PROFITABILITY AND TECHNICAL EFFICIENCY OF CHILLI FARMS *In Cambodia*

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Executive summary

In this study, we examine the revenue, costs, profits and technical efficiency of chilli farms in Cambodia. We employ a representative sample of 542 chilli farming households from Banteay Meanchey, Battambang, Kampong Chhnang, Kampong Cham, Tboung Khmum and Kandal. The sample was randomly selected using a two-stage stratified sampling design, where villages were chosen in the first stage as the primary sampling unit and households engaged in chilli production were selected in the second stage as the secondary sampling units. The selection of primary sampling units was proportional to the number of households engaged in chilli farming in each sampled village, and the secondary sampling units were randomly chosen using a systematic sampling approach. Face-to-face interviews were conducted by experienced and qualified enumerators using tablets, and data collection was monitored and cleaned daily. Researchers employed two analytical frameworks: (1) a revenue-costs framework to calculate profits and (2) a stochastic frontier analysis with a Cobb-Douglas production function to estimate technical efficiency and to investigate its determinants. The analysis is conducted at the plot level, encompassing a total sample of 719 plots.

The results show that bird's eye, lady's finger (cayenne pepper), white chilli and Hawaii (sweet) pepper are popular varieties, with bird's eye and lady's finger being the most cultivated. The average cultivated land area for chilli farming is 0.21 hectare (ha), yielding an average of eight tonnes of fresh chilli per hectare. Farmers can sell fresh chilli at an average price of KHR5,310 (USD1.32)/kg, and dried chilli for KHR10,000 (USD2.5)/kg. On average, farmers could attain accounting profits of KHR18.1 million (USD4,500)/ha. This constitutes approximately 50 percent of the total revenue of KHR36.5 million (USD9,125)/ha. The cultivation of bird's eye chilli tends to provide the highest profits compared to other varieties. Investment consists of expenditures on materials, inputs, hired labour, rent for land use and capital depreciation. Specifically, costs related to inputs (such as seeds, fertiliser and pesticide) and hired labour for land preparation, plantation, care and harvest contribute to 43 percent and 33 percent of the total costs, respectively. About 81 percent of the total hired labour costs are allocated to harvest activities, reflecting the multiple harvests required for chilli cultivation.

The results also indicate that there remains room for improvement in chilli yields, as 71 percent of the plots demonstrate technical efficiency levels of 60 percent or lower relative to the production frontier. Additionally, only about two percent of the plots could attain a technical efficiency level of 80 percent from the frontier, and none could achieve 100 percent efficiency. Farmers operating plots with technical efficiency close to the frontier could achieve an average yield of 15.25 tonnes/ha (95 percent CI: 7.96-22.60) on plots with an average land size of 0.39 ha (95 percent CI: 0.25-0.70). Several factors, including land size, household size, geographical location, and the presence of diseases and insects, are potential determinants influencing the technical efficiency of chilli farming. For instance, smaller land sizes may contribute to lower yields, as can the prevalence of diseases and insects. When asked about the challenges in chilli cultivation, farmers identified low and fluctuating chilli prices, along with issues of diseases and insects, as the main concerns.

The Ministry of Agriculture, Forestry and Fisheries, along with other relevant ministries, could further enhance efficiency of chilli cultivation by exploring the following initiatives.

- Consider the feasibility of expanding cultivated land size, especially for households managing plots smaller than 0.2 ha
- Provide extension services tailored to optimising input utilisation and addressing issues related to diseases and insects
- Explore technological applications aimed at enhancing production efficiency and reducing costs, with a specific focus on mitigating input and labour expenses, given that chilli farming is identified as labour-intensive
- Investigate extending and enhancing production during the wet season (June-October), as chilli farmers commonly encounter challenges in cultivation, leading to comparatively lower yields and quality, consequently reducing prices and profits
- Continue efforts to reduce production costs with a particular focus on minimising expenditures associated with fertiliser, pesticides, electricity and fuel

1. Introduction

Chilli is considered a priority crop in the Royal Government of Cambodia's (RGC) National Agricultural Development Policy (2022-2030) with growing domestic demand and export potential (RGC 2022). The cultivated areas for chilli production have increased from 275 hectares in 2018 to 589.5 hectares in 2021 (General Department of Agriculture [GDA] 2022). Consequently, chilli production reached approximately 2,686 tonnes in 2021. However, Cambodia's fresh chilli exports are just a fraction of Southeast Asia's regional exports. While Thailand remains the primary export destination for Cambodia's fresh and dried chillies, there are emerging opportunities in markets such as Singapore, Malaysia and Indonesia, signalling potential for further export growth.

Despite its potential, chilli cultivation faces several challenges, including low productivity, high input costs, frequent occurrences of diseases and insects, a lack of quality seeds and poor post-harvest handling, to name a few. For instance, chilli cultivation in Cambodia is seasonal, with significant supply in the dry season (November–June) and limited in the rainy season (June–October) (Deutsche Gesellschaft für Internationale Zusammenarbeit [GIZ] 2021). A high level of chemical residual was also found as farmers use large amounts of fertilisers and pesticides. These are bottlenecks affecting the profits, productivity and sustainability of chilli cultivation and limiting the potential for value addition and export.

Against this backdrop, we seek to explore the economics of chilli cultivation in Cambodia by answering the following research questions.

1. What are the revenue, cost and profit components involved in chilli farming?
2. What is the production frontier, representing the maximum yields per hectare achievable based on the current practices and available technologies?

Answering these questions contributes to the existing literature on chilli cultivation, both in the context of Cambodia and elsewhere, in three significant ways. Firstly, to the best of our knowledge, this study represents the first rigorous investigation into the cost and profit structure, as well as production efficiency, of chilli cultivation within the context of Cambodia. The insights from our findings offer guidance to policymakers and relevant stakeholders striving to enhance chilli production, productivity and most crucially, the profitability of chilli farmers. Secondly, we leverage a relatively large sample size of chilli farming households, enabling us to analyse profits and production efficiency at the plot level. This approach allows us to account for plot fixed effects while also controlling for household and village fixed effects. Thirdly, in addition to the main research questions, we examine cost efficiency and explore potential correlations between land size and production efficiency.

Section 2 presents methodology, detailing analytical framework and variables employed in computing revenue, costs and profits as well as analysing production efficiency. Section 3 highlights the sampling design and data collection methods. In Section 4, we present our findings, followed by a discussion of the results in Section 5. Section 6 offers policy suggestions.

2. Methodology

We employ two distinct yet interconnected analytical frameworks to address the main research questions: profitability and technical efficiency and its determinants.

2.1. Analytical framework

2.1.1. Profit function

The revenue-costs framework takes the following form.

$$\pi_{jiv} = r_{jiv} - c_{jiv}$$

where π_{jiv} represents the profits of plot *j* of household *i* in village *v; r_{jiv}* is gross revenue from plot *j* of household *i* in village *v; c_{jiv}* is the costs of farming on plot *j* of household *i* in village *v*. Profits are measured per hectare harvested.

Total revenue comprises sales of fresh and dried chillies with the following formula.

$$r^{f,d}_{jiv} = \sum^{f,d} q^{f,d}_{jiv} \cdot p^{f,d}_{jiv}$$

where $r^{f,d}_{jiv}$ is total revenue of fresh *(f)* and dried *(d)* chillies sold on plot *j* of household *i* in village *v*; $q^{f,d}_{jiv}$ is the quantity of fresh and dried chillies sold on plot *j* of household *j* in village *v*; $p^{f,d}_{jiv}$ is the unit price of fresh and dried chillies sold on plot *j* of household *i* in village *v*.

