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DETERMINANTS OF EXPORT PERFORMANCE OF COCONUT OIL IN SRI LANKA: A TIME-SERIES ANALYSIS

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Abstract

The coconut industry plays a crucial role in Sri Lanka's economy, especially through its strong export performance. Employing data gathered from Coconut Development Authority and the World Bank, this study investigates the factors influencing Sri Lanka's export performance of coconut oil. Autoregressive Distributed Lag (ARDL) model was used to analyze data from 1991 to 2021. Results reveal that the price ratio of coconut oil, inflation rate, and exchange rate negatively affect export performance, while the production volume of coconut oil does not exert a statistical significance on export performance. Interestingly, a significant positive relationship is observed between the import volume of palm oil and export performance of coconut oil. This is due to the substitutability between palm oil and coconut oil, as they share similar properties and applications in cooking, cosmetics, and other industries. Additionally, an increase in palm oil imports often leads to greater opportunities for coconut oil exporters to expand their market presence. These findings offer crucial insights for policymakers and trade experts, facilitating the formulation of targeted strategies to enhance Sri Lanka's coconut oil exports and overall competitiveness. The export performance of coconut oil is more sensitive to price fluctuations and inflation than to production levels. Effective management of these economic variables is crucial for enhancing export performance. By understanding these relationships, strategies can be developed to mitigate negative impacts and leverage positive influences to optimize the export performance of coconut oil. It is essential to note that these recommendations should be tailored to the specific circumstances within the coconut oil industry.

***Keywords**: ARDL model, Coconut oil, Export performance*

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1. Introduction

Sri Lanka has a significant plantation crop in coconut (*Cocos nucifera L.*), which holds economic value across all parts of the plant. As the fourth-largest exporter of coconut products globally, the crop contributed 0.6% to Sri Lanka's GDP in 2020. Coconuts account for approximately 12% of the country's agricultural output, with 409,244 hectares under cultivation in 2017 and an annual yield of 2,500 to 3,000 million nuts (Prasannath, 2020). Coconut products can be broadly categorized into three groups: shell, fibre, and kernel products. Coconut kernel products, which are the most nutritious, include many products such as coconut oil, virgin coconut oil, desiccated coconut, copra etc. (Abeysekara et al., 2020). Sri Lanka earns USD 62.7 million from coconut oil exports, contributing 1.33% to the total global demand for this product.

Sri Lanka dedicates a significant portion of its land to cultivation with coconut serving as one of the most significant plantation crops. Coconut is largely cultivated by smallholders, with most of them owning plots between 2-4 hectares in size. Additionally, coconut is commonly grown in home gardens. The domestic market consumes 70% of the total crop output, while the remaining 30% is supplied to coconut processing enterprises. Sri Lanka boasts one of the highest per capita coconut consumption rates in the world, with an average intake of around 110-115 nuts per year (Mufeeth et al., 2021). Given the strong global demand for Sri Lankan coconut oil products, there is many opportunities for the country to capitalize on this lucrative market.

However, to ensure long-term business sustainability, they will need to address some pressing issues in the industry. The primary challenge is to increase export quantities, but this requires addressing the key issue of raw material scarcity. Despite these challenges, value addition has helped maintain growth momentum. To achieve sustainable growth, industry needs to find a solution to the scarcity of raw materials. Samarasinghe et al. (2023) demonstrate that the growth in Sri Lankan coconut oil exports is substantial, maintaining a significant market share in the global coconut oil market. Hettiarachchi et al. (2023) highlight Sri Lanka as a leading exporter of coconut oil, renowned for its quality, versatility, and unique nutritional profile. Major buyers of Sri Lankan coconut oil include the UK, USA, Germany, Netherlands, Australia, India, Japan, and Middle Eastern countries such as Saudi Arabia, UAE, Qatar, and Kuwait. Despite securing an important position in the global coconut oil market, the export volumes and earnings for all kernel products, including coconut oil, show significant fluctuations (Pathirarja et al., 2015). Therefore, it is imperative to thoroughly examine the export performance of the coconut oil industry and identify the root causes of any fluctuations.

Numerous studies have examined the export of coconut and coconut-based products. However, the main gap found in those studies is the lack of attention to fluctuations in exports and the reasons behind such fluctuation. For instance, Pathiraja et al. (2015) explored the status and future prospects of the coconut industry in Sri Lanka in the context of a changing climate. Hettiarachchi et al. (2023) sought to identify the best time series model for forecasting fresh coconut exports. Samarasinghe et al. (2023) reviewed quality and safety issues in the Sri Lankan coconut oil processing industry, concluding that stringent quality control measures are crucial for the industry's success. Abeysekara et al. (2020) found that coconut oil has become an inferior good. Jayalath and Weerahewa (2014) studied the effects of the export price of desiccated coconut on Sri Lanka's edible oil market, discovering that higher export prices negatively affect tariff levels. Additionally, Kumarasinghe and Savinda (2018) found that export market share positively influences the competitiveness of virgin coconut oil. It is clear from these studies that there is a notable gap in research on the fluctuations in coconut oil exports, despite its significant contribution to the country's export earnings.

Hence, this study aims to deepen our understanding of the factors influencing Sri Lanka's coconut oil export performance by closely examining key determinants and recent trends within the industry and quantify the impact of these selected determinants on export performance. This allows for a more precise assessment of their relative influence.

2. Literature Review

The majority (over 75%) of global coconut production originates from a concentrated region: India, Indonesia, the Philippines, and Sri Lanka. Consumer demand for coconut products is experiencing significant growth, particularly in the American, European, Middle Eastern, and East Asian markets. Traditional products like coconut oil, copra meal, dried coconut, and coir remain relevant, while newer categories like coconut water, virgin coconut oil, coconut milk, and cream are witnessing the most rapid expansion. Technological advancements have led to the introduction of new high-yielding coconut hybrids, with potential copra yields exceeding 7.65 to 9.12 tons per hectare per year (Hoe, 2018).

Sri Lanka's coconut production has shown an upward trend over the past two decades, albeit with periodic fluctuations due to weather events. Diversification of export products has contributed to a continuous rise in export volume despite production fluctuations. Understanding the dynamics of Sri Lanka's coconut production and export earnings from both coconuts and derived products is crucial. The Sri Lankan government has implemented various policies to support the growth of the coconut-based industry (Prasannath, 2020). The demand for coconut-based products is increasing quickly and significantly over the world, which has shown to increase producers' financial returns. Countries should seize this chance to diversify their plantation crop to coconut as their new economic crop if they are largely dependent on a single industrial crop (Hoe, 2018).

Numerous studies have examined the determinants of export success. Epaphra (2016) investigated the determinants of export performance in Tanzania, focusing on the influence of macroeconomic variables. The study examined the impact of foreign direct investment, gross domestic product (GDP), inflation rate, real exchange rate, and terms of trade on export success. This research underscores the significant role of macroeconomic factors in shaping export performance, supporting the thesis that these variables exert a considerable influence on a country's ability to export effectively. According to Dalango (2020) the long-term coefficient outcomes of the model indicate a positive correlation between foreign direct investment (FDI) and per capita GDP with exports in Ethiopia. Conversely, the rate of inflation exhibits a notable and adverse effect. In the short term, Ethiopia's export performance is positively influenced by FDI, per capita GDP, and gross capital formation, as indicated by short-run dynamics. However, despite this, the short-term effect of inflation on exports remains negative and significant.

Darusman et al. (2013) conducted an in-depth analysis of the determinants of Indonesia's crude coconut oil export demand. Their research results clearly indicated that Indonesia's market share varied significantly among the four countries examined, with both export volume and price experiencing fluctuations. Moreover, the demand for Indonesian crude coconut oil exports was found to be influenced by several crucial factors, including the real exchange rate of the IDR to the importing country's currency, the population and real GDP per capita of the importing country, and the export prices of both Indonesian and Philippine crude coconut oil.

Kassa (2012) conducted a study on export performance determinants in Ethiopia. The study found that factors such as real effective exchange rate, openness, RGDP, infrastructure development, and private credit as a percentage of GDP have a positive impact on long-term export performance. Hervé et al. (2014) investigated the determinants of export performance in Zanzibar. This study aims to identify and evaluate the key elements that influence Zanzibar's export performance, with particular focus on the role of human capital development in the growth of the Zanzibar economy. Additionally, it examines the role of FDI in promoting export activities and assesses the influence of main export product prices on export performance.

Ul Hassan et al. (2013) conducted an empirical investigation of the impact of exchange rate and economic growth on Pakistan's export performance. The co-integration method employed in the study revealed a long-term equilibrium link between the country's export performance and its contributing factors. The results show that exchange rate, gross domestic product, and trade openness have positive and significant effects on export performance. However, the analysis suggests that foreign direct investment is insignificant in determining Pakistan's export performance in the long run. On the other hand, FDI has a significant impact on the export of products and services in the short term.

Periyapperuma et al. (2023) find that low production and coconut oil prices badly affect the export earnings from coconut industry in Sri Lanka. It is a fact that high prices lead to less competitiveness in the export market. Although coconut is a dominant export product of Sri Lanka, uncontrolled import products hamper the production of coconut oil. Surprisingly, the country has to spend about 45% of export earnings from coconut kernel products in importing palm oil and oil products (Bandara and Kumari, 2020). Rosyidi et al. (2021) show that exchange rate affects negatively on the agricultural exports implying that depreciation of currency causes a decrease in export earnings. This is an unexpected finding as the local currency depreciation favours the exports and increases export competitiveness. Das (1986) highlights the fact that coconut market is not capable of short adjustment to price fluctuations. According to Pathiraja et al. (2018), when coconut processer face shortage in coconut, they import fresh nuts from other countries during extreme climate events such as droughts. One of the government initiatives is that it imposes tariff on edible oil imports to secure domestic producers. As results, demand for coconut oil increases due to the increase in palm oil price.

In analysing the determinants of export performance, time series data are utilized with time series modelling. For example, a recent study examined the export performance of oilseeds in Ethiopia from 1974 to 2009, utilizing macroeconomic time series data from yearly reports of the National Bank of Ethiopia (Allaro, 2012). Additionally, determinants of export performance in Tanzania were analysed using time series data spanning 20 years (1990-2009) to account for exogenous and endogenous variables (Epaphra, 2016). Furthermore, a study conducted over the 32-year period between 1985 and 2016 explored the variables affecting Ethiopia's horticulture export performance (Dube et al., 2018). The impact of foreign direct investment (FDI) on export performance has received considerable attention in recent research and most of studies have utilized time series models. Hervé et al. (2014) adopted a different methodological approach. They analysed time series data from 1980-2005 (26 years) using Ordinary Least Squares (OLS) regression to identify key determinants influencing export performance in Zanzibar. This study highlights the importance of data length and relevant variable selection for obtaining reliable results from time series econometric models.

In summary, there is a lacuna of literature related to export performance of coconut oil industry in Sri Lanka. Furthermore, there are a few studies conducted to find out the export performance of coconut industry. However, they have not separately considered the coconut oil industry, and less weightage has been put on it. Therefore, this study is attempted to fill this gap in literature.

3. Methodology

3.1 Data

This study uses secondary data from various published sources to analyse the determinants of export performance in Sri Lanka's coconut oil industry. Data sources include annual reports from the Central Bank of Sri Lanka, export performance reports from the Export Development Board, and publications from the Coconut Development Authority. As literature suggested a minimum of 20 observations is required for robust time series analysis (Epaphra, 2016). Therefore, the data collection period spans 31 years (1991-2021) to capture fluctuations in both exogenous (external) and endogenous (internal) factors affecting export performance. The extended timeframe of 31 years ensures sufficient sample size for reliable statistical inferences.

First, we assume that the Export Performance of coconut oil is a function of the following variables.

$EXP_t = f\ (PR_t, PQ_t,\ ImprtPQ_t,\ ER_t, INF_t)$ ....Eq 1

The equation (1) takes the econometric form;

$EXP_t = \beta_0 + \beta_1 PR_t + \beta_2 PQ_t + \beta_3\ ImprtPQ_t + \beta_4\ ER_t + \beta_5 INF_t + \mu_t$ ....Eq 2

To reduce the likelihood of making specification mistakes, the variables were converted into natural logarithms. A log-linear functional form was employed to mitigate the potential or severity of heterogeneity and to directly estimate export elasticities with respect to the regressors. The transformation is therefore stated as;

$lnEXP_t = \beta_0 + \beta_1 lnPR_t + \beta_2 lnPQ_t + \beta_3 lnImprtPQ_t + \beta_4 lnER_t + \beta_5 lnINF_t + \mu_t$ ....Eq 3

Where;

$lnEXP_t$	– Log of export performance
$lnPR_t$	– Log of price ratio
PQ_t	– Log of production quantity
$ImprtPQ_t$	– Log of import amount of palm oil
$lnER_t$	– Log of official exchange rate
$lnINF_t$	– Log of inflation rate
μ_t	–Error term

β_1, β_2, β_3, β_4, β_5 are the long-run elasticities of the independent variables and t is time period. β_0 is Intercept or constant.

Table 1. Description of variables

Variables	Notation	Description	Source of Data
Export performance of coconut oil (CO)	EXP_t	Export volume growth rate = [(Export volume in the current period - Export volume in the previous period) / Export volume in the previous period)] x 100	The export performance report of the Coconut Development Authority
Price Ratio of CO	PR_t	(Local Market Price/FOB price)	CDA Report
Production Quantity of CO	PQ_t	Production volume (Metric Tons (MT)	CDA Report
Import volume of Palm Oil	$ImprtPQ_t$	Import volume (Metric Tons (MT)	CDA Report
Official Exchange Rate	ER_t	(rupees per US$)	World Development Indicator (WDI)
Inflation Rate	INF_t	Inflation, consumer prices (annual %)	WDI

Export performance of coconut oil exports (EXP_t**)** was measured as export growth where it measures percentage growth in export volume over a prior time period. It displays the rate at which export activity is growing or shrinking. The price ratio (PR_t) can be measured as the local market price divided by the FOB price. By comparing the local market price to the Free on Board (FOB) price, the ratio helps determine the competitiveness and profitability of exported goods. A higher ratio indicates that the local market price is significantly higher than the export price. It could be due to various factors such as higher domestic demand, limited supply, or market inefficiencies. Conversely, if the ratio is lower, it implies that the export price is higher, possibly due to higher quality standards or increased demand in the international market. Production quantity of coconut oil (PQ_t) is used to track the volume or amount of goods or services produced within a specific timeframe. It serves as a vital indicator of overall economic output and productivity. Palm oil is a substitute for coconut oil. If the price of coconut oil increases, the consumers tend to substitute palm oil for coconut oil. Therefore, depending on the local market demand for coconut oil, the demand for palm oil will change ultimately as the import demand for palm oil also increases. Therefore, the variable $ImprtPQ_t$ provides greater insights into the effect of the substitutability between coconut oil and palm oil in presence of palm oil imports. The variable inflation rate (INF_t**)** reflects in the cost of production of any good. It is a known fact that high inflation leads to increase in cost of labor, raw materials and energy making more costly to export, which finally affects the export competitiveness as the export price of coconut oil increases. Exchange rates relate to the appreciation or depreciation of the local currency. If the local currency is depreciated, the coconut oil exports become cheaper and more attractive to foreign buyers whereas appreciation of local currency implies that our exports become more expensive and less competitive. Thus, this study uses exchange rates (ER_t) as an important predictor of coconut oil exports.

3.2 Empirical framework

The Autoregressive Distributed Lag (ARDL) method is an econometrical statistical technique that models the long- and short-term relationships between two or more time series variables. Its primary application is in analysing the dynamics and causality between these variables within a time series context. ARDL is particularly useful when investigating potential cointegration relationships between the variables of interest. Compared to other cointegration techniques, ARDL is more statistically significant for identifying cointegrating relationships in small samples. Moreover, it can be applied regardless of whether the regressors are I (1) or I (0), whether the results are all unit root or all stationary, or even if mixed results are obtained. Unlike standard cointegration techniques, ARDL does not require the pre-classification of variables as I (1) or I (0), thereby avoiding pre-testing issues. (Pahlavani et al., 2005).

Autoregressive Distributed Lag (ARDL) model is suitable to analyze the link between the stated determinants and export performance variations of the coconut oil in Sri Lanka as both short-term and long-term dynamics between the variables are supported by the ARDL model.

specify the model of the form:

$$\Delta lnEXP_t = \beta_0 + \beta_1 lnEXP_{t-1} + \beta_2 \ln(PR_{t-1}) + \beta_3 \ln(PQ_{t-1}) + \beta_4 \ln(ImprtPO_{t-1}) + \beta_5 ln(ER_{t-1}) + \beta_6 INF_{t-1} + \sum_{i-1}^{q} \alpha_i \Delta ln(\mathrm{EXP}_{t-i}) + \sum_{j-1}^{r} \alpha_j \Delta ln(\mathrm{PR}_{t-j}) + \sum_{k-1}^{s} \alpha_k \Delta ln(\mathrm{PQ}_{t-k}) + \sum_{l-1}^{v} \alpha_l \Delta ln(ImprtPO_{t-l}) + \sum_{m-1}^{y} \alpha_m \Delta ln(ER_{t-m}) + \sum_{n-1}^{x} \alpha_n \Delta ln(INF_{t-n}) + \mu_t \quad \text{..........Eq 4}$$

q, r, s, v, y, and x are the lag lengths with their respective variables, and μ_t error term, which is believed to be serially uncorrelated, Δis the first difference operator. To address problems with non-stationarity, cointegration, and serial correlation and to make the coefficients in the model more understandable in terms of changes over time, taking the first difference (Δ) is an important step in time series analysis. It enables us to consider long-run relationships in the data while concentrating on short-run dynamics. Coefficients β_1, β_2, β_3, β_4, β_5 and β_6 are used to quantify long-run elasticities between the variables while α_i, α_j, α_k, α_l, α_m, and α_n denote coefficients that assess the variables' short-run elasticities among the variables (Dalango, 2020).

