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Explaining technical inefficiency and the variation in income from apple adoption in highland Ethiopia: The role of unequal endowments and knowledge asymmetries

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Abstract

This paper considers the performance and quality of apple fruits and seedlings production in Chencha district of southern Ethiopia. The estimated, three-factor (labour, land and capital) production frontier reveals that the technical inefficiency is 60 % and 48 % for fruits and seedlings production, respectively. Endowments in land, apple plantation and manure are important production factors for both fruits and seedlings, while labour is significant only for seedlings production. We could not reject constant returns to scale, neither for apple fruits nor for seedlings. Apart from capital and labour endowments, producer knowledge on apple cultivation is a positive and significant determinant of the level of output, product quality, and income generated from apples. The insignificance of the education variable for fruits and seedlings production suggests that what matters in the apple business is specific knowledge of apple-growing technology rather than formal education, at least beyond primary education.

Keywords: performance, knowledge, quality, apple fruits, apple seedlings, elasticity, returns to scale

1 Introduction

Apple (*Malus domestica*), a temperate climate zone fruit tree, is not an indigenous crop to Ethiopia and can thus be considered relatively ‘new’ for Ethiopian farmers (Ashebir *et al.*, 2010). According to Hayesso (2008) and Girmay *et al.* (2014) it was introduced to the country some fifty years ago by missionaries from Europe and North America. However, it is only after active promotion by NGOs, which led to the establishment of a marketing cooperative in 1998, that the product became widely known to a large number of producers and taken up as a means of income by those living in the highland agro-climatic zones of Chencha. Chencha, located in the Gamo Gofa administrative zone of the Southern Nations, Nationalities and Peoples’ Regional State (SNNPRS), is the leading district in the country to adapt this fruit to the Ethiopian context and distribute the seedlings (plantlets)[1] to other parts of the country (Dagnew *et al.*, 2009). Nowadays, a number of other highland regions as well are becoming competent producers of different varieties of apple fruits and seedlings (Hruy *et al.*, 2012), assisted by government policies that promote apple as a strategic crop.

The farming systems of the Chencha district are mixed systems based on crop production and livestock rearing. According to the local Agricultural and Rural

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[1] The correct horticultural term for a grafted rootstock would be ‘plantlet’ rather than ‘seedling’, but for ease of comprehension we will refer to ‘seedling’ only, i.e., to distinguish this economic activity from fruit production in a consistent manner.

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Development Office (personal communication with experts; Fetena et al., 2014), the district has a total area of 37,650 ha, situated at an altitude ranging from 1,600–3,200 m asl with an average annual rainfall of 1,100–1,300 mm. The mean annual temperature is around 17°C (min. 11°C to max. 23°C). The cereals most commonly grown in the area are wheat and barley, while beans and peas are the most popular leguminous crops. Potato and enset (false banana) are the dominant root crops in the area. In terms of livestock ownership, cattle, sheep, horses, mules and chickens feature most prominently. Being the most important cash crop, apple orchards are estimated to cover 728 ha in total. The commonly used rootstalk varieties are MM106, MM111, M26, M27, M9, M4 and what is locally known as CH6. Especially MM106 is a widely used variety (Fetena *et al.*, 2014). The common varieties used as scion wood are Ana, BR, CP29, Crispin, Princesa, Dorset, Red delicious, Jonica, Red Jonagold, and Galla must, among others. Some farmers produce their own rootstalk and scion, and sell the leftovers on the market.

Several researchers have studied the impacts of apple fruit[2] adoption in the highlands around Chencha (Hayesso, 2008; Dagnew *et al.*, 2009; Freeman, 2013; Fetena *et al.*, 2014; Girmay *et al.*, 2014). While using different methods, ranging from large-scale surveys to ethnographic fieldwork, the studies agree on the fact that the income generated from apple varies dramatically among those households who have adopted the crop. Dana Freeman, an anthropologist who has done extensive fieldwork in the locality of Masho, observed that the introduction of apple has led to a ‘major increase in inequality’ (Freeman, 2013). This is borne out in the study by Girmay *et al.* (2014), who calculated from their survey among 141 households who commercialise apple in eight different *kebeles* in and around Chencha, that the top 5 % of producers accounted for no less than 75 % of total income generated from apple, while the bottom 60 % fail to generate even 5 % of the total surplus.

In explaining this extreme heterogeneity in performance, Girmay *et al.* (2014) stressed the unequal distribution in production factors, not only in terms of available land and the number of mother trees acquired, but also for instance in the possession of livestock for manure or capital to purchase modern grafting and pruning equipment. At the same time, however, the research alluded to the existence of knowledge gaps. For instance, the finding that roughly three out of four producers interviewed failed to prune and graft their seedlings properly, is explained by ‘the lack of technical know-how’, in addition to the non-availability of equipment (ibid.). Fetena *et al.* (2014), who conducted a study among 181 apple farmers in the same area, confirmed the variation in knowledge levels. For instance, they observed that there is ‘no standard for manuring and weeding of apple orchards in the study areas’ (p.13), which signals that not all farmers have converged to best practice. This is also illustrated by the fact that sizeable portions of the respondents could neither identify insect pests and crop diseases nor know what control strategies are available. Unfortunately, both studies only presented selective descriptive statistics on both factor constraints and knowledge asymmetries and did not perform a statistical test to relate these directly to income differentials, so that the relative importance of endowments and knowledge remained unclear. This, however, is of interest from a policy point of view, as unequal access to endowments like capital, labour and land likely requires different types of interventions than differentiated access to, and mastery of, knowledge about apple cultivation. This paper purports to provide such an empirical test based on survey data from 380 apple-producing households from four selected localities in Chencha district.