The additive and linear cost function takes the following form.

$$c_i(q_1,..., q_m; c_1 ,..., c_m) = \sum_{i=1}^{m} q_i \cdot c_i$$

where c_i is the total cost of inputs *i*; q_i is the quantity of inputs *i* used; c_i is price of inputs *i*. To calculate accounting and economic costs, the former contains expenses on the following: (1) materials (e.g., hired draft power, storage items, repairs and maintenance and transportation, etc.), (2) inputs (e.g., seeds, fertiliser, pesticide, electricity, oil and gas), (3) actual rental charges of land, (4) hired and exchanged labour for land preparation, plantation care and harvest and (5) imputed depreciation of farm implements, machinery and durable assets. The latter encompasses accounting costs and expenses on an individual's own and family labour. The rental charges for land use are imputed for all households.

Imputed rental charges for land use, for households who own or use the plot for free, are based on self-reported rent for the plot. An individual's own and family labour contribution on land preparation, seeding, care and harvest takes the following form.

$$LV = \sum (T \,.\, W)$$

where *LV* is labour value; *T* is time spent by individuals on each activity; *W* is assigned wage value. We estimate labour value for male and female adults and children aged 15 or below.

2.1.2. Stochastic frontier analysis

Stochastic frontier analysis is employed to determine the level of technical efficiency of chilli farming. In this analysis, the production frontier represents the maximum feasible output that can be produced within a given set of inputs and technology. The technical efficiency of each unit is then calculated as the ratio of its actual output against the maximum output predicted by the frontier. The random error term captures unobserved factors affecting efficiency, while the model also considers the impact of observable inputs on output.

The stochastic frontier analysis is applied in the context of the Cobb-Douglas production function in our analysis. The production function takes the following form.

$$Q = A \,.\, \prod_{j}^{\square} x_{i}^{a^{j}} \,.\, \prod_{i}^{\square}$$

where Q is the output; A is the total factor productivity; x_i is a set of inputs used in production (e.g., capital, labour, land); Z_i includes household village characteristics; a is the output elasticity of inputs. The Cobb-Douglas production has three main assumptions. Firstly, the function assumes constant return to scale. That is, $F(t \,.\, X) = t \,.\, F(X)$, where t is the scaling factor. This implies a doubling in inputs would result in a doubling in outputs. Secondly, all inputs have positive marginal products, meaning that increasing an input, holding the other constant, will increase output. However, the function depicts diminishing marginal product to inputs.

$$MP_j = \frac{\Delta Q_j}{\Delta X_j}$$

where if ΔX_j rises, MP_j would fall. Lastly, all inputs used are independent and additive.

The empirical specification of the production function is given by:

$$log(Q)_{jiv} = logA_{jiv} + alogX_{jiv} + \beta logZ_{jiv} + \zeta_v + \varepsilon_{jiv}$$

where Q_{jiv} is outputs of plot j of household i in village v; A_{jiv} is Total Factor Productivity (TFP) of plot j of household i in village v; X_{jiv} is a set of inputs used for plot j of household i in village v; Z_{iv} represents household and village characteristics; ζ_v is village fixed-effects; ε_{jiv} is an error term assumed to have zero conditional mean $E(\varepsilon_{jiv}|X, Z) = 0$.

The technical efficiency scores are the ratio of observed outputs (Q_j) and potential outputs (Q_j*) of plot j. We then regress the scores on select explanatory variables.

$$TE_{jiv} = \beta_0 + aX_{jiv} + \beta Z_{iv} + \zeta_{iv} + \varepsilon_{jiv}$$

where TE_{jiv} represents technical efficiency scores (0 – 1); X_{jiv} is a set of explanatory variables at plot j (e.g., land size); Z_{iv} represents household and village characteristics; ζ_{iv} is village fixed-effects; ε_{jiv} is an error term assumed to have zero conditional mean $E(\varepsilon_{jiv}|X, Z) = 0$.

2.2. Description of variables

This section describes indicators used to calculate the revenue, costs and profits and to estimate technical efficiency. As shown in Section 2.1, revenue is the product of unit price (p) and quantity (q) sold. p is the price per kilogram of fresh and dried chillies sold, whereas q is the quantity of fresh and dried chillies sold. The cost structure contains expenses on fixed capital, inputs, hired and exchanged labour, an individual's own and family labour, actual and imputed rent for land use and depreciation of farm implements, machinery and durable assets. Table 1 lists itemised costs by category.

Table 1: Categories and items of cultivation

Category	Items
Fixed capital	• Hired draft power (tractors/animals) for land preparation, seeding, care and harvest • Storage items (e.g., burlap bags, plastic sheeting, pipe, etc.) • Repair and maintenance of farmhouse and farm equipment • Transportation of produce, inputs and equipment • Rent paid to owner of equipment
Inputs	• Seeds, seedlings and young plants (includes purchased and one's own) • Chemical fertiliser • Pesticide, weedicide and fungicide • Animal and plant manure(includes purchased and one's own) • Electricity, oil and gas for farming • Water charges
Hired and exchanged labour	• Hired and exchanged labour for land preparation • Hired and exchanged labour for seeding and care • Hired and exchanged labour for harvest
Contribution of an individual and their family's labour	• An individual and their family's labour for land preparation • An individual and their family's labour for seeding and care • An individual and their family's labour for harvest
Land rent	• Rental charges (actual and imputed) for land use
Capital depreciation	• Imputed use-value of farm implements, machinery and durable goods owned by farmers

Source: Authors' preparation

The contribution of an individual and their family's labour to chilli farming encompasses the imputed expenses associated with land preparation, seeding, care and harvest. The considered wage is the prevailing rate in the village for each activity, collectively including that of male, female and child labour (aged 15 or younger).[1]

Included is the capital depreciation of 29 farm implements, types of machinery and durable assets (refer to Part 7 of the household questionnaire for the items). Without the age of these farm implements, machinery and durable assets, we used depreciation rates published by the General Department of Taxation within the Ministry of Economy and Finance (Ministry of Planning [MOP] 2021). The rates cover the following:

- Buildings, infrastructure of buildings and construction (five percent per annum)
- Small cars, large vehicles, furniture and office supplies (25 percent of the remaining value)
- Other assets (20 percent of the remaining value)

Table 2 presents dependent and explanatory variables used in the calculation of technical efficiency and its determinants (e.g., Nymeck et al. 2003; Wadud and White 2000; Latruffe et al. 2005; Yu and Fan 2011).

1 Gathered from data on employment and wage structures categorised by job types within each village. Daily wage rates for tasks such as land preparation, sowing, weeding, pruning, input applications and harvesting were documented for male, female and child labourers. The findings indicate an average daily wage of KHR40,000 (USD10.00) for males, KHR35,000 (USD8.75) for females and KHR15,000 (USD3.75) for children.