Additionally, previous studies have conducted various tests to improve the quality of the research. One of the key tests used to determine whether a time series of data is stationary or non-stationary is the unit root test. This test examines the stationarity of EXP, PR, PQ, ImprtPQ, ER, and INF using the ADF test and PP tests, with the secondary goal of transforming non-stationary series into stationary ones. When choosing the lag length for incorporation into the ARDL model, it is important to select the best lag duration. This can be achieved by utilizing information criteria such as the Schwarz Bayesian Criterion (SBC) or the Akaike Information Criterion (AIC). The Akaike Information Criterion (AIC), introduced by Akaike (1974) is a model selection technique that helps identify the optimal model. The AIC serves as an asymptotically unbiased estimator, with the model having the smallest AIC value considered the best approximation of the "true" model. On the other hand, the Schwarz Bayesian Criterion (SBC), developed by Schwarz (1978) adjusts depending on the sample size n. The model with the lowest SBC value is deemed the best representation of the "true" model.

Furthermore, the correlation matrix and variance inflation factor (VIF) were calculated. If the VIF value for all pairs of independent variables is less than 10, it can be inferred that there is no significant association among the variables, as per the data. Thus, it can be concluded that multicollinearity is not a concern in the data (Ditta et al., 2020). The strength of the association between various variables is assessed through correlation analysis, while bivariate quantitative analysis is utilized to examine the relationship between different variables (Ali Iteh and Oyeanu, 2021). Then ARDL analysis was estimated. The first step in the ARDL technique involves conducting a bound test to determine whether there is a long-run relationship between the variables. To assess the significance of the predicted coefficients, critical values need to be calculated, and an F-test needs to be carried out. The null hypothesis, which states that there is no long-run co-integration, would be rejected based on the F-statistic being above the upper bound values at 10%, 5%, 2.5%, and 1% (Dalango, 2020). To further analyze the short-run dynamics and better understand the immediate effects of the independent factors on export performance, it is crucial to ascertain the significance and signs of the lagged coefficients in the ARDL model.

Johansein and Olayiwola (2010) emphasizes the importance of employing error correction models (ECMs) when cointegration exists between dependent variables and their fundamental determinants. In such cases, the model incorporates a lagged error correction term among its regressors. This term, derived from the residuals of a static long-run regression, captures the deviation from the long-run equilibrium. It is included alongside the non-stationary variables to account for both short- and long-term dynamics in the data (Epaphra, 2016). ECMs are a common choice for analyzing non-stationary time series data and testing for cointegration.

The fundamental form of an ECM can be represented by the following equation:

$$\Delta Y_t = \alpha + \beta_1 \Delta Y_{t-1} + \beta_2 \Delta Y_{t-2} + \cdots + \beta_k \Delta Y_{t-k} + \gamma_1 \Delta X_{t-1} + \gamma_1 \Delta X_{t-2} + \cdots + \gamma_k \Delta X_{t-k} + \theta ECM_{t-1} + \varepsilon_i \text{..........} \text{Eq 5}$$

where:
ΔY_t: Change in the dependent variable (export performance) at time t
ΔX_t: Change in the independent variables at time t
ECM_{t-1}: Lagged error correction term
α, β, γ, θ: Coefficients to be estimated
ε_i: Residual term

The error correction term (ECM_{t-1}) reflects the adjustment process towards the long-run equilibrium relationship between the variables captured by the cointegrating vector. It indicates the speed at which the dependent variable responds to deviations from this equilibrium (Epaphra, 2016). Finally, diagnostic tests were done to assess the validity of the model and identify potential violations of assumptions. Those tests were Serial Correlation test to evaluate the presence of autocorrelation in the residuals, Breusch-Pagan-Godfrey (BPG) test to examine the presence of heteroscedasticity, Jarque-Bera test to assess the normality of the residuals and Cumulative Sum of Recursive Residuals (CUSUM) test to check the stability of the model's parameters over time.

4. Results and Discussion

It is essential to utilize descriptive statistics as a tool to understand the behaviour of various variables. Table 2 depicts the results of the descriptive statistics for specific variables.

Table 2. Descriptive Statistics

	EXP	PQ	PR	ImprtPQ	INF	ER
Mean	3375.452	43387.36	61093.83	116673.9	8.488418	104.8682
median	2567.000	43038.00	889.7642	98150.00	7.575926	103.9600
Maximum	8853.000	84788.00	991206.5	330291.0	22.56450	198.4127
Minimum	949.000	10913.00	365.8475	22403.00	2.135038	41.37000
Std.Dev.	2032.396	19466.85	233844.0	75065.47	4.453224	43.37239
Skewness	1.282576	0.353365	3.568387	1.179280	1.135437	0.351533
Kurtosis	4.056930	2.450883	13.79539	4.105097	4.527234	2.362458
Jarque-Bera	9.942097	1.034621	216.3206	8.762721	9.673691	1.163484
Probability	0.006936	0.596122	0.000000	0.012508	0.007932	0.558924

Source: Author's calculation

For the period under consideration, the average export volume (EXP) is 3375.452 metric tons with a standard deviation of 2032.396 metric tons. The average quantity of coconut oil production (PQ) is 43387.36 metric tons with a standard deviation of 19466.85 metric tons. Furthermore, the mean value of the price ratio (PR) and the import amount of palm oil (ImprtPQ) are 61093.83 and 116673.9 metric tons with standard deviations of 233844.0 and 75065.47, respectively. The mean values of the inflation rate (INF) and exchange rate (ER) are 8.48% and 104.86 LKR per US$, with standard deviations of 4.45% and 43.37LKR per US$, respectively.

When taking the skewness of the variables into account, it is evident that all variables are somewhat skewed. Specifically, EXP, PQ, PR, ImprtPQ, INF, and ER are positively skewed. Additionally, considering kurtosis, which measures the flatness or peakness of the distribution of the series, the values in Table 02 indicate that PQ and ER are platykurtic (kurtosis value less than 3), whereas EXP, PR, ImprtPQ, and INF have kurtosis values greater than 3, making them leptokurtic. The Jarque-Bera test combines skewness and kurtosis and helps assess or confirm normality. If the test results in 0, the data do not have a normal distribution. The findings in Table 2, demonstrate that all variables have a normal distribution, except for PR. When the PR value stands at zero, the data does not exhibit a normal distribution.

Table 3: Results of Correlation analysis

	LNEXP	**LNPQ**	**LNPR**	**LNImprtPQ**	**LNINF**	**LNER**
LNEXP	1					
LNPQ	-0.099227	1				
LNPR	0.131395	-0.170340	1			
LNImprtPQ	-0.104421	-0.310864	-0.017572	1		
LNINF	-0.509372	0.147007	0.052816	-0.1934633	1	
LNER	0.195142	-0.073130	0.306773	0.6756008	-0.503434	1

Source: Author's calculation

The results of the Table 3 suggests that LNPQ, LNImprtPQ, and LNINF show negative correlations with LNEXP, while LNPR and LNER are positively related. As the correlation between variables present, Variance Inflation Factor was also checked. In the Autoregressive Distributed Lag (ARDL) approach, the Variance Inflation Factor (VIF) is used to assess multicollinearity among the independent variables. Multicollinearity occurs when two or more independent variables in a regression model are strongly correlated with each other. Based on the VIF values in the table, we can conclude that multicollinearity is not an issue in this study, as the VIF values are all less than 10.

Table 4. Results of VIF

Variables	VIF value
LNImprtPQ	3.23
LNPQ	1.48
LNPR	1.71
LNINF	1.89
LNER	4.49

Source: Author’s calculation

The analysis commenced by conducting unit root tests to examine stationarity in the variables, ensuring that the data met the necessary assumptions for subsequent statistical tests. After confirming stationarity, the analysis progressed to the Autoregressive Distributed Lag (ARDL) bounds test for cointegration, with the results of this test being presented and interpreted alongside the findings from the estimated error correction model (ECM).

To assess the model's reliability, diagnostic tests were utilized to evaluate various aspects of the model's fit and identify potential violations of underlying assumptions. These tests included the Serial Correlation (LM) test, the Heteroskedasticity test, the Ramsey RESET test, the Normality test, as well as Stability Tests such as the Cumulative Sum of Recursive Residuals (CUSUM) test and the Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ) test.

Table 5. Results of ADF Unit Root test

Variables	**ADF Test**						**Order of integration**
	Levels			1st Difference			
	C	C&T	None	C	C &T	None	
LNEXP	-2.86* (0.0620)	-2.72 (0.2341)	0.37 (0.7849)	-6.34*** (0.0000)	-6.21*** (0.0001)	-6.46*** (0.0000)	I (I)
LNImprtPQ	-2.65* (0.0950)	-2.61 (0.2776)	0.26 (0.7562)	-6.03*** (0.0000)	-6.05*** (0.0001)	-6.12*** (0.0000)	I (I)
LNPQ	-3.42** (0.0179)	-3.38* (0.0724)	-0.05 (0.6574)	-6.58*** (0.0000)	-6.45*** (0.0001)	-6.70*** (0.0000)	I (0)
LNPR	-3.08** (0.0418)	-0.45 (0.9802)	0.90 (0.8973)	-5.17*** (0.0002)	2.38 (1.0000)	-5.10*** (0.00000)	I (I)
LNINF	-3.57** (0.0125)	-4.49*** (0.00062)	-0.95 (0.2964)	-5.96*** (0.0000)	-5.85*** (0.0003)	-6.04*** (0.0000)	I (0)
LNER	-1.16 (0.6789)	-1.70 (0.7252)	6.21 (1.0000)	-5.09*** (0.0003)	-5.12*** (0.0015)	-0.74 (0.3862)	I (I)

Source: Author’s calculation

*, **, *** Significant at 10%, 5% and 1% probability level

Note: C= Constant and C & T= Constant, Linear Trend. The Schwarz information criterion (SIC) was used in this test, with the automatic lag selection set to 7 lags

The ADF unit rate test was run to check if the data set is stationary or non-stationary by having the two hypotheses where the alternative hypothesis (H_1) suggests that there is no Unit Root (Stationary), while the null hypothesis (H_0) indicates the presence of a Unit Root (Non-stationary). According to Table 05, the null hypothesis is rejected for the log-transformed production quantity (LNPQ) and inflation rate (LNINF) of CO [p=0.0179, 0.0125 at 5%], suggesting that LNPQ and LNINF are integrated at level 1(0). Furthermore, the log of export performance (LNEXP), import amount of palm oil (LNImprtPQ), price ratio of coconut oil (LNPR), and exchange rate (LNER) are stationary at their 1st difference 1(1) form.

Table 6. Results of Phillip Perron Unit Root test

Variables	Phillip Perron Test						Order of integration
	Levels			1st Difference			
	C	C&T	None	C	C &T	None	
LNEXP	-3.00** (0.0462)	-2.89 (0.1774)	0.37 (0.7849)	-6.68*** (0.0000)	-6.54*** (0.0000)	-6.82*** (0.0000)	I (I)
LNImprtPQ	-2.65* (0.0950)	-2.61 (0.2776)	0.42 (0.7990)	-6.14*** (0.0000)	-6.43*** (0.0001)	-6.20*** (0.0000)	I (I)
LNPQ	-3.44** (0.0173)	-3.39* (0.0706)	0.03 (0.6842)	-7.55*** (0.0000)	-7.44*** (0.0000)	-7.75*** (0.0000)	I (0)
LNPR	-0.35 (0.9049)	-0.45 (0.9802)	0.90 (0.8973)	-5.17*** (0.0002)	-5.61*** (0.0004)	-5.10*** (0.0000)	I (I)
LNINF	-3.57** (0.0125)	-4.43*** (0.0072)	-0.78 (0.3666)	-14.84*** (0.0000)	-13.78*** (0.0000)	-13.41*** (0.0000)	I (0)
LNER	-1.12 (0.6928)	-1.79 (0.6800)	5.22 (1.0000)	-5.15*** (0.0002)	-5.15*** (0.0013)	-2.61** (0.0109)	I (I)

Source: Author's calculation
*, **, *** Significant at 10%, 5% and 1% probability level
Note: C= Constant and C & T= Constant, Linear Trend. The Bartlett Kernel and Newey-West Bandwidth were used in this test

The PP test adjusts for any serial correlation and heteroskedasticity in the errors of the test regression. The test results of the Table 06 further suggest that LNPQ and LNINF are stationary at 1(0) level while the log of export performance (LNEXP), import amount of palm oil (LNImprtPQ), price ratio of coconut oil (LNPR), and exchange rate (LNER) are stationary at their 1st difference 1(1) form. Given these results and because of many advantages over alternative methods, the ARDL bounds testing approach developed by Pesaran et al. (2001) is utilized for establishing the existence of a cointegration relationship between variables. Firstly, unlike standard cointegration methods such as Engle-Granger (1987) and Johansen-Juselius (1990), which require variables to be integrated at the same level, the ARDL approach can be applied regardless of whether the regressors are I(0) or I(1). Secondly, it allows for the simultaneous estimation of short-run and long-run parameters through an unrestricted error correction model (UECM) derived from the ARDL model, effectively integrating short-run dynamics with long-run equilibrium. Thirdly, the ARDL method provides more robust and reliable results, especially in finite and small sample sizes. Finally, it treats all variables as endogenous, as highlighted by Pesaran and Shin (1999) and Panopoulou and Pittis (2004)

Table 7. Results of ARDL bound test

Variable	Coefficient	Std. Error	t-Statistic	Prob
LNImprtPQ	0.53	0.28	1.89*	0.0833
LNPQ	0.12	0.25	0.50	0.6245
LNPR	-1.32	0.40	-3.27***	0.0067
LNINF	-1.59	0.39	-4.073***	0.0015
LNER	-2.75	0.64	-4.31***	0.0010
C	25.28	3.45	7.32***	0.0000

Source: Author's calculation (2023)

*, **, *** Significant at 10%, 5% and 1% probability level

The results of the estimation of ARDL model reveal that the import amount of palm oil has a significant effect on the export performance of coconut oil, as indicated by a probability value of 0.0833 for the co-efficient. It also shows a positive relationship between the import amount of palm oil and the export performance of coconut oil. Specifically, a 1% increase in the import volume of palm oil is associated with a 0.53% increase in the export performance of coconut oil. Palm oil and coconut oil are substitutes for their properties in cooking, cosmetics and in other related applications. If the price of the coconut oil increases within the domestic market, consumers substitute palm oil to coconut oil. Therefore, demand for coconut oil decreases and as a result, the export of coconut oil increases. When exporters find more profitable if they export coconut oil export, exporters tend to somehow buy coconut oil domestic market and export it creating a shortage in the domestic market. It leads to increase the price of coconut oil and consumers substitute palm oil to coconut oil so that the demand for palm oil increases and ultimately palm oil imports also increase.

While coconut oil production quantity exhibits a positive relationship, its insignificance (p-value = 0.6245) suggests a limited individual effect. This could be due to minimal year-to-year fluctuations in production data, potentially requiring a larger sample size for significance. In contrast, the price ratio of coconut oil displays a significant negative impact (p-value = 0.0067). A 1% increase in the price ratio leads to a 1.32% decrease in export performance, indicating a strong negative relationship. Price ratio is an indicator of the export competitiveness and profitability of exported goods. FOB price is the price at the point of departure excluding shipping and insurance cost. If the price ratio increases, it implies that the domestic price becomes higher than exported products. As a result, coconut oil becomes less competitive in the international market as the domestic products become costly, and it may lead to reduce exports. Similarly, the inflation rate demonstrates a significant negative influence (p-value = 0.0015). A 1% rise in inflation results in a 1.59% decline in export performance. When inflations become greater, it may lead to increase in cost of production due to high prices. Therefore, out products become less competitive in the world market due to high cost of production and the high price of coconut oil. These findings suggest that coconut oil export performance is more sensitive to price fluctuations and inflation than to mere production levels.

In addition, based on the findings, it is evident that the exchange rate has a detrimental impact on the export performance of coconut oil. The coefficient value of the exchange rate is notably significant, as indicated by a probability value of 0.0010. This signifies a negative relationship between the exchange rate and the export performance of coconut oil. Specifically, a 1% increase in the exchange rate is associated with a 2.75% decrease in the export performance of coconut oil. This is an unexpected result. According to the theory, where local currency depreciates, Sri Lankan coconut becomes cheaper and export demand for coconut oil should increase. However, opposite can happen when there are supply constraints in the coconut oil in the country. It is a known fact that the coconut production in the country cannot fulfil the higher demand in the market. We have a shortage in the production. This has led to no significant boost in coconut oil production. Economic instability due to very many factors such as political instabilities, thirty-year war, COVID 19 pandemic, east bomb attack etc. also may have affected the coconut oil exports.

F bounds Test statistics is used to find the presence of long-run relationships (cointegration) between variables in ARDL model. The results are shown in the Table 08. The analysis indicates that the F-statistic value is 6.76, surpassing the critical value of 3.38 at a 5% significance level. Finally, bound test results indicate that there is a long-run equilibrium relationship between the variables, and they move together over time despite short-term fluctuations

Table 8. Results of F Bound Test

Test Statistic	**Value**	**Significant**	**1(0)**	**1(1)**
		10%	2.08	3
F. Statistics	6.76	5%	2.39	3.38
K	5	2.5%	2.7	3.73
		1%	3.06	4.15

Source: Author’s calculation

An Error Correction Model (ECM) is a powerful tool for analysing both short-term and long-term relationships between time series variables that are cointegrated. Table 9 displays the findings over the short term and the relationship between the dependent and independent variables.