In order to distinguish between input constraints and knowledge asymmetries, we first estimate the stochastic frontier production functions for apple fruits and apple seedlings in the area. Subsequently, we use the production function to estimate the output for each household, given their endowments, and then compare the ‘fitted’ output levels to the actual ones reported by the households. The degree of *technical efficiency* will be obtained by taking the ratio of the actual to fitted frontier output levels. This degree of efficiency, as well as the deviations between original and predicted values are then regressed on a knowledge index. We also link the knowledge index to quality differences in output, taking the shares of first and second grade apples in total production as dependent variables. Finally, we present an integrated regression that shows the relative importance of resource constraints and knowledge differentials. It is important to note that the current paper does not explore the various types of market and governance failures that may underlie both the inequality in endowments and the differentiated access to relevant knowledge. In this respect we should point out that limited resources devoted to apple production do not necessarily represent struc-

[2] While we will use the term ‘apple fruits’ throughout the paper, it should be pointed out that this also includes different varieties of pears. Local producers treat pears as a variety of apple, so we also ignore the distinction here. Apple is by far the dominant crop in terms of output and value, however.

tural inequalities. Households who are engaged in other types of agricultural production or in non-farm activities may deliberately choose to make limited investments in apple cultivation, even if their endowments are abundant.

2 Technical efficiency as performance measure

There is a wide array of literature that relates the use of various agricultural technologies to performance (Squires & Tabor, 1991; Bravo-Ureta & Pinheiro, 1993; Bravo-Ureta & Evenson, 1994; Kalirajan & Shand, 2001; Haji, 2007). A powerful measure of performance is the widely used notion of economic efficiency, which in turn can be decomposed into technical and allocative efficiency (Farrell, 1957). Allocative (or price) efficiency measures the firm's success in choosing the optimal input combination, i.e., where the ratio of marginal products for each pair of inputs is equal to the ratio of their market prices (Bravo-Ureta & Pinheiro, 1993). By contrast, a farmer's technical efficiency measures a farmer's ability to produce the maximum possible level of output from a given input and production technology (Squires & Tabor, 1991). Hence, technical inefficiency refers to the failure of attaining this maximum level. Since our dataset does not have complete information about prices and costs, we confine our analysis to technical efficiency only.

Technical efficiency is a concept that compares each farmer's production performance with the input-output relationship that is deemed 'best practice' (Squires & Tabor, 1991). The best practice can consist in the performance of a researcher in a farmer's field or the practice of the most efficient farmers in a comparable environment. Technical efficiency is then measured as the deviation of individual farmers from this best practice frontier. In our case the practice of the best producers has been taken as a benchmark.

Stochastic frontier analysis and data envelopment analysis (DEA) are two alternative methods for estimating frontier functions and thereby measuring efficiency of production (Coelli *et al.*, 1998). DEA involves the use of linear programming, whereas stochastic frontiers involve the use of econometric methods. The stochastic frontier production model incorporates a composite error structure with a two-sided symmetric error and a one-sided component as proposed by Aigner *et al.* (1977) and Meeusen & van den Broeck (1977). The one-sided component reflects inefficiency (u), while the two-sided error (v) captures the random effects outside the control of the production unit, including measurement error and other random factors that can affect the relationship (Bravo-Ureta & Pinheiro, 1993; Coelli *et al.*, 1998). The estimation of the stochastic frontier function can be accomplished using maximum likelihood estimation or corrected ordinary least squares (COLS) (Richmond, 1974), depending on whether an explicit distribution for the error term of the efficiency component is assumed or not (Bravo-Ureta & Pinheiro, 1993). When assumptions are made explicit, exponential, gamma or half-normal distributions are commonly used.

Several agricultural efficiency analyses have been carried out in the Ethiopian context, of which the studies by Gebreegziabher *et al.* (2004), Seyoum *et al.* (1998) and Haji (2007) stand out. Seyoum *et al.* (1998) estimated the stochastic frontier production function for maize farmers in eastern Ethiopia, distinguishing between participants and non-participants in a project that promotes high-input maize technologies (Sasakawa-Global 2000 project). They established that project farmers are technically more efficient than those who remained outside the project. The study by Haji (2007) estimated technical, allocative and economic efficiency levels for mixed farmers in eastern Ethiopia who are predominantly engaged in growing vegetables. Using non-parametric data envelopment analysis they revealed technical, allocative and economic efficiency of 91, 60 and 56 %, respectively. Finally, using a similar methodology, Gebreegziabher *et al.* (2004) found 80 % technical efficiency among farmers in northern Ethiopia in producing commonly grown crops in the region. They used the value of overall crop output (in birr) as a dependent variable.

