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Long-Run Cost Efficiency and Minimum Efficient Scale in Thai Rubber Farming

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ABSTRACT

This study examines the long-run production cost structure and economies of scale of rubber farming in Thailand. Conventional cost assessments generally focus on annual fixed and variable costs and therefore do not adequately account for the time value of money, despite rubber farming being a long-term investment with a production cycle of approximately 25 years. The study integrates primary information obtained from rubber farmers, agricultural experts, and relevant government agencies with secondary production and cost data. A long-run average cost model is constructed for plantation sizes ranging from 3 to 100 rai, with future costs and output discounted to present values using a 5% discount rate. In addition, a Cobb–Douglas production function is estimated for the productive period from years 7 to 25 to evaluate input elasticities and returns to scale. The results reveal a U-shaped long-run average cost curve, with the mathematical minimum occurring at approximately 27 rai. However, plantations within the broader range of 20–40 rai exhibit similarly low and stable average costs, indicating a practical cost-efficient operating range rather than a single rigidly optimal farm size. Discounting changes the level of average cost but does not materially alter either the minimum point or the broader efficient range. The estimated output elasticities of labor and capital services are approximately 0.860 and 0.343, respectively, indicating increasing returns to scale during the productive period. The findings support lifecycle-based cost policies, collective farm management, and improved access to skilled labor, capital services, and shared production technologies that enable smallholders to operate more efficiently within the cost-efficient scale range.

INTRODUCTION

Thailand is one of the world's leading producers and exporters of natural rubber and intermediate rubber products. Rubber farming remains an important source of income for agricultural households, particularly in the southern, eastern and north-eastern regions of the country. Although Thailand's total rubber plantation area declined from approximately 25.96 million rai in 2015 to 23.81 million rai in 2024, national output remained relatively stable at more than 4.7 million tons annually (Office of

Agricultural Economics, 2025). This demonstrates the continuing economic importance of the rubber sector despite structural changes in land use and declining average productivity.

Table 1. Rubber Plantation Area, Production, and Yield per Rai, 2015–2024

Year	Planted Area (1,000 rai)	Tappable Area (1,000 rai)	Production (1,000 tons)	Yield per Rai (kg/rai)
2015	25,962	18,529	4,423	239
2016	25,957	19,028	4,445	234
2017	25,757	19,866	4,663	235
2018	25,349	20,791	4,923	237
2019	25,041	21,490	4,849	226
2020	24,753	21,984	4,860	221
2021	24,467	21,976	4,892	223
2022	24,229	22,029	4,786	217
2023	24,044	22,493	4,810	214
2024	23,813	22,471	4,789	213

Source: Office of Agricultural Economics (2025)

Thai rubber farmers remain highly exposed to fluctuations in world rubber price, as shown in Table 2. Although Thailand is a major global supplier, individual farmers generally operate as price takers and have limited influence over market prices. Consequently, fluctuations in farm-gate prices directly affect household income, farm maintenance, investment decisions and the long-term viability of rubber cultivation. During periods of low prices, farmers may reduce fertilizer application, postpone plantation maintenance, replace rubber with other crops or leave rubber farming altogether (Nicod et al., 2020).

Table 2. Rubber: Farm-Gate Prices and Value of Production, 2015–2024

Year	Farm-Gate Price (Baht/kg)	Value of Production (Million Baht)
2015	44.17	195,351
2016	48.81	216,984
2017	55.81	260,229
2018	40.96	201,650
2019	41.04	199,011
2020	44.85	217,955
2021	51.97	254,238
2022	51.67	247,281
2023	45.77	215,439
2024	68.94	330,157

Source: Office of Agricultural Economics (2025)

A major limitation of existing cost assessments is their concentration on short-run annual costs. Rubber cultivation, however, is a long-term investment (Jayasuriya et al., 1981; Lekshmi & George, 2003). Farmers incur substantial establishment and maintenance costs during the first six years, while commercial latex production generally begins in the seventh year. Treating costs and output occurring in different years as having equal economic value may therefore underestimate the actual financial burden borne by farmers.