Table 9. Results of Error Correction Model

Variables	Coefficient	Std. Error	t-Statistic	Prob.
D(LNEXP)	-0.331	0.1002	-3.3042***	0.0063
D(LNImprtPQ)	-0.470	0.0929	-5.0582***	0.0003
D(LNImprtPQ)	-0.494	0.1246	-3.9650***	0.0019
D(LNIR)	-0.547	0.0809	-6.7525***	0.0000
D(LNIR(-1))	0.272	0.0972	2.7963**	0.0162
D(LNPQ)	-0.308	0.0981	-3.1472***	0.0084
D(LNPR)	- 0.005	0.0295	-0.1716	0.8666
D(LNPR(-1))	1.374	0.1660	8.2743***	0.0000
D(LNPR(-2))	1.114	0.3068	3.3611***	0.0034
CointEq(-1)*	-0.919	0.1091	-8.4243***	0.0000
R^2 = 0.88			**D.W. = 1.5757**	
Adj R^2 = 0.82			**Prob (F. statistic) =10.215**	
S.E of regression =0.18			**F. Statistic = 0.000125**	

Source: Author's calculation

*, **, *** Significant at 10%, 5% and 1% probability level

According to the findings, the R-square value is 0.88 and the adjusted R-square value is 0.82. This indicates that 88% of the variation in the dependent variable (EXP) is accounted for by the variation in the independent variable, with the remaining 12% unexplained by the model due to error. The cointegration between the variables in the model was validated by the negative and significant coefficient of the error correction model (ECM (-1)) (Dube et al., 2018). The ECM(t-1) value of -0.919 reflects the long-term adjustment speed of the model. Should any short-term disequilibrium arise, it is expected to be temporary and resolved at a rate of 91.9% annually. The Durbin-Watson test with a value of 1.57 indicates the absence of autocorrelation issues in the data. This aligns closely with the conventional range of 1.5 to 2.5 for the Durbin-Watson (D-W) statistic (Epaphra, 2016).

In the short run, there is a statistically significant negative impact on the export performance of coconut oil at the 1% significance level. Additionally, the import volume of palm oil and the production quantity of coconut oil also have a negative effect on the export performance of coconut oil in the short term, at a 1% significance level. The coefficients of the first lagged inflation rate were found to be statistically significant in the short run as well. Moreover, it was observed that the lagged values of the price ratio of coconut oil at two different periods have a significantly positive impact on the export performance of coconut oil at less than the 1% significance level in the short run.

In order to validate the regression model, the study conducted the several tests to identify any potential flaws. The Serial Correlation LM test is used to determine whether autocorrelation exists in the residuals of a regression model. Serial correlation occurs when the error terms in a regression model are correlated across different time periods, which can lead to inefficient estimates and invalid inference. Breusch-Godfrey Serial Correlation LM Test is run and the results suggest that there is no autocorrelation.

Table 10. Results of the Serial Correlation (LM) Test

F statistic	**Prob.F**	**Obs *R-squared**	**Prob. Chi-square**
1.18	0.3468	5.34	0.0691

Source: Author's calculation

Among the tests to validate regression model, the Breusch-Pagan-Godfrey (BPG) Test is applied in the study to check if the variance of the errors is constant or in other words the test is used to detect heteroscedasticity in a regression model. Results of the Table 11 suggests that the regression model does not exhibit heteroskedasticity.

Table 11. Results of Breusch-Pagan-Godfrey (BPG) Test

F-statistic	**Prob. F (3,66)**	**Obs*R-squared**	**Prob. Chi-Square (3)**	**Scaled explained SS**	**Prob. Chi-Square (3)**
0.79	0.6683	13.95	0.5295	4.3992	0.9961

Source: Author's calculation

A diagnostic test called the Ramsey RESET (Regression Specification Error Test) is used in regression analysis to detect model specification errors and assess the suitability of the model's functional form. This test helps identify whether the model specification is accurate and if any variables or nonlinearities that could be influencing the dependent variable have been omitted (Ditta et al., 2020). The results in the Table 12 shows that the functional form is correctly specified.

Table 12. Result of Ramsey RESET test

Null Hypothesis	**Probability**	**F-Statistic**	**Decision**
The current model is correctly specified (meaning there are no omitted variables or misspecification of the functional form)	0.1568	2.31	Accept the null hypothesis

Source: Author's calculation

To assess the normal distribution of the residuals, the study employed the Jarque-Bera test. The results of the test confirm that the residuals are normally distributed showing that the results of analysis are highly valid.

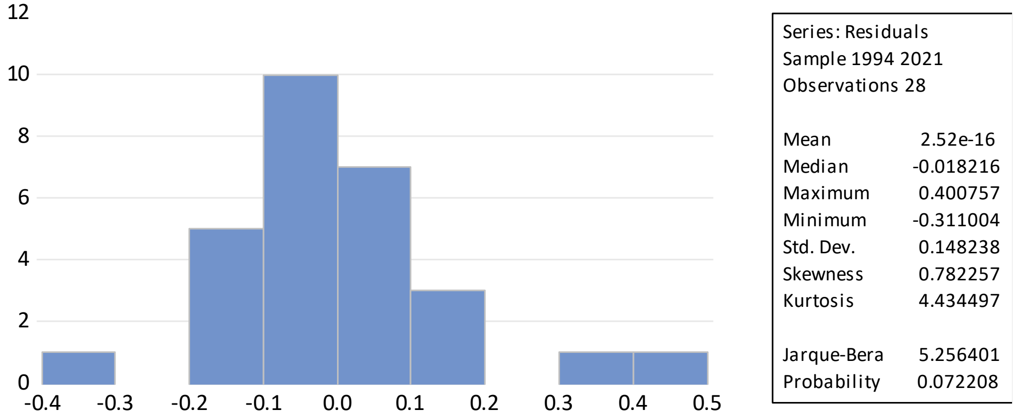

Figure 1. Histogram - Normality Test (coconut oil)

Finally, the stability of coefficient of the model overtime is checked using Cumulative Sum of the recursive residuals (CUSUM) and Cumulative Sum of the square of the recursive residuals (CUSUMsq) tests for Stability. The results lead to the conclusion that there is no structural break, and the long-run estimates remain stable (Dalango, 2020).

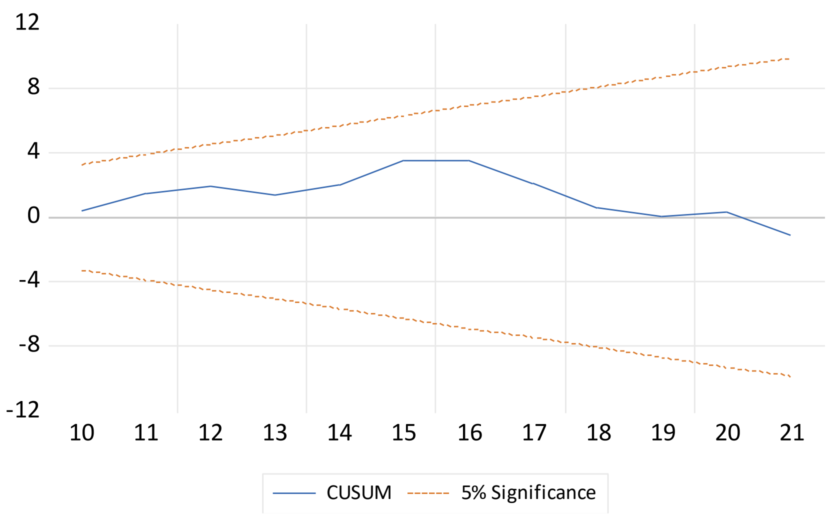

Figure 2. CUSUM Test (Coconut oil)

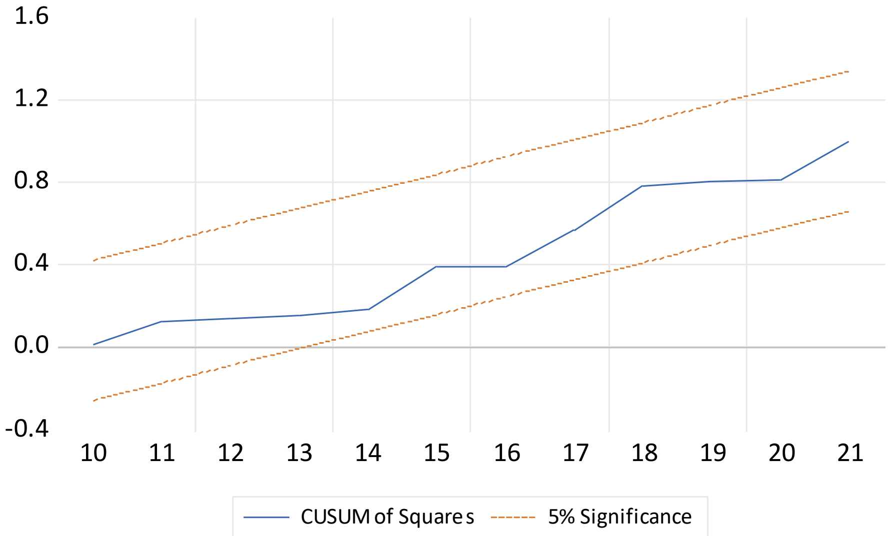

Figure 3. CUSUMsq Test (Coconut oil)

Conclusions

The research investigated the determinants of export performance in Sri Lanka's coconut oil sector employing secondary from 1991 to 2021 using time series data. The analysis focused on the influence of macroeconomic factors such as the import volume of palm oil, volume of domestic coconut oil production, price ratio, inflation rate, and exchange rate on the export performance of coconut oil. The study explored both short-run and long-run effects of these independent variables on coconut oil export performance.

Accordingly, the import amount of palm oil significantly affects the export performance of coconut oil. This indicates that palm oil and coconut oil serve as substitutes in cooking, cosmetics, and other applications. An increase in coconut oil prices within the domestic market leads consumers to switch to palm oil, reducing domestic demand for coconut oil and increasing exports of coconut oil. Although coconut oil production quantity shows a positive relationship with export performance, its insignificance suggests a limited individual effect. This may result from minimal fluctuations in production data year-to-year, indicating a need for a larger sample size to achieve significance. Sri Lankan coconut requirement is around 4000 million nuts although the actual production is 2800 million nuts to 3000 million nuts. The country exports coconut oil even it does not have a real capacity. The price ratio of coconut oil has a significant negative impact on export performance of coconut oil implying that that higher domestic prices relative to FOB prices make coconut oil less competitive in international markets, reducing exports. Higher inflation rates have made the coconut oil industry less competitive in the global market. Contrary to typical expectations where currency depreciation boosts exports, Sri Lanka's coconut oil production cannot meet the higher. The export performance of coconut oil is more sensitive to price fluctuations and inflation than to production levels. Effective management of these economic variables is crucial for enhancing export performance. The significant negative impact of the exchange rate highlights the need for addressing supply constraints and economic stability to realize the benefits of currency depreciation on exports.

The findings highlight the complexity of the factors influencing the export performance of coconut oil. While imports and production levels negatively impact exports, historical price ratios and inflation rates play significant roles in shaping short-term export outcomes. These insights can help policymakers and industry stakeholders make informed decisions to enhance export performance by addressing short-term economic dynamics effectively. By understanding these relationships, strategies can be developed to mitigate negative impacts and leverage positive influences to optimize the export performance of coconut oil. It is essential to note that these recommendations should be tailored to the specific circumstances within the coconut oil industries. Additionally, future studies could explore the influence of trade policy, fiscal policy, government consumption, and foreign prices on coconut oil export performance. The limitations of this research, such as the challenge of handling numerous variables and the deviations from previous studies, warrant further investigation with a broader range of variables.

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IS SMALL BEAUTIFUL? SCALING-UP OF FARMING AND AGRICULTURAL MODERNIZATION FOR POVERTY REDUCTION IN SRI LANKA

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Abstract

The food crop sector in Sri Lanka has not realized its full potential in terms of supplying food at reasonable prices and providing acceptable incomes for the farm families. While this failure is widely acknowledged, the current efforts to develop the sector mainly focus on agricultural intensification. This paper argues that intensification may not solve the food crop sector problems without scaling up and modernization. The long-held belief of inverse relationship between farm size and productivity is being challenged by recent research findings. As the per capita income levels increased, most of the developed countries transformed their agriculture through land consolidation to ensure farm families earn sufficient incomes to remain in agriculture. Some upper middle- income countries are also scaling up farming. This paper reviews literature on farm size and productivity and international land consolidation experiences. It asserts that the food crop sector needs land consolidation for its modernization to support full-time farm families with acceptable incomes. The paper proposes, focused research on returns on agricultural intensification and feasibility of land consolidation in Sri Lanka giving due consideration for country specific socio-cultural factors and land ownership patterns.

1. Introduction

Agriculture plays an important role in Sri Lankan economy despite its relative contribution has been declining over time. There are approximately 2.3 milli[2]on hectares of agricultural land, of which 1.5 million hectares are used for non-plantation crops in 2021 (DOA, 2022). The sector that includes paddy, maize and other cereals, pulses, root and tubers, and condiments like chili, onion, fruits and vegetables, and other crops, is known as the food crop sector. Most food crops are grown primarily for domestic consumption. In 2021, the non-plantation food crop sector accounted for 2.4% of Sri Lanka's GDP, with the agriculture sector, apart from fisheries and forestry, contributing 5.9% to GDP (CBSL,2022). This article discusses the performance of Sri Lanka's non-plantation food crop sector, farm size and productivity and points out that agriculture sector modernization requires scaling-up of farming through well thought out land consolidation program.

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[2] Productivity in this paper refers to both land and labour productivity in food crops

Agriculture sector in any country plays a main role in sustaining economic growth and development. Performance of the agriculture sector is evaluated against two main criteria: (i) its ability to supply food and raw materials at a reasonable cost, and (ii) its ability to provide a decent standard of living for the farm families. The agriculture sector provides employment and livelihood for the majority of the rural population in early stages of development (Rostow,1959). Also, safeguarding the nutritional security of a country is largely dependent on the agriculture sector. It supplies labor for industrial and service sectors at later stages of development and facilitates industrial development. Thus, the role of the agriculture sector goes beyond simple food production, as the sector plays a dynamic role in economic transformation. Agriculture sector modernization to ensure higher farm productivity, particularly labor productivity, is a must in transformation of the economy from traditional low-income agriculture-based economy to a modern, high income diversified economy.

A brief review of the available information shows that the agriculture sector in Sri Lanka has failed to supply food at a reasonable cost. The Household Income and Expenditure Survey (HIES) in 2019 shows that a considerable portion of total spending (35.1%) is allocated to foods and nonalcoholic beverages and, in the estate sector, this portion exceeds 50% of the total expenditure. This highlights the agriculture sector in Sri Lanka is not providing food to people at an affordable price. Developed countries like Australia, the United States, and the United Kingdom spend about 9.4%, 6.2%, and 7.9% of the household income, respectively, for food. The middle -income developing countries like Thailand, Vietnam and China spend about 22.4%, 31.1%, and 19.4% of the household income for food, respectively. Sri Lankan situation, however, seems a bit more favorable than some countries such as Bangladesh (52.7%), Pakistan (38.6%), and the Philippines (42.2%).

Food price inflation also indicates that food is not cheap in Sri Lanka. Figure 1 Shows the Colombo Consumer Price Index (CCPI) of food and non-alcoholic beverages and CCPI of all the Goods from 2003 to 2022. The blue line represents the CCPI of food and non-alcoholic beverages and the red line represents the CCPI of all Goods. Both lines show an upward trend with time, indicating a price increase over time. Food prices increased at a higher rate than the rest of the prices since late 2007. In 2022, there is a significant jump of 6.9% in Food prices compared to 2021. Expenditure on food and food price inflation shows that the food crop sector in Sri Lanka is unable to supply food to consumers at an affordable price.

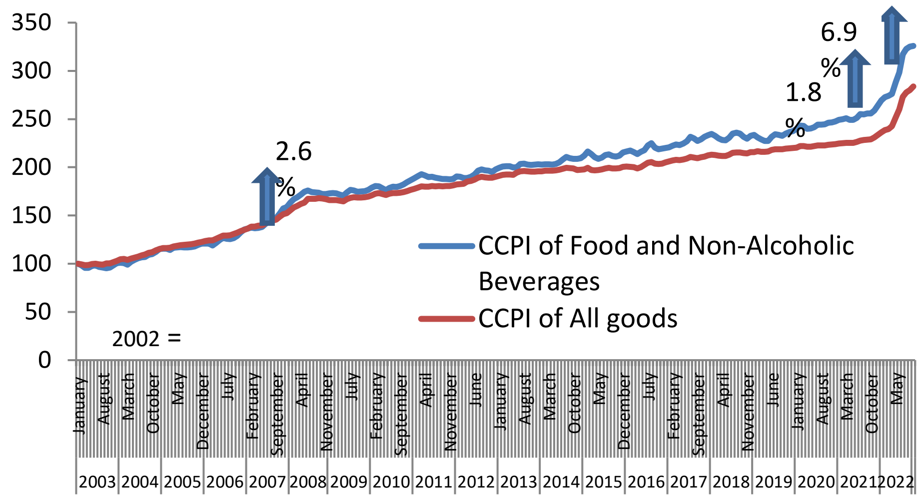

Figure 1. CCPI of Food and Non-Alcoholic Beverages and All Goods from 2003 to 2022

Increasing worker income is a crucial approach to reducing poverty. However, the agricultural sector has low capacity to make a substantial contribution to this goal because of its poor productivity. The World Bank (2021) report on livelihood strategies and the non-farm sector in Sri Lanka states that, a rural farmer's average monthly income from farming activities alone come to LKR 16,040. In contrast, a rural worker engaged solely in non-farm activities earns an average of LKR 28,399 per month, which is considerably higher than the income from farming.

The food sector, thus, has failed to supply food at a reasonable price and farming does not provide sufficient income for farm families, in comparison to the earnings in the rest of the economy. This is due to several persistent problems of the food crop sector in Sri Lanka. These problems include: low farm productivity; marketing problems that suppress farm gate prices and inflate consumer prices; inefficient agricultural extension resulting poor technology adoption; higher post - harvest losses; information and coordination failures which frequently result in shortages or oversupply; less than optimal level of mechanization; and incomplete property rights that suppress long term investments and less than optimal scale of farming Persistence of these problems has resulted in lack of interest of the younger generation to engage in agriculture. Thus, the sustaining the food crop agriculture in Sri Lanka has become a major concern. This paper asserts that many of the above problems cannot be solved without increasing the scale of the farming.

