, of the recent focus on increasing the

1 Bond (1983) finds low agricultural supply response to changes in prices in nine SSA countries. Similarly, Muchapondwa (2009) finds inelastic aggregate agricultural supply response for Zimbabwe. Studies that find low crop-specific supply responses for SSA includes Kavinya and Phiri (2014), and Mose et al. (2007). Furthermore, supply responses of farmers were unaffected by market liberalization policies in Uganda (Rudaheranwa et al. 2003) and Kenya (Mose et al. 2007).
marketed supply and value added of crops, and of the fast growth in physical, institutional, and communication infrastructure have not been studied. The lack of evidence on the impacts of such developments on food security and agricultural productivity, which crucially depend on the supply response of smallholder farmers, among other factors, makes this study important.

This study is intended to fill this gap in the evidence by measuring output supply responses of smallholder farmers in Ethiopia to changes in crop prices and costs of production using a dataset that covers the period from 2003/4 to 2011/12. The analyses use a panel dataset that includes information on the production of grain crops. During the period covered in the study, grain accounted for 96 percent and 86 percent of total agricultural area and output in the country, respectively. To achieve our study objective, we develop a simple dynamic farm household model. An estimable acreage demand equation is derived and estimated using zone level aggregated input-output data. Estimates of acreage demand elasticities, together with demand elasticities of other inputs, such as labor and fertilizer, are used to determine the importance of cultivated area vis-à-vis other inputs in output supply responses – that is, whether any observed increases in grain output resulted from an extensive margin, where cropland is increased, or from an intensive margin, where increases in input use, play a major role in increased grain production. From this we obtain information not only on how smallholders in Ethiopia had been coping with land scarcity, but also the extent to which efforts that aimed at increasing smallholders’ productivity through intensive application of modern inputs succeeded.

There are four remaining sections to the paper. In the second section, a simple dynamic model of farm household input demand choices is provided from which the long and short-run factor demand elasticities are derived and the empirical econometric model provided. The third section describes the data used in the analyses. In the fourth section, the results of the analyses are discussed. The last section provides a summary of our findings and conclusions.

2. DYNAMIC SUPPLY RESPONSE MODEL

This section has two parts. In the first part a simple dynamic farm household model is presented. The model is used to investigate the effect on intertemporal acreage demand of changes in crop prices and in opportunity cost of production. In the second part, which deals with the empirical methods used, the empirical acreage demand equation is specified first. This is then used to derive the long- and short-run acreage demand elasticities. Finally, the econometric methods employed are discussed.

2.1. A Dynamic Model of Farm Household Production Choice

Consider a representative infinitely-lived dynastic farm household, which maximizes its discounted expected inter-temporal utility via its consumption, production, and saving choices. The farm household is assumed to have a linear one-period utility function, \( u(x_{t+j}) \). That is:

\[
u(x_{t+j}) = \xi_0 + \xi_1 x_{t+j}; \quad \xi_0, \xi_1 > 0, \quad t, j = 0,1,...
\]

where \( x_{t+j} \) represents consumption in period \( t+j \). In other words, the household is assumed to be risk-neutral, whereby the impact of the randomness of some variables on their production choices is considered without modeling their behavior towards risk. We further assume that the intertemporal utility function is additively separable and that in each period yield and price risks are realized before consumption decisions are taken. Under these circumstances, the farm household's production and consumption decisions are separable.

Using its exogenously given total cultivable land, \( \bar{A}_{t+j} \), and subject to yield risk, the farm household is assumed to produce two types or groups of annual crops using the same linear fixed-proportions production technology. The technology is linear in crop acreage, stochastic, and involves a one-period lag between cultivation and harvest. That is, harvest at \( t+j \) is a function of acreage at \( t+j-1 \). Formally:

\[
Q_{1,t+j} = y_1 A_{1,t+j-1} + \epsilon_{1,t+j}; \quad y_1 > 0, \quad t, j = 0,1,...
\]

\[
Q_{2,t+j} = y_2 A_{2,t+j-1} + \epsilon_{2,t+j}; \quad y_2 > 0, \quad t, j = 0,1,...
\]

2 The model is a variant of the linear rational expectations model [Sargent (1987), Hansen and Sargent (1980)] as applied to agricultural supply response analysis [Eckstein (1984, 1985), Tegene, Huffman, and Miranowski (1988), Taffesse (2003)].
where \( Q_{i,t+j} \) is output of crop \( i \) \((i=1, 2)\) at time \( t+j \); \( y_{i,u} \) are positive parameters; and \( e_{i,t+j} \) are exogenous shocks to production of crop \( i \) during \( t+j \), which have zero mean, constant variance, and are serially uncorrelated. \( A_{i,t+j} \) is the proportion of total acreage allocated to crop \( i \) at time \( t+j \) or \( A_{i,t+j} = a_{i,t+j} / \bar{A}_{t+j} \), where \( a_{i,t+j} \) is land in hectares sown to crop \( i \) and \( \bar{A}_{t+j} \) represents total cultivated area at period \( t+j \). Consequently, at any period \( t+j \), the acreage shares allocated for crops 1 and 2 sum up to 1 or:

\[
1 = A_{1,t+j} + A_{2,t+j} - 1; \quad t, j = 0, 1, \ldots 
\]

Consistent with the biological gestation period involved in crop production, the one-period lag captures the phenomenon that the farm household has to decide on its crop acreage based on expectations about unknown future output prices. This introduces price risk into the decision-making process. We further assume that the direct non-land cost of producing crop \( i \) is linearly related to the acreage allocated for its production. This cost has two components: costs incurred or known at the time of planting, and costs at the time of harvest. The latter is to capture flexibility in input use after planting and up to and including harvest and the uncertainty of output given the lag in production. It is assumed that there are additional adjustment cost-like expenses related to both crops. To capture these costs as well as the direct costs, we use the following quadratic cost function:

\[
C_{1,t+j} = c_{1,t+j} A_{1,t+j}^2 + \frac{b_1}{2} A_{1,t+j} + d_1 A_{1,t+j} A_{1,t+j-1} 
\]

\[
C_{2,t+j} = c_{2,t+j} A_{2,t+j}^2 + \frac{b_2}{2} A_{2,t+j} + d_2 A_{2,t+j} A_{2,t+j-1} 
\]

In equations (5) and (6), \( b_1, b_2 > 0 \) and \( d_1, d_2 \geq 0 \) are parameters. \( c_{i,t+j} \) represents direct non-land costs associated with crop \( i \), where \( i=1, 2 \), and \( c_{i,t+j} = (v_{i,t+j-1} + f_{i,t+j}) \) with \( v_{i,t+j-1} \) and \( f_{i,t+j} \) representing non-land costs at the time of cultivation (\( t+j-1 \)) and at the time of harvest (\( t+j \)), respectively. For each crop \( i \), \( \frac{b_i}{2} A_{t+j}^2 \), captures decreasing returns to scale in the long-run. As noted by Eckstein (1985), two counteracting dynamic effects are captured by \( d_i \). The first is the tendency to rotate crops if successive cultivation of the same crop on a plot substantially reduces soil fertility and increases the cost of production. The second is the incentive to re-cultivate the crop planted last period if land preparation costs decline with successive cultivation of a plot with the same crop. The sign of \( d_1 \) and \( d_2 \) is thus determined by the factor that dominates costs in the production of each crop.

The household maximizes its discounted expected utility by first maximizing its discounted expected profits, \( \pi_{t+j} \), and subsequently choosing the level of consumption and savings subject to the corresponding budget constraint. The farm household’s profit function is given as:

\[
\pi_{t+j} = (P_{i,t+j} Q_{i,t+j} - C_{i,t+j}) + (P_{2,t+j} Q_{2,t+j} - C_{2,t+j}) 
\]

where \( P_{i,t+j} \) is crop \( i \)’s price. The budget constraint is defined as:

\[
x_{t+j} + s_{t+j} = (1+r)s_{t+j-1} + \pi_{t+j}; \quad t, j = 0, 1, \ldots 
\]

where \( s_{t+j-1} \) is savings from the previous period that accrues returns at a rate of \( r \), which is assumed to remain constant over time. Savings represent the cash-equivalent of different saving instruments and inventory of outputs.

With the characterization and assumptions above, the farm household maximizes its discounted intertemporal expected utility by choosing decision rules for consumption, savings, and acreage allocations under yield and price risk. These choices are made subject to a sequence of constraints. The optimization problem is setup and solved in Appendix A1.

The solution to household’s optimization problem is:
\[ A_{t+j} = \alpha_{t+j} A_{t} - \frac{\lambda_1}{d} \left\{ \sum_{i=0}^{\infty} (\beta \lambda_2)^i E_{t+j} \left[ R_{t+j} V_{t+j+1+i} - V_{t+j} \right] \right\} - \frac{\lambda_1 k}{(1 - \beta \lambda_1)} \]  
\[ (9) \]

where \( \beta \) is the rate at which future consumptions are discounted, such that \( 0 < \beta < 1 \) and we define \( b = b_1 + b_2 \), \( d = d_1 + d_2 \), and \( k = \beta d_2 / (d_1 + d_2) \). In equation (9), the roots \( \lambda_1 \) and \( \lambda_2 \) satisfy \( \lambda_1 + \lambda_2 = -b / \beta d \) and \( \lambda_1 \lambda_2 = 1 / \beta \) and \( \lambda_1 \) is the smaller of the roots satisfying \( |1 / \lambda_1| = -\beta \lambda_1 - b / d \). Furthermore, \( V_{t+j} = (c_{1,t+j} - c_{2,t+j}) \) and \( R_{t,j} = \mu_{2,t+j} \). The sum of \( R_{t,j} \) and \( V_{t+j} \) captures the total (actual and opportunity) costs of producing crop 1.

Equation (9) does not constitute a decision rule, as it includes the processes \( E_{t+j} P_{1,t+j+1+i} \), \( E_{t+j} R_{1,t+j+1+i} \), and \( E_{t+j} V_{t+j+1+i} \). To make the equation a decision rule, it is necessary to express the three processes as functions of elements of the current information set, \( \Omega_{t+j} \). The decision rule is derived in Appendix A2 by invoking the rational expectations hypothesis. Nevertheless, as it stands, the equation can be used to derive expressions for long- and short-run acreage demand elasticities. The elasticities are derived in Appendix A3.

2.2. Empirical Analysis

In this subsection, first, the empirical specification of the acreage demand equation is derived. Following this, the empirical versions of long and short-run acreage demand elasticities are provided. Finally, the estimation procedure is described.

EMPIRICAL SPECIFICATION

Equation (9) is transformed into an empirical acreage demand decision rule, estimated with data available in Appendix A2. The acreage decision rule is given as:

\[ A_{t,j} = \kappa_0 + \kappa_1 A_{t-1} + \kappa_2 A_{t-2} + \kappa_3 P_{t} + \kappa_4 P_{t-1} + \kappa_5 R_{t} + \kappa_6 R_{t-1} + \epsilon_t \]  
\[ (10) \]

where, among others, \( \kappa_0, \ldots, \kappa_6 \) are defined in Appendix 2.

In the empirical analyses of equation (10) crop 1 is replaced with teff while 20 non-teff grain crops replace crop 2 as a group. Accordingly, acreage share, price, costs, and other variables associated with crop 1 are replaced with those pertaining to teff. Consequently, \( \epsilon_t \) represents shocks to non-land costs of producing teff. These shocks can also be used to include random errors of optimization and errors in data (Epstein and Yatchew 1985). The following section discusses the importance of teff.