This study addresses this limitation by developing a lifecycle-based long-run average cost model for Thai rubber farming. The model incorporates establishment costs, operating costs, tapping expenses, farm-level fixed costs, management overhead and replanting expenditure over a 25-year production cycle. The analysis compares cost estimates calculated with and without discounting and identifies the minimum efficient scale of rubber plantations. The study also estimates a Cobb–Douglas production function to examine the contributions of labor and capital to rubber output and to determine whether production exhibits increasing, constant or decreasing returns to scale. The combined analysis provides information relevant to farmers' investment decisions and to government policies concerning income support, farm consolidation, agricultural finance and production efficiency.

1. LITERATURE REVIEW

Previous studies have shown that rubber production costs vary with plantation location, product form, labor arrangements, farm-management practices, and processing technology. Raw rubber sheets, for example, generally involve higher costs than fresh latex or cup lump because sheet production requires additional labor, equipment, and processing facilities (Intraskul et al., 2018). Cost levels may also be influenced by soil suitability, terrain, and transport accessibility. Over the plantation lifecycle, these expenses can be divided into two broad phases (Boontim, 2016). During the immature period, farmers bear the costs of land preparation, seedlings, planting, fertilization, weed control, and plantation maintenance without receiving latex income. During the productive period, the principal operating expenses include tapping labor, equipment, fertilizer, pest control, transportation, maintenance, and any additional processing required for the selected product form.

Financial appraisal methods such as net present value, internal rate of return, and the benefit–cost ratio are commonly used to assess whether rubber cultivation is financially viable (Cherdchom et al., 2002; Tran, 2020). Although these measures are useful for evaluating overall investment returns, they do not directly determine the plantation size at which average lifecycle production cost is minimized. A long-run average cost framework is therefore more appropriate for examining the relationship between farm scale and cost efficiency.

In production theory, the long run refers to a period in which all inputs can be adjusted (Samuelson & Nordhaus, 2010; Varian, 2014). For rubber farmers, such adjustments may include plantation size, rubber variety, labor organization, capital equipment, and management systems. The long-run average cost curve is generally expected to be U-shaped (Varian, 2014; Pindyck & Rubinfeld, 2018). Average cost declines initially as fixed costs are spread over greater output and resources are used more efficiently. Beyond the minimum efficient scale, however, cost may rise because of increasing coordination, supervision, internal transportation, disease-control, and managerial requirements.

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The production relationship is represented by a Cobb–Douglas production function, which provides a widely used framework for examining the relationship between output and productive inputs (Cobb & Douglas, 1928; Chambers, 1988):

$$Q = AL^{\beta}K^{\gamma}$$

where Q denotes rubber output, L is labor input, K is capital services, A is a technology-related constant, r represents the time-related component, and β and γ are output elasticities with respect to labor and capital.

The output elasticity of rubber production with respect to capital E_K is calculated as follows:

$$E_K = \frac{\partial Q}{\partial K} \cdot \frac{K}{Q} = \gamma A K^{\gamma-1} L^{\beta} \cdot \frac{K}{AK^{\gamma}L^{\beta}} = \gamma$$

Similarly, the output elasticity of rubber production with respect to labor E_L is calculated as follows:

$$E_L = \frac{\partial Q}{\partial L} \cdot \frac{L}{Q} = \beta A K^{\gamma} L^{\beta-1} \cdot \frac{L}{AK^{\gamma}L^{\beta}} = \beta$$

The sum of the input elasticities determines the nature of returns to scale. When ($\gamma + \beta = 1$), production exhibits constant returns to scale. A value greater than one indicates increasing returns to scale, whereas a value below one indicates decreasing returns to scale.