The paper is organized as follows. Section two reviews the literature on the farm size and productivity. The section three discusses the land consolidation as an avenue for productivity and farm income improvement, and the following section discusses the international experience of land consolidation taking Norway and China as examples. The final section provides concluding remarks which propose to undertake necessary research and initiate a dialogue with the relevant stakeholders to develop a socio -culturally acceptable land consolidation model taking into account the country specific factors into account.

2. Farm Size and Productivity

Based on the empirical findings from 1960s up to recent times, there was a widely held belief that small farms are more productive than the large farms. This widely agreed "inverse relationship" between farm size and productivity has had a major policy impact on the scale of farming. A large majority of the developing country governments and the donor community were reluctant to support land consolidation programs that enabled increasing the scale of farming. However, there is evidence in the most recent research that the inverse relationship no longer exist and larger farms are more productive.

A study conducted by International Fund for Agricultural Development (IFAD) in 2018 found that there is a weak but positive relationship between farm size and farm productivity across countries. Nevertheless, there is a much stronger positive relationship existing between farm size and agricultural output per unit of labor. But, when considered within individual countries, the relationship between farm size and yield is often negative. However, even within the individual countries, there is a robust positive relationship between farm size and labor productivity[1].

The importance of farm size on poverty reduction among the rice and wheat farmers in Eastern India was studied by Urfels et al. (2023). According to the study, farm size works as a restricting factor to reduce poverty in the area even with intensification, driven by irrigation. In contrast to the widely held belief of the inverse relationship between farm size and productivity, a study by Foster and Rosenzweig (2022) points out that increasing farm size in low-income countries may not reduce agricultural productivity. The authors assert that small-scale farming in India is both a symptom and a cause of underdevelopment. This Yale University study further asserts that "*Consolidating farms in India to reach the optimal size of 24.5 acres would decrease the number of farms by 87% and reduce the number of farmworkers by 16%* (Foster & Rosenzweig, 2022).

Foster and Rosenzweig (2022) theorizes as to how productivity increases as farm size increases. As shown in Figure 1, family labor is enough to manage the farm efficiently to gain higher productivity on small farms at the beginning.

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[1] Labor productivity is a main determinant of agricultural wages and hence the farm incomes.

Increasing farm size at that stage can reduce productivity due to organizational inefficiencies and expenses involved in hiring more workers for the farm. As the farm size increases further the advantages of adding more employees eventually begin to outweigh the disadvantages. This happens when the farm can take advantage of economies of scale by integrating machinery into their operations. At this stage farm productivity begins to rise with the size of the farm. This change is also linked to the higher agricultural wages experienced in most of the developing countries in the last two decades. This is complemented by the improved ability of farmers to efficiently manage a larger land area, which raises overall productivity.

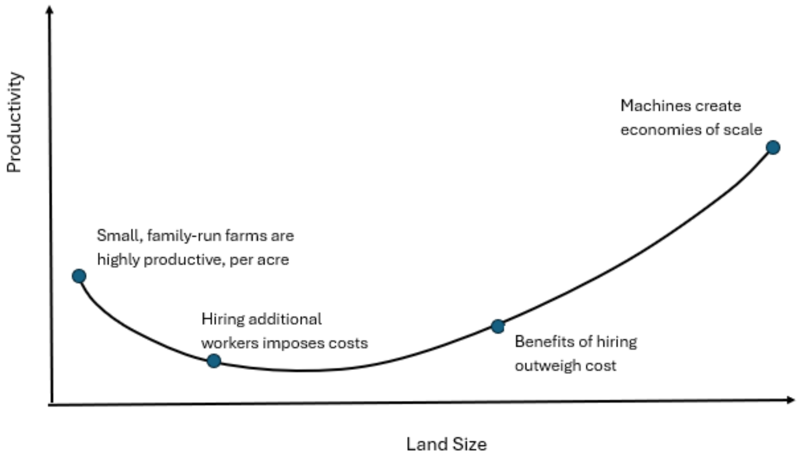

Figure 2. Foster and Rosenzweig' (2017) U-shape curve

Thus, the better productivity in larger farms is related to two factors. First, it is related to increase in rural wage rates in many developing countries during the last two decades. Rural wages have been increasing in most of Asia and the rate of increase is accelerated since 2000s (Wiggins and Keates, 2015, see Table 2). This is due to two main reasons; rural labor force growth has declined and many developing countries because industrialization has attracted rural labor for industries. Second, as agricultural wages increase, intensification of farming with more labor becomes costly and mechanization becomes economically feasible. As a combined effect, the higher wages (and reduced use of labor) and use of machines will increase the land and labor productivity of the larger farms.

Table 1. Changes in Agricultural Wages in Selected Asian Countries

Country	Time Period	Increase in Agricultural Wages
Bangladesh	2005-2010	45%
India	2005 -2012	35%
China	2003 -2007	92%
Nepal	1995/96 – 2010/2011	59%
Sri Lanka	2007 - 2012	38%

Sources: (Wiggins and Keates, 2015)

The role as well as the impacts of small-scale farming on development has been discussed in literature for a long time. For example, Conroy et al. (1996) discussed the inability of many developing countries to achieve a satisfactory level of development because of various issues related to their small farms: *"It is our belief, that the sort of inequity and poverty the peasantry must face actually blocks true development. The rural masses are so poor that they have little purchasing power. They thus do not constitute an important market for domestic industry. This in turn means that domestic markets are too small to stimulate much economic activity, so production (in other sectors of the economy) is largely directed toward foreign markets and urban elites. Consequently, the level of demand in the economy is too narrow to sustain broad based, effective development"*

While citing the inherent disadvantages of small-scale farming, the authors suggest that these negative effects are due to lack of emphasis on the small farms and their suggestion is to protect and subsidize the small farming sector. More recent literature, however, does not subscribe to this view. A careful review of Sri Lankan food crop sector also shows that fertilizer subsidy, protectionism and other support provided by the government has not helped the small-scale farmers to come out of the poverty (Yatawara, 2005).

Literature in 1970, 80 and 90 provided overwhelmingly supportive evidence for inverse relationship (IR) between farm size and productivity (land). However, the more recent literature provides a changing scenario. Carletto et al. (2013), amongst the more recent literature, show the existence of inverse relationship between farm size and prodctivity in Uganda using an improved measure of land size. Harris, and Orr (2014) studied the agriculture's potential to reduce poverty with rainfed crop production in Africa and India. As they show, crop production could be a way out of poverty where smallholders are able to increase farm size or where markets stimulate crop diversification, commercialization and increased farm profitability. For most smallholders, however, small farm size and limited access to markets mean that returns from improved technology are too small for crop production alone to lift them above the poverty line. However, small-scale farming still plays a role in is improving household food security.

Giller et al. (2021) study food security and farm size in number of African countries (Ethiopia, Ghana, Mali, Malawi, Tanzania and Uganda). Their results show a strong interplay between population density, farm size, market access, and agroecological potential on food security and household incomes. Within each location, farm size is a major determinant of food self-sufficiency and a household's ability to rise above poverty. Recognizing that small farms do not generate sufficient income, the study highlights the importance of off-farm employment.

Giller et al. (2021) perceives that persistence of small farms in Asia as a major impediment for development. As they assert, consolidation of farms proceeds at a very slow pace in South-east Asia and 70% of farms in India are 'ultra-small' – less than 0.05 ha. Also in Africa, where one finds smallholder farms are much smaller than often assumed (< 1 ha), farming households are often food insecure. A set of pro-poor policies and investments are needed to stimulate small-scale agriculture as part of a broader focus on rural development to address persistent poverty and hunger. Smallholder farms will remain an important source of food and income, and a social safety net in absence of alternative livelihood security. But with limited possibilities for smallholders to 'step-up' the agricultural engine of growth appears to be unfeasible. Giller et al. (2021) conclude that smallholder agriculture cannot deliver the rate of economic growth assumed by many policy initiatives in Africa.

Chamberlin et al. (2014) assert that the potential for profitable smallholder-based cropland expansion in the short to medium term in most African countries is likely to be much more limited than it is typically perceived to be. Harris (2018) studied the sustainable intensification[1] of agriculture in sub-Saharan Africa. Eleven thousand seven hundred and eighty nine households in 15 countries were used to calculate an intensification benefit index (IBI) that reflects how much a household will benefit if investment on intensification occurs. Fifty percent of all households had IBI values less than 0.075 cents/dollar, 70% less than 0.125 cents/dollar and 90% less than 0.225 cents/dollar. Returns of $1000/ha/year investment would result in fewer than 15% of households crossing a $2/person/day poverty line; $2500/ha/year would be required to lift 50% of the sample above the poverty line; and even with $4000/ha/year, more than 30% of households would remain below the poverty line. Since mean net returns from three sub-sampled sites were only $78, $83 and $424/ha/year the gap between potential- and actual performance is large but, theoretically, amenable to closure through adoption of improved technologies. However, surveys have shown that the available technologies would struggle to bridge the gap completely for rural households with small farms. For many small farms, the gains from adopting improved technologies

[1] Agricultural intensification refers to optimal use of all the inputs i,e. better seeds, fertilizer, agronomic practices, pest and disease control, while keeping land farm size as it is.

are unlikely by themselves to lift them out of poverty and so might not be as attractive as scientists would wish.

Jayne et al. (2016) assesses changes over the past decade in the farm size distributions of Ghana, Kenya, Tanzania, and Zambia, drawing on two or more waves of nationally representative population-based and/or area-based surveys. This study suggests a new and hitherto unrecognized channel by which medium-scale farmers may be altering the strength and location of agricultural growth and employment multipliers between rural and urban areas. Given current trends, medium-scale farms are likely to soon become the dominant scale of farming in many African countries.

Jayne et al. (2010) uses small-scale farm survey data from five countries of eastern and southern Africa to highlight four underappreciated issues: (i) how land distribution patterns constrain the potential of crop technology and input intensification to enable many small farms to escape from poverty; (ii) why most smallholders are unable to produce more than a marginal surplus or participate meaningfully in commodity markets; (iii) why most farmers are directly hurt by higher grain prices; and (iv) why the marketed agricultural surplus is exceedingly concentrated among a small group of relatively large smallholders. Policy and public investment options are reviewed in the light of these Issues that were not adequately addressed in literature. The authors question the future of small-scale farming in southern African countries.

Lowder et.al. (2016) uses agricultural census data to show that there are more than 570 million farms worldwide, most of which are small, and family operated. It shows that small farms (less than 2 ha) operate about 12% and family farms about 75% of the world's agricultural land. They show that the average farm size decreased in most low- and lower-middle-income countries for which data are available from 1960 to 2000, whereas average farm sizes increased from 1960 to 2000 in some upper middle- income countries and in nearly all high-income countries.

Muyanga et al. (2014) measures how Kenyan farmers and farming systems have responded to changes in population density and associated land pressures. Evidence is derived from a five-round panel survey between 1997 and 2010. They find a negative relationship between localized population density and farm size, and a positive relationship between population density and measures of population density up to roughly 500 persons/km^2. Beyond this threshold, rising population density is not associated with further increases in land intensification. Some measures of intensification show an alarming decline beyond this population density threshold. They also find a relatively weak relationship between population density and off-farm income. Overall, total household income per adult equivalent is found to decline significantly as population density rises. These findings raise serious policy questions about feasible pathways for rural poverty reduction in the context of increasingly land-constrained farming systems.

Ritzema et al. (2017) assess whether the benefits of sustainable agricultural intensification would be realized by farm households considering highly diverse resource endowments, household and farm characteristics, and agroecological contexts. In this study, they use a simple energy-based index of food availability of 1800 households from research sites in 7 countries in East and West Africa. They estimate the effects of two production intensification strategies on food availability: increased cereal crop production from crop-based options, and increased production of key livestock products from livestock-based options. The findings that intensification has had limited success point out that intensification strategies must be augmented with transformational strategies to reach the poorest households.

As per the Sitko and Jayne (2014) Zambia has witnessed a rapid increase in the number of medium-scale ‘‘emergent farms’’ cultivating 5–20 ha of land the last decade. This study analyzes the factors underpinning this growth. They find that the growth of emergent farmers in Zambia is primarily attributable to land acquisition by salaried urbanites and by relatively privileged rural individuals. They found little evidence to support the hypothesis that the rise of emergent farmers primarily represents a process of successful accumulation by farmers who began farming with less than 5 ha of land. This study highlights the potential distributional implications of unplanned land consolidation.

As per early literature, lots of expectations were built on the role of small farms in ensuring food security and rural development. Even in highly advanced countries like USA, there was lot of hype about the role of small farms[1]. Small Farms are assumed to provide higher quality of life for farm families; take better care of soils; be more energy efficient; discourage out migration to cities, generate more social benefits of publicly funded programs like research and extension; supports the vitality of the nearby cities, and promote competitive environment. Tweeten (1983) examined the validity of 8 similar hypotheses in relation to US agriculture and conclude that there is no basis to accept any of the eight hypotheses. As he further asserts whether any size of farm can be viewed as optimal, the strongest case is for the typical moderate-size family farm of today rather than for small farms or large industrial-type farms.

Hazell, et al. (2010) discusses the advantages and disadvantages of small-scale farming. In terms of efficiency, small farms typically make intensive use of land by using much labor, since the costs of supervising family labor are low. This will be beneficial at the early stages of development where rural wages are low. Large farms, on the other hand, have lower costs when transacting with

[1] Small farms in USA are quite different from those of the developed countries as they are much bigger than small farms in developing countries.

the outside world in procuring inputs, marketing produce, and gaining access to credit. Further, it is argued that small-farm households spend their incomes, they tend to spend them on locally produced goods and services, thereby stimulating the rural nonfarm economy and creating additional jobs.

Smallholdings face many more challenges. When new technologies require more capital input, mechanization, or high levels of education, these requirements may disadvantage smaller farms. More worrying are the implications of changes to marketing chains. Supermarket operators are becoming increasingly important in many parts of the developing world. The supermarkets impose stricter standards for the quality, consistency, and timeliness of supply. They may also require the ability to trace consignments back to the source to confirm how they have been produced (traceability). Supermarkets expect their suppliers to adjust rapidly to changing consumer demands. Small-scale, undercapitalized, and often uneducated farmers find it particularly difficult to meet these requirements. Especially traceability and credence (that is, characteristics that relate to production methods like pesticide use but cannot be proved by examining the product) are not easy with small farms. Will small farms be marginalized from the new supply chains? Much depends on whether they grow, where credence attributes matter and whether supermarkets can obtain their supplies from large farms. When supermarkets can deal with a few large farms, they will; when credence attributes are less important or there are no alternatives to small farms, then smallholders are likely to become part of the evolving supply chains. Equally important is how quickly supermarkets come to dominate food supply chains. Supermarkets thrive in growing economies, so as their control of marketing increases and some small farmers are excluded, chances are that new jobs are being created for them in non-farm activities.

The literature, thus, suggests that the inverse relationship between farm size and productivity, particularly, labor productivity has been changing. Evidence is emerging that larger farms are more productive. As the per capita income increases, the scale of farming has to increase to provide an income for the full-time farmers that is far from the other sectors of the economy. Agricultural intensification with small scale farming has limited potential for supporting farm families to come out of poverty. Almost all the developed countries have gone through an agricultural land consolidation process to ensure modernization and sustaining farming. The upper middle-income countries also show the trend of increasing farm size. Despite the current set back due to the economic crisis, it is timely for Sri Lanka to examine the need and feasibility of agricultural land consolidation.

Table 2. Productivity improvements needed to achieve 50% per capita national utilizing farmer's current land extent.

Crop	Average farm holding size (ha)	Productivity (Kg/ha) needed to achieve 50% of per capita average household income	Current average productivity in SL (kg/ha)	% Chang e
Rice	2.60[a]	42,333	5,574[d]	659%
Maize	3.64[b]	21,527	4,400[e]	389%
Potato	0.30[c]	65,146	16,000[f]	272%
Pumpkin	0.30[c]	124,743	15,000[f]	732%
Carrot	0.30[c]	44,156	35,000[f]	26%
Tomato	0.0[c]	60,776	25,000[f]	143%

Source: Authors calculation; Sources of data: (Janani et al., (2022)[a] , Kiriveldeniya & Rosairo,(2020)[b] , Champika, (2016)[c] DCS, (2016)[d] , Wangmo et al., (2024)[e] , Department of Agriculture [DOA], n.d.)[f.] Assumptions: Household size=3.7, GDP per capita per annum = 4000 USD, Exchange rate (USD to LKR) =300 LKR, Share of Income for the total household income = 50%, Crops are cultivated in Both Yala and Maha seasons.

3. Agricultural Land Consolidation

Land consolidation is a comprehensive land reallocation process in rural areas that suffer from fragmentation of agricultural lands. The objective of land consolidation is to improve land holdings and to promote efficient and appropriate use of the scarce land resources in a country. In addition to resolving the boundary disputes, land consolidation aims to increase the net income from the holdings by increasing the volume of production or by lowering the cost of production (Sky, 2002). Sustaining agricultural systems is difficult without land consolidation as countries reach higher income levels. Moreover, the persistent problems of marketing, poor adoption of technology, post-harvest losses and mechanization in the face of increasing labor scarcity and labor costs cannot be achieved without scaling up of farming. The ongoing land consolidation in China is a case in point.

The process of land consolidating involves combining land plots through land exchanges, to form bigger plots that are better adapted to their proper use. In addition to actual land exchanges, improvement of the road and drainage network and other infrastructures are usually parts of the land consolidation. Landscaping, environmental management and conservation projects may be implemented, and/or at least taken into consideration in a land consolidation process. Land consolidation is effective instrument in rural development because it can facilitate the creation of competitive agricultural production arrangements by enabling farmers to have farms with fewer parcels that are larger and better shaped, and to expand the size of their holdings.