Equation (10) is directly estimated as an unrestricted reduced form of the structural model. In this regard, no attempt is made to recover the structural parameters. Although the restrictions implied cannot be exploited by the theoretical model, the unrestricted version can be used to estimate the acreage demand elasticities, which is one of the primary objective of this study.

ACREAGE DEMAND ELASTICITIES

The empirical long-run acreage demand elasticity is derived from equation (10) by differentiating the unconditional expectation of acreage demand, \( E(A_1) \), WRT \( E(P_1) \), and weighting the result by the ratio of the unconditional means \( E(P_1) \) and \( E(A_1) \). That is:

\[ \frac{\partial L}{\partial A_1} = \left( \frac{\kappa_3 + \kappa_4}{1 - \kappa_1 - \kappa_2} \right) \frac{EP_1}{EA_1} \]  
\[ (11a) \]

\[ \frac{\partial L}{\partial A_1} = \left( \frac{\kappa_5 + \kappa_6}{1 - \kappa_1 - \kappa_2} \right) \frac{ER_1}{EA_1} \]  
\[ (11b) \]
Note that the elasticities of teff supply with respect to the price of teff and the opportunity cost of teff production are also equal to the respective acreage demand elasticities given above. This is a consequence of the linear relationship between teff acreage and teff supply, \( Q_{t+j} = y_i A_{i,j,t+j} + \varepsilon_{i,t+j} \), given by equation (2). The equation that follows, which derives the long-run teff supply elasticity, is the same equation as for teff acreage demand elasticity given in equation 11a.

\[
\varepsilon^L_{A,t} = \frac{dQ_i}{dP_i} \frac{EP_i}{EQ_i} = \frac{y_i dA_i}{dP_i} \frac{EP_i}{y_i EA_i} = \left( \frac{\kappa_3 + \kappa_4}{1 - \kappa_1 - \kappa_2} \right) \frac{EP_i}{EA_i} = \varepsilon^L_{A,p}
\]

The short-run acreage demand elasticities are evaluated at the unconditional mean of expected prices and opportunity cost as:

\[
\varepsilon^S_{A_1, P_1} = \kappa_3 \frac{EP_1}{EA_1} \tag{12a}
\]

\[
\varepsilon^S_{A_1, R_1} = \kappa_3 \frac{ER_1}{EA_1} \tag{12b}
\]

**ESTIMATION PROCEDURE**

The teff acreage demand and teff price equations are estimated using administrative zone level aggregated panel data. We justify the use of zonally aggregated data in the next section. The data extends over the nine year period from 2004/05 to 2012/13. Equations (10) and (A.15) are restated by introducing zone specific effects as follows:

\[
A_{i,t} = \kappa_0 + \kappa_1 A_{i-1,t} + \kappa_2 A_{i-2,t} + \kappa_3 P_{i,t} + \kappa_4 P_{i-1,t} + \kappa_5 R_{i,t} + \kappa_6 R_{i-1,t} + \eta^A_i + \upsilon^A_{i,t} \quad \text{where } t \geq 3 \quad (13)
\]

\[
P_{i,t} = \theta P_{i-1,t} + \eta^P_i + \upsilon^P_{i,t} \quad \text{where } |\theta|<1 \text{ and } t \geq 2 \quad (14)
\]

where the superscript \( t \) in \( A_{i,t} \), \( P_{i,t} \), and \( R_{i,t} \) stands for teff; \( i = 1, \ldots, 53 \) identifies the 53 zones included in the analyses and \( t = 1, 2, \ldots, 7 \) represents the years during the period 2006/07 to 2012/13, whereby the first two-years are lost because of the two lagged acreage variables included in the right of equation (13). Note that in equations (13) and (14) \( \eta_i + \upsilon^A_{i,t} = \varepsilon_{i,t} \) and \( \gamma_i + \upsilon^P_{i,t} = u_{i,t} \) represent the fixed effects decomposition of the disturbance terms commonly adopted in panel data models, with \( \upsilon^A_{i,t} \) and \( \upsilon^P_{i,t} \) assumed to be white noise. To ensure stationarity in equation (13), it is assumed that, \( \kappa_1 + \kappa_2 < 1 \), \( \kappa_2 - \kappa_1 < 1 \), and \( \kappa_2 > -1 \).\(^5\)

Given that both equations (13) and (14) include as explanatory variables lagged values of the dependent variable, they must be estimated using dynamic panel data (DPD) models. Application of either ordinary least squares (OLS) or panel data methods, such as the within-groups estimator on the equations, results in biased parameter estimates (Nickell 1981; Hsiao 1986). OLS estimates are biased because \( A_{i,j-k} \) is correlated with \( \varepsilon_{i,t} \) through the individual specific effect, \( \eta^A_i \), and \( P_{i,t-k} \) is correlated with \( u_{i,t} \) through \( \eta^P_i \) for \( k=1, 2 \). For the within-groups estimator, in which the variables are transformed by subtracting their time-means, the cause is the correlation between the lagged dependent variables, \( A_{i,j-k} \) and \( P_{i,j-k} \), and the time-mean of \( \varepsilon_{i,t} \) and \( u_{i,t} \), respectively.

Among methods developed to estimate the parameters of such models, two standard dynamic panel data (DPD) models are used. The first is the Arellano and Bond (1991) linear dynamic panel-data method, which is denoted as Linear-

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3 We omit discussing the \( R_{i,t} \) equation similar to (14). However, estimates of the equation are discussed in section 4.

4 The data comprises 5, 10, 17, and 21 zones in Tigray, Amhara, Oromiya, and SNNP regions, respectively.

5 These conditions define the triangle that ensures the stationarity of an AR(2) process (Davidson and MacKinnon 1993, 342). Recall that in the present case, \( |\kappa_1| + |\lambda_1| + |\rho| < 2 \), and \( |\kappa_2| + |\lambda_1| + |\rho| < 2 \), since \( |\lambda_1| < 1 \) and \( |\rho| < 1 \).
AB in Tables 4 to 7 below. The second method, due to Arellano and Bover (1995) and Blundell and Bond (1995), is the systems estimator that uses additional moment conditions to those used in Linear-AB. Results obtained using this method are reported under the heading System-ABBB.

3. THE DATA

The input-output data used in the econometric analyses are described here. These data, which extend for nine years from 2004/05 through 2012/13, were collected by the Central Statistical Agency (CSA) of Ethiopia through its Annual Agricultural Sample Surveys (AgSS) series (CSA 2005, 2006,…, 2013). The surveys cover a large number of smallholder farmers. For instance, the 2004/05, 2008/09, and 2012/13 AgSS covered 50,287, 45,000, and 44,200 farm holders, respectively.

The analyses in this study include 21 types of grain, four of the 11 regions in Ethiopia, and the main agricultural season, locally known as meher, in which over 95 percent of national grain output is produced. The decision to limit our analyses to grain and the four regions is made due to the following considerations:

1. During the 2004/05 to 2012/13 period, grain crops, which comprise cereals, pulses, and oilseeds, accounted for an average of 86 percent of the total agricultural output and 96 percent of the area. While grain crops were cultivated in all administrative zones included in this study, most of the remaining crops were limited to some zones or miss data that is essential in the analysis for a number of years covered in the study.

2. During the period studied, only some of the zones in the two mostly nomadic regions of Afar and Somali, were covered in CSA AgSS. Moreover, data is unavailable in a number years for all zones of Benishangul-Gumuz and Gambella regions. As a result we exclude the latter four regions from the analyses. The remaining three regions of Harar, Dire Dawa, and the capital city, Addis Ababa, are urban regions. The four regions included in this work – Tigray, Amhara, Oromiya, and the Southern Nations, Nationalities, and Peoples' (SNNP) Region – on average accounted for over 96 percent of the nationwide agricultural area and output during the period studied.

As pointed out earlier, we use administrative zone-level aggregated data. This is because lower levels of administrative units, such as woredas (districts), as well as households, are resampled in each AgSS survey year such that the survey is only representative at the administrative zone-level. As a result, it is impossible to construct from the AgSS survey series a panel of survey households and, similarly, to construct a panel dataset for lower administrative units.6

Estimating acreage demand and price equations using zonally aggregated data may appear to violate one of the assumptions of the model. The assumption that individual farmers take market prices as given is often made in similar studies. The assumption will not hold if zones were production units, because the zonal supply of a given crop will influence its price. However, despite the data being aggregated at zone-level, the actual production units are competitive farm households, which, among others, form expectations on prices and use the information to make production and supply decisions.

However, to avoid inconsistent results, we conduct pairwise Granger causality tests between prices and outputs of teff and non-teff grains. The results, which test the null hypotheses of outputs do not Granger cause prices and vice versa, are provided in Appendix Table B1. The results indicate that both null hypotheses are not rejected for both teff and aggregated non-teff grains. In addition to the Granger causality tests, a method proposed by Geweke (1982) for infrequent data, such as annual data, is used to test the null hypothesis: output and prices do not have instantaneous feedback. The null hypothesis is not rejected for both teff and aggregated non-teff grains.7 Given these results, we conclude that no causality exists between prices and outputs of teff and aggregated non-teff grains.

ACREAGE ALLOCATION PATTERNS

Table 3.1 summarizes the acreage share of teff out of all types of grain (descriptive statistics of non-teff grains is provided in Appendix Table B2). In Ethiopia, cereals are the most important perennial crop, accounting for 79 percent of the total area under grain crops in an average year during the 2004/05 to 2012/13 period. Pulses and oilseeds on average accounted for 15 percent and 5 percent of the area cultivated with grain, respectively. Teff is an important cereal crop accounting for 21.4

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6 In rural Ethiopia, farmers’ associations constitute the smallest administrative units. Woredas (districts) are composed of farmers’ associations, while zones and regions constitute the two larger units in the administrative spatial hierarchy, respectively.

7 We conduct the tests for non-teff grain crops separately. The tests provide mixed results. The null hypothesis that outputs do not cause prices is rejected in seven of the 20 crops, while the null hypotheses that prices do not cause outputs is rejected in five crops. Moreover, the null hypothesis that output and prices do not have instantaneous feedback is rejected in eight crops.
percent of the area under grain, and cultivated by 47 percent of farmers that cultivated grain crops. Although there were regional differences in the acreage share of crops, teff was either the first or second most important in all regions and it was the most important of all grain crops in an average zone in the four regions.

Moreover, teff is in high demand as a food crop, particularly in urban areas. Partly as a consequence of this demand, it is the most commercialized food crop with more than 27 percent of teff output sold during the 2008/09 to 2012/13 period relative to the 20 percent sales of the output of other types of grains and 16 percent of the output of other types of cereals (CSA 2009, 2010, ..., 2013). In many parts of the country, teff constitutes the major source of cash income for farmers.