Production-function analysis is particularly relevant to natural rubber farming because latex output depends heavily on labor-especially skilled tapping labor-as well as on productive assets, farm management, and other capital-related inputs. Empirical studies of smallholder rubber production have therefore used production functions to examine input productivity, resource-use efficiency, and returns to scale, consistently identifying labor as a major determinant of output because tapping remains both labor-intensive and skill-dependent (Ambali & Momoh, 2012; Giroh & Nachandiya, 2022). At the same time, long-term investment analysis is essential because rubber cultivation requires substantial establishment and maintenance expenditure during the immature period before generating returns over a lengthy productive phase. Accordingly, previous studies have combined production-function estimation with discounted investment criteria, including net present value, benefit-cost ratio, and internal rate of return, to evaluate both production performance and the financial viability of rubber farming (Goswami & Challa, 2007; Tran, 2020).

This study contributes to the literature by integrating production-function estimation with lifecycle-based long-run cost analysis. It therefore provides both a technical measure of input productivity and an economic measure of efficient plantation size. This combined approach helps explain how input productivity and returns to scale are related to the downward-sloping portion of the long-run average cost curve, while also recognizing that managerial and coordination costs may eventually cause average cost to increase as plantation size expands.

2. RESEARCH METHODOLOGY

The study combines primary and secondary data. Primary information was obtained through in-depth interviews and semi-structured group discussions with researchers, rubber research officers, government officials, representatives of agricultural institutions and rubber farmers. Participants were selected purposively on the basis of their knowledge and practical experience in rubber production, agricultural economics and plantation management.

Secondary data included rubber cultivation area, output, yield, farm-gate prices, production inputs and cost information obtained from relevant agricultural organizations and previous studies. Information from the primary and secondary sources was used to establish representative cost and output assumptions for the lifecycle model.

The analysis covers a 25-year rubber plantation cycle, with commercial production assumed to begin in year 7. Total fresh latex output over the plantation lifecycle is estimated at 6,970 kilograms per rai, increasing during the early tapping years, reaching its peak during the mature period, and subsequently declining as the trees age. The analysis considers eight plantation sizes-3, 5, 10, 20, 30, 50, 70, and 100 rai and incorporates both variable and fixed production costs. Variable costs include seedlings, planting and tapping labor, tapping materials, fertilizer, soil improvement materials, pesticides, harvesting, and post-harvest transportation, while fixed farm costs comprise infrastructure, equipment maintenance, farm administration, and financing expenses. In addition, replanting expenditure is included in year 25.

To represent diseconomies of scale, the model incorporates an additional convex overhead-cost component. This component reflects the increasing costs of supervising workers, coordinating operations, transporting latex within large plantations, controlling pests and diseases and administering geographically dispersed production areas.

The undiscounted long-run average cost is calculated by dividing total lifecycle cost by total lifecycle output. The time-adjusted model converts annual costs and output into present values using a discount rate of 5%:

$$LRAC_{PV} = \frac{\sum_{t=1}^{25} \frac{TC_t(Q)}{(1+r)^t}}{\sum_{t=1}^{25} \frac{Q_t}{(1+r)^t}}$$

where TC_t represents total production cost in year t, Q_t represents output in year t, and r is the discount rate. Both costs and output were converted into present values using the same discount rate to ensure temporal consistency between the numerator and denominator of the long-run average cost calculation. The minimum efficient scale was then identified as the plantation size at which the estimated long-run average cost reached its lowest level.

The Cobb–Douglas production function is estimated using observations from years 7–25 because rubber output is zero during the immature period and therefore cannot be transformed into logarithmic form. Labor input includes tapping and plantation-maintenance services, while capital input covers equipment use, depreciation, repairs, and other capital-related expenditures. Starting from the general Cobb–Douglas production function for rubber production. The equation is transformed into a log-linear form to facilitate parameter estimation using the Ordinary Least Squares (OLS) method. The estimable equation is expressed as:

$$lnY_t = \alpha + \beta lnL_t + \gamma lnK_t + \varepsilon_t$$

The choice of capital input is an important methodological issue in agricultural production-function estimation. Capital stock alone may not adequately represent the actual use of long-lived assets, such as irrigation systems, equipment, farm buildings, and rubber trees, because it excludes depreciation, financing costs, and maintenance expenditure.