If the land market is fully liberalized with owners having clear titles, land consolidation may happen through market mechanism to some extent. Even when there are legal restrictions for market exchanges of agricultural lands, informal leasing may allow operation of larger farms. Such arrangements are evident in some colonization schemes such as Mahaweli System H. However, such arrangements are suboptimal as they don't realize the full benefits of the land consolidation. Market driven mechanisms can be suboptimal too because of the coordination failures. Small scale farmers trying to negotiate would require negotiating with numerous small landowners, and the restrictions on access to information and/or the non-transparency conditions of the land markets are other circumstances which may have influence on the process. These factors lead to high transaction costs, which, in many cases, will not permit to achieve final agreements when these costs are higher than the value of the land which is going to be transferred. The access to reliable information, in many cases, is the main constraint which conditions the operation of the land markets. Therefore, government interventions are necessary to achieve optimal level of agricultural land consolidation.

Land consolidation is seen as a solution to multiple problems faced by small farms. Sometimes contract farming or cooperatives are also viewed as an alternative for land consolidation in solving small farm problems. Lack of access to formal credit, risk-aversion, and the high costs acquiring information and adaptation of technology, poor bargaining power in marketing by small holders provide incentives for firms to contract with them (Key and Runsten, 1999). By acting as intermediaries, firms can profit from the willingness of smallholders to pay more for credit and insurance than larger landholders would. Hence, even if small-scale producers are not competitive in the open marketplace, they may be the most profitable type of growers with whom the firms could contract. The main disincentive for firms to contract with smallholders appears to be the transaction costs associated with providing input, credit, extension services, and product collection and grading. The case study described by Key and Runsten, (1999) show many of the difficulties firms faced in the Mexican frozen vegetable industry and implementing contracts that allow them to minimize the costs of working with large numbers of heterogeneous growers. While some firms have been able to structure the delivery of their services to reduce transaction costs – as described in this case study — many firms have found it easier and more profitable to deal with a few large growers.

Sri Lankan experience of contract farming with small holders are similar. Some companies, for example Chemical Industries of Colombo (CIC), have attempted to provide credit, extension, technical backstopping on pest and disease control in a buy-back arrangement with a predetermined price. At the time of harvesting if the market price is higher than agreed price, the small holders breach the contract and sell the product in the open market while defaulting on the credit. Prosecuting large number of small farmers is prohibitively expensive, and politically sensitive. Therefore, the companies gave up these buy-back systems after one or two seasons. Contract farming or buy-back systems worked reasonably well with egg and chicken meat producers but failed in the food crop sector. These and numerous other examples show that organized private sector participation in agriculture through buy-back systems also requires land consolidation first.

Cooperative farming theoretically produces similar results to those of land consolidation as scale advantage can be reached with the cooperative farms. However, cooperatives movement in Sri Lanka shows that it didn't work well. Success of cooperatives requires an incentive system and regulatory mechanisms to ensure everybody involved benefit from the cooperative arrangements. Cheating of the elected officials and various corruption issues have destroyed cooperative systems and given previous experiences as well as the culture of lying and cheating in Sri Lanka can easily derail the cooperative systems. Collapse of the widespread cooperative systems that operated in 1960 and 70s as well as more recent examples of fisheries association in inland fisheries are indicative of the difficulties to sustain cooperative arrangements. Moreover, even if the cooperative farms overcome some issues related to scale, small farms will not provide sufficient income for the farm families.

It is unlikely that young generation will engage in farming unless they can earn at least 50% of the national average income. Table 3 presents the required extent of cultivation, if a full-time farming family is to receive an income equal to 50% of the capita income. A paddy farmer should cultivate at least 8 ha, and a maize farmer should cultivate about 7 ha to earn 50% of the average per capita income. Such incomes are not feasible with small farms.

Table 3. Required Extent of Cultivation by a Fulltime Farmer to Earn the Average Per Capita Income

Crop	**Average yield (kg/ha)**	**Average profit per kg (LKR)**	**Area needed to cultivate (ha)**
Rice	5574	24.92	7.99
Maize	4400	16.32	15.46
Potato	22500	56.14	1.03
Pumpkin	17500	29.32	2.16
Tomato	25000	60.17	0.74
Carrot	35000	82.83	0.38
Crop	5574	24.92	7.99
Rice	4400	16.32	15.46

Source: Authors calculationAssumptions: Household size=3.7, GDP per capita per annum = 4000 USD, Exchange rate (USD to LKR) =300 LKR, Share of

Income for the total household income = 50%, Crops are cultivated in Both Yala and Maha seasons.

Table 4. Food Crop Sector Problems and Solutions Provided by Land Consolidation

Food Crop Sector Problem	Solution Provided by the Land Consolidation
Low farm productivity	There is emerging evidence of higher productivity of bigger farms
Marketing problems	Large scale commercial farmers have better bargaining power, and ability to store the products and sell when the price is high. Moreover, when there is a small number of bigger farms, they can do collective bargaining[1].
Agricultural extension	Large scale farmers have better abilities to access information or involve in a buy-back system with a company that provide extension services
High post-harvest losses	Large scale commercial farmers can invest on loss reducing technologies
Low level of mechanization	Land consolidation combines small plots with suitable shape and provide road and other infrastructure for mechanization. Commercial farmers with correct scale have ability to invest on machines or access credit to purchase machines
Low farm family income	Combination of the above provide better income in far with the rest of the economy.
Lack of interest on farming by younger generation	One of the main reasons for lack of interest is low income. Higher stable income will provide incentives for younger generation to do farming. Commercial farmers with better income also provide a solution for the lower social status of small holder farmers

As described above, land consolidation is a catalyst for rural development. It has positive impacts on agricultural production, employment, and local economies. It enhances optimal use because larger and better-shaped plots are used for efficient land utilization. A comprehensive land consolidation program can potentially enhance the road network and drainage network in consolidated

[1] Wheat farmers in Norway decide a floor price and communicate it to all the wheat farmers. The price is determined by the cost of production of the year and an allowed profit margin. There is a regulatory mechanism to ensure farmers' collective action does not result in monopoly power. Farmers sell at the floor price or above and the mechanism ensure that farmers earn a reasonable income.

areas. It allows long-term development planning and reduction in in construction costs (e.g., railways, motorways). Moreover, implementation of environmental and nature conservation projects can be integrated to land consolidation.

4. International Experience

4.1. Norwegian Experience

Norway joined a developed community of Europe after 1960s with the discovery of deep-sea oil. Before that Norway had very land fragmentation problems and. As its incomes rapidly increased in 1960s, Norway recognized the need to undertake a land consolidation. In 1950 there were 200,000 farms in Norway, many very small, and offering only a part-time livelihood in agriculture, forestry, and related rural occupations. Today there are slightly over 50.000 active farms, many of which still offer only part-time livelihoods. Land fragmentation, i.e. non-contiguous landholdings, represented an important problem in agricultural activity in many regions. It may cause production losses, but the main problem is that it increases production costs due to high supervision costs and increased time requirement.

The official name of the land consolidation activities in Norway is Jordskifte. This concept is normally translated into "land consolidation" in English. A more precise translation would be "reallocation of holdings by pooling and redistribution". The execution and decision-making body on land consolidation in Norway is organized as a special kind of court, called "The Land Consolidation Court". This body has become a permanent public institution, within the framework of the judicial system. In addition to the reallocation of holdings, the land consolidation court activities include actions as, for example: dissolving a system of joint ownership under which land or rights are jointly owned by estates; reallocating landed property through the exchange of land; prescribing rules relating to the use of any areas that are subject to joint use by estates or prescribing rules relating to the use of any area that is not subject to joint use by estates when the land consolidation court finds that the attendant circumstances make such use particularly difficult; eliminating outdated rights of use, and assigning compensation.

Procedure of land consolidation (LC) in Norway involve in 5 steps

1. **Starting of the LC case (Application)**: Persons who can apply for land consolidation are the owners of officially registered real property and any person who has a perpetual right of use
2. **Clarification of land issues:** (**Boundaries and rights**): Documentation on rights and ownership to land is often imperfect in Norway. Therefore, boundary (and rights) disputes are triggered by disagreements between owners. In general, the process follows these main stages:

- request (claim) for delimitation of boundaries
- technical investigation
- main hearing / oral proceeding claim / statement of claim
- survey
- mediated settlement or verdict
- marking of boundaries
- formal conclusion

3. **Rearrangement of properties, parcels and rights**: The process has the following steps.
    - application for land consolidation (normally by one or a number of landowners, but it could also be initiated by public authorities in some cases)
    - decision whether the case shall proceed.
    - after the acceptance of the case, the court starts the identification process (clarification of boundaries and mapping of the land consolidation area).
    - valuation of anything that is subject to be exchanged.
    - preparation of a draft consolidation plan (the different parcels are pooled or put together. The judge, together with the assistants, creates a plan where the same numbers of holdings emerge but in new physical and legally recognizable shapes).
    - presentation of the plan to the parties for discussion.
    - comments from the parties.
    - alteration on the basis of comments on the plan that the court deems right and proper.
    - formal adoption of the plan (made by court decisions).
    - marking out of all new boundaries in the fields.
    - formal conclusion of the land consolidation proceeding in court

Leasing also represents an alternative to many people, especially the large elderly population, who can no longer work the land themselves. While leasing can be beneficial, it seems just a partial solution to the problem. The small and fragmented parcels are just as inefficient for the tenant as well as for the owner, and because of the small size of the parcels in a holding and their distribution over a wide area, consolidation is difficult. The LC legislation restricted the holding size forcing the land consolidation. It also provided incentives in addition to legal and institutional arrangements for LC; larger farms receive higher per unit subsidies.

Table 5. Effects of Land Consolidation in Norway

Description	Economic and Spatial	Legal	Social	Environmental
Number of Case studies	9	7	7	3
Positive effect	8 (89%)	5 (71%)	4 (57%)	2 (67%)
Negative effect	0	0	3 (43%)	1 (33%
No Effect	1 (11%)	2 (29%)	0	0

Source; Elvestad & Sky (2019)

Elvestad and Sky (2019) summarized the overall impacts of land consolidation in Norway by reviewing available case studies. They show that economic and spatial impact of Norwegian land consolidation is significantly positive as 8 out of 9 case studies show positive results. Legal effects are also largely positive while there can be some negative social and environmental effects. Dissolution of joint ownerships and a reduction in the number of property boundaries, reduction in number of owners, acquiring and selling abandoned properties, which the owner does not wish to farm, are positive legal effects. Social effects are described as how land consolidation affects individuals and the relationships between people. Dispute resolution does not always make all the parties involved happy resulting in negative social impacts. Negative environmental effects are increased danger of erosion because of larger plots, monoculture, removal of border zones between plots and intensified use of agrochemicals. Elvestad and Sky (2019) while acknowledging the need to undertake more systematic rigorous impact assessment conclude that the Norwegian land consolidation program is beneficial to the society.

4.2. Chinese Experience

China has been undertaking a massive nation-wide land consolidation program since 1986. Since the mid-1990s, construction land in China has continued to increase with rapid industrialization and urbanization, while agricultural land has continued to decrease (Wang et al., 2012; Ning et al., 2018). Since the reform and opening up in 1978, rapid socio-economic development and urbanization have inevitably led to the occupancy of large amount of agricultural lands (Liu et al., 2014; Deng et al., 2015). Land consolidation has played an important role in increasing the amount of cultivated land and ensuring the requirement of 1.8 billion mu[1] of arable land (Ying et al., 2020).
The land consolidation in China has undergone through four stages. The preliminary stage was from 1986 to 1997 (Zhou et al., 2020). Land consolidation in this period was mainly cropland consolidation and land reclamation, without construction land consolidation. The second stage was the

[1] 1 mu = 666.5 square meters

land reclamation and consolidation stage, which began in 1998 and ended in 2007. The land consolidation aim during this period was to increase cultivated land, reduce fragmentation, and promote agricultural productivity. The third stage of land consolidation was the multi-type land consolidation stage from 2008 to 2012. The scope of land consolidation in this stage was extended to urban and rural inefficient, unused, abandoned industrial and mining, and damaged land. The aim of land consolidation shifted toward the integrated goals of increasing cropland, reducing fragmentation, improving agriculture infrastructure and environmental quality, and promoting agricultural productivity (Du et al., 2018).

The fourth stage started in 2013 and was named the comprehensive land consolidation stage. Comprehensive land consolidation is defined as a systematic approach for enhancing agricultural production and increasing the scale of operation of agricultural to improve rural living and eco-environmental condition, promote rural population concentration, and stimulate industrial agglomeration and urban–rural integration through the comprehensive improvement of lands, waters, roads, forests and villages in a certain area. The development process of land consolidation indicates that land consolidation is an important way of increasing the amount and improving the quality of cultivated land, improving the ecological environment, and promoting the coordinated development of urban and rural areas.

Chinese land consolidation is, thus, combined with its industrialization and urbanization. Rural farming communities are settled in urban centers in apartment buildings. These urban centers are fully developed with access to water supply and sanitation, electricity and other urban amenities and they are established in close proximity to industrial centers. Farmers are given training and other support to move out of agriculture and work in other sectors of the economy. Released agricultural lands are subjected to landscaping, spatial planning and consolidation to mediums to large size farms. This enables modern mechanized farming with sufficient scale that generates incomes comparable with the rest of the economy.

There are number of studies which document the impacts of land consolidation in China. The evaluation results of Zhang et al. (2019) show that after land transfer and consolidation, farmland fragmentation in Langwan project area is effectively reduced, with the total number of plots decreasing from 1738 to 92 and the average plot size increasing from 0.11 to 2.00 ha, and plot shape tends to be enlarged and regular, which is conducive to large-scale and mechanized farming. Besides, agricultural infrastructure and soil quality are both improved, which facilitates the implementation and mechanization of field work, and other operations such as transportation, irrigation, pesticides and fertilizers application. Janus & Markuszewska (2019) also show similar results.

Zhou et al. (2019) claim that land consolidation in China is promoting rural development and revitalization because of its social, economic and ecological benefits, However, authors alert about the eco-environmental risks and negative effects brought by land consolidation projects. Ying et al. (2020) highlight the importance of land consolidation to regional rural economies in mountainous and hilly areas and provides valuable insights for promoting the efficiency of regional rural land consolidation arrangements in the future. They sampled 4710 land consolidation projects during 2006–2016 and recorded their benefits to the rural economies within the project area. The results showed that land consolidation contributed to the promotion of rural economies. They found 67% increase in grain production, 55% increase in net agricultural income 37% increase in land rental income, and 43% increase in labor income respectively. They also noted that technological efficiency such as the mechanized agricultural area and the land-leveling area could also make primary contribution to grain production increment and net agricultural income increment.

Jin et al. (2017) assessed land productivity in 5328 land consolidation projects implemented between 2006 and 2010. The results indicated that 79 % of the projects in 2006 and 78 % of those in 2007 proved effective in either improving or stabilizing productivity. However, only 41 % and 34 %, respectively, were effective in both aspects (Du et al., 2018). Land consolidation can also effectively reduce rural poverty and, to some extent, coordinate man–land relationship to promote the development of rural areas. Wang and Li (2019) analyzed the mechanism and path of land consolidation in boosting poverty alleviation. Degraded land consolidation could optimize the rural economic structure and mitigate rural poverty through integration with agriculture, industry, and tourism.

Li et al., (2018) has proposed that the land consolidation effect should be evaluated not only from the perspective of rural human–land relationship but also from the perspective of urban–rural human–land relationship. Zhou and Cao (2020) analyze the implementation and distribution characteristics of the land consolidation project completed in Shaanxi Province in 2018. Land consolidation in Shaanxi province is mainly land reclamation. Authors caution that changes of urban–rural human–land relationship, should be given due consideration in continuation of land reclamation projects in China. As cautioned by the authors, China should be prudent in or stop advancing land reclamation to increase cultivated land. While recognizing that cropland consolidation and high-standard cropland construction are vital ways to achieve China's food security, Zhou and Cao (2020) emphasize that rural settlement consolidation should be carefully conducted in remote areas under the background of urbanization.

Zhou et al. (2019) while citing the potential benefits of land consolidation pointed out the need of third-party assessment of the whole process of socio-economic and ecological impacts of land consolidation. Shan et al. (2019) studied the ecological environment quality changes before, during, and after land consolidation and discovered that the ecological environment quality initially decreased, increased later, and then decreased overall, with characteristics of degenerating during the construction period, improving during the restoration period, and degenerating in the overall process. Shan et al. (2019) pointed out the need for a long-term monitoring of the environmental quality in with land consolidation.

Jin et al. (2017) show that the overall effectiveness of land consolidation in improving agricultural productivity is low, which lies in contrast to optimistic estimates based on regional statistical analysis and theoretical approaches. For projects ($n = 560$) implemented in 2006, about 29.5% showed significant ($p < 0.05$) increasing trends. For 2007–2010, lower percentages (e.g., 25.9% in 2007 and 13.5% in 2010) of projects showed significant increasing trends. Furthermore, authors found effectiveness of land consolidation projects displayed clear regional differences and driving factors are inconsistent with policy design. Shao et al. (2017) anticipate their research to be a starting point for a more comprehensive evaluation of land consolidation involving longer time-series and higher spatial resolution data.

Overall, the ongoing land consolidation program is improving he productivity and farm incomes in China. However, there is some room for improvement in enhancing productivity and environmental management.

5. Conclusions

Food crop sector in Sri Lanka plays an important role in ensuring nutritional security and alleviating poverty. This paper shows that this sector has not been able to provide food at a reasonable price. Moreover, the food crop sector does not provide sufficient income for full-time farming families. The persistent problems and resultant low incomes in this sector have substantially reduced the younger generation's interest in farming. Therefore, sustaining the food crop sector is a major concern and a sector's transformation into a mechanized modern sector is a must if the sector is to play its vital role in the economy.