Table 2: Variables and definition

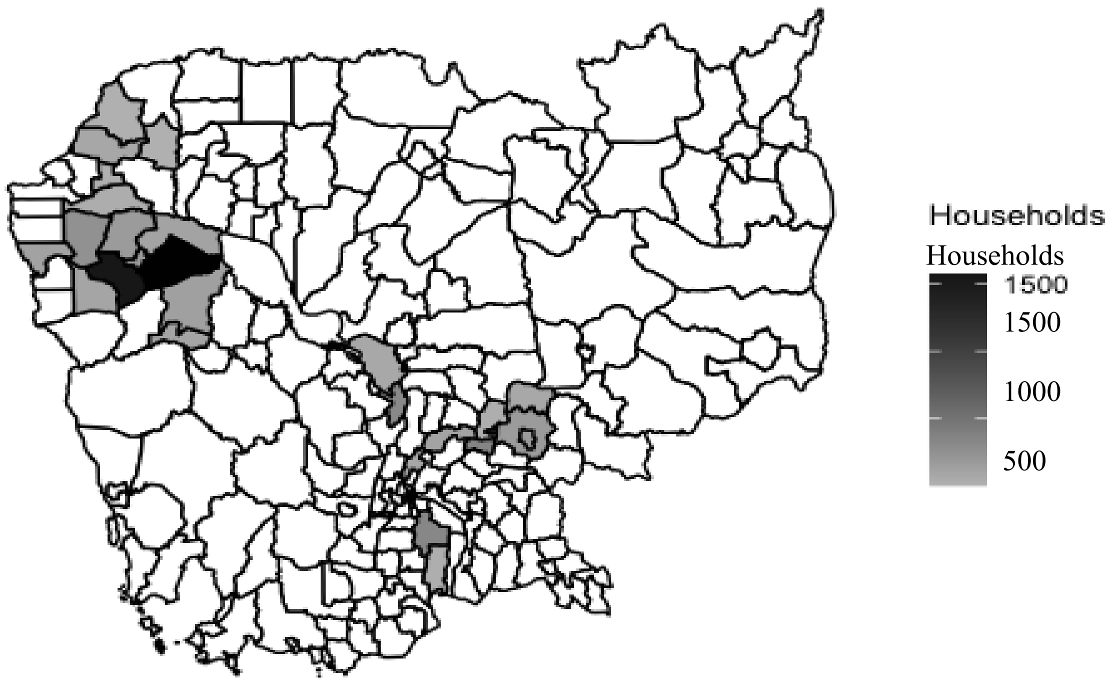
Variable	Type	Description
Outputs		
Yields	C	Quantity produced per hectare (t/ha)
Inputs		
Fixed capital	C	Expense of materials (KHR m/ha)
Inputs	C	Expense of inputs (KHR m/ha)
Hired and exchanged labour	C	Expense of hired and exchanged labour (KHR m/ha)
One's own and family labour	C	Expense of an individual and their family's labour (KHR m/ha)
Land rent	C	Rental charges of land use (KHR m/ha)
Capital depreciation	C	Use value of farm implements, machinery and durable assets (KHR m/ha)
Household controls		
Household size	C	Total number of household members residing with the family
Gender of household head	B	1 if the household head is female
Education of household head	B	1 if the household head completed primary education or lower
Experience	C	Number of years the household has grown chilli
Members of farmer organisations	B	1 if household members are in a farmer organisation
Geographical location	B	1 if the household resides in Battambang
Village controls		
Distance to permanent markets	C	Distance from the village to permanent markets (km)
Soil type	B	1 if the soil in the village is clayey
Disease and insects	B	1 if the village chief reported the existence of diseases and insects

Notes: C—Continuous; B—Binary. KHR—Cambodian riel; t—tonne; m—million; ha—hectare. Source: Authors' preparation

3. Data

We constructed a representative sample of chilli farmers through a two-stage stratified sampling design. In the first stage, we selected villages (primary sampling unit), and in the second stage, we targeted households actively involved in chilli production (secondary sampling unit). We requested information from officials at the provincial Department of Agriculture, Forestry and Fisheries in our target provinces (Banteay Meanchey, Battambang, Kandal, Kampong Cham, Kampong Chhnang and Tboung Khmum) to compile a comprehensive list of chilli farming households with administrative details. This listing served as the sampling frame from which we drew a representative sample. Figure 1 illustrates the distribution of households engaged in chilli farming at the district level in the target provinces. Battambang had the highest number of chilli farmers, constituting 72 percent of approximately 6,000 listed households.

Figure 1: Population of chilli farming households at the district level in target provinces



Source: Authors' preparation

We determined the required sample size for villages and households with a margin of error (precision level) of 0.05, an assumed equal population proportion of 0.5 and a 95 percent confidence level for a two-sided sample test (Z=1.96). Based on these parameters, our sample consists of 30 sample villages, with 18 households selected in each village, resulting in a total sample of 540 households. It should be noted that the final number of sample villages is 31, encompassing 542 chilli farming households. This adjustment was made by replacing villages with an insufficient number of households to conduct interviews. We employed a systematic sampling technique, where every n^{th} item in a population is selected after a random starting point, to choose representative households in sample villages. The enumerators coordinated with village chiefs to obtain the list of chilli farming households. The enumerators then calculated the sampling interval (k) using this formula: $k_j = \frac{N_j}{n_j}$, where k_j is the sampling interval in the sample village (j), N_j represents the total number of households engaging in chilli production in the sample village (j), and n_j is the sample households in the sample village (j). For instance, if the population is 100 and the sample is 10, k = 100/10 = 10. The enumerators selected a random starting point by using the last digit of the riel serial number. They then employed a systematic sampling method by initiating the selection process at the randomly chosen starting point and choosing every k^{th} element thereafter until the desired sample size was achieved. For instance, if k = 10 and the random starting point is 3, the enumerator would select elements 3, 13, 23, 33, and so on until the desired sample size is met.

The research team administered tablet-based village and household questionnaires designed using CSPro, a data collection tool. The questionnaires were pre-tested and revised before the data collection, which took three weeks to complete (December 8-29, 2023). The collected data was monitored and cleaned daily using R and Stata, statistical software for data processing, cleaning and analysis.

4. Results

4.1. Profits

Table 3 displays the means of cultivated and harvested land areas, yields and chilli prices categorised by chilli type. On average, the cultivated land size is 0.21, while the harvested land size is slightly smaller at 0.19 hectare. Chilli farmers achieved an average harvest yield of eight tonnes per hectare and sold approximately seven tonnes of fresh chillies per hectare harvested. The mean price of fresh chillies stands at KHR5310 per kilogram, with a 95 percent confidence interval ranging from KHR5125 to KHR5494 per kilogram. Hawaii (sweet) peppers produce the highest yields, averaging 11 tonnes per hectare harvested, while bird's eye, lady's finger and white chilli offered similar yields, ranging from six to eight tonnes per hectare harvested. Nonetheless, bird's eye chilli could fetch the highest price at KHR7074 per kilogram of fresh chillies, followed by lady's finger (KHR3668/kg), white chilli (KHR4040/kg) and Hawaii (sweet) pepper (KHR2,101/kg).

Table 3: Land size, price and yields of chilli cultiva

	All N = 719[1]	Bird's eye N = 377[1]	Lady's finger N = 221[1]	White chilli N = 42[1]	Hawaii (sweet) pepper N = 79[1]	p-value[2]
Cultivated land size (ha)	0.21 [0.19-0.22]	0.17 [0.15-0.19]	0.21 [0.18-0.23]	0.28 [0.19-0.37]	0.31 [0.25-0.38]	<0.001
Harvested land size (ha)	0.19 [0.18-0.21]	0.16 [0.14-0.18]	0.20 [0.17-0.22]	0.25 [0.17-0.33]	0.30 [0.23-0.36]	<0.001
Yields harvested (t/ha)	8 [7.1-8.0]	7 [6.2-7.3]	8 [6.9-8.6]	6 [4.9-7.9]	11 [9.4-13.0]	<0.001
Yields sold (t/ha): fresh	7 [6.9-7.8]	7 [6.1-7.3]	7 [6.3-8.0]	6 [4.8-7.8]	11 [9.3-13.0]	<0.001
Price (KHR/kg): fresh	5,310 [5,125-5,494]	7,074 [6,884-7,265]	3,668 [3,502-3,833]	4,040 [3,512-4,567]	2,101 [1,869-2,332]	<0.001

Notes: [1]Mean

[2]One-way ANOVA of differences in characteristics across chilli types. Ninety-five percent confidence intervals are in brackets. N–number of plots. t–tonne; ha–hectare. Source: Authors' calculations

Table 4 displays the revenue, costs and profits associated with the cultivation and sales of fresh and dried chillies per hectare harvested. The mean revenue chilli farmers could obtain is KHR36.5 million per hectare harvested (95 percent CI:33.9-39.1), whereas the accounting costs of cultivation are approximately KHR18.4 million per hectare harvested (95 percent CI:17.4-19.4). This results in accounting profits of KHR18.1 million per hectare harvested (95 percent CI:16-20.2). It should be noted that chilli farmers could operate at a loss if expenses of their own and family's labour are considered. The economic costs are nearly twice as high as revenue, totalling KHR51.9 million per hectare harvested (95 percent CI:49.2-54.5). This results in negative economic profits of KHR-15.4 million per hectare harvested, as expenses of labour comprise more than half of the total economic costs.