Table 3.1. Mean regional teff acreage shares, 2004/05-2013/14, percent

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<td>All regions</td>
<td>21.7 (1.5)</td>
<td>19.7 (1.4)</td>
<td>21.6 (1.6)</td>
<td>23.2 (1.9)</td>
<td>21.3 (1.4)</td>
<td>21.8 (1.5)</td>
<td>22.3 (1.5)</td>
<td>21.4 (1.6)</td>
<td>19.8 (1.5)</td>
<td>21.4 (0.5)</td>
</tr>
<tr>
<td>Tigray</td>
<td>17.6 (1.8)</td>
<td>18.3 (2.2)</td>
<td>16.6 (2.0)</td>
<td>17.3 (1.7)</td>
<td>17.7 (1.7)</td>
<td>18.7 (1.9)</td>
<td>17.4 (2.0)</td>
<td>15.7 (2.2)</td>
<td>16.6 (2.2)</td>
<td>17.3 (1.4)</td>
</tr>
<tr>
<td>Amhara</td>
<td>24.9 (1.8)</td>
<td>24.6 (2.2)</td>
<td>25.2 (2.0)</td>
<td>26.5 (1.7)</td>
<td>24.8 (1.7)</td>
<td>24.6 (1.9)</td>
<td>24.1 (2.0)</td>
<td>23.0 (2.2)</td>
<td>24.8 (2.2)</td>
<td>24.7 (0.6)</td>
</tr>
<tr>
<td>Oromiya</td>
<td>18.7 (3.0)</td>
<td>18.0 (2.8)</td>
<td>19.8 (3.2)</td>
<td>19.2 (3.1)</td>
<td>19.8 (2.8)</td>
<td>20.7 (3.0)</td>
<td>20.7 (3.1)</td>
<td>20.6 (3.1)</td>
<td>19.5 (3.1)</td>
<td>19.7 (1.0)</td>
</tr>
<tr>
<td>SNNP</td>
<td>23.5 (2.6)</td>
<td>19.2 (2.3)</td>
<td>22.6 (2.8)</td>
<td>26.2 (3.6)</td>
<td>21.6 (2.6)</td>
<td>22.2 (2.6)</td>
<td>24.0 (2.9)</td>
<td>22.5 (2.6)</td>
<td>18.5 (2.4)</td>
<td>22.3 (0.9)</td>
</tr>
</tbody>
</table>

Source: Authors’ computation using CSA AgSS data (CSA 2005-2013).
Note: Figures in parentheses are standard deviations.

TEFF PRICES

CSA has recorded producers’ prices for more than 120 items monthly since 1995/96 in almost all zones of the country (CSA 2014a). Nominal prices are deflated using regional general price indices (CSA 2014b). The data on monthly real prices of teff are summarized in Table 3.2, while Appendix Table C3 provides a similar summary for non-teff grains. Given no data on weights, such as volumes of sales, simple means of monthly prices are considered. The summary in Table 3.2 indicates real teff prices averaged about 3.6 birr/KG in December 2006 prices, and annual growth in real teff prices averaged 3.6 percent. Despite slightly higher real teff prices in Tigray and Amhara, average annual growth was about the same in all regions.

Table 3.2. Average regional real teff prices, 2004/05-2012/13, in Dec. 2006 birr/kg

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All regions</td>
<td>2.9 (0.37)</td>
<td>3.2 (0.37)</td>
<td>3.7 (0.35)</td>
<td>4.2 (0.41)</td>
<td>4.7 (0.58)</td>
<td>4.7 (0.49)</td>
<td>4.7 (0.41)</td>
<td>3.5 (0.37)</td>
<td>3.2 (0.43)</td>
<td>3.7 (0.66)</td>
</tr>
<tr>
<td>Tigray</td>
<td>3.4 (0.36)</td>
<td>3.2 (0.48)</td>
<td>3.3 (0.32)</td>
<td>4.7 (0.39)</td>
<td>5.1 (0.38)</td>
<td>3.9 (0.43)</td>
<td>3.6 (0.39)</td>
<td>4.0 (0.33)</td>
<td>4.0 (0.31)</td>
<td>3.9 (0.65)</td>
</tr>
<tr>
<td>Amhara</td>
<td>3.2 (0.36)</td>
<td>3.4 (0.48)</td>
<td>3.8 (0.32)</td>
<td>4.4 (0.39)</td>
<td>5.0 (0.38)</td>
<td>3.8 (0.43)</td>
<td>3.5 (0.39)</td>
<td>4.0 (0.33)</td>
<td>4.1 (0.31)</td>
<td>3.9 (0.64)</td>
</tr>
<tr>
<td>Oromiya</td>
<td>2.8 (0.30)</td>
<td>3.1 (0.33)</td>
<td>3.7 (0.36)</td>
<td>4.1 (0.39)</td>
<td>4.5 (0.57)</td>
<td>3.2 (0.50)</td>
<td>3.1 (0.44)</td>
<td>3.6 (0.33)</td>
<td>3.4 (0.39)</td>
<td>3.5 (0.64)</td>
</tr>
<tr>
<td>SNNP</td>
<td>2.8 (0.30)</td>
<td>3.2 (0.38)</td>
<td>3.8 (0.32)</td>
<td>4.2 (0.40)</td>
<td>4.6 (0.62)</td>
<td>3.4 (0.46)</td>
<td>3.1 (0.32)</td>
<td>3.6 (0.32)</td>
<td>3.5 (0.32)</td>
<td>3.6 (0.65)</td>
</tr>
</tbody>
</table>

Source: Authors’ computation using CSA (2014a, 2014b).
Note: Figures in parentheses are standard deviations.

OPPORTUNITY COST OF TEFF ACREAGE

Table 3.3 summarizes the opportunity cost of teff acreage. The value of this variable, represented by $R_i$ in the equations above, is calculated as a weighted sum of the marginal value product of 20 non-teff grains. That is:

$$R_i = \sum_{g=2}^{21} P_g \cdot y_g \cdot A_g$$

where $g=1, 2, \ldots, 21$ represents the 21 crops included in the analyses and $g$=f (teff) is omitted in computing $R_i$. $P_g$ in the summation stands for the price of crop $g$ and $y_g$ stands for the marginal product of land in crop $g$ production, which we proxy
using yields of the respective crops. In computing $R_t$, the importance of each crop is weighted using the acreage share of each crop out of the area under non-teff grains, $A_g$, where $A_g = (\text{Crop g area} / \text{Total area under non-teff grains})$.

The summary in Table 3.3 indicates that the opportunity cost of a hectare used in teff production over the study period averaged 3,660 birr in December 2006 prices and grew at average annual rate of 8.5 percent. This positive average annual growth occurs despite the decline in $R_t$ in most years and is due to the considerably fast growth in all three years where growth was positive. There were slight differences in growth rates across regions whereby $R_t$ growth averaged 8.1 percent in Oromiya, 8.4 percent in Amhara, 9.1 percent in SNNP, and 10.0 percent in Tigray.

Table 3.3. Regional average real opportunity cost of teff acreage, 2004/05-2012/13, in Dec. 2006 birr/ha

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>All regions</td>
<td>2510</td>
<td>3086</td>
<td>3016</td>
<td>4715</td>
<td>3758</td>
<td>3227</td>
<td>4421</td>
<td>4281</td>
<td>3929</td>
<td>3660</td>
</tr>
<tr>
<td>(739)</td>
<td>(784)</td>
<td>(928)</td>
<td>(1032)</td>
<td>(818)</td>
<td>(928)</td>
<td>(1078)</td>
<td>(1049)</td>
<td>(921)</td>
<td>(1156)</td>
<td></td>
</tr>
<tr>
<td>Tigray</td>
<td>2951</td>
<td>3297</td>
<td>3321</td>
<td>5656</td>
<td>4939</td>
<td>4666</td>
<td>5951</td>
<td>5493</td>
<td>5229</td>
<td>4941</td>
</tr>
<tr>
<td>(620)</td>
<td>(438)</td>
<td>(605)</td>
<td>(781)</td>
<td>(447)</td>
<td>(540)</td>
<td>(462)</td>
<td>(402)</td>
<td>(314)</td>
<td>(1325)</td>
<td></td>
</tr>
<tr>
<td>Amhara</td>
<td>2707</td>
<td>3299</td>
<td>3604</td>
<td>5088</td>
<td>4161</td>
<td>3710</td>
<td>4937</td>
<td>4755</td>
<td>4510</td>
<td>4086</td>
</tr>
<tr>
<td>(620)</td>
<td>(438)</td>
<td>(605)</td>
<td>(781)</td>
<td>(447)</td>
<td>(540)</td>
<td>(462)</td>
<td>(402)</td>
<td>(314)</td>
<td>(191)</td>
<td></td>
</tr>
<tr>
<td>Oromiya</td>
<td>2685</td>
<td>3318</td>
<td>3389</td>
<td>5122</td>
<td>3881</td>
<td>3215</td>
<td>4407</td>
<td>4608</td>
<td>4028</td>
<td>3850</td>
</tr>
<tr>
<td>(533)</td>
<td>(606)</td>
<td>(778)</td>
<td>(746)</td>
<td>(500)</td>
<td>(638)</td>
<td>(860)</td>
<td>(727)</td>
<td>(471)</td>
<td>(976)</td>
<td></td>
</tr>
<tr>
<td>SNNP</td>
<td>2171</td>
<td>2747</td>
<td>2360</td>
<td>3984</td>
<td>3185</td>
<td>2666</td>
<td>3822</td>
<td>3524</td>
<td>3263</td>
<td>3080</td>
</tr>
<tr>
<td>(798)</td>
<td>(974)</td>
<td>(890)</td>
<td>(980)</td>
<td>(796)</td>
<td>(819)</td>
<td>(918)</td>
<td>(1075)</td>
<td>(794)</td>
<td>(1065)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ computation using CSA (2005-2013) and CSA (2014a, 2014b).
Note: Figures in parentheses are standard deviations.

4. RESULTS

Results of the analyses are presented and highlighted in this section. Since the analyses use variables with both cross-section and time-series dimensions, particularly price series, the variables are first tested for stationarity. That is, stationarity of levels and first-differenced teff acreage, price, and opportunity cost variables are tested. We use routines in Stata statistical software to implement six panel unit-root testing methods under three specifications (standard, demeaned, and with trend). Results of the tests are provided in Appendix Table C1. The null hypothesis that the series are unit-root in all panels is rejected in all specifications by three of the methods: Levin, Lin, and Chu; Breitung; and Im, Pesaran, and Shin. The null hypothesis was also rejected in all three specifications for all variables except real teff price by two of the remaining three methods (Fisher and Harris-Tzavalis). Stationarity of real teff price was rejected in the two methods when it is specified with a trend term. Hadri’s panel unit-root method tests the null-hypothesis: the series are stationary in all panels. This method rejects the null hypothesis if a variable is non-stationary in one or more zones. Accordingly, the test rejected the null hypothesis in two of the three specifications for all three variables. All methods and specifications reject the null hypotheses of non-stationarity of the variables in first differences. Given these results, we conclude that the variables are stationary.

Tables 4.1 to 4.3 below report estimates of teff price, opportunity cost, and acreage demand equations, respectively. The tables also report statistics testing the joint significance of all variables, the regressors excluding time dummies, and only time-dummies, which are referred as $\chi^2$-equation, $\chi^2$-regressors and $\chi^2$-time dummies, respectively. In all equations the three groups of variables are jointly significant statistically at the 1-percent level. The $m_1$ and $m_2$ rows report statistics of first- and second-order serial correlation tests of residuals. Since the first-differenced residuals are MA(1) processes, the null hypothesis of first-order serial correlation is not rejected at the 1-percent level of significance in all equations. The last value reported is the Sargan test of the overidentifying (moment) restrictions, which is given in the $\chi^2$-Sargan/Hansen test rows.

4.1. Teff Price Equation Estimates

Table 4.1 provides estimates of the AR(1) teff price equation (equation 14) and its AR(2) version to empirically select the appropriate autoregressive order of teff price. Estimates of all teff price equations satisfy the stability conditions. Moreover, all significant coefficients are positive except the twice lagged teff price coefficient in the AR(2) Systems-ABBB estimator.

---

8 Recall that stability is insured in the AR(1) teff equation if the coefficient of lagged teff price, $\theta_{t-1}$, is such that $|\theta_{t-1}| < 1$. Similarly stability is insured in the AR(2) specification if $\theta_{t-1} + \theta_{t-2} < 1$, $\theta_{t-2} - \theta_{t-1} < 1$, and $\theta_{t-2} > -1$ where the subscripts of $\theta$ indicate the lags of teff price.
The AR(2) specification estimated using the Systems-ABBB estimator rejects the null hypotheses of optimal instruments and induces a second-order serial correlation, indicating that the estimates are inconsistent.