There are two approaches to improve the food crop sector in Sri Lanka; agricultural intensification while keeping the current small-scale farming as it is; and structural change on the sector to allow medium scale, modern farming. All the agricultural agencies in the country, by and large, concentrate on the intensification without examining the benefit of intensification. Evidence in other countries, particularly in Africa, shows that returns to agricultural intensification is low. After realizing the green revolution yield jump, a similar substantial increase may not be possible without a technological revolution.

Therefore, to is timely to undertake some focused research on the potential benefits of the agricultural intensification in Sri Lanka. Our assessment show the necessary increase in productivity for small farmers to earn reasonable income is unrealistically high.

The confidence in the inverse relationship between farm size and productivity has been changing. More evidence is emerging to support the idea that larger farms are more productive. The psychological barrier in the mind of policy makers against promoting medium to large scale farming is being broken. Almost all the developed countries went through a land consolidation process as the per capita incomes increase to ensure sufficient farm family incomes for the full-time farmers. China's ongoing land consolidation is a case in point. The paper argues that land consolidation can potentially provide a solution to persistent problems of low farm productivity; marketing problems; inefficient agricultural extension; higher post - harvest losses; information and coordination failures; and less than optimal level of mechanization. Moreover, resourceful farmers who generate substantial profits may be able to withstand the risk brough about by climate change. Sri Lankan specific information on farm size and productivity as well as benefits of medium to large scale farming, and the best process of consolidation is lacking and more research on the relevant aspects are timely.

The paper proposes initiation of a research program and a wider discussion on land consolidation in Sri Lanka. Information base should be improved before embarking on a serious land consolidation program. The paper presents the land consolidation programs in Norway and China. The two models of land consolidation are quite different, and they reflect the differences in socio cultural, economic and governance patterns in the two countries. Land consolidation is a complex process and given the overall poor governance in the Sri Lanka, a poorly planned land consolidation programs can bring many social problems too. Therefore, the properly researched land consolidation model should be developed in consultation with relevant stakeholders that suit the socio cultural, economic and governance patterns of the country.

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THE MULTIDIMENSIONAL NATURE OF FOREST RELIANCE IN TIMES OF SOCIOECONOMIC SHOCKS: A HOUSEHOLD-LEVEL ANALYSIS OF SRI LANKA'S RURAL DRY ZONE

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Abstract

As Sri Lankan rural households faced the compounded pressures of a national economic collapse and the COVID-19 pandemic, longstanding livelihood vulnerabilities were brought into sharper focus particularly among forest-adjacent communities in the dry zone. This study investigates how such overlapping crises reshaped household income sources, access to welfare programs (WPs), and forest dependence. Drawing on data from 370 households, the research employs McNemar's and Bowker's tests to examine pre- and post-crisis livelihood shifts, and logistic regression to assess predictors of forest use. To complement these analyses, a scenario-based simulation was developed to estimate conditional probabilities of forest reliance across all viable combinations of WP access, income level, household size, and land ownership. Findings reveal that forest dependence was highest among large, low-income households without access to formal support schemes including Samurdhi Program, pensions and senior citizen allowances, and disability (health related) allowances. Conversely, households with WP support, particularly those that were smaller in size, showed more moderate and stable levels of forest use. These results underscore the interaction of demographic pressure, institutional exclusion, and land access in shaping coping strategies, challenging simplistic associations between poverty and forest use. The study concludes that current social protection mechanisms, while partially effective, are insufficient to prevent environmentally extractive fallback behavior among structurally vulnerable households. It advocates for integrated social welfare and environmental policy frameworks to address both livelihood insecurity and ecological degradation in forest-adjacent rural regions.

1. Introduction

The dual crises of the COVID-19 pandemic and Sri Lanka's subsequent economic downturn severely disrupted income generation for rural households, particularly in forest-proximate communities. These communities already marked by precarious livelihoods faced job losses, market shutdowns, and

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constrained mobility, all of which contributed to a breakdown in formal and informal income channels (Dixon et al., 2021; Rahman, 2021). With traditional modes of employment under pressure, many households adapted by seeking alternative income streams, including those derived from forests, informal work, and social assistance. Research has long recognized that rural livelihoods in forest-adjacent areas are characterized by diversified income portfolios, which often include farming, wage labor, remittances, and resource extraction (Wunder et al., 2014). During economic shocks, however, this balance tends to shift. For instance, Angelsen and Dokken (2015) observe that environmental income becomes a more dominant coping mechanism in times of hardship. Similarly, Miller and Hajjar (2020) argue that forests act as de facto safety nets, especially for asset-poor households who lack access to formal credit or insurance mechanisms.

Sri Lanka's forest-edge communities present a compelling case of how informal economies expand when formal safety nets falter. While some income sources, such as pensions and disability payments, increased during the crisis, other state welfare schemes, most notably the *Samurdhi* program, appear to have contracted in coverage (Pamela et al., 2022). This contradiction raises questions about targeting efficiency and equity in WP delivery during emergencies. Meanwhile, a surge in ad-hoc income from fuelwood collection, home industries, and forest-based labor mirrors trends observed in other parts of South and Southeast Asia (see Golar et al., 2020; Saxena et al., 2021). Studies in Indonesia and India provide parallel findings. Golar and colleagues (2020) report that forest product reliance spiked during the pandemic, especially among informal households excluded from government relief. Likewise, Saxena et al. (2021) note that the combination of return migration and income shocks increased community pressure on forests, both legally and illicitly. These examples highlight the dynamic and often invisible ways households recalibrate livelihoods during prolonged economic distress. The present study contributes to this body of knowledge by analyzing pre- and post-crisis shifts in income composition and household characteristics in Sri Lanka's dry zone. Using McNemar's and Bowker's tests, it identifies statistically significant transitions in formal, informal, and state-supported income types. In doing so, it provides empirical insight into how households adapt and, in some cases, are forced to adapt under conditions of systemic crisis.

Against this backdrop, the present study investigates how forest-adjacent households in Sri Lanka's dry zone adapted their livelihood strategies in response to overlapping crises. It examines pre- and post-crisis shifts in income composition, access to WPs, and household characteristics, while also modeling how demographic and structural factors interact to influence forest dependence. By integrating statistical tests with scenario-based simulation, the study offers both empirical and predictive insight into the conditions under which rural households turn to forests as coping mechanisms. In doing so, it contributes to a deeper understanding of how institutional exclusion and livelihood fragility can reinforce environmental reliance raising critical implications for WP reform, ecological governance, and rural resilience planning.

1.2 Theoretical background

This section synthesizes theoretical frameworks and empirical evidence on rural livelihoods, forest dependency, informal income strategies, and social protection systems providing a robust scholarly basis for the empirical analysis in Section 3.

1.3 Crisis driven livelihood strategies and the limits of resilience

The Sustainable Livelihoods Framework (SLF) emphasizes that households reduce vulnerability by diversifying their assets and income sources (Ellis, 2000; Scoones, 1998). Under normal conditions, a varied livelihood portfolio can buffer against shocks and improve adaptability. However, recent evidence suggests that during large-scale crises, such as the COVID-19 pandemic, diversification often becomes distress-driven rather than strategic (Der Tambile et al., 2024; Furbush et al., 2024). Drawing on studies from Ethiopia, Malawi, and Nigeria, Furbush et al. found that while multiple income streams helped mitigate small disruptions, they were inadequate during systemic shocks. Rather than strengthening resilience, diversification during crises reflected the erosion of stable livelihoods and the absence of formal support systems. In Sri Lanka, similar patterns emerged. Pandemic-related lockdowns, job losses, and rising costs of living sharply curtailed off-farm income opportunities, especially in forest-adjacent regions. Singh et al. (2023) report that by mid-2021, 75–80% of rural households faced food insecurity, and nearly half resorted to distress sales of assets such as livestock. In forest-edge communities, this led to increased dependence on subsistence farming and forest resources for food, fuel, and income. These trends show that diversification alone is not a sufficient indicator of resilience. Without access to stable markets, WPs, and environmental governance, households often turn to unsustainable coping mechanisms, reinforcing their long-term vulnerability.

1.4 Forests as natural safety nets

Forests have long played a crucial role as informal safety nets for rural households, especially during periods of crisis. Wunder, Angelsen, and Belcher (2014) define forests as “natural safety nets,” emphasizing their function in providing subsistence goods such as fuelwood, wild foods, and medicinal plants when other income sources fail. These resources offer a low-entry, low-capital fallback that becomes particularly valuable to poor and vulnerable households excluded from formal financial or social protection systems. This role became particularly evident during the COVID-19 pandemic. Golar, Wahyuni, and Rahman (2020) observed a marked increase in forest product extraction in Indonesian forest-edge communities following widespread job losses and disruption of agricultural value chains. Households turned to the collection and sale of firewood, rattan, and wild fruits not only for subsistence but as an alternative income stream in the absence of wage labor. Wider regional trends reinforce this pattern. The UNEP–UNDP Asia-Pacific Forest Sector Survey Reports (2021, 2022) documented a notable increase in forest resource use across several countries during the pandemic. Declines in forest patrols and monitoring enabled a rise in informal and sometimes illegal extraction, particularly in dry forests and community-managed reserves. The reports warned that this spike in forest use, while understandable as a survival strategy, risks long-term ecological damage if not paired with supportive and regulated livelihood alternatives.

In the Sri Lankan context, empirical evidence from Perera, Weerakoon, and Dissanayake (2024) confirms that forest-edge households in the dry zone intensified their reliance on forests during the pandemic. Their study found that households affected by job loss, reduced remittances, or delays in *Samurdhi* social benefit transfers turned to the forest for fuelwood, yams, leafy vegetables, and income from informal timber extraction. The research also highlighted that this reliance was especially pronounced among large households, those with disabled members, and elderly-headed family's groups often structurally excluded from consistent state WP access. While forests thus offer a critical buffer during livelihood crises, they are not without trade-offs. Miller and Hajjar (2020) caution that forest-based coping strategies, while immediately beneficial, can have long-term ecological and economic costs. Overreliance on open-access or weakly regulated forest resources can lead to degradation, conflict over access, and even legal penalties, particularly where the customary use overlaps with protected areas. In Sri Lanka, such concerns are especially relevant given the fragmented forest governance structure and growing competition over land in rural districts (Suraweera et al., 2023).

1.5 Rural forest dependence and ecological trade-offs

Sri Lanka's dry-zone forests, which comprise nearly 70% of the country's forest cover, are ecologically vital, harboring endemic flora and fauna adapted to monsoonal variability (Gunatilleke et al., 2021; Ranawana et al., 2021). However, growing human reliance, especially during crises has intensified anthropogenic pressures on these landscapes. Forest-edge communities often depend on forest products such as fuelwood, poles, wild foods, and medicinal plants for subsistence or informal income. This dependence typically rises during times of economic or climatic instability (Wunder et al., 2014; Miller and Hajjar, 2020). Recent evidence shows that these coping mechanisms come at a cost. Suraweera et al. (2024) documented increasing degradation in Sri Lanka's dry-zone forests, driven by overharvesting and illegal timber extraction, especially during the COVID-19 pandemic and ensuing economic crisis. They report that prolonged drought, coupled with weakened enforcement, amplified both legal and illicit human activity in protected forest areas. Similarly, Wijesekera et al. (2024) identified smallholder-driven forest-to-agriculture conversion particularly under chena (slash-and-burn) farming as a key driver of deforestation in post-crisis periods.

Comparable trends are observed in other parts of South Asia. Qin et al. (2022) report that return migration and collapsing off-farm employment led to forest encroachment in Nepal and India during lockdowns. Saxena et al. (2021) further observed that economic distress coupled with policy gaps exacerbated forest dependence among tribal and low-income households in central India. In Sri Lanka, institutional weaknesses compound ecological stress. Perera and Gunatilleke (2022) critique the fragmented forest governance structure, with overlapping mandates across agencies and limited local participation. This incoherence reduces regulatory capacity, especially during systemic shocks. Although participatory forest management (PFM) has gained policy attention, implementation remains inconsistent, particularly in dry-zone districts. The ecological implications are far-reaching. Habitat degradation threatens species with narrow ecological ranges, disrupts ecosystem services, and undermines conservation goals (Ranawana et al., 2021). Thus, while forests serve as fallback systems for vulnerable households, unsustainable extraction under crisis conditions risks triggering long-term environmental decline. Integrated strategies that align rural livelihood security with biodiversity conservation are increasingly necessary.

1.6 Shifting roles of non-timber forest products (NTFPs) in rural livelihoods

Non-Timber Forest Products (NTFPs) play a vital role in sustaining rural livelihoods, particularly in forest-adjacent communities across the Global South. NTFPs include fuelwood, medicinal plants, wild fruits, resins, honey, and fibers, which may be used for subsistence, emergency support, or informal trade. According to global reviews, NTFPs account for between 10% and 60% of rural household income, depending on forest access, market proximity, and land tenure (Pandey et al., 2015; Mukul et al., 2015). Their role becomes especially pronounced during economic or climatic shocks when formal income streams decline. Empirical research in South Asia confirms the strategic value of NTFPs during periods of vulnerability. In a study of Bangladeshi forest-edge communities, Mukul et al. (2015) found that 19% of households depended on NTFPs as their primary or emergency income source, with fuelwood and medicinal plants being the most frequently used. Similarly, Pandey et al. (2015) documented NTFP contributions of up to 25% of total household income in parts of India and Nepal, with collection intensity peaking during lean agricultural seasons or job losses. The COVID-19 pandemic further underscored the importance of NTFPs as fallback income. A study by Aryal et al. (2022) in Nepal found that the proportion of households harvesting fuelwood increased from 23.2% to 25.6% during the pandemic period, reflecting both energy insecurity and heightened forest reliance. Other NTFPs such as medicinal herbs and wild edibles were also increasingly harvested, in part due to fears of supply chain disruptions and rising food prices.

In Sri Lanka, dry-zone communities have historically relied on NTFPs for both consumption and cash needs. During the economic crisis and COVID-19 lockdowns, field-based reports and localized surveys indicated a noticeable uptick in NTFP collection, particularly among households facing delays in payments from WPs or agricultural input shortages (Perera et al., 2024). Commonly collected items included *mee* (Madhuca longifolia) fruit, *kaluwara* (Diospyros ebenum) bark, wild leafy greens, and firewood for sale in local markets. These practices were more prevalent among female-headed households and those with elderly or disabled dependents groups with limited access to formal wage labor. While NTFPs offer a low-capital coping mechanism, concerns remain about sustainability and overharvesting, especially in unregulated forest zones. Without community management or replanting strategies, intensified collection can contribute to forest degradation, undermining both ecological and economic resilience in the long term (Shackleton et al., 2011).

1.7 Informal livelihood expansion and the fragility of social protection

During periods of economic collapse, such as the COVID-19 pandemic and the ensuing macroeconomic crisis in Sri Lanka, rural households often turned to ad-hoc and informal income sources to survive. These included casual labor, home-based production (e.g., food sales, crafts), small-scale vending, and forest-related income such as firewood collection and illegal logging. These strategies reflect a broader shift from structured livelihoods toward survivalist coping mechanisms, particularly where formal employment and agricultural income collapsed. Pamela, Rana, and Fleischman (2022), in a study of South Asian forest-edge communities, observed that households excluded from formal WPs such as *Samurdhi* often compensated by intensifying forest product collection and informal labor. Saxena et al. (2021) reported similar patterns in India, where return migrants unable to re-integrate into urban employment relied on forest-based and ad-hoc work. These responses were especially prevalent among economically marginalized groups, including female-headed households and those with elderly or disabled dependents. The substitution of forest resources for lost income points to a growing dependence on informal, unstable, and ecologically sensitive income strategies during systemic shocks.
This growing reliance on informal income sources is closely tied to the limitations of Sri Lanka's formal social protection systems, particularly the *Samurdhi* program. As the country's main anti-poverty initiative, *Samurdhi* has faced long-standing challenges with targeting accuracy, political capture, and administrative inefficiencies. Priyanath and Hathella (2022) found that the program's high transaction costs and patronage networks often undermine its effectiveness in delivering sustainable livelihood outcomes. According to a

2023 World Bank assessment, more than 50% of Sri Lanka's poorest households were excluded from SP, while a significant portion of beneficiaries were not poor reflecting issues of misallocation and favoritism. In contrast, more universal or categorical transfer programs, such as pensions, disability allowances, and elderly support schemes, demonstrated greater continuity during crisis periods. These programs were less subject to political discretion and maintained disbursement even during administrative disruptions. The launch of *Aswesuma* in 2022, a proxy-means-tested cash transfer system, has marked a partial improvement. As of mid-2023, it covered over 1.7 million households and aimed to rationalize social protection delivery (World Bank, 2023). Yet, Pamela et al. (2022) caution that even with improved targeting mechanisms, households dropped from or excluded from formal transfers tend to substitute with forest-based or informal income raising concerns about the ecological costs of WP exclusion and the fragility of rural safety nets in the absence of effective institutional protection.

While a growing body of literature explores livelihood diversification, forest-based coping strategies, and social protection mechanisms in rural contexts, several critical gaps remain particularly in relation to crisis-driven behaviors in South Asian forest-edge communities. Much of the empirical work on forest dependency under stress has been concentrated in sub-Saharan Africa and parts of Southeast Asia (e.g., Wunder et al., 2014; Golar et al., 2020; Miller & Hajjar, 2020), with comparatively limited attention to the South Asian dry-zone ecologies and the socioeconomic specificities of Sri Lanka. Moreover, existing studies tend to examine livelihood strategies or social protection in isolation, often neglecting the interlinkages between WP exclusion, informal income strategies, and forest reliance during systemic shocks such as the COVID-19 pandemic and economic collapse. Within the Sri Lankan context, research on forest-based livelihoods has largely focused on conservation, biodiversity, or community forestry initiatives (Gunatilleke et al., 2021; Perera & Gunatilleke, 2022) but seldom addresses the economic adaptations of vulnerable households during compounded crises. The recent expansion of WP reforms (e.g., *Aswesuma*) and growing forest pressure among *Samurdhi*-excluded populations remain understudied from an integrated socio-ecological perspective. There is limited understanding of how informal and ad-hoc income strategies including NTFP extraction interact with WP gaps, demographic vulnerabilities, and forest governance failures.