Farmers cultivating bird's eye varieties could attain the highest revenue, amounting to KHR46.7 million per hectare harvested (95 percent CI:42.5-50.9), followed by lady's finger (KHR26.5 million), white chilli (KHR24.5 million) and Hawaii (sweet) pepper (KHR22.3 million). Farmers cultivating bird's eye varieties also face the highest accounting costs, amounting to

KHR22.0 million per hectare harvested (95 percent CI:20.6-23.5). Consequently, they achieve accounting profits of KHR24.6 million per hectare harvested (95 percent CI:21.1-28.2).

Table 4: Revenue, costs and profits of chilli cultivation (KHR m/ha)

	All N = 719[1]	Bird's eye N = 377[1]	Lady's finger N = 221[1]	White chilli N = 42[1]	Hawaii (sweet) pepper N = 79[1]	p-value[2]
Revenue	36.5 [34-39]	46.7 [42-51]	26.5 [23-30]	24.5 [18-31]	22.3 [18-27]	<0.001
Accounting costs	18.4 [17-19]	22.0 [21-23]	16.3 [15-18]	9.9 [7.7-12]	11.4 [9.3-14]	<0.001
Economic costs	51.9 [49-55]	60.3 [56-64]	46.3 [43-50]	29.4 [24-35]	39.0 [32-47]	<0.001
Itemised costs						
Fixed capital	2.1 [2.0-2.3]	2.6 [2.4-2.8]	1.9 [1.7-2.0]	1.1 [0.83-1.4]	1.2 [0.99-1.5]	<0.001
Inputs	8.0 [7.5-8.4]	9.1 [8.5-9.8]	7.3 [6.5-8.2]	3.9 [3.1-4.8]	6.3 [4.9-7.6]	<0.001
Hired labour	6.0 [5.4-6.6]	7.7 [6.8-8.7]	4.7 [3.9-5.5]	4.3 [2.8-5.8]	2.5 [1.7-3.2]	<0.001
Land rent (actual)	0.1 [0.04-0.07]	0.0 [-,-]	0.1 [0.07-0.12]	0.0 [-,-]	0.2 [0.15-0.31]	<0.001
Land rent (imputed)	1.4 [1.3-1.5]	1.5 [1.4-1.6]	1.2 [1.1-1.4]	1.1 [0.82-1.4]	1.6 [1.2-1.9]	0.020
Capital depreciation	2.2 [2.1-2.4]	2.6 [2.4-2.8]	2.3 [1.9-2.7]	0.5 [0.35-0.69]	1.2 [0.87-1.5]	<0.001
Accounting profits	18.1 [16-20]	24.6 [21-28]	10.2 [7.7-13]	14.6 [9.7-20]	11.0 [7.3-15]	<0.001
Economic profits	-15.4 [-18- -13]	-13.6 [-18- -9.5]	-19.8 [-24- -16]	-4.9 [-11- 0.98]	-16.7 [-23- -11]	0.045

Notes: [1]Mean

[2]One-way ANOVA of differences in revenue, costs and profits across chilli types. Ninety-five percent confidence intervals are in brackets. [-,-] indicates insufficient observations. N–number of plots; KHR–Cambodian riel; m– million; ha–hectare. Source: Authors' calculations

Expenses on inputs (e.g., seeds, fertiliser, pesticide, electricity, oil, gas and water charges) as well as hired and exchanged labour for land preparation, plantation, care and harvest constitute 76 percent of the total accounting costs. Materials and capital depreciation expenses each contribute about 12 percent to the total accounting costs. Expenses of one's own and their family's labour account for 62 percent of the total economic costs, followed by the expenses of inputs (15 percent) and of hired and exchanged labour (12 percent). We also analyse expenses on hired and one's own labour across the main cultivation activities: land preparation, plantation, care and harvest. The findings reveal that chilli farmers allocate approximately 81 percent of the total costs to hiring labour for harvesting and 17 percent to planting and caring for the young seedlings. However, the majority (76 percent) of the contribution from one's self and their family's labour is dedicated to plantation and care activities, with harvest activities accounting for 22 percent.