All estimates of teff price are positive in the well behaved equations – both AR(1) and AR(2) Linear-AB and AR(1) Systems-ABBB specifications. This is consistent with what was expected and indicates that current price is a positive function of its lagged values. Moreover, estimate of lagged teff price is higher than its twice-lagged counterpart, indicating that current prices are influenced more by immediately past prices.

Table 4.1. Systems and linear dynamic panel data estimates of teff price equation

<table>
<thead>
<tr>
<th>Variables</th>
<th>System-ABBB</th>
<th>Linear-AB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AR(1)</td>
<td>AR(2)</td>
</tr>
<tr>
<td>Teff price$_{t-1}$</td>
<td>0.417†</td>
<td>0.427†</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.015)</td>
</tr>
<tr>
<td>Teff price$_{t-2}$</td>
<td>-0.118†</td>
<td>0.099†</td>
</tr>
<tr>
<td></td>
<td>(0.015)</td>
<td>(0.037)</td>
</tr>
<tr>
<td>Constant</td>
<td>2.001†</td>
<td>2.709†</td>
</tr>
<tr>
<td></td>
<td>(0.049)</td>
<td>(0.056)</td>
</tr>
<tr>
<td>χ²-equation</td>
<td>13284†</td>
<td>9193†</td>
</tr>
<tr>
<td>χ²-regressors</td>
<td>881†</td>
<td>843†</td>
</tr>
<tr>
<td>χ²-time dummies</td>
<td>5848†</td>
<td>4664†</td>
</tr>
<tr>
<td>m₁</td>
<td>-4.96†</td>
<td>-4.83†</td>
</tr>
<tr>
<td>m₂</td>
<td>0.94</td>
<td>1.69*</td>
</tr>
<tr>
<td>χ²−Sargan/Hansen test</td>
<td>44</td>
<td>44*</td>
</tr>
<tr>
<td>Number of observations</td>
<td>424</td>
<td>371</td>
</tr>
</tbody>
</table>

Source: Authors’ analysis using CSA (2014a, 2014b).

Notes: Figures in parentheses are standard errors. Coefficients with †, ‡, and * are significant at 1, 5, and 10 percent, respectively.

4.2. Opportunity Cost of Teff Acreage

The results in Table 4.2 indicate that estimates of teff opportunity cost equation satisfy stability conditions of the respective autoregressive systems. The AR(2) specification causes a rejection of the null hypotheses of optimal instruments in both Systems-ABBB and Linear-AB estimators. Only the AR(1) Linear-AB and Systems-ABBB teff opportunity equations behave well or satisfy all requirements. The estimate of lagged teff opportunity variable is significant and positive in both well behaving equations. This indicates that current teff opportunity cost is a positive function of its lagged values.

Table 4.2. Systems and linear dynamic panel data estimates of teff production opportunity cost

<table>
<thead>
<tr>
<th>Variables</th>
<th>System-ABBB</th>
<th>Linear-AB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AR(1)</td>
<td>AR(2)</td>
</tr>
<tr>
<td>Opportunity cost of teff$_{t-1}$</td>
<td>0.413†</td>
<td>0.383†</td>
</tr>
<tr>
<td></td>
<td>(0.012)</td>
<td>(0.014)</td>
</tr>
<tr>
<td>Opportunity cost of teff$_{t-2}$</td>
<td>-0.135†</td>
<td>0.115†</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.043)</td>
</tr>
<tr>
<td>Constant</td>
<td>20.7†</td>
<td>21.3†</td>
</tr>
<tr>
<td></td>
<td>(0.383)</td>
<td>(0.605)</td>
</tr>
<tr>
<td>χ²-equation</td>
<td>12564†</td>
<td>10112†</td>
</tr>
<tr>
<td>χ²-regressors</td>
<td>1275†</td>
<td>829†</td>
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<tr>
<td>χ²-time dummies</td>
<td>6799†</td>
<td>5379†</td>
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<tr>
<td>m₁</td>
<td>-4.43†</td>
<td>-4.65†</td>
</tr>
<tr>
<td>m₂</td>
<td>-0.43</td>
<td>0.99</td>
</tr>
<tr>
<td>χ²−Sargan/Hansen test</td>
<td>45</td>
<td>44*</td>
</tr>
<tr>
<td>Number of observations</td>
<td>424</td>
<td>371</td>
</tr>
</tbody>
</table>

Source: Authors’ analysis using CSA (2005-2013) and CSA (2014a, 2014b).

Notes: Figures in parentheses are standard errors. Coefficients with †, ‡, and * are significant at 1, 5, and 10 percent, respectively.
### 4.3. Teff Acreage Demand Equation Estimates

Results obtained estimating the teff acreage demand equation (equation 13), which uses AR(1) teff price and AR(1) opportunity cost equations, both of which performed relatively well, are reported in the *AR(1) teff price* columns [1 and 3] of Table 4.3. Estimates using an AR(2) teff price and AR(1) teff opportunity cost are reported in the *AR(2) teff price* columns. Estimates of AR(2) and AR(3) teff price and opportunity cost equations are provided in Appendix Table C2, while estimates of teff acreage demand equations obtained using AR(2) and AR(3) teff price and opportunity cost equations are reported in Appendix Table C3. The specifications in Table 4.3 are also estimated using ordinary least-squares and fixed-effects estimators. The results are provided in Appendix Table C4.⁹

Estimates of the two lags of teff acreage variable satisfy stationarity conditions of an AR(2) process in all specifications reported in Table 4.3. The Linear-AB acreage demand equations [3 and 4] induce second order serial correlation in all AR orders of teff price and opportunity cost (Table 4.3 and Appendix Table C4). Therefore, the specification is omitted from the discussions below.

#### Table 4.3. Systems and linear dynamic panel data estimates of teff acreage demand equation

<table>
<thead>
<tr>
<th>Variable</th>
<th>AR(1) teff price</th>
<th>AR(2) teff price</th>
<th>AR(1) teff price</th>
<th>AR(2) teff price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teff acreage_{t-1}</td>
<td>0.481†</td>
<td>0.411†</td>
<td>0.647†</td>
<td>0.672†</td>
</tr>
<tr>
<td>Teff acreage_{t-2}</td>
<td>-0.096†</td>
<td>-0.054</td>
<td>0.222†</td>
<td>0.207†</td>
</tr>
<tr>
<td>Teff price_{t}</td>
<td>0.022†</td>
<td>0.011</td>
<td>0.017†</td>
<td>0.019†</td>
</tr>
<tr>
<td>Teff price_{t-1}</td>
<td>0.017†</td>
<td>0.008</td>
<td>0.008</td>
<td>0.012†</td>
</tr>
<tr>
<td>Teff price_{t-2}</td>
<td>0.001</td>
<td>0.007</td>
<td>-0.013†</td>
<td>0.006</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t}</td>
<td>-0.0051†</td>
<td>0.0004</td>
<td>-0.0043†</td>
<td>-0.0016†</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t-1}</td>
<td>0.0034†</td>
<td>0.0003</td>
<td>0.0026†</td>
<td>0.0016†</td>
</tr>
<tr>
<td>Constant</td>
<td>0.060*</td>
<td>0.031</td>
<td>-0.048†</td>
<td>-0.036†</td>
</tr>
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<td>χ2-equation</td>
<td>3708†</td>
<td>1437†</td>
<td>5538†</td>
<td>3807†</td>
</tr>
<tr>
<td>χ2-regressors</td>
<td>1038†</td>
<td>380†</td>
<td>3348†</td>
<td>2983†</td>
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<tr>
<td>χ2-time dummies</td>
<td>424†</td>
<td>208†</td>
<td>643†</td>
<td>297†</td>
</tr>
<tr>
<td>m1</td>
<td>-4.29†</td>
<td>-3.49†</td>
<td>-3.05†</td>
<td>-3.13†</td>
</tr>
<tr>
<td>m2</td>
<td>-0.98</td>
<td>-1.32</td>
<td>-2.89†</td>
<td>-2.82†</td>
</tr>
<tr>
<td>χ2−Sargan/Hansen test</td>
<td>36</td>
<td>39</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Number of observations</td>
<td>371</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ analysis using CSA (2005-2013) and CSA (2014a, 2014b).

Notes: SE stands for standard error. Coefficients with †, ‡, and †† are significant at 1, 5, and 10 percent, respectively.

Lagged teff acreage is positive in both AR(1) and AR(2) Systems-ABBB specifications, while twice-lagged teff acreage is negative in the AR(1) and insignificant in the AR(2) specification of the same estimator. Both current and lagged teff price are significant and positive in the AR(1) Systems-ABBB model [column 1], while in the AR(2) specification only lagged teff price is significant. That the estimate of lagged teff price is relatively lower in the AR(1) specification indicates that current acreage responses incorporate effects of price changes that already occurred. In both Systems-ABBB equations the contemporaneous and lagged teff opportunity cost variables are negative and positive, respectively. The estimate of current teff opportunity cost as well as the sum of current and lagged teff opportunity cost variables are negative. This implies that teff acreage declines with both temporary and permanent increase in teff opportunity cost (see equations 12b and 11b).

### 4.4. Teff Acreage Demand Elasticities

Table 4.4 provides the long- and short-run elasticities of teff acreage demand with respect to (WRT) teff prices and opportunity cost computed using equations 11a through 12b and the estimates in the corresponding columns of Table 4.3.

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⁹ All of the analyses in Tables 4.1 to 4.4 and Appendix Tables C2-C4, were also conducted using logarithms of the variables. Those results, which can be obtained up on request, generally perform poorly. First, all teff opportunity cost equations and all teff price equations except one either induce second-order serial correlation or result in a rejection the null hypothesis of optimal instruments. Secondly, all except one of the long-run supply response elasticities with respect to teff opportunity cost have the wrong sign.
All elasticities have the expected sign. Short-run teff acreage demand elasticities WRT teff price are less than the corresponding long-run elasticities. This is consistent with expected effects of permanent and temporary price changes in teff price on its acreage demand. Teff acreage demand elasticities WRT the opportunity cost of teff obtained from the AR(1) and AR(2) Systems-ABBB model are -0.48 and -0.45, respectively. These elasticities are lower in absolute terms than the corresponding short-run elasticities.

The Systems-ABBB teff acreage equation using AR(1) teff price (number 1 in Table 4.3) performs better relative to the AR(2) specification and relative to other specifications in Appendix Table C4. The specification is preferred, because it does not induce second-order serial correlation nor a rejection of the null hypothesis of optimal instruments, and its long- and short-run acreage demand elasticities have the correct sign. Moreover, among all specifications that are parsimonious, all estimates of the variables, particularly of current teff price, are significant in only this specification.

**Table 4.4. Long-run and short-run elasticity of teff acreage demand**

<table>
<thead>
<tr>
<th>Acreage demand elasticity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>System-ABBB</td>
<td>Linear-AB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AR(1) teff price</td>
<td>AR(2) teff price</td>
<td>AR(1) teff price</td>
<td>AR(2) teff price</td>
</tr>
<tr>
<td>Long-run elasticity with respect to:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teff price</td>
<td>1.067</td>
<td>0.913</td>
<td>3.300</td>
<td>2.657</td>
</tr>
<tr>
<td>Opportunity cost of teff</td>
<td>-0.484</td>
<td>-0.451</td>
<td>-0.095</td>
<td>-0.141</td>
</tr>
<tr>
<td>Short-run elasticity with respect to:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teff price</td>
<td>0.368</td>
<td>0.179</td>
<td>0.295</td>
<td>0.329</td>
</tr>
<tr>
<td>Opportunity cost of teff</td>
<td>-0.871</td>
<td>-0.728</td>
<td>-0.273</td>
<td>-0.285</td>
</tr>
</tbody>
</table>

Source: Authors’ analysis.