Following Jorgenson (1963), this study measures capital input as capital services:

$$KS_t = (i + \delta)K_t + I_t$$

where: i = 0.05 is the cost of capital
δ = 0.10 is the depreciation rate
K_t is the value of the capital stock at the beginning of year t
I_t is annual repair and maintenance expenditure

Capital services provide a more economically meaningful measure because they reflect the annual cost of using capital. Therefore, the Cobb–Douglas production function is estimated as:

$$lnY_t = \propto + \beta lnL_t + \gamma lnKS_t + \varepsilon_t$$

3. EMPIRICAL RESULTS

The estimated long-run average cost curves display a clear U-shaped pattern, as shown in Figure 1. The solid line represents the case in which production costs and output are converted into present values using a discount rate, whereas the dashed line represents the undiscounted case. Both curves exhibit the same general cost structure, with relatively high average costs among small plantations, declining costs over the medium-scale range, and rising costs once plantation size exceeds the minimum efficient scale. In the undiscounted case, the average production cost is approximately THB 101.92 per kilogram for a 3-rai plantation, declining to THB 73.68 at 5 rai, THB 53.21 at 10 rai, and THB 44.81 at 20 rai. This downward movement reflects economies of scale arising from the distribution of fixed establishment and management costs over a larger volume of output, more efficient utilization of tapping labor, shared use of equipment, and improved coordination of routine plantation activities. The average cost reaches its lowest observed level within the medium-scale range, at approximately THB 44.01 per kilogram for a 30-rai plantation, while interpolation of the estimated cost function indicates that the minimum efficient scale occurs at approximately 27 rai.

When differences in average cost are considered more closely, the estimated long-run average costs for plantations of approximately 20–40 rai are found to be very similar. This range may therefore be interpreted as a cost-efficient operating zone in which average production cost remains relatively low and stable. Although the mathematical minimum occurs at approximately 27 rai, farms within the broader 20–40 rai range may achieve nearly comparable cost performance. This finding is important because it suggests that production efficiency should not be interpreted as requiring farmers to operate at one exact plantation size. Rather, there is a practical range of plantation sizes within which farmers can obtain most of the available economies of scale without facing a substantial increase in average cost.

Beyond this cost-efficient range, the long-run average cost begins to rise. In the undiscounted case, the estimated cost increases to THB 47.89 per kilogram at 50 rai, THB 54.78 at 70 rai, and THB 68.19 at 100 rai. This upward movement indicates diseconomies of scale associated with increasingly complex labor supervision, higher internal transportation costs, difficulties in coordinating tapping schedules, greater pest-management requirements, and additional administrative, machinery, and infrastructure expenses. Once plantation size exceeds approximately 40 rai, these additional requirements gradually outweigh the benefits obtained from spreading fixed costs and improving resource utilization.

The present-value curve shown by the solid line follows a closely comparable pattern. Discounting the streams of production costs and output over the plantation lifecycle slightly changes the estimated level of average cost but does not materially alter the shape of the LRAC curve, the location of its minimum point, or the broader range of cost-efficient plantation sizes. The minimum efficient scale therefore remains approximately 27 rai under both the discounted and undiscounted approaches, while the 20–40 rai range continues to exhibit relatively low and stable average costs. This stability suggests that the underlying production technology and the relationship between fixed and variable costs remain broadly consistent when the time value of money is incorporated into the analysis.

For small plantations, average cost remains high under both approaches because establishment expenditure is concentrated in the early years, labor and equipment are not fully utilized, and the limited volume of output restricts the ability to spread fixed costs across production. As plantation size increases, these constraints are reduced and average cost declines toward the cost-efficient range. Beyond that range, however, additional coordination, supervision, transportation, labor, machinery, and infrastructure requirements cause average cost to increase under both valuation methods.

The similarity between the solid and dashed curves has important analytical and policy implications. It indicates that discounting affects the monetary level of estimated production cost but does not change the structural pattern of economies of scale, the approximate minimum efficient scale, the broader cost-efficient range, or the emergence of diseconomies of scale. Nevertheless, the present-value approach remains necessary because it provides a more economically meaningful representation of farmers' financial burdens over the plantation lifecycle, particularly establishment, maintenance, and replanting expenditures. These findings can therefore support the design of replanting funds, subsidies, agricultural credit, and other policy measures that are more closely aligned with the lifecycle cost structure of rubber production.