Figure 2: Cost structure of chilli cultivation

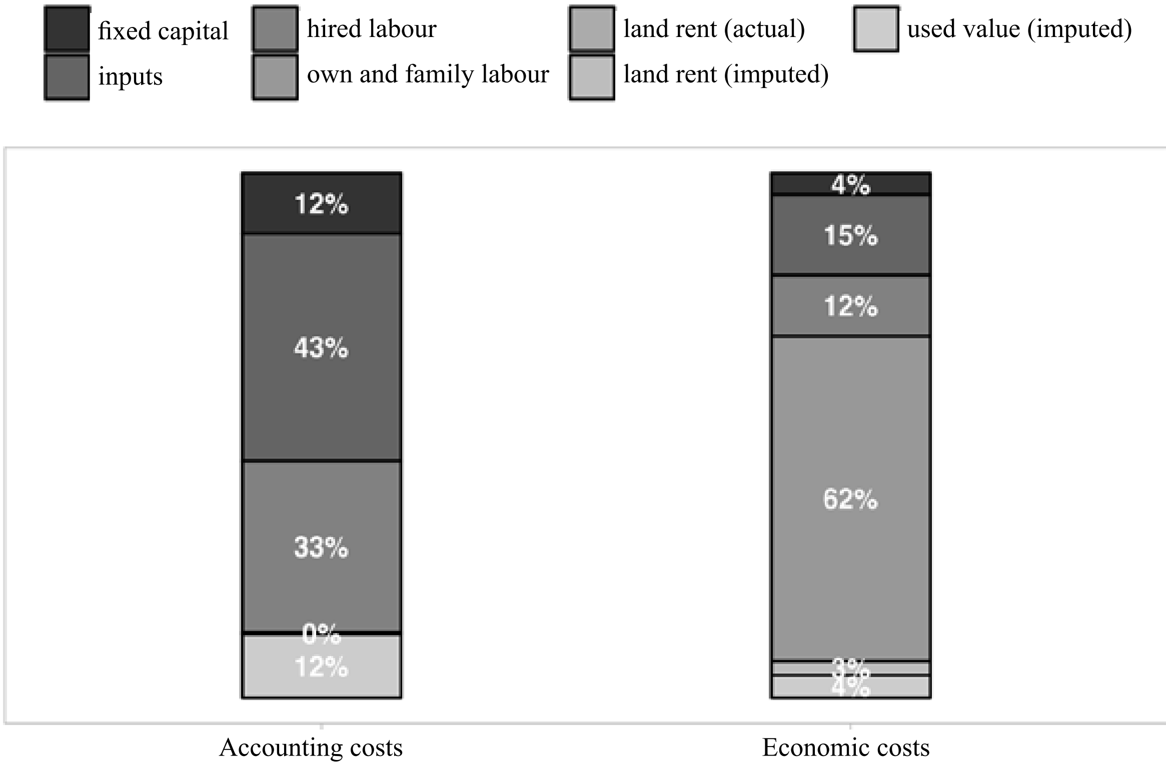
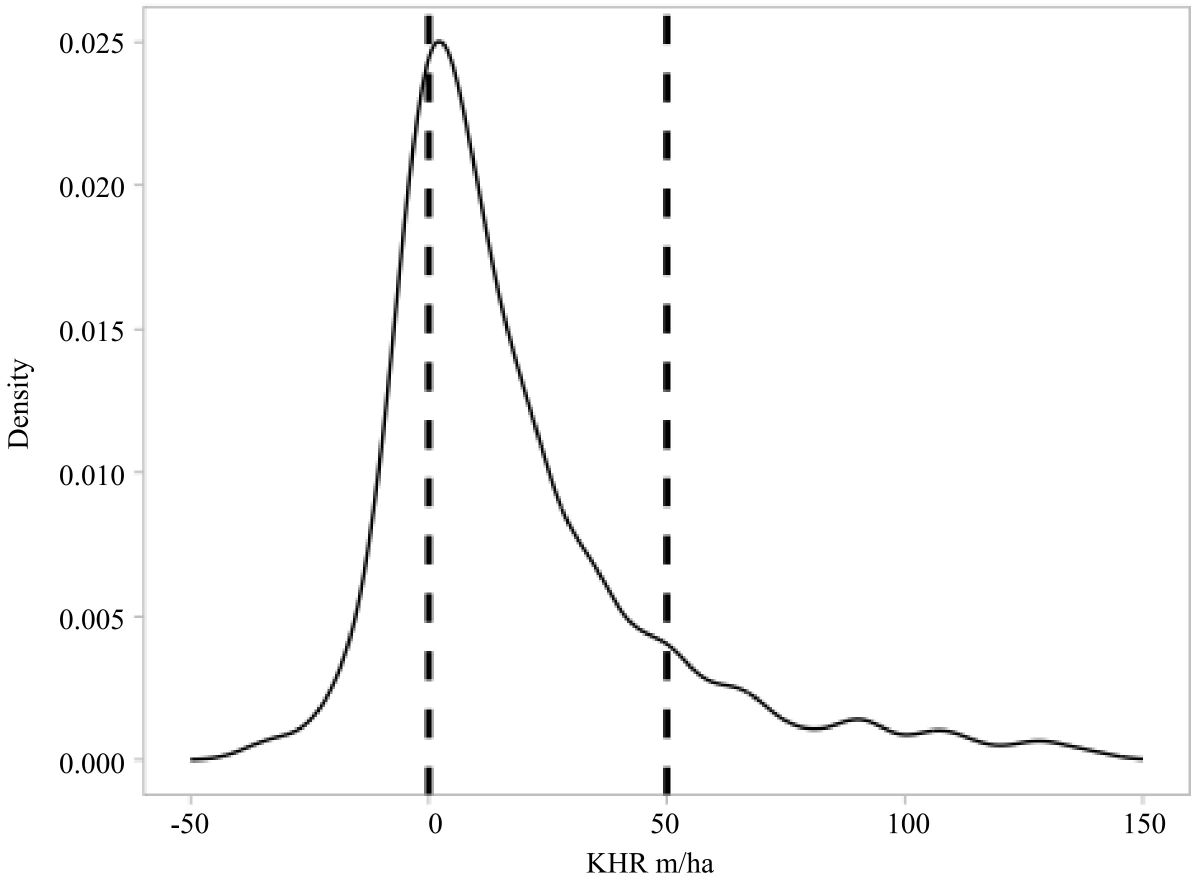


Figure 3: Cost structure by cultivation activity

Source: Authors' calculations

Considering accounting profits, about 25 percent of the plots operate at a loss (Figure 4). For plots making profits, accounting profits per hectare mainly range from KHR0–50 m/ha.

Figure 4: Distribution of profits



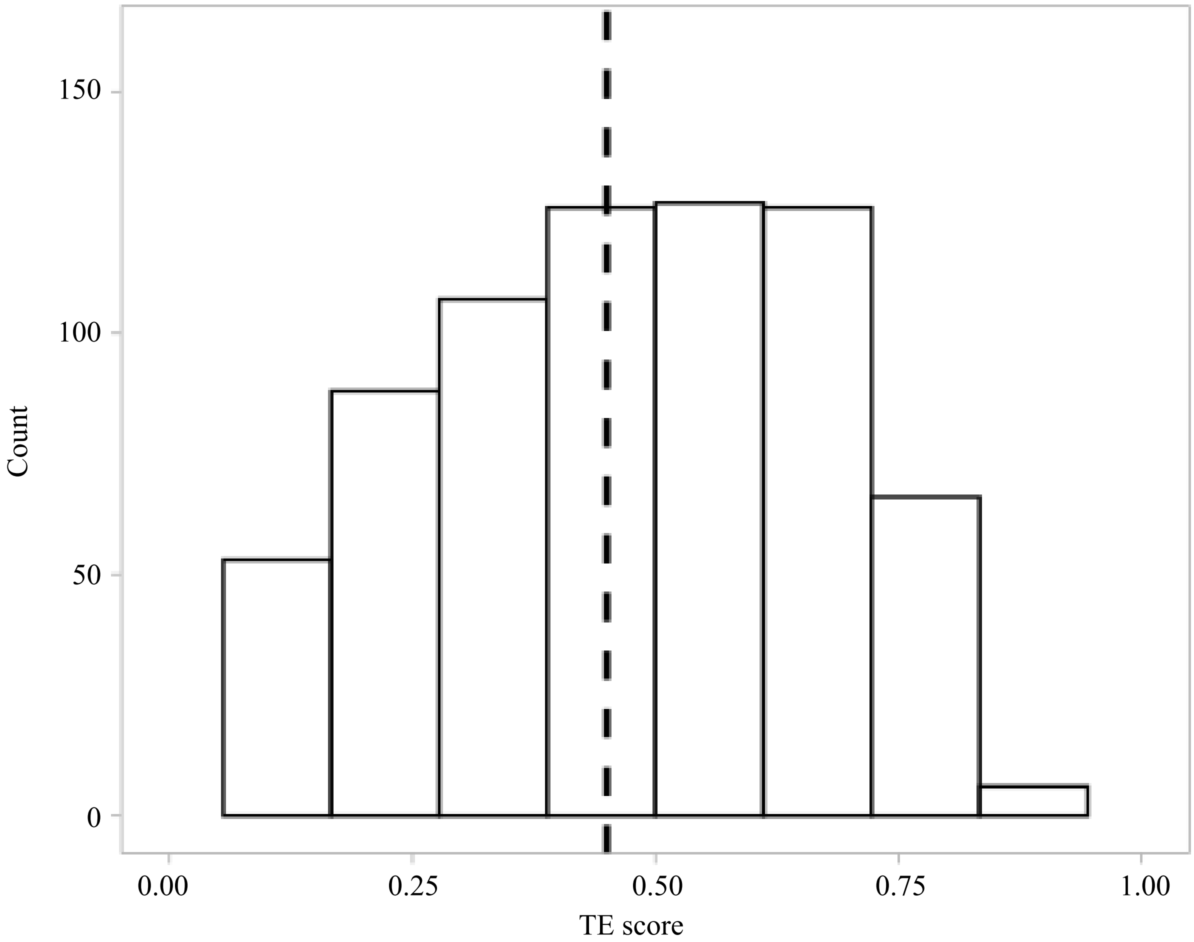
Source: Authors' calculations

4.2. Technical efficiency and its determinants

Figure 5 shows the distribution of technical efficiency, ranging from zero (the least efficient) to one (the most efficient). The mean technical efficiency is 46 percent, resulting in a 54 percent gap in technical efficiency at the frontier given the available farming practices and technology. About 71 percent of the plots have a technical efficiency below 60 percent, with about two percent having technical efficiency rates ranging between 80 and 90 percent, but none were above this.