The long-run teff supply elasticity of about 1.1 obtained from the preferred specification implies that farmers’ teff supply response increases slightly faster than a permanent increase in the real teff price. Growth in teff acreage demand is also reinforced by the relatively slow growth in non-teff grains, which implies slow growth in the opportunity cost of teff production. Particularly, the data indicate that real teff prices increased faster than the average price of non-teff cereals and oilseeds. Moreover, the increase in teff prices was faster than crop specific prices of non-teff cereals and oilseeds, with the exception of rice (cereal) and linseed and rapeseed (oilseeds). More importantly, the increase in teff prices was faster than the increase in prices of four other cereals, which, along with teff, dominate the nationwide cultivated area. Accordingly, real teff price increase was over 2.2, 1.3, 1.4, and 2.1 times faster than increases in barley, maize, sorghum, and wheat prices, respectively. Increase in real prices of pulses, which was dominated by increases in vetch and soy bean prices, was slightly higher than the increase in the teff price. Excluding the two crops, the average prices of pulses grew slower relative to teff and the same held in four of the remaining five pulses crops. The six non-teff grains whose price increased relatively faster than teff over the study period are relatively minor crops – together they accounted for 3.4 percent of the area of grain in an average year during the period from 2004/05 to 2012/13. That is, in an average year the share of teff in total grain area was more than six times the share of these six crops combined.

Teff is not only a staple food in the four main agricultural regions of the country considered in this study, but also it has been increasingly adopted by consumers in other parts of the country. This may have contributed to the higher increase in teff price and thus for a faster growth in teff supply response. The share of spending on teff in food expenditure is highest in urban areas and increased by 3.4 percent nationwide between 2005 and 2010, during which period the share of all other cereals declined (Worku et al. forthcoming). Finally, the fast growth in teff demand added to the limited research that has been conducted on teff, may have resulted in the recent focus by the Ethiopian government to increase teff productivity through dissemination of high yielding teff varieties and production methods (Minten and Taffesse forthcoming).

The long-run and short-run acreage demand elasticities with respect to teff prices of 1.07 and 0.37 obtained from the preferred specification in this study are higher than the corresponding corn (maize) acreage elasticities of 0.2 and 0.011 Tegene et al. (1988) compute for Iowa, U.S.A. These elasticities are close to the respective grain acreage elasticity of 0.808 and 0.274 obtained in Yu et al. (2010) for Henan province in China. The elasticities in this study are lower than those in Ahouissoussi et al. (1995) with long- and short-run soybean acreage demand elasticity of 1.98 and 1.21 computed for Georgia, U.S.A. Moreover, the long- and short-run soybean acreage elasticity with respect to wheat price, a proxy for the opportunity cost of soybean acreage, were -1.57 and -2.11 in Ahouissoussi et al. (1995). In contrast, the long- and short-run
cotton acreage demand elasticities WRT the opportunity cost of cotton production in Egypt obtained in Eckstein (1984) are -0.13 and -0.11.

This study is similar to that of Taffesse (2003) in the theoretical and econometric methods employed and in focusing on Ethiopia, thus making the comparison of results in the two studies free from methodological differences. Accordingly, the long-run acreage demand elasticity WRT teff price obtained in this work is considerably higher than that of 0.48 found by Taffesse (2003), while the short-run elasticity in the latter, 0.31, is close to the elasticity we obtain. Moreover, acreage demand elasticity WRT teff opportunity cost obtained in Taffesse (2003) was -0.93, which is about twice that calculated in this study, -0.48, while the short-run elasticity obtained in this work, -0.87, is nearly 7 times the elasticity of -0.13 calculated by Taffesse (2003).

Unlike the period studied in this work, Taffesse (2003) studied the period from 1974 to 1991 that was marked in Ethiopia by a command economic system. Consequently, the difference in the results may have resulted from the economic environment that prevailed during the specific periods of study. One of the changes that occurred during the period considered in our study was the abolition of the proportion or quota of grain output that farmers were required to deliver to a government agency at a fixed price. However, the difference in long-run acreage demand elasticities that the two works obtain is large, even after accounting for the negative acreage demand elasticity of compulsorily delivered grain quota that Taffesse (2003) obtained, -0.04.

The period covered in the study was marked by a number of changes that positively affect agricultural supply response. Among these were the abolition of government control of inputs and output markets during the early 1990s. Moreover, since mid-1990s, the Ethiopian government implemented a number of policy packages targeted at increasing the productivity of smallholder farmers (Bachewe et al. forthcoming). Agricultural supply response is likely to be positively affected by improved integration of farmers with markets as a consequence of increased road construction, increased access to telephone services, and other infrastructure development that has occurred since mid-1990s. The country suffered frequent droughts and famines during the 1974-1991 period. The lower severity and infrequency of unfavorable weather, particularly drought, more recently has likely impacted supply response positively. Finally, the government's decision to allow a limited renting-in and -out of land may also have positively impacted the acreage demand elasticity.

5. SUMMARY AND KEY FINDINGS

Agriculture in Ethiopia is dominated by smallholder farmers that cultivate grain mostly for their own consumption. This study investigates the parallel characterization that smallholder farmers respond little to changes in economic incentives such as prices. In particular, we study teff supply response. For that purpose we develop a simple dynamic model of input demand choices of a representative farm household producing two types or groups of crops under a rational expectations hypothesis. In the model developed, teff supply is a linear function of teff acreage demand. We derive a teff acreage demand equation, estimating the equation using zone level aggregated data. We also compute the long- and short-run teff supply responses and acreage demand elasticities.

The results indicate that teff acreage demand increases slightly faster than permanent increases in its price, while acreage demand increases by about 37 percent for a temporary increase of 100 percent in the real teff price. Moreover, the results indicate that increases in the opportunity cost of teff acreage, gauged by revenue obtainable from other crops, leads to a fall in teff acreage. Teff acreage demand declines by about 50 percent and 90 percent for a permanent and temporary increase of 100 percent in the real revenue per hectare obtainable in the production of non-teff grain crops, respectively. The faster growth in teff supply response may have resulted from a combination of the direct effect of increases in its real price and from its indirect effect through the opportunity cost of teff.

Some studies on supply responses in other countries obtain higher short- and long-run teff supply response elasticities than those obtained in this study, while others obtain lower elasticities. The long-run acreage demand elasticities obtained in this study are considerably higher than the results obtained in Taffesse’s (2003) work in Ethiopia. This difference is largely attributable to the different economic policy regimes that prevailed during the different periods the two studies cover. Policies that favor agriculture, infrastructural development, and favorable weather, are likely to have contributed to the faster growth in overall agricultural supply response seen in the study here.

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10 Indeed Taffesse (2003) indicates that “it is reasonable to expect that the process of market liberalization, which begun with the abolition of CGD [compulsory grain delivery] in 1990, stimulates greater supply responsiveness....”
REFERENCES


APPENDICES

Appendix A. Mathematical Appendix

A1. OPTIMIZATION AND SOLUTION PROCEDURE

Optimization

Given the setup of the problem in section 2.1 the farm household’s optimization problem can be summarized as:

$$\max_{\{s_{t-j},\ast_{t-j},A_{t-j}\}} \lim_{T \to \infty} E \left\{ \sum_{j=0}^{T} \beta^{j}(\xi_{0} + \xi_{1}x_{t+j}) / \Omega_{j} \right\} ; \quad t=0,1,... (A1)$$

subject to

$$x_{t+j} + s_{t+j} = (1+r)s_{t+j-1} + \pi_{t+j} ; \quad t, j = 0,1,... (A2)$$

$$Q_{1_{t+j}} = y_{1}A_{1_{t+j-1}} + \epsilon_{1_{t+j}} ; \quad t, j = 0,1,... (A3)$$

$$Q_{2_{t+j}} = y_{2}A_{2_{t+j-1}} + \epsilon_{2_{t+j}} ; \quad t, j = 0,1,... (A4)$$

$$1 = A_{1_{t+j-1}} + A_{2_{t+j-1}} ; \quad t, j = 0,1,... (A5),$$

and $$A_{t+j-1}, s_{t-1} \text{ given}.$$ 

$$\Omega_{j}$$ is the information set available for the household at time $$t.$$ Using equations (2) to (6) in equation (7) and the latter in equation (8), the maximization problem can be restated as:

$$\max_{\{s_{t-j},\ast_{t-j},A_{t-j}\}} \lim_{T \to \infty} E \left\{ \sum_{j=0}^{T} \beta^{j}[(\xi_{0} + \xi_{1}x_{t+j}) - s_{t+j} + (P_{t+j}y_{1} - R_{t+j} - V_{t+j} + (b_{1} + b_{2}))A_{1_{t+j-1}} - 1/2(b_{1} + b_{2})A_{2_{t+j-1}} - (d_{1} + d_{2})A_{1_{t+j-1}} - d_{2}A_{2_{t+j-2}} + h)] \right\} (A6)$$

subject to $$A_{t+j-1}$$ and $$s_{t-1} \text{ given}$$ and where $$E_{t} \equiv E(\cdot|\Omega_{j}), R_{1_{t+j}} \equiv P_{1_{t+j}}y_{2}, V_{t_{j}} \equiv (c_{1_{t+j}} - c_{2_{t+j}}),$$ and $$h = P_{2_{t+j}}y_{2} - (c_{2_{t+j}} + b_{2} / 2 + d_{2}) + P_{t+j}e_{1_{t+j-1}} + P_{2_{t+j}}e_{2_{t+j}}.$$ 

The Euler equations of problem (A6) with respect to (WRT) $$s_{t+j}$$ and $$A_{t+j}$$ are given as:

WRT $$A_{t+j}$$:

$$E_{t}\{\beta^{T-t}[u'(x_{t+j+1})](P_{1_{t+j+1}}y_{1} - R_{1_{t+j+1}} - V_{1_{t+j+1}} + (b_{1} + b_{2})A_{1_{t+j}} - (d_{1} + d_{2})A_{2_{t+j-1}} - u'(x_{t+j+1})\beta((d_{1} + d_{2})A_{1_{t+j-1}} - d_{2})] = 0 \} (A7a)$$

WRT $$s_{t+j}$$:

$$E_{t}\{\beta^{T-t}[u'(x_{t+j+1})] - \beta(1+r)u'(x_{t+j+2})] = 0 \} (A7b)$$

The associated transversality conditions are:

$$\lim_{T \to \infty} E_{t}\{\beta^{T-t}u'(x_{T+t+1})(P_{1_{t+T+1}}y_{1} - R_{1_{t+T+1}} - V_{1_{t+T+1}} + (b_{1} + b_{2}) - (d_{1} + d_{2})A_{1_{t+T}} - (d_{1} + d_{2})A_{2_{t+T-1}}]A_{1_{t+T}} \} = 0 \} (A8a)$$

$$\lim_{T \to \infty} E_{t}\{\beta^{T-t}u'(x_{T+t+1})(1+r)s_{t+T}] = 0 \} (A8b)$$

First-order conditions (A7a) and (A7b) imply that, under the specified circumstances, production and consumption decisions are separable. As a first step towards a solution, we apply the law of iterated conditional expectations on (A7a) to restate it as:

$$E_{t}\{(P_{1_{t+j+1}}y_{1} - R_{1_{t+j+1}} - V_{1_{t+j+1}} - \beta(d_{1} + d_{2})A_{1_{t+j+1}} - (b_{1} + b_{2})A_{1_{t+j}} - (d_{1} + d_{2})A_{1_{t+j-1}} + \beta d_{2})]\} = 0 \quad \text{for all} \quad t = 0,1,... \text{ and } j = 0,1,..., T - 1 \quad (A7a')$$
For all values of \((P_{t+j}, R_{t+j}, V_{t+j})\) equation (A7a') holds only if:

\[
\beta E_{t+j}[A_{t+j+1} + \frac{b}{\beta d} A_{t+j} + \frac{1}{\beta} A_{t+j-1}] = \frac{1}{d} E_{t+j}[P_{t+j+1}y_1 - R_{t+j+1} - V_{t+j+1}] + k
\]

for all \(t = 0, 1, \ldots\) and \(j = 0, 1, \ldots, T - 1\) \(A9\)

where \(b \equiv b_1 + b_1, d \equiv d_1 + d_1,\) and \(k \equiv \beta d_2 / (d_1 + d_2)\). Recall that \(d_1 > 0\) \(d_1 < 0\) if costs of producing crop 1 increase (decline) with successive cultivation of plots with the crop.

