LAND TENURE AND TECHNICAL EFFICIENCY OF SMALLHOLDER TEA PRODUCERS: THE CASE OF YA'AN CITY, CHINA

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Abstract: *70 percent of the world and 80 percent of China's tea production produced by smallholder farmers. However, the tea production per unit area significantly unchanged in the past decades. Understanding factors affecting the technical efficiency of smallholder tea producers is very important to maximize tea production. Aimed at examining the impact of land tenure security and land certification on smallholder tea producers' technical efficiency, this paper employs the Cobb-Douglas Stochastic Production Frontier (CD-SPF) and Translog Stochastic Production Frontier (TL-SPF) methods for Maximum Likelihood Estimate (MLE) with cross-sectional data collected from 161 randomly selected tea farm plot households in Ya'an city, China. We found that an 1 mu (0.067 ha) increase in the tea farm size will produce a 1.086 tea yield advantage for smallholder tea farmers. We also found that the values of input-output elasticity of land size, household income and labor decrease in turn with 0.144, 0.105 and 0.010 respectively. The results show that farm size is a more crucial input for tea production than income and labor. Moreover, we identify the determinations which enhance the technical efficiency of smallholder tea producers such as land certification, land tenure security age, education, farming experience, total farm size holding, chemical fertilizer, plot steepness and plot distance from home and find that the elimination of land tenure insecurity through land registration and certification makes a clear difference in that. We therefore recommend that tea farmland need to expand and enlarge for better production through comprehensive land consolidation program. We also suggest endorsing the land certificates of all land holders as this will help improve land tenure security, enhance technical efficiency and promote the tea production of smallholder producers.*

Keywords: *China, land tenure, technical efficiency, SFA, smallholder.*

JEL Classification: *Q15, D13.*

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Introduction

Has been enjoyed for millennia, tea has a long and complex history in China. In recent times, more than 1,500 types of propagated clones of tea plants have been developed and cultivated in more than 36 countries as a cash crop plantation (Lighton et al., 2014). Smallholder farmers account for more than 70% of the world's tea and 80% of China's tea production (Chang, 2015). Although tea plantation and production has increased over the past three decades, its productivity per unit area has not significantly changed, which contrasts with other agricultural products across the globe and China in particular (Basu et al., 2010). This may be because smallholder farmers are confronted by many challenges that affect the quality and quantity of tea production. A number of contributions (Tan et al., 2006; Wang et al., 2010, 2014; Zhao, 2010,) identify the common challenges that confront smallholder farmers in China, which include a lack of modern agricultural machinery, fragmented and small farm plots, a lack of access to an irrigation and drainage system, labor shortages, poor soil quality, pests, diseases, drought and climate change.

The Chinese government sought to overcome the challenges of smallholder farmers and maintain rural agricultural production and livelihoods by establishing the Land Consolidation and Rehabilitation Center in the 1990s and also by launching the National Land Consolidation Plan that incorporated the country's National Five Year Strategic Plan. China has invested large amounts of manpower and material and financial resources and this has enabled it to achieve remarkable results in reclaiming poor-quality soils by transforming them into medium and high-quality soils; small and fragmented parcels have also been enlarged and reshaped. New agricultural infrastructures, including irrigation and drainage systems, have also been added, and road networks have also been established in many project areas. These improvements have been particularly pronounced in many rural areas of Sichuan province (Wang et al., 2014; Li et al., 2014). Land consolidation does not only seek to maintain agricultural land and thereby promote improved production; to the same extent, it also seeks to enhance private property rights related to contracted land use by enabling the certification and registration of land and the establishment of a legislative body (FAO, 2003; Thomas, 2006).

China's Constitution and Land Resource Management Law establishes that, in accordance with the legal regulation, land resources in the rural region are owned by the collective economic organization. The law establishes that individual rural farm households can only obtain contracted land-use rights for 30 years but cannot sell and transfer (lease, assign or mortgage) their land-use rights (Benjamin & Brandt, 2002). The right to lease, assign, exchange and carry out other contracted land transactions are outlined, and this could improve and facilitate land market transfers that are still uncertain in the country. This could cause tenure insecurity and affect long-term investment in land quality improvement and agricultural infrastructures such as road, irrigation and drainage systems and promote the use of new agricultural technologies (fertilizer, machinery, pesticides and variety) that could help to promote sustainable agriculture and rural development (Ma et al., 2013).

Property Right Theory deals with relationships, both between individuals or groups that relate to land and natural resources. It establishes a set of rules that determine how the land right is used, allocated, transferred, controlled, leveraged, sold, and disposed of within the societies, and it is associated with responsibilities and restraints (Ghebru & Holden, 2015). These rules might be established by the state, custom or societies and the rights might be accredited to individuals, communities or organizations (Bruce et al., 2010). These rights are also an engine for agricultural development that encourage different positive behaviors toward land development (e.g. investment) and that promote dispute resolution between others. The establishment of implicit property right and the improvement of existing land tenure security levels can enhance land investment (Deininger & Jin, 2005) and the land user's production efficiency. The Central Government's market-oriented land tenure reforms in the late 1990s enhanced the country's legal tenure security (Ma et al., 2013).