2. Methodology

2.1 Sample selection and survey

The Anuradhapura District, located in Sri Lanka's North Central Province, hosts a larger expanse of dry-zone forest in the country. According to Ranagalage (2020), the district recorded forest cover exceeding 240,000 hectares, ranging from 297,785 ha in 1992 to 242,763 ha in 2019, making it a critical ecological zone. Notably, Anuradhapura also experienced the highest cumulative forest loss in the dry zone, with over 55,000 hectares lost over three consecutive decades, underscoring the urgency of understanding how forest-adjacent communities navigate economic and ecological pressures. To capture the dynamics of forest-based livelihoods and vulnerability to covariate shocks, this study selected three Divisional Secretariat Divisions (DS Divisions) within the district: *Medawachchiya, Nachchadoowa, and Rambewa* (figure 1). These divisions were chosen for their proximity to forested areas, ecological representativeness, and exposure to both environmental stress and socio-economic marginalization. Each area reflects varying degrees of dependence on forest resources and agriculture particularly paddy farming providing a heterogeneous yet comparable setting for analyzing household coping strategies.

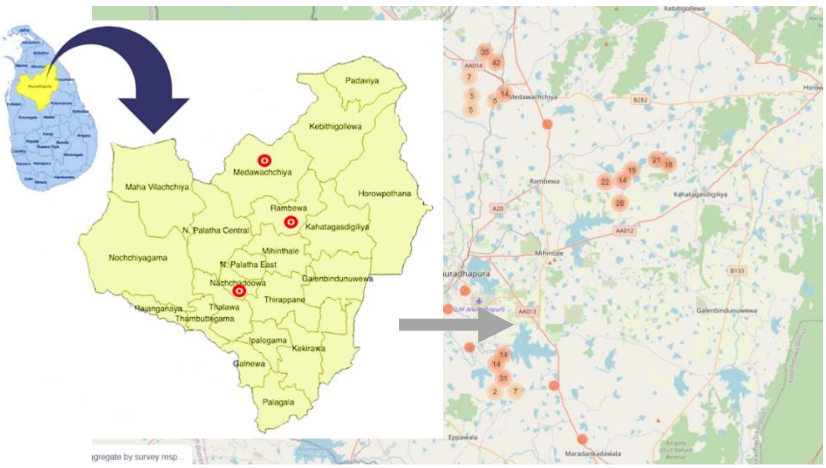

Figure 1. Approximate spatial extent of *Medawachchiya, Rambewa*, and *Nachchadoowa* DS divisions in Anuradhapura, based on GPS household points from KoboToolbox survey data.

These divisions also reflect broader patterns found across Sri Lanka's dry-zone agricultural regions, where livelihoods are closely tied to seasonal rainfall, land access, and state support systems. The overlap between ecological vulnerability and agricultural dependence makes this region particularly well-suited to studying the interactions between forest reliance, income shocks, and social protection exclusion. A stratified random sampling method was employed to ensure representation across key household categories, including gender of household head, landholding size, and proximity to forest boundaries. A total of 370 households were surveyed across the three DS divisions using a semi-structured questionnaire on KoboToolbox survey application. Wherever possible, the household head was interviewed. In their absence, typically due to external employment or migration the spouse or next most informed adult respondent was selected, following a predefined respondent hierarchy to maintain consistency. This sampling strategy offers both geographic relevance and demographic diversity, facilitating a nuanced understanding of how different household types respond to systemic livelihood shocks in forest-adjacent dry-zone regions.

2.2 Analytical methods

The analysis combined descriptive statistics, inferential testing, and scenario-based modeling to examine household-level changes and forest dependence. McNemar's and Bowker's tests were employed to assess statistically significant changes in categorical variables before and after the crisis period. To complement the statistical analysis, a scenario-based simulation was conducted to estimate the conditional probabilities of forest use under various household configurations (significancy proved variables from above two tests). The simulation systematically evaluated all possible combinations of key categorical variables WP access, household income level, household size, and farmland size excluding only empty sets with no observed data. WP access was defined inclusively to capture households receiving income from pension and senior citizen allowances, disability benefits, or the *Samurdhi* program. Each scenario's probability of forest use was calculated empirically, providing a grounded understanding of how structural and demographic conditions shape forest dependency. McNemar's and Bowker's tests and probability models were implemented in MATLAB version R2024b using paired categorical data functions, while the scenario-based probability model was operationalized through grouped aggregation to calculate conditional proportions of forest use across household profiles.

The simulation model was grounded in an empirical, non-parametric approach. For each unique combination of the categorical variables (a "scenario"), the "probability of forest use" was calculated as the observed proportion of households within that specific profile that reported forest reliance. This is expressed as conditional probability.

$$\frac{\mathrm{P\ (Forest\ use)} = \ \#\{\mathrm{ForestUse} = 1\ \cap\ (\mathrm{W} = \mathrm{w}, \mathrm{I} = \mathrm{i}, \mathrm{S} = \mathrm{s}, \mathrm{L} = \mathrm{l})\}}{\#\{(W = w, I = i, S = s, L = l)\}}$$

Where,
W = WP access (yes/no)
I = income level (low, medium, high)
S = household size (small, medium, large)
L = farmland size (small, medium, large)
 # {ForestUse=1 ∩ (W=w, I=i, S=s, L=l) =
Number of households using the forest in scenario (w, I, s, l)
 # {(W=w, I=i,S=s, L=l) = Total households in scenario (w, i, s, l)

= count of households/cardinality
∩ = AND (intersection of conditions)

Importantly, the variables incorporated into the simulation were not arbitrarily chosen. Instead, the model was restricted to those household characteristics that showed statistically significant shifts in the McNemar's and Bowker's tests. This ensured that the predictors, WP access, household income, household size, and farmland size were empirically validated as relevant to crisis-driven livelihood changes before being included in the probability estimation. While several other variables also emerged as statistically significant in the tests, only this subset was retained for the simulation. This decision was guided by three considerations. First, these variables capture the most structurally consequential dimensions of household livelihood strategies, directly tied to social welfare policy, land access, and demographic pressure where all factors strongly linked to forest-use behavior. Second, including a larger set of predictors would have created an excessive number of scenario combinations, many with very few or no households, reducing the stability and interpretability of the probability estimates. Third, variables such as education or marital status, while statistically significant, offered limited policy leverage or introduced higher within-category variability, making them less suitable for scenario-based policy analysis. This approach was selected over parametric models such as logistic regression for its intuitive interpretability and its ability to capture complex interactions among categorical predictors without imposing linearity or additivity assumptions. The use of categorical discretization further enhances interpretability by aligning results with policy-relevant thresholds (e.g., low vs. medium income, small vs. large households). Including unobserved factors, social networks, or proximity to forests were not explicitly included, the model captures the most structurally significant drivers of household reliance in this case. However, future work could further enhance this framework by integrating additional continuous variables and behavioral factors, thereby reducing discretization bias and more fully reflecting the complex decision-making processes of rural households.

3. Results

The empirical analysis reveals notable shifts in household income composition, WP access, and demographic characteristics before and after the onset of the COVID-19 pandemic and the economic crisis in Sri Lanka's dry zone. Utilizing McNemar's and Bowker's tests, the study identifies statistically significant changes in several key variables, illuminating how forest-adjacent households adapted to systemic shocks.

Table 1. McNemar's and Bowker's statistical test results

Variable	Chi-Sq statistic	p-value
McNemar's Test for paired binary (yes/no) categorical variables		
Income from agriculture	0.1290	0.7194
Income from salary	8.2581	0.0041
Income from self-employment	1.8846	0.1698
Income from ad-hoc sources	11.2941	0.0008
• Income from pension and senior citizen allowance	11.1304	0.0008
• Allowances for disability or health problems	31.2432	0.0000
• *Samurdhi* benefit	9.6000	0.0019
• Income from remittances	0.2500	0.6171
Steady household income	0.7500	0.3865
Paddy farming participation	0.9615	0.3268
Cereal farming participation	2.2655	0.1323
Livestock ownership	0.8780	0.3487
Other farming activities	0.0000	1.0000
Bowker's Test for non-binary (≥3) categorical variables		
Marital status of household head	26.2000	0.0002
Education level of household head	270.7460	0.0000
Household income	162.3333	0.0006
Household head's income	281.0000	0.0000
Number of working household members	4.3333	0.7407
Household size	281.7094	0.0000
Agricultural land size	247.5739	0.0000
Seasonal agricultural income	230.5000	0.1582
Off-farm income	129.0772	0.0054

Statistically significant differences between pre- and post-crisis periods. Significance is determined at the 5% level ($p < 0.05$), with lower p-values indicating stronger evidence of change. McNemar's Test assesses paired binary categorical changes (e.g., yes/no responses), while Bowker's Test evaluates changes in non-binary categorical variables with three or more categories.

Table 2. Direction of change (Pre to Post) of statistically significant variables

Variable	Mean Δ	↑ %	↓ %	↔ %
Marital status of household head	0.190	11.2%	2.0%	86.8%
Education level of household head	-0.007	4.7%	7.1%	88.1%
Income from salary	0.058	8.1%	2.4%	89.5%
Income from ad-hoc sources	0.085	12.9%	4.4%	82.7%
Income from pension and senior citizen allowance	0.058	6.8%	1.0%	92.2%
Allowances for disability or health problems	-0.119	0.3%	12.2%	87.5%
Samurdhi benefit	0.044	4.7%	0.3%	94.9%
Household income	-5650.756	14.9%	82.4%	2.7%
Household head's income	-613.559	2.0%	4.4%	93.6%
Household size	-0.061	1.0%	3.1%	95.9%
Agricultural land size	0.042	44.7%	40.3%	14.9%
Off-farm income	-620.847	41.0%	33.9%	25.1%

↑ *indicates the % of households that experienced an increase in the given variable from pre- to post-crisis*

↓ *indicates the % of households that experienced a decrease in the given variable from pre- to post-crisis*

↔ *represents the % of households with no change in that variable from pre- to post-crisis*

3.1 Shifts in income sources

Income from salaried employment declined significantly during the crisis period ($\chi^2 = 8.26$, $p = 0.0041$), reflecting widespread job losses and labor market contraction. In contrast, ad-hoc income sources saw a statistically significant increase ($\chi^2 = 11.29$, $p = 0.0008$), with 12.9% of households reporting new reliance on these activities. These findings are consistent with broader regional trends that point to an expansion of informal economies during periods of state WPs retrenchment. When considering the ad hoc gains, income from pensions and disability transfers both displayed significant shifts, although in divergent directions. Pension and senior citizen allowance related income rose moderately ($\chi^2 = 11.13$, $p = 0.0008$), suggesting greater reliance on WP less susceptible to administrative disruption. Conversely, disability-related allowance decreased markedly ($\chi^2 = 31.24$, $p < 0.0001$), with 12.2% of households reporting loss of access to health-related WPs during crisis. This decline may reflect bureaucratic breakdowns or re-targeting processes that marginalized vulnerable recipients. Sri Lanka's primary poverty-targeted safety net, the *Samurdhi* program, also exhibited significant change ($\chi^2 = 9.60$, p = 0.0019), showing a modest net expansion in coverage, with 4.7% of households newly included and 0.3% losing access. This paradoxically modest expansion aligns with qualitative accounts of inconsistent delivery and politicized targeting during crisis periods. Both household income and household head's incomes registered significant reductions ($\chi^2 = 162.33$, $p = 0.0006$; $\chi^2 = 281.00$, $p < 0.0001$ respectively), with 82.4% of households reporting a decline in overall income. This trend underscores the magnitude of livelihood disruptions and the fragility of income-generating mechanisms during prolonged crises.

3.2 Household livelihood adjustments

While income from paddy and cereal farming, as well as livestock ownership, did not undergo statistically significant shifts, the increase in ad-hoc and forest-related income sources underscores a pattern of distress-driven diversification. Forest dependence became more visible as a coping strategy amid constrained formal employment and delayed protection from WPs. Although agricultural land size exhibited significant variability (Bowker's $\chi^2 = 247.57$, $p < 0.0001$), the near-even split between households gaining (44.7%) and losing land (40.3%) points to dynamic land transactions, potentially driven by distress sales or short-term leasing under financial duress and expanding lands by encroaching forest patches. Off-farm income experienced a statistically significant decline (Bowker's $\chi^2 = 129.08$, $p = 0.0054$), with 41.0% of households reporting reduced earnings from this source. This reduction further corroborates the collapse of supplementary income avenues, especially for rural household's dependent on mobility-sensitive livelihoods.

3.3 Shifts in demographic dimensions and welfare programs

Significant transitions were also observed in household composition and socio-demographic indicators. The marital status of household heads shifted (Bowker's $\chi^2 = 26.20$, $p = 0.0002$), potentially reflecting migration, widowhood, or separations exacerbated by economic strain. Educational attainment showed significant but directionally mixed changes (Bowker's $\chi^2 = 270.75$, $p < 0.0001$), which may indicate disruptions to intergenerational educational continuity, particularly in remote areas. Household size and the number of working members both remained statistically stable, yet the marginal declines observed (↓3.1% in household size; ↓4.4% in working members) could imply the out-migration of working-age adults in search of income, consistent with return migration and labor mobility constraints noted elsewhere in the region.

3.4 Forest use probabilities across welfare program accessibilities and livelihood scenarios

The scenario-based analysis tested all possible combinations of key livelihood variables access to WPs, income level, household size, and farmland size excluding only empty sets where no households in the dataset matched the specified conditions. The following discretization thresholds were used to classify household characteristics into categorical levels for scenario analysis:

Table 3. Categorical scale definitions

Variable	Category	Definition
Household income (overall)	Low	0–50,000 LKR per month
	Medium	50,001–150,000 LKR per month
	High	Above 150,000 LKR per month
Household size (number of family members)	Small	1–2 members
	Medium	3–4 members
	Large	5 or more members
Farmland size	Small	0–1 acre
	Medium	1.1–3 acres
	Large	More than 3 acres

The resulting scenarios reflect empirically grounded probabilities of forest reliance under varied structural and demographic contexts. In the table 4, the column labelled “Access to WP” encompasses households that received at least one of the following: Income from pension and senior citizen allowance; Allowances for disability or health problems; *Samurdhi* benefit.

The disaggregated scenario results reveal that households without access to WPs exhibit the highest variability in forest use, driven primarily by income poverty and larger household sizes. Among low-income households with no WP support, forest reliance ranged from 0.125 (small households with small land) to 0.620 (large households with medium-sized farmland). This suggests that the absence of state transfers amplifies reliance on forest-based coping strategies, especially when labor availability (large household size) and land proximity enable resource extraction. By contrast, households with *Samurdhi* or other WP support demonstrated more stable and moderate forest use probabilities. For low-income groups, small and medium households receiving benefits from WPs exhibited consistent forest use around 0.333, whereas large households maintained a higher probability (0.500), regardless of farmland size. This indicates that WP support helps buffer forest reliance, particularly for smaller, labor-constrained households, but is less effective in reducing dependence among structurally vulnerable groups with greater subsistence needs. Notably, households with high income, whether or not they received support from any WP, reported zero forest use reaffirming the inverse relationship between formal income security and environmental fallback strategies. Medium-income households showed mixed patterns: forest use was generally low among small households, but persisted among large households with land, especially in the absence of support from a WP. Therefore, this scenario framework confirms that forest reliance emerges not only from income shortfall but from an interplay of demographic pressure, land access, and limited institutional support. While WPs contribute to reducing forest dependency, their reach and adequacy remain insufficient for high-need households. These findings underscore the importance of targeted, multidimensional interventions that consider household structure, landholding, and existing livelihood capacity particularly in forest-adjacent rural regions.

Table 4. Simulation results for forest use probabilities across WP accessibilities and livelihood scenarios

Access to WP	Household income level	Household size	Farmland size	P (Forest use)
No	Low	Small	Small	0.125
No	Low	Small	Medium	0.333
No	Low	Small	Large	0.500
No	Low	Medium	Small	0.375
No	Low	Medium	Medium	0.589
No	Low	Medium	Large	0.143
No	Low	Large	Small	0.286
No	Low	Large	Medium	0.620
No	Low	Large	Large	0.560
No	Medium	Small	Small	0.000
No	Medium	Small	Medium	0.000
No	Medium	Medium	Small	0.200
No	Medium	Medium	Medium	0.333
No	Medium	Medium	Large	0.000
No	Medium	Large	Small	0.353
No	Medium	Large	Medium	0.489
No	Medium	Large	Large	0.485
No	High	Medium	Medium	0.000
No	High	Large	Medium	0.000
Yes	Low	Small	Small	0.333
Yes	Low	Small	Medium	0.333
Yes	Low	Medium	Medium	0.333
Yes	Low	Large	Small	0.500
Yes	Low	Large	Medium	0.500
Yes	Low	Large	Large	0.500
Yes	Medium	Medium	Large	0.500

P – Probability

4. Discussion

This study examined how households in Sri Lanka's dry-zone forest-adjacent communities adapted their livelihood strategies during the dual crises of the COVID-19 pandemic and economic collapse, with a focus on shifts in income sources, demographic changes, and patterns of forest reliance. The results contribute to a growing body of research on crisis-driven environmental dependence (Angelsen & Dokken, 2015; Miller & Hajjar, 2020; Pamela et al., 2022), while offering novel insight into how formal access to WPs or its absence shapes household coping strategies at the forest margin. The empirical findings revealed statistically significant transitions in multiple livelihood components. Income from formal wage labor declined sharply, while ad-hoc and informal income sources including forest-based activities increased substantially. This aligns with regional evidence from Indonesia and India, where informal forest use surged during lockdowns (Golar et al., 2020; Saxena et al., 2021). Meanwhile, changes in access to WPs were uneven while more formal transfers such as pensions and adult allowances increased marginally, disability and health related allowances declined, and *Samurdhi* coverage showed only a modest and inconsistent rise. This suggests that Sri Lanka's social protection system, particularly its flagship *Samurdhi* program, struggled to provide timely and targeted support during a moment of acute rural vulnerability, consistent with critiques by Priyanath and Hathella (2022) and the World Bank (2023).