Table 5 highlights plot and household characteristics by technical efficiency levels. Plots with technical efficiency rates between 0.8 and 1.0 could produce average yields of 14.82 tonnes/ha, compared to 2.14 tonnes produced by plots with the lowest efficiency (0–0.299). The most efficient plots tend to be larger than the least efficient ones (0.39 compared to 0.14 ha). The differences in yields and land sizes across efficiency levels are statistically significant at the one percent level. There seem to be no differences in household size or age of household head across efficiency levels. Experience does not seem to be statistically different between the least and most efficient plots.

Figure 5: Distribution of technical efficiency scores



Notes: TE– technical efficiency
Source: Authors' calculations

Table 5: Plot and household characteristics by technical efficiency

	TE score (0-1)				
	0-0.299 N = 182[1]	0.3-0.599 N = 326[1]	0.6-0.799 N = 194[1]	0.8-1.000 N = 17[1]	p-value[3]
TE score (mean)	0.183 [0.17-0.20]	0.454 [0.45-0.46]	0.687 [0.68-0.69]	0.826 [0.82-0.84]	<0.001
Yields (t/ha)	2.14 [1.90-2.40]	6.56 [6.1-7.0]	13.64 [13-15]	14.82 [12-18]	<0.001
Land size (ha)	0.14 [0.12-0.16]	0.19 [0.17-0.21]	0.23 [0.19-0.27]	0.39 [0.27-0.51]	<0.001
Household size (#)	4.60 [4.40-4.90]	5.0 [4.8-5.2]	5.1 [4.8-5.4]	5.4 [4.6-6.1]	0.095
Age of household head (years)	53 [52-55]	53 [51-54]	52 [50-54]	59 [53-65]	0.12
Experience growing chilli (years)	8 [7.0-9.4]	10 [9.4-11]	11 [9.8-12]	9 [5.6-13]	0.008

Notes: [1]Mean
[2]One-way ANOVA of differences in characteristics across levels of technical efficiency. Ninety-five percent confidence intervals are in brackets. N–number of plots. TE– technical efficiency.
Source: Authors' calculations

Table 6 presents the ordinary least squares regression results, highlighting factors that may contribute to the technical efficiency (or inefficiency) of chilli farms. The results indicate that technical efficiency in chilli farming is influenced by several factors, including land size, household size, geographical location and the occurrence of chilli diseases and insects. Larger land sizes among chilli farmers are associated with higher technical efficiency scores, and this difference is statistically significant at the one percent level. However, we find some evidence of diminishing marginal returns of land size to technical efficiency with a maximum land size of 0.9 hectares, beyond which technical efficiency may decline with land size. Larger households have a positive association with increased technical efficiency. Additionally, chilli farmers in Battambang exhibit lower efficiency compared to those in other sampled provinces. Regions experiencing incidences of chilli diseases or insects tend to have lower technical efficiency.

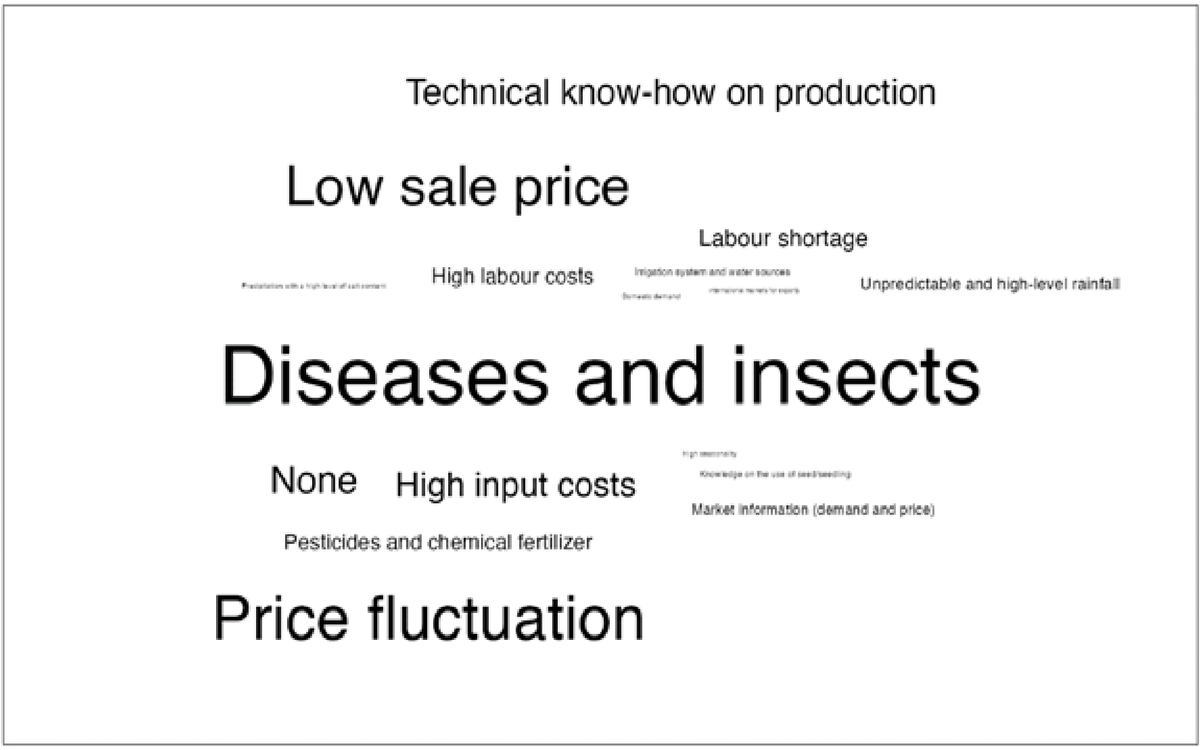
Table 6: Ordinary least squares regression results of determinants of technical efficiency

	Dependent variable: TE score	
	All	Bird's eye and lady's finger
Land size (ha)	0.244*** (0.082)	0.324*** (0.097)
Land size (ha, squared)	-0.125* (0.073)	-0.211** (0.095)
Household size (#)	0.009*** (0.004)	0.012*** (0.004)
Gender of household head (1= female)	0.002 (0.019)	-0.010 (0.020)
Education of household head (1= primary or lower)	-0.008 (0.015)	-0.008 (0.016)
Experience (years of chilli cultivation)	0.001 (0.001)	0.001 (0.001)
Member of farmer organisation (1= yes)	0.013 (0.026)	0.036 (0.028)
Geographical location (1= Battambang)	-0.180*** (0.018)	-0.174*** (0.019)
Distance to permanent markets (km)	-0.0001 (0.002)	-0.005** (0.003)
Soil type (1= clayey)	0.015 (0.015)	-0.004 (0.016)
Diseases and insects (1= yes)	-0.134*** (0.028)	-0.131*** (0.027)
Constant	0.574*** (0.039)	0.565*** (0.041)
Obs.	719	598
R^2	0.233	0.192

Notes: Robust standard errors are in parentheses. *Obs*. indicates the number of plots. *p<0.1; **p<0.05; ***p<0.01. TE–technical efficiency. Ha–hectare. Source: Authors' calculations

Figure 6 shows self-reported challenges in chilli cultivation. We asked the respondents to report challenges in dry and wet seasons. The results indicate that diseases and insects, low prices and price fluctuation are the main concerns. Lack of technical knowledge in production was also reported.

Figure 6: Self-reported challenges in chilli farming



Source: Authors' calculations

5. Discussion

Price stands as a significant determinant of revenue, and thus, profits. In 2023, farmers could secure higher prices compared to the previous year, possibly the highest levels seen since the Covid-19 pandemic. Market demand and the quality of chilli are potential factors contributing to higher prices. Moreover, effective cost management, efficient oversight of production costs, labour expenses and other operational overheads, can significantly bolster profitability. Another factor enhancing the potential profitability of chilli farming is the farmers' capacity to diversify their products. One such value-added product derived from chilli is dried chillies. As shown, nearly all sampled chilli farmers sell fresh chillies during the growing season. Through diversification, farmers can access various markets, thereby expanding their opportunities for sales and revenue.