The land rights with high security and long-term are among the fundamental preconditions for guaranteeing basic rural livelihood, encouraging the commitment of smallholder farmers to sustainable investments in land, promoting the orderly development and smooth the functioning of rural land transfer market and ensuring a continuity of rural income growth. Land registration and certification are important ways of implementing and confirming secure and long-term land rights. Land certification (officially documented land use rights that are verified by land certificates) does not only enhance tenure security and ownership of the land but also promotes short-term or long-term investment in land. It also encourages the maintenance and protection of land, the adoption of modern agricultural technology and the use of farmers' land as collateral to obtain loans for investment purposes that could increase farm productivity and technical efficiency (Deininger & Jin, 2005; Ghebru & Holden, 2015).

The Chinese government is currently testing methods that could quickly and accurately register the land of rural households. Land registration and certification was introduced in 2008 before being piloted in many rural areas of China. The rural land registration system was initiated with the aim of solidifying China's land system and helping to establish fully-fledged economic institutions. It also sought to provide effective legal protection that would help farmers obtain secure and stable returns from land and promote food production and income generation. Other goals included normalizing rural land transfers in a way that would facilitate the establishment of the sound rural land transfer market; reducing land disputes and empowering farmers in the process of land-taking; protecting agricultural lands from rapid industrial, retail and residential land development programs; delivering detailed rural land information; and helping government extend and deepen favorable policies on agricultural and rural development (Christopher, 2011). But land registration and certification have not yet finished and it is expensive and time-consuming.

Many factors can potentially affect the technical efficiency of smallholder agriculture. The profound relationship between land tenure security and technical efficiency is not well documented, and this is especially true of China. Michler and Shively (2012) studied tenure and technical efficiency among Philippine rice farmers by applying the SFA approach. They found that land tenure has a positive and significant effect on efficiency and also noted that smallholder farmland is more efficient than larger counterparts. Kolawole and Titus (2016) identify the effect of land tenure security on technical efficiency by using cross-sectional farm-level data taken from 252 rice farmers in Thailand, and find that land ownership enhances the technical efficiency of the country's smallholder rice farmers. Abdulai and Huffman (2000) engage non-farm employment, education, credit availability, age of household head, rice share of total area, distance to market, and regional dummies and consider them as explanatory variables for profit inefficiencies. Tan et al. (2010) examine the impact of land fragmentation on the technical efficiency of 339 rice producers from three villages in China's North-East Jiangxi province. They find that land fragmentation, plot size and number of plots are important determinants of the technical efficiency of early rice producers. However, plots that are located far away from the homestead can lead to technical inefficiency.

In addition to engaging potential smallholder farmer's tea productivity differentials that relate to technology input use differences, this study seeks to examine the effort that smallholder tea producer's land certification and tenure security have on their technical efficiency. It achieves this by drawing on a rural household cross-section dataset and applying Stochastic Frontier Analysis. It also tests relevant determinants that affect the technical efficiency of smallholder farmers, and focuses in particular on areas where land consolidation and rehabilitation program are implemented. The findings will provide insight into factors that affect smallholder tea producers' TE and tea yield outputs. These contributions can then be used by policymakers, extension and development agents, tea cooperatives and social sectors who work with tea plantation and production, and this will help to enhance smallholders' livelihoods. Section 1 will now discuss the material and methodology; Section 2 will discuss the empirical results and discussions; and Section 3 will outline the main conclusions and provide suggestions.

1. Material and Method

1.1 Description of the Study Area

Ya'an is an administrative division in Sichuan province that is a leading tea producer. It is located at the western edge of the Sichuan Basin and on the upper reaches of the Yangtze, and covers the transition between the Chengdu Plain and the Tibetan Plateau. It is 120 km away from Chengdu City, the capital of Sichuan. It is situated on a 29°58' N latitude and a 103°00' E longitude that covers an area of 15,300 square kilometers. It is in a highly mountainous area with an elevation range of between 500 and 5,793 meters (above sea level). It has a subtropical humid monsoon climate and is largely mild and humid. Its average monthly maximum temperatures range between 25.5 °C and 26 °C, and its average monthly minimum temperatures between 6.1 °C and 7.1 °C. It frequently rains throughout the year and annual rainfall is 1,567 mm (SPSB, 2016). Various infrastructures (including bridges, drainage canals, irrigation, rural roads and water harvesting dams) have been implemented through land consolidation and rehabilitation programs over the past decade.