In this work we assume \(d \equiv d_1 + d_2 \not= 0\). If \(d_1 + d_2 = 0\) then \(A_{t+j+1}^{1}, A_{t+j-1}^{1}\) drop out of equation (A7a') and the problem becomes static. The assumption \(d_1 + d_2 \not= 0\) is made not only to retain the dynamic nature of acreage allocation decisions but also cases where \(d_1 + d_2 = 0\) are untenable in the long-run. Suppose \(d_1 > 0,\) \(d_2 < 0,\) and \(d_1 + d_2 = 0\). Then, holding other factors constant, the household will in the long-run specialize in the production of crop 2. Indeed the argument just made implies either \(d_1, d_2 \not= 0\) or \(d_1, d_2 \not= 0\) hold in the long-run. However, for our purposes it suffices to assume \(d_1 + d_2 \not= 0\).

If the effect of successively cultivating plots with the two crops is equal and opposite then, and holding other factors constant, the household will in the long-run specialize in the crop which results in declining costs when cultivated on the same plot successively.\(^{11}\) Indeed this argument implies that costs either increase or decrease with successive cultivation of plots in both crops or \(d_1, d_2 > 0\) or \(d_1, d_2 < 0\). However, it is sufficient to assume \(d_1 + d_2 \not= 0\).

**Solution procedure**

Equation (A9) forms a set of linear stochastic Euler equations, possible to explicitly solve for the optimal decision rule if the exogenous stochastic processes \(\{P_{t+j+1}\}_{j=0}^\infty, \{R_{t+j+1}\}_{j=0}^\infty,\) and \(\{V_{t+j+1}\}_{j=0}^\infty\) are assumed to be mean exponential order of less than \(1/\sqrt{\beta}\) so that processes are bounded in the mean. In the following this assumption is made to apply the solution method suggested by Sargent (1987, P. 395) and solve for \(A_{t+j}\). The solution procedure that follows uses the forward operator \(B\), which for some integer \(i\), is defined as:

\[
B^{i} E_{t+j}(X_{t+j+i} | \Omega_{t+j}) = E_{t+j}(X_{t+j+i} | \Omega_{t+j}) \quad (A10)
\]

And \(\frac{1}{d} E_{t+j}[P_{t+j+1}y_1 - R_{t+j+1} - V_{t+j+1}] + k \equiv E_{t+j}Z_{t+j+1}\) to rewrite equation (A9) as:

\[
\beta[B^{2} + \frac{b}{\beta d} B^{-1} + \frac{1}{\beta}] E_{t+j}A_{t+j-1} = E_{t+j}Z_{t+j+1} \quad (A11)
\]

The term in the square brackets in (A11) can be written as:

\[
[B^{2} + \frac{b}{\beta d} B^{-1} + \frac{1}{\beta}] = (B^{2} - (\lambda_1 + \lambda_2)B^{-1} + \lambda_1 \lambda_2) = (\lambda_1 - B^{-1})(\lambda_2 - B^{-1}),
\]

where the roots \(\lambda_1\) and \(\lambda_2\) satisfy \(\lambda_1 + \lambda_2 = -\frac{b}{\beta d}\) and \(\lambda_1 \lambda_2 = \frac{1}{\beta}\). Then:

\[
\beta(\lambda_1 - B^{-1})(\lambda_2 - B^{-1})E_{t+j}A_{t+j-1} = E_{t+j}(Z_{t+j+1}) \quad (A12)
\]

\(^{11}\) An alternative to this proposed assumption which is made in Eckstein (1985), is to assume that only crop 1 has dynamically interrelated acreage allocation.
If \( \lambda_1 \) is selected to be the lower of the two roots such that \( |\lambda_1| < 1 \) and \( \lambda_2 = 1/\beta \lambda_1 \). Then \( |1/\lambda_2| > 1 \) and \( \beta \lambda_1 < \beta \).

Using these in \( |1/\lambda_2| = -\beta \lambda_1 - b/d \) implies that \( b/d > 1 + \beta \). Then together with \( \beta (\lambda_1 + \lambda_2) = -b/d \) these results imply that \( |\lambda_2| > 1/\beta > 1 \cdot |\lambda_1| \). Both sides of equation (A12) can be divided by \( \beta (\lambda_2 - \beta^{-1}) \) and the equation rearranged as:

\[
(\lambda_1 - \beta^{-1}) E_{t+j} A_{t+j-1} = \frac{1}{\beta \lambda_2 (1 - \frac{1}{\lambda_2} \beta^{-1})} (E_{t+j} Z_{t+j+1}) + c \lambda_2^{\prime+j}
\]

where \( c \) is a constant.\(^{12}\)

Since \( |1/\lambda_2| < 1 \), it implies

\[
\frac{1}{(1 - \frac{1}{\lambda_2} \beta^{-1})} = 1 + \left(\frac{1}{\lambda_2}\right) \beta^{-1} + \left(\frac{1}{\lambda_2}\right)^2 \beta^{-2} + \ldots
\]

Moreover, \( E_{t+j} A_{t+j-1} = A_{t+j-1} \) and \( \beta^{-1} E_{t+j} A_{t+j-1} = E_{t+j} A_{t+j} = A_{t+j} \) hold because \( A_{t+j-1} \) and \( A_{t+j} \) are in the information set of period \( t+j \) and by the definition of the operator \( \beta^{-1} \).

Equation (A13) can be rewritten using the preceding as:

\[
\lambda_1 A_{t+j-1} - A_{t+j} = \frac{1}{\beta \lambda_2} \left[1 + \left(\frac{1}{\lambda_2}\right) \beta^{-1} + \left(\frac{1}{\lambda_2}\right)^2 \beta^{-2} + \ldots\right] (E_{t+j} Z_{t+j+1})
\]

or as:

\[
\lambda_1 A_{t+j-1} - A_{t+j} = \frac{1}{\beta \lambda_2} [E_{t+j} Z_{t+j+1} + \left(\frac{1}{\lambda_2}\right) E_{t+j} Z_{t+j+1} + \left(\frac{1}{\lambda_2}\right)^2 E_{t+j} Z_{t+j+2} + \ldots]
\]

Given \( 1/\lambda_2 = \beta \lambda_1 \) and substituting back \( E_{t+j} Z_{t+j+i} \), the later expression can be rewritten as:

\[
A_{t+j} = \lambda_1 A_{t+j-1} - \frac{\lambda_1}{d} \left\{ \sum_{i=0}^{\infty} \left(\beta \lambda_1\right)^i (E_{t+j} \left[P_{t+j+i+1} + R_{t+j+i+1} - V_{t+j+i+1}\right]\right\} - \frac{\lambda_1 k}{(1 - \beta \lambda_1)} \quad (A14)
\]

### A2. Explicit Solutions for the Acreage and Fertilizer Decision Rules

As noted in the text, equation (A14) does not constitute a decision rule. To transform the equation into a decision rule it is necessary to express variables in expected values as a function of elements of the current information set \( \Omega_{t+j} \). One way of transforming equations (A14) into a decision rule, involves first postulating autoregressive processes for \( P_t, R_t \), and \( V_t \), and then applying the Weiner-Kolmogorov prediction formula to solve for the expectational variables (see Hansen and Sargent 1980).

A simple strategy is adopted for selecting from among alternative specifications. First, autoregressive models of the first-order, AR(1), and second-order, AR(2), are specified for \( P_t, R_t \), and \( V_t \), and then applying the Weiner-Kolmogorov prediction formula to solve for the expectational variables (see Hansen and Sargent 1980).

A combination of joint and partial tests of parameter significance is used to select the better specification. While the following specifications are selected in this manner, details of the latter exercise are reported with other results in section (4).

\[
P_{t+j} = \theta P_{t+j-1} + u_t^P \quad \text{where} \quad |\theta| < 1
\]

Moreover, the stochastic variables \( R_{t+j} \) and \( V_{t+j} \), are assumed to be generated by the following AR(1) processes:

\[
R_{t+j} = \alpha R_{t+j-1} + u_t^R \quad \text{where} \quad |\alpha| < 1
\]

\(^{12}\) Note that \( c \lambda_{1+j} \) is the general solution to a first-order homogenous difference equation when \( E_{t+j} Z_{t+j+1} = 0 \) while (A13) is an extension of that to the non-homogenous case.

\(^{13}\) Solutions analogous to (A22) below can still be obtained by postulating higher-order and/or vector autoregressive process for \( P_{t+j} \) (see Hansen and Sargent 1980). Indeed, the ideal procedure is to postulate AR processes without specifying the order, and then empirically choose the appropriate lag length.

\(^{14}\) Data on \( V_t \) is unavailable. Consequently, it is excluded from this effort. However, it is assumed to be generated by an AR(1) process.
\[ V_{1,t} = \rho V_{1,t-1} + u_i^r \quad \text{where} \quad |\rho| < 1 \]  
(A17)

where \( u_i^r \), \( u_i^s \), and \( u_i^\gamma \) are zero-mean, constant-variance, and serially uncorrelated random variables and the assumptions \(|\theta| < 1\), \(|\alpha| < 1\), and \(|\rho| < 1\) ensure the existence of moving average representations of \( P_{1,t}\), \( R_{1,t}\), and \( V_{1,t}\). Two remarks made about the 3 equations above. First, the farm household is assumed to derive its decisions rule taking the price and cost stochastic processes as given. Second, the specific AR processes for \( P_1 \) is selected via a simple procedure involving estimation and testing. This procedure is legitimate only under rational expectations. The reason is that, under rational expectations, the models used by the farm household to form expectations about random variables are identical to the actual laws of motion of those variables (Epstein and Yatchew 1985).

The farm household’s acreage decision rule is solved by first restating equation (A14) for \( j=0 \), to simplify notation:

\[
A_{t,i} = \lambda_i A_{t,i-1} - \frac{\lambda_i}{d} \left\{ \sum_{i=0}^{\infty} (\beta \lambda_i)^i L_i \left[ P_{1,t+1+i} y_i - R_{1,t+1+i} - V_{1,t+1+i} \right] \right\} + k
\]  
(A18)

where \( k = -\lambda_i d / d(1 - \beta \lambda_i) \).