3 Materials and methods

3.1 Sampling, data and measurement

The sampling strategy for the survey was based on random selection of four out of six *kebeles* in the district, all of which have experience in apple production. In the selected villages all apple-producing farmers were surveyed. Hence, the survey was in fact a census, ensuring representativeness for these four localities. In total 380 households were interviewed.

In order to estimate the average and stochastic frontier Cobb-Douglas production function, the dependent variables are 1) apple fruits output and 2) number of seedlings produced. The explanatory variables include 1) plot size allocated to fruits and seedlings production, 2) labour used in the production of fruits and seedlings in man-days, 3) reported value of apple plantation owned, and 4) amount of manure applied. Together with apple plantation value, manure is considered to represent a capital input. Since there is no market for manure in Chencha, livestock wealth is the dominant constraint on the application of manure. All variables are transformed into logarithms.

The general performance in apple production among the surveyed households is proxied by the technical efficiency measure and individual performance is assessed by the ratio $\frac{(Y-\hat{Y})}{\hat{Y}}$, where Y is the original observation of output and $\hat{Y}$ is the predicted value of output after fitting the logarithmic transformation of the Cobb-Douglas production function. This ratio has been generated for fruits and seedlings separately. The same procedure has been applied to income generated from apple and seedlings, which is the performance indicator that is of prime interest to explain the observed disparity in welfare outcomes from apple production.

The level of a producer's knowledge on apple 'technology' is measured by scoring this producer on a knowledge index. This index is constructed based on weighting the individual's knowledge on the 'best practices' in the various stages of cultivation of the crop. These stages were categorised into six; variety identification, grafting, tree management, pest control, post-harvest handling, and marketing. For instance, farmers who lack knowledge on variety identification may not properly graft their seedlings with the appropriate variety. Likewise, those who do not know the benefit of pruning might be unable to manage the size of their tree and thereby jeopardize the quality of the fruits. Knowledge pertaining to each stage of production has been scored on a five-point Likert scale, based on self-reports. The overall index scale for knowledge has been generated using principal components analysis (PCA). Three principal components with eigen values higher than unity were taken from the six knowledge level variables.

Apple fruits and seedlings quality is measured by the respective ratios of first grade output to total production, which are used as dependent variables in the quality regressions. In addition to the knowledge index, the models control for other explanatory variables hypothesised to affect performance, including a number of demographic and socioeconomic characteristics of farmers and their households, market availability, membership in a cooperative, and village dummies.

3.2 The model

The stochastic frontier Cobb-Douglas production function with the following form is assumed:

$$Y = A\, f(K^{\alpha}, L^{\beta}, N^{\gamma})\, e^{\varepsilon_i}, \tag{1}$$

where Y = apple fruits output or the number of seedlings produced, K, L and N are capital, labour, and land that have been used in the production of apple fruits and seedlings, $\varepsilon_i = v_i - u_i$ is the composite error term containing the random error (v) and the technical efficiency component (u), A is production technology, and α, β and γ are the elasticity coefficients of output with respect to capital, labour and land, respectively. All the inputs are assumed variable. Land for a given individual in a season is fixed but in cross-sectional data it varies across observations.

Equation (1) can be expressed in linear form by using the following logarithmic transformation:

$$\ln Y = \beta_0 + \alpha \ln K_i + \beta \ln L_i + \gamma \ln N_i + v_i - u_i \tag{2}$$

Therefore, to estimate elasticity parameters of each input, we run OLS regression on equation (2). These elasticity coefficients from the OLS estimation indicate the percentage change in output for a unit percentage change in the respective inputs. The sum of the elasticity coefficients is an indicator of the returns to scale in production, i.e., $\alpha + \beta + \gamma = 1$ indicates constant returns to scale and a sum < 1 (> 1) decreasing (increasing) returns to scale.

Based on the estimation of the stochastic frontier model of equation (2) using maximum likelihood estimation and the half-normal distribution assumption for the error term, the technical efficiency coefficients for each individual producer can be calculated by dividing the actual production figures by the predicted values of the frontier function $TE = \frac{Y}{\hat{Y}}$, and range between 0 and 1. The level of inefficiency $(1-TE)$ is subsequently used in the regression.

The other output performance indicator, $\frac{(Y-\hat{Y})}{\hat{Y}}$, is modeled as follows:

$$Z = \sigma + \lambda X + e, \tag{3}$$

where $Z = \frac{(Y-\hat{Y})}{\hat{Y}}$, X is a vector of explanatory variables, σ the constant term, λ is a vector of parameters to be estimated, and e is the error term.

The ratio of first grade to total production, denoted by $\frac{Q_1}{Q_T}$, has been taken as a dependent variable to explore factors affecting product quality, where Q_1 is first grade quantity and Q_T is total quantity of production. This ratio is calculated for fruits and seedlings quantities separately. A similar model as in equation (3) has been fitted for quality performance. For the inefficiency and quality analyses a Tobit model has been applied, while the other analyses are run using OLS regression techniques.