1.2 Data Collection and Sampling Methods

Cross-sectional data was collected from 161 randomly selected smallholder farmer tea producers. Face-to-face interviews were, with the help of local agricultural officers, conducted between May and June 2016. A household socioeconomic and farming system questionnaire sought to collect qualitative and quantitative primary data and perceptions of certification, land registration and land tenure security, along with other relevant data.

1.3 Model Specification

The Stochastic Frontier Approach (SFA), which was originally developed by Aigner et al. (1977), was adopted. It is particularly well-suited to hypothesis testing because it uses statistical techniques to estimate the parameters. It has also been widely applied by studies of cost, production, profit, revenue and other models of goal attainment (Abdulai & Huffman, 2000; Tan et al., 2010; Michler & Shively, 2012; Kolawole & Titus, 2016).

The Cobb-Douglas Stochastic Production Frontier Function (CD-SPF) and Translog Stochastic Production Frontier Function (TL-SPF) are the two SFA methodologies that are most frequently used to detect the Maximum Likelihood Estimate (MLE) and technical (in)efficiency (Battese & Coelli, 1995). The TL-SFP has a higher order and a more flexible functional form and it is therefore to be expected that it will fit the data more tightly and will therefore produce higher efficiency estimates than the CD-SPF assumption (which consistently generates lower efficiencies). However, this study does not depend on this choice of methods or model specification, and the collected cross-section data were therefore estimated by applying the Frontier 4.1 software package developed by Coelli (1996).

Our SFA model assumes that the amount of tea yield output (Q_i) that farmers produce only varies in accordance with differences in the level of household resource endowment (X_{ij}) and the level of efforts that they exert in order to optimally utilize input factors such as tea farm size (A), household income (K) and household labor (L), in addition to external factors that do not vary across farmers (e.g. climate).

The Cobb-Douglas Stochastic Production Frontier (CD-SPF) can be estimated as:

$$Q_i = \beta_0 + \sum_{i=1}^{j} \beta_j X_{ij} + (V_i - U_i) \tag{1}$$

We can rewrite formula (1) as:

$$\begin{aligned} \ln Q_i = \beta_0 + \beta_1 \ln A_i + \beta_2 \ln K_i + \\ + \beta_3 \ln L_i + (V_i - U_i) \end{aligned} \tag{2}$$

The Stochastic Production Frontier, Translog production frontier (TL-SPF) can be estimated as:

$$\begin{aligned} Q_i = \beta_0 + \sum_{i=1}^{j} \beta_j X_{ij} + \\ + \frac{1}{2} \sum_{i=1}^{j} \sum_{i=1}^{d} \beta_{jd} X_{ij} X_{id} + (V_i - U_i) \end{aligned} \tag{3}$$

We rewrite formula (3) as:

$$\begin{aligned} \ln Q_i = \beta_0 + \beta_1 \ln A_i + \beta_2 \ln K_i + \beta_3 \ln L_i + \\ + \beta_4 \ln A_i^2 + \beta_5 \ln K_i^2 + \beta_6 \ln L_i^2 + \\ + \beta_7 \ln A_i \ln K_i + \beta_8 \ln A_i \ln L_i + \\ + \beta_9 \ln K_i \ln L_i + (V_i - U_i) \end{aligned} \tag{4}$$

where Q_i is the quantity of tea yield obtained from a particular tea farm of the *i*-th farmers in kg; A_i is the size of the tea farm of the *i*-th farmer in mu (where, 1 mu is equivalent to 0.067 ha); K_i is the cumulative (on-farm and off-farm) annual income of the *i*-th farmer in Yuan (1 Yuan is equivalent to 0.145 USD during the study period); and L_i is the household labor share of the *i*-th farmer who actively participates in the tea farm. β_0 is the intercept and β_j are the maximum likelihood estimates coefficients (MLE) of the input variables. V_i is the random variable that is assumed to be independent and identically distributed (*iid*) N ($0, \sigma_v^2$), and independent of the U_i, which is a non-negative random variable assumed to account for technical (in)efficiency in production and which is assumed to be independently distributed as truncations at zero of the N (m_i, σ_u^2) distribution; and m_i is technical (in)efficiency. All of the stochastic frontier variables were transformed into natural logarithms (*ln*).

The relationship between farm size and productivity is very ambiguous. Some econometric studies identify an inverse relationship between plot size and productivity, which suggests that small farm plots are, when compared against large farm plots, more productive. This is explained by the relative advantage of using more family labor that may reduce the monitoring and supervision costs of hired labor (Feder, 1985). But other scholars suggest that the adoption of new technologies by large farmers may yield more of an advantage than smallholder farmers (Fan & Chan-Kang, 2005). But this study hypothesizes that the MLE sign of tea farm size (*A*) will, when considered in relation to tea yield output (*Q*), be found to be positive.