The laws of motion of \( P_{1,t}\), \( R_{1,t}\), and \( V_{1,t}\) can be written as:

\[
\theta(L)P_{1,t} = u_i^r, \quad \alpha(L)R_{1,t} = u_i^s, \quad \text{and} \quad \rho(L) = u_i^\gamma
\]

where \( \alpha(L) = (1 - \omega L) \) for \( \omega \in (\theta, \alpha, \rho) \) and \( L \) is the lag operator where \( L^i x_i = x_{i-k} \).

Finally, the Wiener-Kolmogorov prediction formula provided by Hansen and Sargent (1980) that solves for

\[
\sum_{i=0}^{\infty} (\beta \lambda_i)^i E_i x_{i+1+i} \]  
is modified to solve the expression specific to this study, \( \sum_{i=0}^{\infty} (\beta \lambda_i)^i E_i x_{i+1+i} \). The solution is provided as:

\[
\sum_{i=0}^{\infty} (\beta \lambda_i)^i E_i x_{i+1+i} = (\beta \lambda_i)^{-1} \left\{ \sum_{i=0}^{\infty} (\beta \lambda_i)^i E_i x_{i+i} - (\beta \lambda_i)^{-1} E_i x_i \right\}
\]

where \( x \in (P, R, V) \). Substituting for \( \sum_{i=0}^{\infty} (\beta \lambda_i)^i E_i x_{i+1+i} \) from the Hansen-Sargent version provides the desired formula.

This modified version of the Wiener-Kolmogorov prediction formula is applied to obtain:  

\[
\sum_{i=0}^{\infty} (\beta \lambda_i)^i E_i P_{1,t+1+i} = \frac{\theta}{1 - \beta \lambda_i \theta} P_{1,t}
\]  
(A19)

\[
\sum_{i=0}^{\infty} (\beta \lambda_i)^i R_{1,t+1+i} = \frac{\alpha}{1 - \beta \lambda_i \alpha} R_{1,t}
\]  
(A20)

\[
\sum_{i=0}^{\infty} (\beta \lambda_i)^i V_{1,t+1+i} = \frac{\rho}{1 - \beta \lambda_i \rho} V_{1,t}
\]  
(A21)

Substituting expressions (A19)-(A21) in (A18):

\[
A_{t,i} = \alpha_0 + \alpha_1 A_{t,i-1} + \alpha_2 P_{1,t} + \alpha_3 R_{1,t} + \alpha_4 V_{1,t}
\]  
(A22)

---

15 As applied to the problem in this study the Wiener-Kolmogorov prediction formula appears as:

\[
\sum_{i=0}^{\infty} (\beta \lambda_i)^i E_i z_{i+1+i} = \left\{ (\beta \lambda_i)^{-1} \left[ \omega (\beta \lambda_i)^{-1} \right] \left[ 1 + \sum_{k=1}^{s} \left( \sum_{i=0}^{s-k} (\beta \lambda_i)^{-1} \omega \right) L^k \right] - (\beta \lambda_i)^{-1} \right\} z_t
\]

where: \( z \in (R, V), \omega \in (\theta, \alpha, \rho), \omega (\beta \lambda_i) = \left( 1 - \omega \beta \lambda_i - \omega_2 (\beta \lambda_i)^2 - \omega_3 (\beta \lambda_i)^3 \right) \). When \( s=1 \), these expressions reduce to those stated in the text. For details regarding the derivation of the Weiner-Kolmogorov formula (see Hansen and Sargent (1980)).
where \( \omega_1 = -k \), \( \omega_1 = \lambda_1 \), \( \omega_2 = -\frac{\lambda_s\theta}{d(1-\beta_1 \theta)} \), \( \omega_3 = -\frac{\lambda_s\alpha}{d(1-\beta_1 \alpha)} \), and \( \omega_4 = -\frac{\lambda_s\rho}{d(1-\beta_1 \rho)} \).

Under the assumptions above (A22) represents an optimal decision rule for \( A_{1,t} \). However, as it stands, the equation is nonstochastic. All right-hand-side variables are elements of the farm household’s information set at period \( t \), \( \Omega_t \).

Moreover, data on \( V_{1,t} \) is unavailable. A solution to both is provided by the Koyck transformation. Applying the Koyck transformation on (A22) and using \( (1-\rho L)V_{1,t} = u_t^V \) from (A17) leads to:

\[
A_{1,t} = \kappa_0 + \kappa_1 A_{1,t-1} + \kappa_2 A_{1,t-2} + \kappa_3 P_{1,t} + \kappa_4 P_{1,t-1} + \kappa_5 R_{1,t} + \kappa_6 R_{1,t-1} + \epsilon_t \quad \quad \text{(A23)}
\]

In equation (A24) \( \kappa_0 = \omega_0(1-\rho) \), \( \kappa_1 = \lambda_1 + \rho \), \( \kappa_2 = -\rho \lambda_1 \), \( \kappa_3 = \omega_2 \), \( \kappa_4 = -\rho \omega_2 \), \( \kappa_5 = \omega_3 \), \( \kappa_6 = -\rho \omega_3 \), and \( \epsilon_t = \omega_4 u_t^V \). Equation (A23) provides a stochastic acreage demand equation estimable with available data.

**A3. DERIVATION OF LONG AND SHORT-RUN ACREAGE DEMAND ELASTICITIES**

In the following, the long- and short-run acreage demand elasticity of crop 1 with respect to changes in its price and opportunity and direct non-land costs of production are derived starting from equation (9) in the text. This equation is provided below for ease of reference:

\[
A_{1,t+j} = \lambda_{1_1} A_{1,t+j-1} - \frac{\lambda_{1_1}}{d} \left( \sum_{i=0}^{\infty} (\beta_{1_1})^i E_{t+j} R_{1,t+j+1+i} - V_{1,t+j+1+i} \right) - \frac{\lambda_{1_1} k}{(1-\beta_{1_1})} 
\]

**Long run elasticities**

The long-run acreage demand elasticities gauge the impact of permanent changes in expected prices and costs on the farm household’s mean acreage demand.

A. The long-run elasticity of expected acreage demand with respect to (WRT) expected market price of crop 1, \( \varepsilon_{A_1,R}^L \), is derived by differentiating the unconditional expectation of acreage demand, \( E(A_1) \), WRT \( E(P_1) \), and weighting the result by the ratio of the unconditional means \( E(R_1) \) and \( E(A_1) \). That is:

\[
\varepsilon_{A_1,R}^L = -\frac{\lambda_1 y_1}{d(1-\lambda_1)(1-\beta_1 \lambda_1)} \frac{EP_1}{EA_1} \geq 0 
\]

That \( \lambda_1 \lambda_2 = 1/\beta \) and \( 0 < \beta < 1 \) imply that \( \lambda_1 \) and \( \lambda_2 \) have the same sign. The latter together with \( b > 0 \) and \( \lambda_1 + \lambda_2 = -b/\beta d \) imply \( \lambda_1 \) and \( \lambda_2 \) have opposite signs. Moreover, \( y_1 > 0 \) is given and \( (1-\lambda_1)(1-\beta_1 \lambda_1) > 0 \) follows from \( \beta, \lambda_1 \ll 1 \). Together, these imply \( \varepsilon_{A_1,R}^L \geq 0 \).

B. The long run elasticity of acreage demand with respect to \( R_1 \) and \( V_1 \) is given as:

\[
\varepsilon_{A_1,R}^L = \left( \frac{\lambda_1 y_1}{d(1-\lambda_1)(1-\beta_1 \lambda_1)} \right) \frac{ER_1}{EA_1} \leq 0 
\]

and

\[
\varepsilon_{A_1,V}^L = \left( \frac{\lambda_1 y_1}{d(1-\lambda_1)(1-\beta_1 \lambda_1)} \right) \frac{EV_1}{EA_1} \leq 0 
\]
\( L_{A_1, R_1} \leq 0 \) holds because a rise in revenue per hectare which is obtainable from cultivating crop 2, \( R_{1,t} \), induces the household to switch into crop 2 and out of crop 1. Similarly, an increase in permanent non-land costs of producing crop 1, \( V_{1,t} \), leads to decrease in acreage allocated for crop 1 production or \( L_{A_1, V_1} \leq 0 \).

**Short run elasticities**

A. Elasticity of current acreage demand WRT changes in period i+1 crop 1 price evaluated at unconditional mean of expected prices is derived using equation (9) as:

\[
\xi_{i+1}^{i+1} A_{i+1, P_1} = -\frac{\beta_1^{i+1} \lambda_1 EP_1}{d EA_1} \quad \Diamond \quad 0
\]  

(A27)

The sign of short-run elasticity of acreage demand is indeterminate and depends on the sign of \( d \). Recall that \( d > 0 \) \((d < 0)\) if the net effect of successive cultivation of crops 1 and 2 on same plots increases (decreases) costs.

Accordingly, if \( d < 0 \) then \( \xi_{i+1}^{i+1} A_{i+1, R_1} \geq 0 \). However, if \( d > 0 \) such that \( \lambda_1 < 0 \) then \( \lambda_1^{i+1} \) is negative if \( i \) is even and positive if \( i \) is odd, which respectively imply, \( \xi_{i+1}^{i+1} A_{i+1, R_1} \geq 0 \) and \( \xi_{i+1}^{i+1} A_{i+1, V_1} \leq 0 \). We use three examples to illustrate this result.

i) Suppose costs increase due to successive cultivation of both crops, \( d > 0 \). Suppose also, the price of crop 1 is expected to increase next period (\( i = 0 \)). Then, the household will allocate more land for the production of crop 1 as it has become more profitable with the expected increase in its price. Note also that the effect on acreage demand elasticity of the expected change in price increases with marginal productivity of land in crop 1 production, \( y_1 \), and it declines with \( i \) (the farther is the projection period from the current period).

ii) Suppose \( d > 0 \) and \( i=1 \) or the household expects prices will increase 2 periods from now. This provides the household with the incentive to reduce the acreage allocated for both crops, particularly that of crop 1 acreage, so that it will allocate more land next period to take advantage of the higher expected price in the period that follows. As a result, if crop 1 price is expected to increase in two periods, its acreage declines in the current period.

iii) Suppose the household expects an increase in crop 1 price \( i \) periods from now. Suppose also \( d < 0 \) or costs decline due to successive cultivation of both crops. Then, the household will use more land to cultivate crop 1 in the current period. Given revenue per unit of crop 1 output and acreage will be higher, \( i \) periods from now will induce the household to allocate more land for crop 1 at the \( i \)th period. Moreover, the household will take advantage of the price increase at the \( i \)th period if it uses more land to cultivate crop 1 in the current period.

B. The short-run acreage elasticity with respect to \( R_1 \) and \( V_1 \) are given by:

\[
\xi_{i+1}^{i+1} A_{i+1, R_1} = \left( \frac{\beta_1^{i+1} \lambda_1^{i+1}}{d} \right) ER_1 \quad \Diamond \quad 0
\]  

(A28)

\[
\xi_{i+1}^{i+1} A_{i+1, V_1} = \left( \frac{\beta_1^{i+1} \lambda_1^{i+1}}{d} \right) EV_1 \quad \Diamond \quad 0
\]  

(A29)

\( \xi_{i+1}^{i+1} A_{i+1, R_1} \approx 0 \) if \( d < 0 \). If \( d > 0 \), \( \xi_{i+1}^{i+1} A_{i+1, R_1} \) and \( \xi_{i+1}^{i+1} A_{i+1, V_1} \) are negative if \( i \) is even and positive if \( i \) is odd.
Appendix B. Descriptive Statistics of Non-teff Grains

Appendix Table B1. Results of pairwise Granger causality and instantaneous feedback tests of zonal crop output and prices of grains

<table>
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<th>Crop</th>
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<th>Price does not Granger cause output</th>
<th>Output and price do not have instantaneous feedback</th>
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Source: Authors' analyses using CSA (2005a, 2005b).
Note: Figures in parentheses are standard deviations.