Chilli cultivation exhibits a seasonal pattern, characterised by extensive cultivation and increased yields during the dry season (November-June), contrasted by diminished activity and lower yields during the wet season (June-October). During the wet season, chilli cultivation is prevalent in plateau and mountainous regions due to the suitability of their elevated terrains for this crop. Despite typically lower quantities supplied during the wet season, chilli prices tend to be lower compared to those in the dry season. This difference in prices primarily stems from the relatively lower quality of wet-season chillies.

When juxtaposed with various other agricultural endeavours, chilli farming emerges as a lucrative option, offering competitive income potential. In our study sample, chilli farming demonstrates the capacity to provide the highest annual income, amounting to KHR8.1 million, representing 28.4 percent of the total household annual income. This figure surpasses the earnings from other agricultural ventures (KHR6.8 million) and non-agricultural businesses

(KHR6.4 million). Figures on annual income per capita from chilli farming indicate similar trends, totalling to KHR1.8 million (KHR2.9 million per working-age adult).

Table 7: Cost structure of chilli cultivation by land size

	Land size (ha)					
	0.0-0.999 N = 279[1]	0.1-0.199 N = 206[1]	0.2-0.299 N = 91[1]	0.3-0.399 N = 61[1]	0.4-2.000 N = 82[1]	p-value[2]
Fixed capital (KHR m/ha)	2.99 [2.7-3.3]	1.90 [1.7-2.1]	1.44 [1.2-1.7]	1.40 [1.2-1.6]	0.98 [0.83-1.1]	<0.001
Inputs (KHR m/ha)	9.79 [9.0-11]	7.61 [6.8-8.4]	6.78 [5.6-7.9]	6.33 [4.8-7.9]	4.97 [4.0-5.9]	<0.001
Hired labour (KHR m/ha)	4.96 [4.0-5.9]	7.48 [6.3-8.7]	6.05 [4.6-7.5]	6.88 [4.8-8.9]	5.25 [3.9-6.6]	0.009
Actual land rent (KHR m/ha)	0.07 [0.03-0.11]	0.13 [0.07-0.18]	0.14 [0.06-0.23]	0.12 [0.01-0.22]	0.15 [0.06-0.24]	0.300
Capital depreciation (KHR m/ha)	3.80 [3.5-4.2]	1.76 [1.6-2.0]	0.94 [0.77-1.1]	0.88 [0.73-1.0]	0.36 [0.29-0.43]	<0.001
Seeds (KHR m/ha)	1.18 [1.1-1.3]	0.85 [0.73-0.97]	0.79 [0.62-0.96]	0.80 [0.57-1.0]	0.52 [0.42-0.63]	<0.001
Fertiliser (KHR m/ha)	3.67 [3.3-4.1]	3.08 [2.7-3.5]	2.79 [2.2-3.4]	2.30 [1.7-2.9]	1.71 [1.3-2.1]	<0.001
Fertiliser (kg/ha)	1,531 [1,158-1,905]	940 [804-1,076]	841 [658-1,024]	706 [517-896]	536 [411-660]	<0.001
Pesticide (KHR m/ha)	1.67 [1.5-1.9]	1.43 [1.2-1.6]	1.23 [0.94-1.50]	1.11 [0.78-1.4]	1.12 [0.82-1.4]	0.006

Notes: [1]Mean
[2]One-way ANOVA of differences in cultivation costs across land size. Ninety-five percent confidence intervals are in brackets. N—number of plots. KHR—Cambodian riel; m—million; ha—hectare.
Source: Authors' calculations

The empirical results also indicate that there is considerable scope to enhance efficiency of chilli cultivation, both for the least and most efficient plots in the sample. A crucial determinant of efficiency is land size. Larger land areas tend to have higher efficiency compared to smaller ones. Inefficient uses of inputs and lack of economies of scale among farmers operating smaller land plots are possible explanations. Table 7 shows the cost structure of chilli cultivation by land size. The use of most inputs is higher among farm sizes of 0.399 hectare or lower compared to that of the largest farm size in the sample. The difference on all inputs used is statistically significant at a one percent level, except expenses on actual land rent. For instance, farmers operating the largest farm size used 536 kg/ha of fertiliser compared to 1,531 kg/ha used by farmers operating the smallest size. Fertiliser expenses on the largest farm plots are also lower than those on the smallest ones, indicating the ability of farmers with large farms to buy in large quantities at a relatively lower unit price. A similar pattern is seen for the expenses of chilli seeds. Small-scale chilli farmers also incur high depreciation costs compared to farmers operating larger farms, reflecting the economies of scale due to the use of fixed capital (e.g., machinery). The finding is consistent with that of previous studies. In Egypt, for instance, input applications tend to be more substantial in smaller land sizes, especially concerning nitrogen fertilisers (Abay et al. 2022). The authors also note that input utilisation on smaller plots often exceeds the agronomically recommended levels. The total factor productivity is higher for smaller farms than larger ones in Malawi, Tanzania and Uganda (Julien et al., 2019). However, there is a negative association between farm sizes and technical efficiency in Malawi (Khataza et al. 2019).

Despite the positive association between land size and technical efficiency, we find some evidence of diminishing marginal returns of land size to technical efficiency. The evidence seems to suggest an inverted-U relationship between technical efficiency and land size (Table 6). The optimal land size might be 0.99 hectare beyond which technical efficiency might decline as land size rises. High costs of monitoring, care and harvest can be a possible explanation. Depending on various factors such as farm size, quantity and chilli varieties, the average harvest times in our study sample are 13 times per year. This underscores the crucial importance of precise timing in harvesting, as well as the requisite labour or technology needed to accomplish this task effectively.

The results of previous studies on the association between the efficiency of chilli cultivation and land size have been inconclusive. Smaller chilli farms in Thailand are more efficient than larger ones (Krasachat 2023). Specifically, a farm with less than two rai (0.32 ha) of cultivated area is found to be more efficient than a farm with two rai or more ($\geq 0.32ha$) of cultivated area. The association between small farms and technical efficiency is attributed to the fact that farmers with small farms can monitor and care for the land and plantations more thoroughly. They, the author argues, can contribute more of their own and their family's labour to the process, as chilli farms are labour-intensive. In contrast, there are studies which find no association between farm size and technical efficiency (or inefficiency) (e.g., Krasachat 2020; Suresh 2015). They argue that there is no statistical difference in land size as the majority of Thai and Indian chilli farmers are smallholders. Using the Brazilian Agricultural Census in 2006, small farms were found to be more efficient than medium and large farms (Morais et al. 2021). However, no association between technical efficiency and farm size in Thai chilli cultivation was found (Krasachat 2020). In a Thai context, some research indicates that larger cassava and rice farms achieve higher technical efficiency than smaller farms (Jirarud and Suwanmaneepong 2020; Srisompun and Boontang 2020). In Cambodia's context, particularly for paddy rice, some research finds that expansion of cultivated areas has a positive association with paddy production (Yu and Fan 2011). However, the authors see land expansion as a short-term solution, as additional land available for cultivation is limited. Besides land expansion, they point to fertiliser and irrigation as positive determinants of paddy supply and increased productivity as a long-term strategy.

Given the results of our study and those of previous ones, it seems that the association between technical efficiency and farm size might be dependent on the crop examined. While larger farms are more efficient than smaller ones for crops such as rice or cassava, the opposite is likely for chilli cultivation. In other words, we are less likely to achieve economies of scale by expanding farm size for chilli production beyond the optimal size, as we are with rice or cassava. Presumably, chilli cultivation is labour-intensive and needs constant monitoring and care compared to rice or cassava, factors that could be supported by farm mechanisation or the adoption of technological applications.