Households with a high annual income (*K*) are expected to have higher productivity than low income households because high income smallholder farmers can buy and use agricultural inputs that enable a better standard of production than the one achieved by low income smallholder farmers. This study therefore hypothesizes that the MLE of household income will, in relation to tea yield outputs, be found to be positive. Labor (*L*) force plays a significant role in agricultural production in instances where agricultural machinery is scarce. In the study area labor is scarce and expensive and tea farming requires high labor. All smallholder tea producers in the study area used family labor planting, weeding, picking and transporting. On this basis, this study anticipates that family labor may play a positive role in tea production.

TE is defined as the ability to minimize input use while maintaining a given output level, or as the ability to maximize output production while fixing the amount of input use. Input and output-orientated are the two ways that TE is measured (Chen et al., 2003). This study uses the latter because of its widespread application in many empirical studies. The parameters of the stochastic frontier and the (in)efficiency model were simultaneously estimated. In accordance with Battese and Coelli (1995), this was based on the (respective) application of formulas (3) and (4) to CD-SPF and TL-SPF. In order to identify the determinants of smallholder tea producers' technical efficiency (TE), this study applies the following formulas:

$$TE_i = \delta_0 + \sum_{i=1}^{j} \delta_j Z_{ij}\,,\; TE_i = \delta_0 + \sum_{i=1}^{j} \delta_j Z_{ij} \quad (5)$$

where TE_i indicates the efficiency score of the *i*-th farmer and Z_{ij} are the *j*-th variables that might influence the efficiency of the *i*-th farmer; δ_0 is the intercept and δ_j is the determinant parameter to be estimated.

Education, gender, experience, farm size and other environmental and village level dummy variables have previously been used as determinants of smallholder farmers' technical efficiency by many empirical studies (Chen et al., 2003, 2009; Tan et al., 2010).

This study assesses twelve farm household TE determinants, including the farmer's age (AGE), gender (GND), education (EDU) and farming experience (EXP); other determinants include farm land size (FS), plot distance from home (DFH), number of plots owned (PN), plot steepness (ST), irrigation access (IRR), chemical fertilizer use (CF), land tenure security (LTS) and land certification (LC). Definitions and expected signs are presented in Tab. 1.

In traditional farming, older farmers may be more experienced and have accumulated more capital, and this can be extracted from results that show they are more likely to invest in innovation and demonstrate greater efficiency (Huffman, 2001). Older farmers tend to be more conservative and are less able to use new technologies while young farmers tend to be more innovative and risk averse (Adesina et al., 2000; Zhang et al., 2012). But the relationship between aging and production is ambiguous, and this study hypothesizes that aging will be negatively related to technical efficiency as more than half of the respondents are more than 50 years old. Gender is an explanatory dummy variable that the model uses to capture the effectt of female- and male-headed households on tea production. In the smallholder farming system female-headed households are likely to have lower resource endowment and agricultural productivity (in comparison to male-headed households) because farming activities require resource, labor and time and this affects their farm efficiency. On this basis, this study hypothesizes that female-headed households will be less effective.

Farming experience enhances skills and abilities and this increases the capacity to address technical and/or practical problems related to agronomic activities. As the farmer gains more experience, he/she may be able to make critical decisions on the adoption and use of new technology (Huffman, 2001; Namwata et al., 2010). We therefore expected that farming experience could enhance technical efficiency. Education improves the technical knowledge and skills of those who work in the farming system and also enhances agricultural production. An individual's education affects his/her ability to allocate inputs efficiently. But the ability of households to efficiently respond to the market depends on how information systems work (Chen et al., 2003). It was on this basis that the study anticipated that education would enhance farmers' technical efficiency.

The effect that land holding size and the number of plots have on technical efficiency depends on the level of technology use and labor and management activities. Wang et al. (1996) obtain a positive and significant coefficient for the dummy of large farms in the profit efficiency estimation and, on this basis, this study hypothesizes that small and fragmented farm lands can cause technical

Tab. 1: Variable definitions and expected sign

Stochastic production frontier (SPF)					
Factors	Variable			Description	Expected sign
	Code	Definitions	Type		
Dependent variable	*Q*	The amount of tea yield obtained per plot	Continuous	Kilogram	
Independent variables	*A*	Size of the tea plot	Continuous	Mu	+
	K	The annual household income	Continuous	Yuan (RMB)	+
	L	Share of household labor	Continuous	Percent	+
Technical efficiency (TE)					
Determinants	*AGE*	Age of the household head	Continuous	Years	–
	GND	Household gender	Dummy	1 if male headed, otherwise 0	+
	EXP	Farming experience of the household head	Continuous	Years	+
	EDU	Educational status of the household head	Dummy	1 if secondary school and above, otherwise 0	+
	FS	Total size of owned farm	Continues	Mu	+
	STP	Plot steepness (slope gradient)	Dummy	1 if <5% slope, otherwise 0	–
	DFH	Plot distance from home	Continuous	Kilometer	–
	IRR	Plot access to irrigation	Dummy	1 if yes, otherwise 0	+
	CHF	Chemical fertilizer use	Dummy	1 if yes, otherwise 0	+
	NP	Number of plots	Continues	Number	–
	LT	Land tenure security level	Dummy	1 if yes, otherwise 0	+
	LC	Land certificate	Dummy	1 if yes, otherwise 0	+