4 Results

4.1 Descriptive statistics

The descriptive statistics of the surveyed households are shown in Table A1 in the Appendix. The data indicate that the average household size is 6.2 and the maximum number of household members registered equals 14. The age of respondents ranges between 16 and 95 years with an average age of 44.2. The respondent with the best education profile reports having attended school for 16 years, but on average educational careers last for 7.8 years only. Regarding apple and seedlings production, the extent of experience varies widely. One respondent has been producing apple for 34 years, whereas others started as recently as one year ago. On average, respondents have 10.2 years of experience in apple cultivation. Average landholdings are small with 0.9 ha, ranging from a minimum of 0.005 to a maximum of 7.65 ha. Producers on average allot 0.08 and 0.03 ha of land for fruits and seedlings, respectively. The data reveal a strong preference to cultivate apple fruits and seedlings in their own backyard rather than on plots located at some distance from their residence. This might be due to fear of loss from theft [3], ease of management or soil fertility reasons.

The average income of the producers from apple fruits production was 5,555 Birr ($285) [4] in the 2012 production year. The maximum amount earned by a producer was 59,713 Birr ($3,062). Seedlings production generated an income of 17,400 Birr ($892) on average, up to 244,240 Birr ($12,525) in the best of cases in the same production season. First-grade fruits and seedlings fetched a market price that was on average 38 % and 68 % higher than the market price obtained for second-grade fruits and seedlings, respectively. Concerning quality of the produce, 65 % of the total production of fruits and seedlings of the average producer is first grade. Hence, more than a third of production tends to be classified as second grade.

4.2 Production functions

Table 1 reports the result from estimating equation (2) to arrive at the average production function and stochastic frontier for apple fruits and seedlings. As shown in column 2, the output of apple fruits is positively and significantly affected by both capital-intensive inputs and land. The column reports elasticity coefficients of apple fruits output to each factor input. Plantation asset has an elasticity of 0.30 and manure of 0.22. It follows that the elasticity of fruits output to capital is 0.52, which is the sum of the two elasticity coefficients. Therefore, a unit percentage increase in capital input yields a 0.52 % increase in fruits output.

The elasticity of land equals that of capital. Increasing the amount of land in hectares by a unit percentage point raises fruits output by 0.52 percentage points. The elasticity with regard to labour is negative but insignificant. As shown in the fourth column, all input factors make a significant positive contribution to seedlings production. The elasticity coefficients are 0.6, 0.13 and 0.28 for capital, labour and land, respectively.

The Likelihood Ratio test indicates technical inefficiency in the production of both apple fruits and seedlings. The inefficiency was 60 % for fruits and 48 % for seedlings production (Table 1). Table A3 in the annex displays the Tobit regressions of these levels of inefficiency on a set of exogenous explanatory variables. Inefficiency in fruits production is explained by a lack of cultivation experience and by the particular village in which the producer resides. By contrast, inefficiency in seedlings production can be linked to a lack of knowledge on the technology and not being able or willing to join a marketing cooperative. Moreover, older and female farmers tend to be less efficient.

4.3 Productivity

Table A2 of the annex shows the productivity of capital and labour per unit of land. Output per hectare was used as the dependent variable and labour per hectare, manure per hectare, and plantation asset per hectare, were treated as explanatory variables. We find that seedlings production is more intensive in manure than fruits production, while plantation asset is more productive for fruits than for seedlings. Also, the productivity analysis confirms that labour input is important for seedlings, but not significant in fruits production. As a robustness check, we ran an adapted version of the Cobb-Douglas production function in equation 2, in which labour and manure are included as logarithmic transformations while the other variables, including additional explanatory variables, are in levels. The results (available from authors on request) are almost identical to the ones obtained from our original specification.

[3] This particularly applies to seedlings. According to Freeman's (2009) observations in Masho village: "The problem [of theft] has become so intense that nowadays no-one plants apple saplings in regular agricultural plots, which are unfenced and unguarded. Instead people have started to plant the apple saplings within their homesteads." pp.251.

[4] At the time of data collection the average official exchange rate of USD to Ethiopian Birr was 1$(USD) = 19.5 Birr.

Table 1: *Cobb-Douglas frontier production functions for apple fruits and seedlings*

Variables	*Fruits output (in kg)*		*# of seedlings produced*	
	Average function	*Stochastic frontier*	*Average function*	*Stochastic frontier*
Quantity of manure applied (in kg)	0.22 (0.07)**	0.18 (0.06)**	0.39 (0.05)**	0.36 (0.05)**
Value of apple plantation asset (in Birr)	0.30 (0.06)**	0.28 (0.06)**	0.21 (0.05)**	0.20 (0.04)**
Land allocated (in ha)	0.52 (0.06)**	0.54 (0.05)**	0.28 (0.05)**	0.28 (0.04)**
Labour used (in man-days)	–0.05 (0.08)	–0.06 (0.07)	0.13 (0.05)**	0.16 (0.05)**
Constant	2.88 (0.73)**	4.80 (0.73)**	3.00 (0.57)**	3.73 (0.57)**
F-Statistic	56.46	–	94.94	–
Adjusted R-squared	0.39	–	0.55	–
Λ	–	2.27 (0.21)	–	1.63 (0.20)
σ^2	–	3.48 (0.42)	–	1.48 (0.22)
Log Likelihood	–	–561	–	–397.5
χ^2 for $u = 0$	–	22.5**	–	7.87**
Average inefficiency, %		60		48
No. of obs.	343	343	307	307