The regression results further show a negative correlation between the incidence of diseases and insects and technical efficiency. Specifically, areas with frequent occurrences of diseases and insects tend to exhibit lower levels of technical efficiency. This reduced efficiency manifests primarily through diminished yields, as there are no discernible statistical disparities in production costs between areas affected by diseases and insects and those unaffected. Moreover, technical efficiency appears to be lower among plots in Battambang relative to those in other target provinces, potentially attributable to inefficient utilisation of inputs (see Table A.1). Household size tends to positively contribute to technical efficiency, given that larger households typically possess more labour resources, particularly advantageous during the plantation and care stages. The available labour is particularly crucial given the labour-intensive nature of chilli farming.

6. Conclusion

In this study, we estimated profits and measured technical efficiency of chilli farms using a sample of 719 chilli plots from 542 households in Banteay Meanchey, Battambang, Kampong Chhnang, Kampong Cham, Tboung Khmum and Kandal surveyed from December 8-29, 2023. We employed a revenue-costs framework to calculate accounting and economic profits, and stochastic frontier analysis with a Cobb-Douglas production function to estimate technical efficiency and investigate its determinants.

Four chilli varieties–bird's eye, lady's finger (cayenne pepper), white chilli, and Hawaii (sweet) pepper–are cultivated. Bird's eye and lady's finger are the most common, accounting for 52 percent and 31 percent of the total cultivated plots, respectively. The mean cultivated land size is 0.21 ha, while the harvested land size is slightly smaller at 0.19 ha. Chilli farmers achieve average yields of eight tonnes/ha and sell approximately seven tonnes/ha of fresh chilli. Almost all harvested chillies are sold fresh with mean prices of KHR5,310 per kilogram (95 percent CI: KHR5,125 to KHR5,494). Farmers could attain higher price for dried chillies, ranging from KHR10,000 (US$2.5)/kg to KHR20,000 (US$5)/kg.

Farmers could attain accounting profits of KHR18.1 million/ha (95 percent CI:16-20.2), or about 50 percent of the total revenue. Accounting profits vary depending on chilli varieties, with the cultivation of bird's eye chillies securing the highest profits (KHR24.6 million/ha). The higher profits are attributable to a higher price. Farmers could also incur high costs, specifically expenses on inputs (e.g., seeds, fertiliser and pesticide) and hired labour (mainly for harvest). Despite negative economic profits, farmers still have time to attend to other farm and non-farm activities. The high imputed costs of one's own and their family's labour partially indicate that chilli cultivation is labour-intensive, demanding constant care.

There are possibilities to increase efficiency and yields of chilli cultivation on both the least and most efficient plots. Given the available farming practices and technology, the least efficient plots could achieve about two tonnes/ha, whereas the most efficient ones could achieve approximately 14 tonnes/ha. Land size, household size, geographical location and diseases and insects are potential contributing factors to technical efficiency (or inefficiency).

Based on the findings, the Ministry of Agriculture, Forestry and Fisheries, along with other relevant ministries, could further enhance the efficiency of chilli cultivation by considering the following:

- Explore the possibility of increasing cultivated land size, particularly for households operating on plots smaller than 0.2 hectares. It should be noted that this is a rather short-term solution, as additional land is limited. Farm productivity improvement is a more long-term solution.
- Offer extension services, particularly on the efficient uses of inputs and in dealing with diseases and insects.
- Explore technology applications to help improve production and reduce costs, particularly labour and input costs.

- Explore the possibilities of extending and increasing production in the wet season (June-October).
- Continue efforts to reduce production costs, with a particular focus on minimising expenditures associated with fertiliser, pesticides, electricity and fuel.

Future research could explore domestic and export markets for fresh and dried chillies and other chilli-based products, offering valuable insights into market dynamics and potential growth opportunities. It is also of policy relevance to examine how the establishment of farmers' organisations or the adoption of contract farming arrangements among chilli farmers could play a role in ensuring price stability, improving efficiency and elevating quality standards.

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Appendix A: Additional statistics

Table A.1: Costs of chilli cultivation by occurrence of diseases and insects and location

	Diseases and insects				Geographical location			
	No N = 52[1]	Yes N = 667[1]	Diff[2]	p-value[2]	Others N = 350[1]	BTB N = 369[1]	Diff[2]	p-value[2]
Yields (t/ha)	8.96	7.44	1.5	0.10	9.32	5.87	3.4	<0.001
Materials (KHR m/ha)	2.51	2.09	0.43	0.14	1.87	2.36	-0.49	<0.001
Inputs (KHR m/ha)	9.91	7.79	2.1	0.017	7.08	8.75	-1.7	<0.001
Hired labour (KHR m/ha)	13.25	5.45	7.8	<0.001	4.21	7.72	-3.5	<0.001
Actual land rent (KHR m/ha)	0.00	0.12	-0.12	<0.001	0.21	0.01	0.20	<0.001
Capital depreciation (KHR m/ha)	2.11	2.22	-0.11	0.7	1.95	2.47	-0.52	0.004
Seeds (KHR m/ha)	0.49	0.96	-0.47	<0.001	0.95	0.91	0.03	0.600
Fertiliser (KHR m/ha)	4.54	2.93	1.6	<0.001	2.35	3.71	-1.4	<0.001
Pesticides (KHR m/ha)	1.80	1.41	0.39	0.042	1.34	1.53	-0.19	0.10
Fertiliser (kg/ha)	1,357	1,070	287	0.070	753	1,411	-658	<0.001

Notes: [1]Mean
[2] Welch's two sample t-test of differences in characteristics across groups. N indicates the number of plots.

Table A.2: Costs of chilli cultivation by household size

	Household size			
	1-3 N = 168[1]	4-6 N = 421[1]	7-13 N = 130[1]	p-value[2]
Yields (t/ha)	6.93 [5.9-7.9]	7.64 [7.0-8.2]	8.04 [6.8-9.3]	0.300
Materials (KHR m/ha)	2.21 [1.9-2.5]	2.22 [2.0-2.4]	1.67 [1.4-2.0]	0.009
Inputs (KHR m/ha)	7.68 [6.7-8.7]	8.45 [7.8-9.1]	6.63 [5.6-7.7]	0.014
Hired labour (KHR m/ha)	6.05 [4.9-7.2]	6.05 [5.3-6.8]	5.86 [4.4-7.3]	>0.900
One's own and family's labour (KHR m/ha)	35.33 [31-40]	31.94 [29-35]	26.77 [22-32]	0.037
Actual land rent (KHR m/ha)	0.08 [0.03-0.12]	0.14 [0.10-0.18]	0.07 [0.02-0.12]	0.078
Capital depreciation (KHR m/ha)	2.03 [1.7-2.4]	2.34 [2.1-2.6]	2.05 [1.7-2.4]	0.200
Seeds (KHR m/ha)	1.08 [0.93-1.2]	0.90 [0.81-0.99]	0.82 [0.66-0.99]	0.036
Fertiliser (KHR m/ha)	2.85 [2.4-3.3]	3.29 [3.0-3.6]	2.54 [2.1-3.0]	0.029
Pesticides (KHR m/ha)	1.38 [1.1-1.6]	1.54 [1.4-1.7]	1.17 [0.92-1.4]	0.047
Fertiliser (kg/ha)	996 [734-1,258]	1,195 [961-1,430]	876 [661-1,091]	0.300

Notes: [1]Mean
[2]One-way ANOVA of differences in cultivation costs across household size. Ninety-five percent confidence intervals are in brackets. N indicates the number of plots. Source: Authors' calculations.

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