Source: own

inefficiency. Sloppy farm lands are in most cases recommended for perennial cash crops (such as tea and apples) rather than annual cereal or pulse crops, and this is because they are susceptible to land degradation, require huge land management activities and have a stronger effect on farm efficiency than flat or gentle slope farms. But we expect that sloppy tea farms can enhance technical efficiency. Farm plots that are far away from the homestead can increase the transaction cost, which includes the losses farmers incur from traveling, low investment in land (such as input and management) and follow-up. Farm plots that are far removed from the homestead can cause more technical inefficiency than farm plots that are located near to the homestead. Irrigation plays a significant role and assists the growing of agricultural crops in dry areas and is also important in periods of inadequate rainfall. But if there is not a functioning drainage system, then the application of irrigation may not be effective and water logging and yield reduction may result. On this basis, we expect that farm plot access to irrigation may enhance the technical efficiency of smallholder farmers.

Chemical fertilizer can make poor quality soils high quality, and this can improve productivity and efficiency. But care should be taken with the quantity and application of chemical fertilizer because it may burn the soil as well as the plant when the soil moisture is below the threshold. We hypothesize that chemical fertilizer can enhance the TE of smallholder farmers.

Land certification is the document of the title of land registration that the government issues to the land user. Land registration and certification provide the reliable property information of the contracted land user and give prima facie evidence of land ownership. Land certification enhances land tenure security, long-term investment, management and land utilization. We expect that individual land holders WHO issued land certificates will be more technical and efficient than uncertified land holder counterparts.

The land tenure system that upholds land property rights can affect land investment, management, the utilization level of the land holder and the production system. But China's current land laws establish that individual land holders are only entitled to exercise this right in the scope of the laws and cannot sell, mortgage or transfer their land use right. This also makes it impossible to use land as collateral when seeking to obtain loans for long-term investment in land (Ma et al., 2013). We hypothesize that smallholder farmers who have land tenure security will be more technically efficient than their land tenure insecure counterparts.

2. Results and Discussion

2.1 Descriptive Statistics Analysis Result

The snapshot descriptive statistics of smallholder tea farmers in the study area are presented in Tab. 2. Closer consideration of gender shows that the percent of female headed smallholder farmers involved in tea farming is not significantly different from male-headed smallholdings (respectively 46.58% and 53.42%). This indicates that female-headed households and male-headed counterparts actively participate in tea farming in the study area to the same extent in order to sustain their livelihood. The respondents all reach a basic education level and can at least read and write. The results show THAT 57.15% had a primary school education and the remainder had been educated to secondary school level and above. More than half (52%) of respondents were aged between 51 and 77 years of age. This meant that almost two-thirds (64%) of respondents had more than 30 years' tea farming experience. There was an average of five persons for each household, with 5.52 mu farmland and an annual income of 44,700 Yuan (6,840 USD). The results indicate that the per capita farmland in the study area is 0.079 ha, which is higher than the average per capita farmland of Sichuan province (0.049 ha) (SPSB, 2016). But the share of household laborers who actively participated in tea farming was only 54% and the share of tea plot to total farmland was 46.5%. Almost all (95%) main respondent livelihoods were provided by agriculture (tea farming); less than 5% derived their secondary income from it and used at least half of their total farmland for tea farming.

The average tea farm size per household were 2.52 mu (0.17 ha) and average tea plots were 1.04 average tea plots. The tea farms were spatially distributed at an average distance of 430 meter from the homestead, which indicated that 40% of respondents travelled more than 500 m from their tea farm to their homestead; meanwhile, 17% travelled further than 1 km;

Tab. 2: Descriptive statistics for constructed variables

	Minimum	Maximum	Mean	Std. error	Std. dev.
Stochastic production function (SPF) variables					
Q	4.0	346.67	86.69	6.080	77.15
A	0.3	10	2.52	0.153	1.945
K	1,000	210,000	44,701.89	2,623.88	33,293.31
L	0.25	100	53.62	1.735	22.015
Technical efficiency (TE) determinant variables					
SX	0.000	1.000	0.534	0.039	0.500
AG	28.000	77.000	51.429	0.771	9.786
ED	0.000	1.000	0.429	0.039	0.496
EX	7.000	60.000	32.466	0.842	10.687
ST	0.000	2.000	0.267	0.037	0.471
DH	0.005	3.000	0.430	0.039	0.493
IRR	0.000	1.000	0.137	0.027	0.345
CF	0.000	1.000	0.857	0.028	0.351
FL	0.800	27.000	5.416	0.344	4.359
NP	1.000	3.000	1.043	0.018	0.233
LT	0.000	1.000	0.832	0.030	0.375
LC	0.000	1.000	0.789	0.032	0.409