Note: $^{+}$ $p<0.1$; * $p<0.05$; ** $p < 0.01$. The figures in parentheses represent the robust standard errors. All variables are expressed in natural logarithms.
Source: Own survey 2013

4.4 Variation in output performance

Based on the Cobb-Douglas results presented in Table 1, output values have been predicted as well as the corresponding deviations of these predicted values from the actual production values, both for fruits and seedlings. The ratio of these deviations to the predicted values, defined as Z in equation (3), has been used as the dependent variable in the regressions shown in Table 2. We ran OLS for fruits (column 2) and seedlings (column 3) on the knowledge index and a number of exogenous explanatory variables.

The analysis reveals that knowledge positively and significantly contributes to seedlings production, but turns out to be an insignificant determinant of fruits output. Other significant determinants of output (for both fruits and seedlings) include the size of the cultivated area and the number of fruit trees owned by the producer. The age of trees plausibly affects only fruits output. Also, the cultivation experience (in years) of the producers improves output from fruits but not from seedlings. This indicates that new adopters are more inclined towards the production of seedlings, which is evidenced by the age of the producers as well. Age is a negative and significant determinant for seedlings output. Interestingly, market availability positively affects fruits output but is not significant for seedlings.

Another important predictor in the case of seedlings performance is the respondent's engagement in non-farm activities, which negatively affects output from seedlings. This indicates that those who achieve high output levels of seedlings tend to refrain from participation in non-farm activities. Another interesting result concerns (formal) education, which is insignificant in the model. Concerning gender, the sex of the producer only matters for seedlings production, where men outperform women.

Another relevant determinant is location, albeit for fruits production only. Fruits output in Doko Shaye subdistrict is significantly higher than in the reference village of Tolola. Finally, cooperative membership has a positive and significant contribution on both fruits and seedlings production. Cooperative members on average produce 2 % more fruits and 5.2 % more seedlings than non-members, other things being equal.

4.5 Performance on Income

In Table 3 output is replaced by the income that households report to have generated from fruits and seedlings as alternative performance indicator. Quality, to which we turn in the next section, is included as explanatory variable in this analysis. The results indicate that the size of the area cultivated, number of trees, product quality, and cooperative membership are significant and positive contributors towards higher income from the apple business. On the other hand, the knowledge of the producer and quantity of manure applied were found to be positive contributors to income from seedlings production only.

Table 2: *OLS regression for apple fruits and seedlings output performance*

Variables	*Ratio for fruits output*	*Ratio for seedlings produced*
Apple cultivation experience in years	0.29 (0.10)**	–0.08 (0.30)
Market availability (rated 1–5)	1.68 (0.81)*	1.12 (1.47)
Knowledge index on apple technology	–0.14 (0.28)	2.96 (0.93)**
Area covered	9.75 (5.88)+	63.54 (29.65)*
Number of trees	0.05 (0.01)**	0.13 (0.04)**
Average age of trees	0.61 (0.15)**	–0.22 (0.41)
Quantity of manure applied	–0.00 (0.00)	0.00 (0.00)
Age of respondent	–0.03 (0.04)	–0.19 (0.09)*
Sex of household head (male=0; female=1)	1.54 (1.40)	–6.50 (2.11)**
Education, grade completed in years	–0.10 (0.13)	–0.37 (0.27)
Non-farm work participation dummy	0.78 (1.22)	–6.18 (2.76)*
Asset index (value of livestock, equipment & house)	0.24 (0.55)	0.35 (1.97)
Cooperative membership	2.03 (1.12)+	5.20 (2.06)*
Dummy for Doko Shaye village	8.46 (1.66)**	–3.76 (3.00)
Dummy for Doko Losha village	–2.82 (1.74)	–0.85 (3.99)
Dummy for Chencha town	2.24 (1.39)	2.12 (3.45)
Constant	–15.37 (3.58)**	25.23 (9.31)**
F-Statistic	12.69	7.41
Adjusted R-squared	0.42	0.44
No. of obs.	296	310

Note: $^{+}$ $p<0.1$; * $p<0.05$; ** $p<0.01$. The figures in parenthesis represent the robust standard error.
Source: Own survey 2013

Table 3: *Performance on fruits and seedlings income*

Variables	*Ratio for fruits income*	*Ratio for seedlings income*
Area covered	68.45 (32.9)*	341.45 (181.14)+
Number of trees	0.33 (0.06)**	0.67 (0.23)**
Average age of trees	2.52 (0.55)**	–2.11 (2.52)
Quantity of manure applied	–0.01 (0.01)	0.08 (0.03)**
Quality (first grade/total production)	24.76 (8.82)**	47.24 (27.78)+
Sex of household head (male=0; female=1)	5.88 (5.43)	–30.57 (9.31)**
Apple cultivation experience in years	0.38 (0.39)	–1.33 (1.79)
Cooperative membership	11.80 (2.86)**	28.99 (10.95)**
Knowledge index on apple technology	–0.95 (0.92)	16.90 (5.47)**
Constant	–46.21 (9.29)**	27.58 (25.98)
F-Statistic	22.61	8.89
Adjusted R-squared	0.47	0.42
No. of obs.	329	273