Appendix Table B2. Mean regional non-teff cereals, pulses, and oilseeds acreage shares out of total area under grains 2004/05-2013/14, percent

<table>
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<td>Oilseeds</td>
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</tr>
</tbody>
</table>

Source: Authors' computation using CSA (2005-2013).
Note: Coefficients with †, ‡, and * are significant at 1, 5, and 10 percent, respectively.

Appendix Table B2. Mean regional non-teff cereals, pulses, and oilseeds acreage shares out of total area under grains 2004/05-2013/14, percent

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Source: Authors' computation using CSA (2005-2013).
Note: Figures in parentheses are standard deviations.
Appendix Table B3. Mean regional non-teff cereals, pulses, and oilseeds real prices 2004/05-2013/14, in Dec 2006 birr/kg

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</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.09)</td>
<td>(0.65)</td>
<td>(0.20)</td>
<td>(0.12)</td>
<td>(0.10)</td>
<td>(0.16)</td>
<td>(0.13)</td>
<td>(0.08)</td>
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<td>3.7</td>
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<td>4.1</td>
<td>3.7</td>
<td>5.0</td>
<td>4.9</td>
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<td>(0.17)</td>
<td>(0.21)</td>
<td>(0.29)</td>
<td>(0.36)</td>
<td>(0.26)</td>
<td>(0.30)</td>
<td>(0.43)</td>
<td>(0.49)</td>
<td>(0.43)</td>
<td>(0.72)</td>
</tr>
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<td>Tigray</td>
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<td>3.6</td>
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<td>(0.19)</td>
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<td>(0.18)</td>
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</tr>
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<td>4.0</td>
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<td>(0.12)</td>
<td>(0.19)</td>
<td>(0.21)</td>
<td>(0.18)</td>
<td>(0.11)</td>
<td>(0.14)</td>
<td>(0.08)</td>
<td>(0.09)</td>
<td>(0.75)</td>
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<td>4.1</td>
<td>3.5</td>
<td>5.4</td>
<td>4.3</td>
<td>3.3</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.26)</td>
<td>(0.11)</td>
<td>(0.13)</td>
<td>(0.19)</td>
<td>(0.08)</td>
<td>(0.20)</td>
<td>(0.09)</td>
<td>(0.10)</td>
<td>(0.73)</td>
</tr>
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<td>SNNP</td>
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<td>3.9</td>
<td>3.4</td>
<td>4.5</td>
<td>4.9</td>
<td>3.8</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td>(0.02)</td>
<td>(0.03)</td>
<td>(0.10)</td>
<td>(0.04)</td>
<td>(0.04)</td>
<td>(0.17)</td>
<td>(0.08)</td>
<td>(0.06)</td>
<td>(0.59)</td>
</tr>
</tbody>
</table>

Source: Authors’ computation using CSA (2014a, 2014b).
Note: Figures in parentheses are standard deviations.
Appendix C. Results of Tests and Additional Econometric Analyses

Appendix Table C1. Panel unit root tests of teff acreage, teff price, and opportunity cost of teff acreage

<table>
<thead>
<tr>
<th>Panel stationarity test</th>
<th>Specification</th>
<th>Teff acreage</th>
<th>Teff price</th>
<th>Opportunity cost of teff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Standard</td>
<td>De-meaned</td>
<td>With trend</td>
</tr>
<tr>
<td>Levin, Lin and Chu</td>
<td>Level Difference</td>
<td>-15.9†</td>
<td>-11.7†</td>
<td>-18.9†</td>
</tr>
<tr>
<td></td>
<td>Level Difference</td>
<td>-20.0†</td>
<td>-18.3†</td>
<td>-18.5†</td>
</tr>
<tr>
<td>Breitung</td>
<td>Level Difference</td>
<td>-6.2†</td>
<td>-6.1†</td>
<td>-4.5†</td>
</tr>
<tr>
<td>Im, Pesaran and Shin</td>
<td>Level Difference</td>
<td>-10.8†</td>
<td>-11.9†</td>
<td>-7.8†</td>
</tr>
<tr>
<td>Fisher-ADF</td>
<td>Level Difference</td>
<td>226†</td>
<td>251†</td>
<td>183†</td>
</tr>
<tr>
<td>Hadri</td>
<td>Level Difference</td>
<td>2.1†</td>
<td>2.6†</td>
<td>0.2</td>
</tr>
<tr>
<td>Harris-Tzavalis</td>
<td>Level Difference</td>
<td>-17†</td>
<td>-16.3†</td>
<td>-8.8†</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ analysis using CSA (2005-2013) and CSA (2014a, 2014b).

Notes: a) Coefficients with †, ‡, and * are significant at 1, 5, and 10 percent, respectively. b) The null hypothesis of Hadri’s test is that all series are stationary while the null hypothesis of Levin, Lin and Chu and the remaining methods is that the series are unit root with common and individual unit root processes, respectively.

Appendix Table C2. Systems and linear dynamic panel data estimates of AR(3) teff price and opportunity cost equations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Teff price equation</th>
<th>Opportunity cost of teff equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>System-ABBB</td>
<td>Linear-AB</td>
</tr>
<tr>
<td>Teff price(_{t-1})</td>
<td>0.327† (0.037)</td>
<td>0.575† (0.047)</td>
</tr>
<tr>
<td>Teff price(_{t-2})</td>
<td>-0.020 (0.036)</td>
<td>0.062 (0.060)</td>
</tr>
<tr>
<td>Teff price(_{t-3})</td>
<td>-0.011 (0.031)</td>
<td>0.100† (0.037)</td>
</tr>
<tr>
<td>Constant</td>
<td>3.114† (0.128)</td>
<td>1.578† (0.131)</td>
</tr>
<tr>
<td>x2-equation</td>
<td>3759† (3924†)</td>
<td>3761† (199†)</td>
</tr>
<tr>
<td>x2-regressors</td>
<td>369† (599†)</td>
<td>2340† (2662†)</td>
</tr>
<tr>
<td>x2-time dummies</td>
<td>3576† (3924†)</td>
<td>3761† (199†)</td>
</tr>
<tr>
<td>m1</td>
<td>-5.26†</td>
<td>-5.37†</td>
</tr>
<tr>
<td>m2</td>
<td>-0.29</td>
<td>0.45</td>
</tr>
<tr>
<td>x2–Sargan/Hansen test</td>
<td>37 32†</td>
<td>41†</td>
</tr>
<tr>
<td>Number of observations</td>
<td>318 318</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ analysis using CSA (2005-2013) and CSA (2014a, 2014b).

Notes: Figures in parentheses are standard errors. Coefficients with †, ‡, and * are significant at 1, 5, and 10 percent, respectively.
Appendix Table C3. Systems and linear dynamic panel data estimates of teff acreage demand equation, AR(2) and AR(3) teff price and opportunity cost

<table>
<thead>
<tr>
<th>Variables</th>
<th>System-ABBB</th>
<th>Linear-AB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AR(2)</td>
<td>AR(3)</td>
</tr>
<tr>
<td>Teff acreage_{t-1}</td>
<td>0.443†</td>
<td>0.039</td>
</tr>
<tr>
<td>Teff acreage_{t-2}</td>
<td>-0.028</td>
<td>0.047</td>
</tr>
<tr>
<td>Teff price_{t}</td>
<td>0.018</td>
<td>0.014</td>
</tr>
<tr>
<td>Teff price_{t-1}</td>
<td>0.021†</td>
<td>0.006</td>
</tr>
<tr>
<td>Teff price_{t-2}</td>
<td>-0.022†</td>
<td>0.007</td>
</tr>
<tr>
<td>Teff price_{t-3}</td>
<td>0.029†</td>
<td>0.006</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t}</td>
<td>-0.005†</td>
<td>0.001</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t-1}</td>
<td>0.003†</td>
<td>0.0003</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t-2}</td>
<td>0.001†</td>
<td>0.0003</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t-3}</td>
<td>-0.002‡</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

Constant                     0.063       0.048     0.154†      0.043       -0.035‡     0.015     0.006       0.019       
χ2-equation                   1696†       1556†     3493†       11752†      
χ2-regressors                 568†        716†      2865†       7144†       
χ2-time dummies               228†        51†       231†        78†         
m_{1}                         -3.74†      -3.57†    -3.14†       -3.15‡       
m_{2}                         -1.73*      -1.3      -2.87†       -1.78*       
χ2~Sargan/Hansen test         43          43       44           40          
Number of observations        371         318      371          318         

Long-run acreage demand elasticity with respect to:

<table>
<thead>
<tr>
<th>Variables</th>
<th>AR(2)</th>
<th>AR(3)</th>
</tr>
</thead>
</table>
| Teff price                     0.497       -0.304    2.550       1.473       
| Teff opportunity cost          0.019       0.236     -0.050      -0.525      

Short-run acreage demand elasticity with respect to:

<table>
<thead>
<tr>
<th>Variables</th>
<th>AR(2)</th>
<th>AR(3)</th>
</tr>
</thead>
</table>
| Teff price                     0.312       -0.045    0.311       0.355       
| Teff opportunity cost          -0.819      -0.151    -0.291      -0.139      

Source: Authors’ analysis using CSA (2005-2013) and CSA (2014a, 2014b).
Notes: SE stands for standard error. Coefficients with †, ‡, and * are significant at 1, 5, and 10 percent, respectively.

Appendix Table C4. Ordinary least squares and fixed effects estimates of teff acreage demand equation

<table>
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<tr>
<th>Variables</th>
<th>OLS</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AR(1) price and R_{1}</td>
<td>AR(2) price &amp; AR(1) R_{1}</td>
</tr>
<tr>
<td>Teff acreage_{t-1}</td>
<td>0.659†</td>
<td>0.049</td>
</tr>
<tr>
<td>Teff acreage_{t-2}</td>
<td>0.247†</td>
<td>0.049</td>
</tr>
<tr>
<td>Teff price_{t}</td>
<td>-0.003</td>
<td>0.011</td>
</tr>
<tr>
<td>Teff price_{t-1}</td>
<td>0.010</td>
<td>0.011</td>
</tr>
<tr>
<td>Teff price_{t-2}</td>
<td>-0.004</td>
<td>0.009</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t}</td>
<td>-0.001‡</td>
<td>0.001</td>
</tr>
<tr>
<td>Opportunity cost of teff_{t-1}</td>
<td>0.002†</td>
<td>0.001</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.003</td>
<td>0.026</td>
</tr>
<tr>
<td>F statistics</td>
<td>104†</td>
<td>96†</td>
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<tr>
<td>F stat.-regressors</td>
<td>207†</td>
<td>177†</td>
</tr>
<tr>
<td>F stat.-time dummies</td>
<td>5.4†</td>
<td>5.2†</td>
</tr>
</tbody>
</table>

Source: Authors’ analysis using CSA (2005-2013) and CSA (2014a, 2014b).
Notes: Figures in parentheses are standard errors. Coefficients with †, ‡, and * are significant at 1, 5, and 10 percent, respectively.
About the Authors

Fantu Nisrane is an Associate Research Fellow in the Development Strategy and Governance Division of the International Food Policy Research Institute (IFPRI), working within IFPRI’s Ethiopia Strategy Support Program (ESSP) with the Ethiopian Development Research Institute (EDRI) in Addis Ababa. Alemayehu Seyoum Taffesse is a Senior Research Fellow in the Development Strategy and Governance Division of IFPRI, working within ESSP with EDRI in Addis Ababa.

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