Source: own

75.54% of tea farms were situated on flat (gentle slope) land with a slope gradient of less than 5% and only 13.66% of tea farms had access to irrigation and drainage systems. The date of field suveying showed that 79% of smallholder tea farmers in the study area had certified land certificates and 82% felt they had land tenure security. This could help them to invest and implement agricultural technologies in land use such as chemical fertilizer, compost, improved tea clones manure and those essential to chemical management (herbicides, fungicides and pesticides). The study's surveys of smallholder tea farmers showed that 86%, 85%, 83% and 69% (respectively) used chemical fertilizer, natural fertilizer, chemical management and improved tea clones.

2.2 Result of Stochastic Production Frontier

This study applies the Cobb-Douglas (CD-SPF) and Translog (TL-SPF) Stochastic Production Functions, which are the most frequently used Stochastic Frontier Analysis (SFA) methods. The stochastic production frontier result is presented in Tab. 3. Estimates of the variance parameters σ^2 and γ were significantly different at the $P < 0.000$ significance level for both methods. This implies that the level of (in)efficiency might significantly affect the output of smallholder farmer tea yields and result in considerable variation (Chen et al., 2009).

The maximum likelihood estimate (MLE) of the CD-SPF and TL-SPF result indicates that the tea yield output and tea farm size (A) have a significant positive relationship at a $P < 0.000$ significance level. The results show that an increase in tea farm size of 1 mu (0.067 ha) will produce a tea yield advantage of 1.086 for smallholder tea farmers. Kipron et al. (2011) refer to Kenyan smallholder tea farmers and find that tea farm size are positively related to tea production. While income capital (K) and household labor (L) are positively related to tea

Tab. 3: Stochastic production frontier result

Stochastic production frontiers	Maximum likelihood estimate methods							
	TL-SPF				CD-SPF			
	Coeff.	Std. error	T-stat.	Sig.	Coeff.	Std. error	T-stat.	Sig.
Const.	5.527	2.76	2.00	**	3.544	0.302	11.74	***
lnA	1.003	0.434	2.31	***	1.086	0.034	31.49	***
lnK	−0.408	0.382	−1.07		0.028	0.022	1.241	
lnL	0.010	0.639	1.54		0.009	0.036	0.241	
lnA²	−0.065	0.041	−1.59					
lnK²	0.027	0.016	1.66					
lnL²	0.010	0.022	0.44					
lnA×lnK	−0.057	0.035	−1.62					
lnA×lnL	0.193	0.078	2.47	***				
lnK×lnL	−0.013	0.051	−0.26					
$\boldsymbol{\sigma^2} = (\sigma_v^2 + \sigma_u^2)$	0.362	0.054	6.68	***	0.395	0.057	6.854	***
$\boldsymbol{\gamma} = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$	0.957	0.024	40.1	***	0.956	0.024	39.74	***
Log likelihood function			−58.14		−65.36			
LR test of the one-sided error			39.94		38.92			

Source: own

Note: ***, **, * are significant at 1%, 5% and 10% significance levels.

yield output, although not significantly. When the TL-SPF method is applied, the product of tea farm size (A) and household labor (L) has a positive and significant impact on tea yield output at the $P < 0.0001$ significance level. This demonstrates that an 1% increase in the product of tea farm size and labor will produce a tea yield increase of 0.193%.

2.3 Elasticity Scale and Marginal Effect

The corresponding input-output elasticity and marginal effect are also assessed and presented in Tab. 4. The result reveals that the largest and most significant scale of elasticities is provided by farmland size (0.144 value), household income (0.105 value) and labor elasticities (0.01 value). This demonstrates that farm size is a more crucial input into tea production than income

Tab. 4: Input-output elasticities and marginal effects

Variables	Elasticity				Marginal effect			
	ey/ex	Std. error	Z	P>|Z|	dy/dx	Std. error	Z	P>|Z|
lnA	0.144	0.005	31.69	***	1.090	0.045	24.23	***
lnK	0.105	0.090	1.16		0.039	0.034	1.16	
lnL	0.010	0.056	0.18		0.010	0.057	0.18	
Scale of elasticity	**0.259**							

Source: own

Note: ***, **, * are significant at 1%, 5% and 10% significance levels. They are evaluated at the geometric means of the inputs and output; data are calculated using the Delta method.

and labor. Similarly, Chen et al. (2009) and Tan et al. (2010) also found larger input elasticity estimates of land in China's rice production. But the input elasticities scale estimate of smallholder tea producers was found to have a 0.259 value, which is lower than other studies of China's rice production (see Chen et al., 2009; Tan et al., 2010). This may be due to differences in study area, commodity and sample size. The marginal effects results of the input variable were consistent with elasticity estimates. The marginal effect of farmland size on tea yield outputs was, when compared to income and labor, found to be large and significant. Hen et al. (2009) also found that land and capital have the highest marginal effect and note the marginal effect of labor is low.