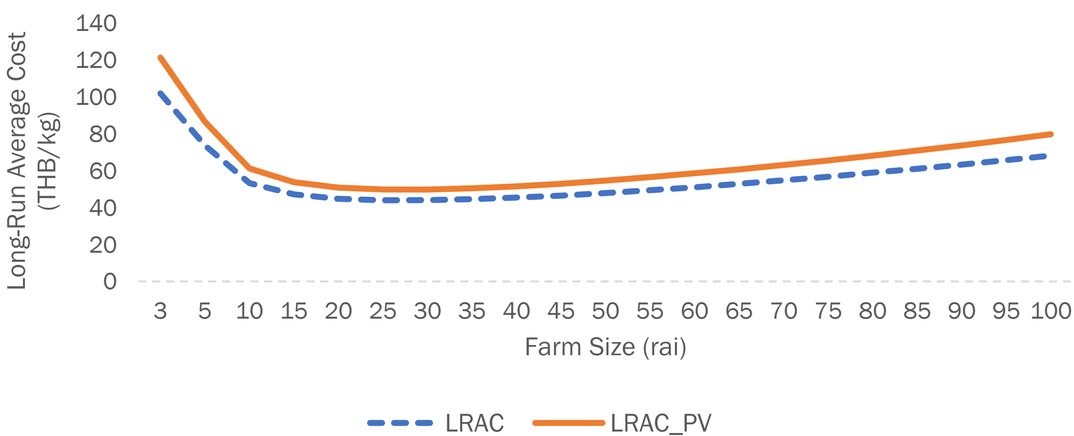

Figure 1. Long-Run Average Cost Curves over the Rubber Plantation Life Cycle: A Comparison between the Undiscounted and Time-Discounted Cases

To further explain the production-side mechanisms underlying the observed U-shaped long-run average cost curve, the analysis examines the relationship between fresh latex output and the principal production inputs. Although the cost analysis identifies the plantation size associated with the lowest average cost, it does not directly reveal how changes in labor and capital services affect output. A Cobb–Douglas production function was therefore estimated in log-linear form to quantify the output elasticities of these inputs and to assess the returns-to-scale characteristics of rubber production over the productive life of the plantation. The estimation used annual data covering plantation years 7–25. The results are presented in Table 3.

Table 3. Statistical Estimation Results of the Rubber Production Function over the Plantation Life Cycle

Variable	Coefficient	Standard Error	t-statistic	Probability
Labor (Lt)	0.859608	0.151750	5.664642	0.0000*
Capital Services (KSt)	0.342547	0.090093	3.802171	0.0016*

Model statistics: R^2 = 0.794530
Adjusted R^2 = 0.768846
F-statistic = 30.93509
n = 19

Note: * indicates statistical significance at the 1% level.

The estimation results indicate that the model provides a statistically significant explanation of variation in fresh latex output. The R^2 and adjusted R^2 values are 0.794530 and 0.768846, respectively, indicating that the model explains approximately 76.88% of the variation in output after adjusting for the number of explanatory variables. This level of explanatory power is satisfactory for agricultural production data, which are often affected by climatic conditions, biological factors, plantation age, and other influences that are not fully captured by the model.

The estimated production function in log-linear form is expressed as follows:

$$lnY_t = 5.7342 + 0.859608 lnL_t + 0.342547 lnKS_t$$

(6.073885) (5.664642) (3.802171)

where the figures in parentheses are the corresponding t-statistics. Both labor and capital services have positive coefficients and are statistically significant at the 1% level, confirming that these inputs play important roles in determining fresh latex output.

Because the model is specified in logarithmic form, the estimated coefficients can be interpreted directly as output elasticities. The labor elasticity is 0.859608, implying that a 1% increase in labor input, holding capital services constant, is associated with an approximately 0.86% increase in fresh latex output. This relatively large elasticity reflects the labor-intensive and skill-dependent nature of rubber production, particularly the importance of tapping labor. The capital-service elasticity is 0.342547, indicating that a 1% increase in capital services, holding labor constant, is associated with an approximately 0.34% increase in output. Capital services in this context represent the productive contribution of tools, equipment, plantation infrastructure, and other capital-related resources used throughout the productive period.