Note: $^{+}$ $p<0.1$; * $p<0.05$; ** $p<0.01$. The figures in parenthesis represent the robust standard error.
Source: Own survey 2013

4.6 Quality

The quality of fruits and seedlings, i.e., the share of first-grade produce, was regressed on a set of explanatory variables, including the level of knowledge of the producer. Table 4 shows the results from the Tobit regression. Knowledge on apple technology turns out to be a positive and significant determinant of both fruits and seedlings quality. Other relevant quality determinants of fruits include market availability, price incentives (first-grade to second-grade price ratio), cooperative membership and the frequency of visiting other producers' orchards. The number of visits paid to the orchards of others likely increases the production abilities of the visitor through sharing experiences and best practices of the producers visited. Location-wise the Doko Shaye village and Chencha town outperform the reference village of Tolola in fruits quality, whereas Doko Losha village produces lower-quality fruits than Tolola. The village dummies did not pick up any location-specific effects on the quality of seedlings.

5 Discussion

The result from the Cobb-Douglas stochastic frontier analysis generated the expected sign for all inputs, except labour, in the production of both fruits and seedlings. Capital is slightly more important for seedlings than for fruits production, but the real difference lies in land and labour endowments. Land availability is far less important in seedlings production, which results from the fact that seedlings can be planted in close range from each other, whereas fruit trees need to be properly spaced in an orchard. Moreover, labour is a significant input in seedlings production, which was not the case for fruits. Since the sum of the elasticities roughly equals unity, we can conclude that seedlings production exhibits constant returns to scale. Nor could we reject the constant returns to scale assumption for fruits, except for the negative sign for labour. While counterintuitive, it is not uncommon to find negative contributions from labour in this type of analysis (Sahota, 1968; Chowdhury *et al.*, 1975). It should be borne in mind that labour in fruits production mainly concerns land preparation and planting, which is a one-time activity in the first season and in consecutive years no additional land preparation is required except for relatively modest labour efforts in tree management activities, such as weeding, pruning, irrigation, and harvesting. Hence, compared to seedlings production, labour input in fruits production is low, except for the early years after planting. Even though it is plausible that labour is not a large contributing factor in apple production, we did not anticipate a (modest) negative effect. Sahota (1968) points to multicollinearity, measurement error or shortage of rain as potential

Table 4: *Tobit model estimation for fruits and seedlings quality*

Variables	*Fruits quality*	*Seedlings quality*
Market availability (rated 1–5)	0.05 (0.01)**	0.00 (0.01)
Density (no. of trees/area)	–0.00 (0.00)	0.00 (0.00)
Per-capita manure applied	–0.00 (0.00)	–0.10 (0.049)*
Price ratio (first grade/second grade)	0.07 (0.03)*	–0.01 (0.01)
Knowledge index on apple technology	0.02 (0.01)**	0.02 (0.01)*
Sex of the respondent	0.03 (0.03)	0.02 (0.03)
Age of the respondent	–0.00 (0.00)	–0.00 (0.00)
Highest grade education in years	–0.00 (0.00)	0.00 (0.00)
Cooperative membership dummy	–0.06 (0.04)$^{+}$	0.00 (0.04)
Frequency of invitation by neighbours	0.03 (0.01)**	0.02 (0.01)**
Dummy for Doko Shaye village	0.14 (0.03)**	0.04 (0.03)
Dummy for Doko Losha village	–0.13 (0.04)**	–0.05 (0.04)
Dummy for Chencha town	0.09 (0.03)**	0.04 (0.03)
Constant	0.30 (0.10)**	0.54 (0.07)**
LR χ^2	(110.08)**	(29.09)**
Pseudo R- squared	–0.71	–0.12
No. of obs.	239	199

Note: $^{+}$ $p<0.1$; * $p<0.05$; ** $p < 0.01$. The figures in parenthesis represent the robust standard error.
Source: Own survey 2013

causes of a negative contribution from labour that resulted from his own work on Indian agriculture. We do not detect multicollinearity problems in our dataset, but cannot rule out measurement error [5].

The level of technical inefficiency is higher in fruits production relative to the seedlings case, which may suggest that people usually plant the trees (orchard) for trial and ignore the management for lack of know-how. Still, it will bear some fruits eventually. Whereas in the seedlings case, most people may not be strongly motivated to try the planting when lacking the necessary techniques and if they try, it will be with some understanding of how it works. Hence, seedlings production is more knowledge-intensive, requiring technical know-how on issues like variety identification, grafting and other intensive seedlings management activities. Therefore, there is more involvement in planting orchards relative to producing seedlings among those with limited information, resulting in higher levels of inefficiency in fruits production.