2.4 Results of Technical Efficiency

TE was simultaneously derived from the stochastic production frontier estimate for each respondent (cases). Tab. 5 shows that the average technical efficiency scores for CD-SPF and TL-SPF were (respectively) 0.66 and 0.67. More than 57% and 60% of respondents (respectively) scored above average for CD-SPF and TL-SPF, and this indicated that the majority of smallholder farmers were efficient. The result resembles the one (0.68) provided by Chen et al. (2009) for Sichuan province and is higher than the one (0.55) provided by Liu and Zhuang (2000) for rice smallholder farmers. The minumum and maximum technical efficiency scores for CD-SPF were 0.16 and 0.94; and 0.18 and 0.95 for TL-SPF.

Tab. 6 shows the TE score range of the respondents and indicates that the higher cases were between 0.61–0.70 and 0.81–0.90 in the CD-SPF model (32 cases, accounting for 20% of the total). In the TL-SPF model, the higher cases (39) were found to be between 0.71–0.80. Whereas in the CD-SPF, 12 cases (7.45%) scored more than 0.91 technical efficiency, this increased to 14 cases (8.70%) in the TL-SPF. The TE score result demonstrated 60–70% of respondents obtained more than 60% of the potential product by using a mixture of production inputs that included capital, labor and land. This implies that, in the short run, tea outputs will be higher when TE is closer to, or higher than, the average value.

2.5 Determinants of Technical Efficiency

The multiple regression Ordinary Least Square (OLS) result was run by using Eviews 9.5 statistical software to identify the determinants of the TE of smallholder tea producers (see

Tab. 5: Technical efficiency (TE) score for smallholder tea farmers in the study area

Model	Obs.	Min.	Max.	Mean	Std. error	Std. dev.
CD-SPF	161	0.159259	0.944303	0.661856	0.014899	0.189044
TL-SPF	161	0.185208	0.947807	0.674684	0.014749	0.187142

Source: own

Tab. 6: Technical efficiency score range of smallholder tea producers

Model	Technical efficiency score range						
		<0.50	0.50–0.60	0.61–0.70	0.71–0.80	0.81–090	>0.91
CD-SPF	No. cases	25.00	29.00	32.00	31.00	32.00	12.00
	% of cases	15.53	18.01	19.88	19.25	19.88	7.45
TL-SPF	No. cases	28.00	19.00	32.00	39.00	29.00	14.00
	% of cases	17.39	11.80	19.88	24.22	18.01	8.70

Source: own

Tab. 7: Determinants of smallholder tea producers' TE

Variable	Dependent variable							
	TL-SPF				CD-SPF			
	Coeff.	S.E	T-stat.	Sig.	Coeff.	S.E	T-stat.	Sig.
AGE	−0.007	0.003	−2.260	**	−0.007	0.003	−2.305	**
GND	0.037	0.030	1.222		0.034	0.030	1.142	
EDU	−0.058	0.029	−1.944	*	−0.051	0.029	−1.716	*
EXP	0.005	0.003	1.850	*	0.006	0.003	1.970	**
FL	−0.006	0.003	−1.974	**	−0.010	0.003	−2.990	**
NP	−0.008	0.062	−0.137		−0.042	0.062	−0.685	
CF	−0.093	0.044	−2.123	**	−0.097	0.044	−2.206	**
DFH	−0.043	0.029	−1.483		−0.049	0.029	−1.702	*
IRR	0.007	0.043	0.162		0.012	0.044	0.273	
ST	−0.111	0.032	−3.454	***	−0.106	0.032	−3.297	***
LC	0.032	0.036	0.890		0.035	0.036	0.972	
LT	0.097	0.042	2.344	**	0.104	0.041	2.514	**
Const.	0.935	0.127	7.356	***	0.967	0.127	7.592	***
R-squared				0.173				0.186
Adjusted R-squared				0.106				0.120
Durbin-Watson stat				1.979				1.945
F-stat. (Prob.)				2.582 (0.004)				2.820 (0.002)
NORM				8.49 (0.01)				5.55 (0.06)
LM test				0.00 (0.98)				0.03 (0.87)
Heteroskedasticity test				1.48 (0.14)				1.37 (0.18)
Ramsey RESET test				3.05 (0.08)				1.23 (0.27)

Source: own

Tab. 7). The results show that the CD-SPF and TL-SPF were most consistent, and the TL-SPF TE estimates were slightly higher than CD-SPF. Age, chemical fertilizer, education, farming experience, land tenure security, plot distance from home, plot steepness and total farm size holding are found to significantly affect the technical (in)efficiencies of smallholder producers. But gender, land certificates and number plots do not significantly affect the efficiency of smallholder tea producers.