Transforming the estimated equation into its original Cobb-Douglas form gives:

$$Y_t = 309.2655 L_t^{0.859608} KS_t^{0.342547}$$

The sum of the estimated labor and capital-service elasticities is approximately 1.20. Since this value exceeds unity, the estimated production technology exhibits increasing returns to scale. In practical terms, a simultaneous 1% increase in both labor and capital services is associated with an approximately 1.20% increase in fresh latex output. This result suggests that farms may obtain production benefits from expanding the joint use of labor and capital services and from improving the coordination of these inputs.

The production-function results are consistent with the declining portion of the LRAC curve. For farms operating below the cost-efficient range, more effective use of labor and capital can raise output proportionately more than input use, thereby reducing average production cost. However, the estimated increasing returns to scale should not be interpreted as evidence that plantation expansion can continue indefinitely without cost disadvantages. The Cobb-Douglas estimates describe the technical relationship between productive inputs and output, whereas the LRAC curve incorporates both production costs and the managerial consequences of plantation expansion. Once plantation size exceeds the farm's organizational and supervisory capacity, the benefits of increased input use may be offset by higher coordination costs, labor-management difficulties, internal transportation expenses, and additional administrative and infrastructure requirements. These factors cause the LRAC curve to turn upward even though the underlying production function continues to indicate increasing returns to the measured inputs.

CONCLUSION

This study develops a lifecycle-based framework for assessing the long-run production costs and production efficiency of rubber farming in Thailand. By combining present-value analysis, a long-run average cost framework, and a Cobb–Douglas production model, the study captures both the timing of plantation expenditures and the technical relationship between key production inputs and output.

The findings indicate that cost efficiency should be interpreted as a practical operating range rather than as a single optimal farm size. Although the estimated LRAC reaches its mathematical minimum at approximately 27 rai, plantations within the broader range of 20–40 rai exhibit similarly low and stable average costs. This range therefore represents a realistic scale at which farms can capture most economies of scale while avoiding the managerial and organizational costs associated with larger operations. Discounting costs and output at 5% changes the estimated cost level only slightly and does not materially alter this efficient range.

The production-function estimates further confirm the importance of labor and capital services in rubber farming, with labor exerting the stronger influence on output. The estimated increasing returns to scale suggest that more effective joint use of these inputs can improve production performance. However, such technical gains do not imply that continuous farm expansion is economically desirable, since coordination, supervision, transportation, and other overhead costs eventually offset the benefits of larger-scale production.

Several policy implications emerge from these findings. First, government compensation, income-support, and price-stabilization programmes should be based on lifecycle production costs rather than uniform annual estimates. Support should reflect plantation age, production stage, regional cost conditions, and farmers' actual cost burdens. LRAC should also be incorporated into a rubber-price early-warning system, with thresholds for early warning, break-even, and danger levels to guide measures ranging from cost-reduction support and working-capital credit to income guarantees, concessional loans, and debt relief.

Second, policies should enable smallholders to achieve economies of scale without requiring land consolidation. Production clusters, cooperatives, community-based management, machinery centers, and rubber-farm service centers can facilitate joint input procurement, shared tapping labor, coordinated production, collective marketing, and access to technology, maintenance, pest management, skilled labor, and market information.

Third, agricultural credit should be aligned with the biological cycle of rubber production. Grace periods and repayment schedules should recognize that commercial latex revenue generally begins only after six or seven years, while preferential credit should support the purchase, maintenance, and shared use of productive assets.

Finally, investment in skilled tapping labor and sustainable farm management should be promoted as a means of improving economic efficiency. Training, occupational certification, proper equipment maintenance, soil and water management, tree-health preservation, pest control, and intercropping during the immature period can raise productivity, extend tapping life, lower long-run average costs, generate supplementary income, and reduce farmers' financial vulnerability.

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