Performance in production is driven by a number of factors. For the fruits, producer's experience and the tree quality and quantity (i.e. age and number of trees) delivers a better outcome, but for the seedlings, technical know-how, age, and sex are important determinants. Young and male producers perform better. This might be due to better access to information relative to the other groups. Another important predictor in the case of seedlings performance is the respondent's engagement in non-farm activities, which negatively affects output from seedlings. This indicates that those who achieve high output levels of seedlings tend to refrain from participation in non-farm activities. Due to the relatively high labour-intensity of seedlings production, it competes for scarce labour with non-farm occupations.

The insignificance of education shows that what matters in apple production is the specific knowledge on the technology rather than the formal education attained by the producer. However, it should be noted that the average level of education of the producers is 7.8 years, so that having completed primary education could still be an important determinant of performance. The observed effect of education in the literature is mixed. Studies have encountered positive, negative and neutral effects. Kalirajan & Shand (1985) obtained non-significant effect of education on rice yield in Tamil Nadu, whereas Pudasaini (1983) found a positive effect of education in modern agriculture compared to the traditional one in Nepal [6]. Concerning the locations, the fieldwork did not bring forward an obvious explanation for this variation in performance across these specific localities, but variation in soil fertility or climatic conditions that affect dormancy may be responsible. No other location effects were detected.

Performance in income is driven by quality of produce and cooperative membership, among others. Since first-grade produce commands a much higher price than its second-grade counterpart, quality producers will benefit more. Cooperatives are the dominant market outlets in the area that increase the earning of the producers who supply to these channels, since they have better market access and reap a higher price compared to the other outlets. Market availability and price ratios of first and second grade produce were important predictors of fruits quality. This might be due to the fact that market demand for seedlings has so far been high, also as a result of government promotion, while demand for fruits is considered a constraint, given that most Ethiopian consumers are not yet very familiar with apples. It is expected that the tables might turn in the future, however. Demand for seedlings is likely to dwindle once other regions have expanded their apple cultivation, while demand for fruits is likely to grow steadily (Girmay *et al.*, 2014). The price gap between first and second grade output sometimes tends to be very large, such that it indirectly discourages production of second grade relative to premium quality, by which it contributes to quality fruits production. Manure application, unexpectedly, failed to show a significant effect on apple quality, while importantly affecting apple yields in volume terms.

6 Conclusion

With the objective to estimate technical efficiency using the Cobb-Douglas stochastic frontier production function and to identify how knowledge of the producer contributes to output and quality in fruits and seedlings production, we have found that; first, the stochastic frontier production function estimation has shown that there was 60 % and 48 % technical inefficiency in the production of apple fruits and seedlings in Chencha district, respectively. Table 5 provides an overview of the key drivers of this inefficiency, for both fruits and seedlings, beyond the 'usual suspects' of disparities in conventional input factors land, labour and capital. When comparing fruits and seedlings, the respective drivers show

[5] Guarding the seedlings 24/7 is an activity done parallel to other activities, especially during daytime, which has likely resulted in some double counting when eliciting a household's time allocation.

[6] See Weir & Knight (2004) and Weir (1999) for a detailed review on the effect of education on agricultural performance.

Table 5: *Summary of results from the regression analysis*

Variable	*Fruits*				*Seedlings*			
	Output Performance	*Income Performance*	*Technical Efficiency*	*Quality*	*Output Performance*	*Income Performance*	*Technical Efficiency*	*Quality*
Knowledge	(–)	(–)	(+)	(+)***	(+)***	(+)***	(+)*	(+)**
Education	(–)		(–)	(–)	(–)		(–)*	(+)
Experience	(+)***	(+)	(+)***		(–)	(–)	(–)	
Age	(–)		(+)	(–)	(–)**		(–)***	(–)
Sex	(+)	(+)	(–)	(+)	(–)***	(–)***	(–)**	(+)
Cooperative membership	(+)*	(+)***	(+)	(–)*	(+)**	(+)***	(+)**	(+)

Note: * $p<0.1$; ** $p<0.05$; *** $p < 0.01$. The + and − signs in parentheses are the signs of the coefficients of the respective variables.
Source: Own survey 2013

considerable overlap. For example, cooperative membership is important in explaining the income obtained from both apples and seedlings, whereas formal education levels fail to emerge as an important determinant in either of these. At the same time, the overlap is only partial. While knowledge impacts positively on the quality of both apples and seedlings, it only boosts income from seedlings through higher output, which does not materialize in the case of fruits. Vice versa, experience in cultivation benefits fruits production, whereas it does not have an impact on the outcome variables for seedlings. The latter are, unlike those for apples, responsive to age and gender of producers.

Since the level of technical efficiency in fruits and seedlings production is quite low, there is ample room to take measures that push inefficient producers towards the frontier. A direct way to achieve this objective is to improve the knowledge of producers. The extension service and other stakeholders are expected to improve the knowledge of the producers on various aspects of the technology, but the potential of other sources of knowledge, such as social networks, training and experience, and their relative contribution to improve the technological competence of the producer, need further research. Second, market access could be optimised through strengthening weak cooperatives or linking farmers to strong cooperatives and other potential customers. Third, since capital is most significant, planting more orchard trees will improve the supply of planting materials for seedlings production and increase the volume of fruits output. Moreover, livestock production needs to be promoted in the absence of a market for manure.