The aging of farmers causes a significant technical inefficiency in tea production even though its magnitude is very small (−0.007). This implies that when age increases by ten years, efficiency will reduce by 0.07%. But farming experience improves technical efficiency significantly at a $P < 0.1$ significance level. In addition, a decade of farming experience will improve efficiency by 0.05%. A comparison of aging against farmer experience at ten year intervals is expected to produce efficiency decines of, on average, 0.02% in tea production. This result is consistent with Chen et al. (2003), who observe that aging impacts on efficiency. But it contradicts Chen et al. (2009) and Tan et al. (2010), who instead claim it positively impacts rice producers' technical efficiency. We also find that education causes a 0.058 inefficiency for smallholder tea producers. The results confirms a 0.058 efficiency gap between farmers with a primary school eduction or lower and farmers with a secondary school education or above. Chen et al. (2003) found a negative significant relationship between education and efficiency in grain production in China.

Smallholders who own large farmlands are more inefficient than small farmland owners and have a very low magnitude. An increase in 10 mu (0.67 ha) of farmland will produce a decline in technical efficiency of 0.06. As the number of farm plots increases, TE also declines. We also found that spatial plots distributed from the homestead affect the TE of smallholder tea producers. The results revealed that farmers were unable to operate, manage, follow-up and supervise if they own large farmlands that are fragmented and located far away from the homestead. Tan et al. (2010) also finds that the distance of the plot from the homestead can produce a decline in the TE of farmers' rice production. Chen et al. (2003) also note that large farm owners are more inefficient than small farm counterparts. The access that tea farm plots have to irrigation and drainage enhance the TE of smallholder tea producers. Tea plantation is ideally suited to mountainous and sloppy areas, and our results also demonstrated that sloppy plots enhance the TE of smallholder tea producers. When farmers who cultivate tea plants on flat areas and steep plots are compared, a 0.11 efficiency gap is found.

Although legal tenure security has increased significantly in many parts of China since 1998, actual tenure security and household perceptions of land tenure security have lagged behind (Ma et al., 2013). The land consolidation program, land registration and certification could play a crucial role inprotecting individual land rights and helping ensure short and long-term investment in land. The study's results show that while land certificates that are endorsed by smallholder tea producers are technically efficient in the study area, this effect is not significant. The efficiency gap between certified and uncertified smallholders was 0.032. Farmers also believed land tenure security was significantly more efficient than the arrangements in place for land insecure farmers. The efficiency gap between land tenure secured smallholder tea producers and unsecured land tenure was found to be 0.097. The results indicated that farmers who enjoyed land tenure security were able to make short and long-term investments in, *inter alia,* chemical fertilizer, compost, manure and pest management activities. Michler and Shively (2012) observe that tenure has a positive and significant effect on the efficiency of Philippine rice farmers. Kolawole and Titus (2016), in referring to the example of Thailand, also observe that land ownership enhances the technical efficiency of rice farmers.

Conclusion and Recommendations

In applying the Stochastic Frontier Analysis (SFA) approach and using the Frontier 4.1 statistical package, this study sought to identify how land tenure security and land certificates impact on the TE of Ya'an smallholder tea producers in China's Sichuan province. The maximum likelihood estimate was estimated through the CD-SPF and the TL-SPF, which are the most frequently used SFA methods. Corresponding scale elasticity and marginal effect were also assessed. We found that tea farm size significantly affects tea yield output, and note that household annual income and labor are not significantly related to tea yield output. Significant and larger input-output scale of elasticity and marginal effect were however found in relation to farm size, although labor and capital has a smaller scale of elasticity and marginal effect on tea production. In referring to both models, we found a technical efficiency average of 0.67 for smallholder tea producers in the study area. This indicated that 67% of the potential tea product was obtained by using by mixture of production inputs that included capital, labor and land. Other significant determinants of smallholder tea producers technical (in)efficiencies included age, chemical fertilisers, education, farming experience, land tenure security, plot distance from home, plot steepness and total farm size holding. But gender, number plots and land certificates did not significantly affect the efficiency of smallholder tea producers.

We therefore recommend that tea farmland need to expand and enlarge for better production through comprehensive land consolidation program. Land consolidation also enhances land tenure security through certification, land readjustment and registration. We also suggest endorsing the land certificates of all land holders as this will help improve land tenure security, enhance technical efficiency and promote the tea production of smallholder producers.

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