Finally, as young producers were performing well, access to land and licensing of knowledgeable seedlings producers might be considered to exploit the maximum benefit from the technology and improve livelihood in highland areas like the Chencha district in Ethiopia.

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Appendix

Table A1: *Descriptive statistics*

Variable	*Obs*	*Mean*	*SD*	*Min.*	*Max.*
Family size	380	6.20	2.51	1	14
Sex of head (0=male; 1=female)	380	0.12	0.32	0	1
Age	380	44.20	13.97	16	95
Education in years	380	7.79	4.64	0	16
Cultivation experience in years	380	10.52	5.47	1	34
Knowledge index	380	0.00	1.99	–4.38	4.45
Asset index	380	0.00	1.19	–1.06	9.89
No. of apple trees	380	47.93	69.55	2	718
Age of trees	380	7.32	3.60	1	27
Manure amount applied for fruits production (in kg)	380	107.4	230.64	1	2,320
Manure amount applied for seedlings production (in kg)	320	78.41	301.86	1	4,140
Total plot size owned (ha)	380	0.90	1.02	0.005	7.65
Plot allotted for apple fruits (ha)	380	0.08	0.12	0.001	1
Plot allotted for seedlings (ha)	314	0.03	0.09	0.0004	1
Labour per fruit tree (man-days)	380	9.18	15.07	0.11	146.4
Labour per seedling (man-days)	312	2.50	5.55	0.02	40.4
Total fruits production in kg	380	307.1	527	1	3923
Total seedlings production in number	314	711.8	1065.1	5	8150
Income from fruits in Birr	380	5,555.6	9,473.8	1	59,713
Income from seedlings in Birr	380	17,398	33,614	1	244,240
Seedlings quality	314	0.66	0.20	0	1
Fruits quality	354	0.64	0.22	0	1
Fruits price ratio ($1^{st}/2^{nd}$) grade	240	1.38	0.32	0.74	3
Seedlings price ratio ($1^{st}/2^{nd}$) grade	200	1.68	0.71	0.81	4.78
Ratio fruits income deviation	334	29.32	46.66	–1	242.65
Ratio seedlings income deviation	277	86.48	145.87	–1	954.26
Ratio seedlings output deviation	312	18.17	26.13	–1	169.22
Ratio fruits output deviation	312	5.98	10.28	–1	67.43
Log fruits produced	354	4.68	1.67	0	8.27
Log seedlings produced	314	5.77	1.36	0	9.00
Log plantation asset	380	9.79	1.38	6.21	13.82
Log fruits land	380	–3.37	1.32	–6.90	0
Log seedlings land	314	–4.35	1.54	–7.82	0
Log labour fruits	343	4.96	0.97	1.94	7.08
Log labour seedlings	310	5.47	1.14	1.80	7.48
Log manure for fruits	380	3.89	1.20	0	7.75
Log manure for seedlings	320	3.18	1.30	0	8.33
Market availability for fruits	363	3.60	1.05	1	5
Market availability for seedlings	364	3.59	.97	1	5
Cooperative membership	380	.81	.40	0	1
Non-farm work participation dummy	380	.72	.45	0	1
Frequency of invitation by neighbours for food or drinks (0 = None . . . 4 = >5 times)	380	2.78	1.27	0	4

Source: Own survey 2013

Table A2: *Cobb-Douglas productivity function*

Variable	*Log of fruits output per hectare*	*Log of seedlings produced per hectare*
Log of manure applied in kilo grams per hectare	0.22 (0.06) **	0.43 (0.05) **
Log of apple plantation asset per hectare	0.303 (0.054) **	0.07 (0.04) *
Log of Labour used in man-days per hectare	–0.12 (0.056) *	0.192 (0.03) **
Constant	3.37 (0.62) **	4.065 (0.53) **
F- Statistic	23.46	9110
Adjusted R- squared	0.16	0.47
No. of obs.	354	311

Note: + $p<0.1$; * $p<0.05$; ** $p < 0.01$. The figures in parenthesis represent the robust standard error.
Source: Own survey 2013

Table A3: *Technical inefficiency (TIE) regressed on selected explanatory variables*

Variable	*TIE for fruits*	*TIE for seedlings*
Gender of household head (0=male; 1=female)	0.057 (0.051)	0.140 (0.060)*
Education in years	0.003 (.004)	0.009 (.004)+
Age in years	–0.000 (0.001)	0.005 (0.001)**
Cooperative membership	–0.064 (.049)	–0.184 (0.072)*
Knowledge index	0.004 (.011)	–0.024 (0.012)+
Cultivation experience	–0.012 (.004)**	–
Doko Shaye village	–0.372 (.052)**	–
Doko Losha village	0.158 (.054)**	–
Chencha Town	–0.126 (.048)*	–
Constant	0.779 (.121)**	0.198 (0.137)

Note: + $p<0.1$; * $p<0.05$; ** $p < 0.01$. The figures in parenthesis represent the robust standard error.
Source: Own survey 2013