Importantly, the scenario-based analysis expanded on these statistical findings by simulating forest use probabilities across a comprehensive set of livelihood profiles. The scenarios confirmed that forest reliance is highest not only among income-poor households, but particularly among large households with limited or no support from WPs and access to medium-to-large plots of farmland. These combinations reflect a structural vulnerability in which both the need for subsistence income and the capacity to extract forest resources co-exist. This supports Wunder et al.'s (2014) conceptualization of forests as "natural safety nets" and echoes findings by Der Tambile et al. (2024) that highlight how crisis-induced diversification often reflects distress rather than resilience. Conversely, forest use was notably lower or entirely absent among high-income households, and more stable (though not eliminated) among those receiving transfers from WPs. This reinforces Ellis's (2000) observation that secure and diverse livelihood portfolios can shield households from environmentally extractive coping. Yet, the persistence of moderate forest use among social benefit-recipient households especially large ones indicates that benefits from WPs alone may be insufficient when demographic and economic stressors compound. Pamela et al. (2022) similarly note that even formally supported households may revert to informal strategies when transfers are inadequate or irregular.

The findings also speak to the ecological implications of systemic gaps in WPs. As Suraweera et al. (2024) and Wijesekera et al. (2024) have documented, increased forest pressure during the pandemic exacerbated forest degradation in dry-zone districts. The scenario results here suggest that this pressure was not uniformly distributed but rather concentrated among structurally disadvantaged groups for whom forests served as a fallback rather than a strategic choice. Without stronger integration between social protection and conservation policy, such coping strategies risk undermining long-term ecological sustainability. Overall, this study underscores that forest reliance is a multidimensional phenomenon, driven by the interaction of income shortfall, WP exclusion, household composition, and land access. The buffering role of WPs like pensions, senior citizen allowances and *Samurdhi* is evident, but partial. More targeted, inclusive, and scalable support is needed to prevent vulnerable households particularly large, labor-abundant, and land-accessing from falling into cycles of environmental dependency during future shocks. As Sri Lanka moves toward WP reform under *Aswesuma*, the findings here offer timely evidence on where and how social protection mechanisms must evolve to enhance both livelihood resilience and forest conservation outcomes.

5. Conclusion

Forest reliance in Sri Lanka's dry-zone communities intensified under the combined stress of pandemic-driven economic disruption and limited coverage of WPs. The highest probabilities of forest use were observed among large, low-income households lacking access to formal support, particularly where land facilitated extraction. In contrast, recipients of WPs, especially smaller households showed more moderate and stable patterns of forest dependence. These findings underscore that forest reliance emerges from the intersection of economic vulnerability, demographic pressure, and institutional exclusion. While programs like Samurdhi provide some relief, they remain insufficient for structurally at-risk groups. Addressing forest pressure in such contexts requires integrated policies that align social protection with ecological sustainability. Prioritizing support for high-need household profiles is essential to mitigate both livelihood insecurity and environmental degradation in forest-adjacent regions.

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TECHNICAL EFFICIENCY OF DAIRY FARMING: EVIDENCE FROM KURUNEGALA DISTRICT OF SRI LANKA

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Abstract

Dairy farming is one of the industries that greatly impacts income and food security in rural communities in Sri Lanka. Nevertheless, 60% of dairy consumption still depends on imports worth 222 million USD in 2022 regardless of debt-ridden economy. This study analyses the technical efficiency of small-scale dairy farmers in the Kurunegala district. The study employed 100 small-scale dairy farmers representing different veterinary divisions selected using a multi-stage random sampling technique. The results indicated that the mean milk production is 12.25 liters per day per farmer. And the results of the Stochastic Frontier revealed that production can be increased by 32% without any additional input. When the inefficiency model is considered, the gender, education, household size, breed type, and experience of the farmer have a positive effect on the efficiency. The age of the farmer and the grazing time have a negative impact on efficiency. In conclusion, dairy farming in the district is 68% efficient and has the potential to be further developed. To enhance education, targeted training programs can be implemented, focusing on practical skills such as animal health management, optimal feeding practices, and modern milking techniques. These programs should be tailored to address local challenges and delivered through accessible formats like on-farm workshops or mobile training units. Extension services can further support farmers by offering regular guidance on best practices, troubleshooting issues, and introducing technologies like automated milking systems or feed formulation tools and thereby enhancing the efficiency of dairy farming in the study area.

***Keywords**: Dairy production; Stochastic Frontier Analysis; Technical efficiency; Kurunegala; Milk production.*

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1. Introduction

The dairy industry has been a key part of Sri Lanka's economy for centuries and today, the dairy sector continues to be essential for food security, job creation, and income generation. The livestock industry contributes one percent to the national Gross Domestic Product (GDP), where twenty one percent of it is from the dairy sector in the country according to the national GDP. Despite the increase in cattle numbers, the annual cow milk yield in 2022 decreased by 1.4 percent compared to the previous year, possibly due to factors such as climatic variations, availability of fodder, and animal health issues (Department of Census and Statistics, 2024).

During 2022, the entire dairy value chain was severely impacted by the scarcity and high cost of animal feeds, unavailability of required chemical fertilisers for pasture and fodder cultivation, and difficulties in storage and transportation facilities caused by the foreign exchange liquidity crisis (Annual report 2022, Central Bank of Sri Lanka). Subsequently, total national milk production declined to 506 million metric tons in 2022 while the cost of production of milk increased notably in the same year and milk consumption in the country declined (DCS, 2023). However, the average farm gate price of a litre of cow milk increased by 17.3 percent to Rs. 115.00 in 2022 (DCS, 2023). Under these circumstances, researchers have suggested that improvement in efficiency is one of the key factors for the survival of dairy sector.

The Northwestern province is the second-largest cow milk producer in Sri Lanka, following the Central province. In 2022, it produced approximately 54.34 million litres of cow milk, accounting for seventeen percent of the country’s total milk production. The province has a cattle population of 183,384, contributing eleven percent of the total cattle population in Sri Lanka, placing it fourth largest area by cattle population in the country. On the other hand, the Northwestern province also has sixty milk chilling centres, second only to the North Central province with sixty-five centres. Within the Northwestern province, the Kurunegala district is particularly noteworthy, housing 125,584 cattle, which is sixty eight percent of the provincial cattle population and eight percent of the national total. The district contributes seventy seven percent of the provincial production and thirteen percent of the national total (Department of Animal Production and Health, 2023). The average daily milk production per cow in Kurunegala is 4.6 litres, a relatively high figure for its agroecological zone. The district also possesses fourty six milk chilling centres with a total capacity of 207,750 litres in 2021 (DAPH, 2023).

Existing literature covers various aspects of the dairy industry, including marketing systems (Gunarathne et al., 2015), sustainable industry pathways (Vidanarachchi et al., 2019), distribution challenges during COVID-19 (Jayatilake et al.,2021), and trend analysis (Damunupola et al., 2022). However, according to Andrew et al, (2017), there is a significant difference between targeted and actual milk production in the area. Therefore, it is evident that there is a notable need for detailed information on productivity and technical efficiency in the Kurunegala district related to the dairy industry. This major milk-producing region contributes ten percent of Sri Lanka's total milk production. This study addresses this gap by focusing on the Kurunegala district's dairy sector, aiming to provide insights for improving productivity and efficiency.

Technical efficiency is crucial in the context of limited agricultural resources, as optimizing input use can increase farmers' incomes and reduce resource consumption. There were different models used to estimate the technical efficiency and among them some researchers have used non-parametric methods such as data envelopment analysis (Wijesundara and Prabodanie, 2022; Hemapala et al., 2023; Herath and Thayaparan, 2024) or an econometric approach such as Stochastic Frontier models. They have either used production functions such as Cobb-Douglas (Dharmadasa and Wijethilaka, 2014; Priyanath et al., 2018; Perera and Dishanka, 2024), cost function (Baten and Begum, 2014; Biamet al., 2016) or profit (Baten & Begum, 2014; Ume et al., 2021) function in the stochastic frontier analysis. These two methodologies have also been used to analyze the potential sources of inefficiencies (e.g., Lawson et al.,2004; Tauer and Mishra, 2006; Chidmi and Murova, 2009). However, Kumbhakar and Lovell (2000), argue that a stochastic frontier model seems to be the most appropriate approach in studies related to the agricultural sector because of its ability to deal with stochastic noise, accommodate traditional hypothesis testing, and allow for single-step estimation of the inefficiency effects.

1.1 Efficiency Analysis

Efficiency and productivity analyses are important tools for managers to measure how effectively inputs are used to achieve maximum output in production processes (Golany and Roll, 1993). Improving agricultural productivity is crucial for sustainable economic development, as emphasized by O'Donnell (2010). Increased productivity in agriculture enables labour and capital to be redirected to non-agricultural sectors, while resources such as land and water can be repurposed for environmental benefits. The calculation of efficiency measures has its origins in the works of Debreu (1951) and Farrell (1957), with Farrell (1957) proposing that overall efficiency (OE) is the product of allocative efficiency (AE) and technical efficiency (TE).

$$OE = AE * TE$$

Mitsopoulos et al., (2021) define technical efficiency in dairy farms as the degree to which actual production differs from maximum potential production, which reflects the managerial and administrative capabilities of the farm. Estimating technical efficiency involves evaluating how well the farm uses its resources and operates within its potential limits. Technical efficiency, scale

efficiency (SE), and allocative efficiency (AE) are important components of this measurement. TE measures the farm's capacity to maximize output using its resources and chosen production technology. Scale efficiency assesses whether the farm operates at its most efficient size, where the average product is maximized based on existing technology, indicating potential inefficiencies if the farm operates below or beyond this optimal scale.
AE evaluates a farm's ability to optimally allocate its inputs based on market prices and manufacturing technology, ensuring resource use is efficient given market conditions (Mitsopoulos et al.,2021). Efficiency on a farm can be impacted by using too much or too little inputs, which can affect overall farm performance. By looking at TE, SE, and AE, researchers can have a better understanding of the farm's performance. This can help identify areas for improvements in resource use, technology application, scale optimization, and input allocation. Breaking down technical efficiency into these elements allows for targeted interventions and policy recommendations to enhance farm performance and productivity. Farrell (1957) and Mitsopoulos et al., (2021) discuss different methods for estimating efficiency, including Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). The SFA approach was introduced by Aigner et al., (1977), and DEA was established by Charnes et al., (1978). These methods have been widely used by economists to measure technical efficiency in various production processes within the agricultural study.

1.3 Data Envelopment Analysis

DEA is a method developed by Charnes et al., (1978), to assess the efficiency of entities that use resources to generate outputs. Initially created for evaluating performance in non-profit organizations, DEA is a fractional programming model that can take into account multiple inputs and outputs. One of its main benefits is that it does not require the specific functional form of the production function, thus avoiding assumptions about the mathematical relationship between inputs and outputs. DEA can manage multiple inputs and outputs in different units, enabling a comprehensive evaluation of efficiency. This adaptability makes DEA a valuable tool for measuring and comparing technical efficiency across different sectors and industries (Theodoridis and Psychoudakis, 2008).

There are several analysis models introduced by different authors suitable for different specific objectives. Charnes, Cooper, Rhodes (CCR) version and Banker, Charnes, and Cooper (BCC) version are such analysis models introduced by these authors. The CCR version is designed specifically to evaluate and compare a decision-making unit's (DMU) effectiveness, represented as DMU in this context. Whereas the BCC version measures the variable return to scale efficiencies.

1.4 Stochastic Frontier Analysis

Parametric Stochastic Frontier Analysis considers deviations from the best practice as a combination of random error and inefficiency, assuming a specific structure for the best-practice frontier. It offers the advantage of conducting formal statistical tests and constructing confidence intervals, providing a rigorous framework for hypothesis testing. However, SFA requires specifying the functional form of the production function and making explicit assumptions about the distribution of the technical inefficiency term (Theodoridis and Psychoudakis, 2008). SFA is particularly popular in agricultural production for its ability to distinguish inefficiency from measurement error and random shocks, making it suitable for industries like dairy production where unobservable factors such as weather and genetics affect productivity.

In the dairy industry, SFA has provided insights into sources of technical inefficiency. According to Farrell (1957) and Chen et al., (2009) TE is the capacity of a decision-making unit to produce the maximum output from a given set of inputs, with technical inefficiency defined as any deviation from this maximum (Coelli et al.,2005). Both parametric and non-parametric methods can measure TE (Simar and Wilson, 2015). SFA has also been used to estimate the impact of technology adoption on TE in the dairy industry. For example, in the Indian dairy industry, Girma, (2019) used SFA to estimate technical efficiency and found that adopting improved cattle breeds and better feed management significantly improved technical efficiency.

The parametric Stochastic Frontier Analysis has an advantage over nonparametric approaches because it considers a composite error term. This term accounts for both statistical noise and technical inefficiency effects. Based on Tenaye 's explanation in 2020, SFA is widely used to measure agricultural efficiency in developing countries like Ethiopia by using stochastic production function models in empirical applications. This is particularly relevant for small-scale production units in these areas, which often rely on family labour, have minimal record-keeping, and deal with data prone to measurement errors. Therefore, the SFA method is better suited for estimating household-level efficiency in agricultural production under these conditions. The use of SFA has led to several interesting findings regarding the sources of technical inefficiency in milk production.

2. Methodology

2.1 Sample Size and Data

The study was conducted in the densely populated Kurunegala District, Sri Lanka, where agriculture, specifically dairy farming, is a vital part of the local economy, providing income and sustenance for rural households. More than ninety percent of the population resides in rural areas, indicating the agricultural dominance of the district (Department of Census and Statistics, 2023).

According to the DAPH (2023), there are 7,819 small-scale dairy farmers (with less than ten animals) in the Kurunegala District. These farmers are divided into two main veterinary regions based on location. Kurunegala, Zone I includes 3,086 small-scale dairy farmers, and Kurunegala Zone II includes 4,733 small-scale dairy farmers. In total, 100 farmers were selected thirty nine percent from Zone I and sixty one percent from Zone II considering the demographic distribution of the farmers. Accordingly, a proportionate number of dairy farmers were selected from each veterinary surgeon division as shown in the Table 1.

Table 1**.** Sample selection.

Vet. Regions	Vet. Divisions	No. of dairy farmers	Sample size
Zone I	Bingiriya	450	16
	Ibbagamuwa	425	15
	Pannala	248	9
Zone II	Panduwasnuwara	789	16
	Galgamuwa	585	12
	Polpithigama	544	11
	Maho	518	11
	Rasnayakapura	516	11

Source: Author's calculation

The multistage random sampling technique was employed when selecting the sample for the study. The primary data was collected using a pre-tested questionnaire through face-to-face interviews. The reference period of the present study was from March to July 2023. The STATA 15 version was utilised as the statistical software in analysing the collected data.

2.2 Cobb-Douglas Stochastic Frontier Model

The Cobb-Douglas production functional form is commonly utilized in economics. Economic theory suggests that a company's output, inputs, and profit are influenced by its production function, profit definition, and profit maximization requirements (Zellner et al.,1966). This function is applied to establish the connection between input and output and to evaluate the impact of various inputs on milk production (Hitihamu et al.,2021). When expressed in logarithmic form, it becomes linear and is suitable for computer analysis. As shown by Lutonja (2023), the estimate of this model is based on the assumption of maximum likelihood estimation (MLE).

2.3 Trans-log Stochastic Frontier Model

This study used Trans-log (Transcendental Logarithmic) Stochastic Frontier Model in econometrics to analyse production efficiency. It provides a flexible functional form that can adapt varying returns to scale and interactions among inputs, making it a powerful tool for understanding production processes. There have been many empirical studies applying the Trans-log stochastic frontier model methodology for estimating production efficiency to agricultural research over the years. For example, Kodagoda and Dharmadasa (2020), and Wai and Hong, (2021) employed the trans-log SFA for estimating TE, AE, and economic efficiency (EE) of rice production.

$$\ln Y_i = \beta_0 + \sum_{j=1}^{6} \beta_i \ln X_{ji} + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln X_i X_j + v_i - u_i \text{..........Eq. 01}$$

Where (ln) represents the natural logarithm, (Y_i) represents the quantity output, (X_i), and represents production inputs such as land, capital, labour etc. (β_i) defines the input coefficient for the resources used in production while (u_i) and (v_i) are random variables assumed to be independently distributed due to the uncontrollable factors for the farmer. (β) is a vector of unknown parameters. An alternative representation of stochastic production frontiers of producers, cost function, can be formulated as follows;

$$\ln C_i = \beta_0 + \beta_y \ln Y_i + \sum_{i=1}^{n} \beta_i \ln P_j + \frac{1}{2} \beta_{yy} [lnY_i]^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} \ln P_i \, ln \, P_j + \sum_i \delta_{iy} \ln P_i \ln Y_i + v_i - u_i \text{................Eq. 02}$$

Assuming that the cost function is linearly homogeneous in input prices, the symmetric restrictions that $(\beta_{ij} = \beta_{kj})$ must satisfy the following additional parameter restrictions such that;

$$\sum_i \beta_i = 1, \ \sum_i r_{ij} = 0, \ \sum_k \delta_{ij} = 0 \text{.......................................Eq. 03}$$

Hence, the most straightforward approach to addressing such constraints on the parameters of the cost function involves normalizing the total cost and other input prices using a single input price. According to Wai and Hong (2021), there is no economic or statistical difference in which input price is utilized to standardize the equation. Consequently, assuming a linear homogenous set of input prices, equation 04 is derived as a normalized log-linear trans-log cost functional form:

$$ln\left[\frac{C_i}{P_4}\right] = \beta_0 + \beta_y \ln Y_i + \sum_{i=1}^{n} \beta_i \, ln\left[\frac{P_i}{P_4}\right] + \frac{1}{2}\beta_{yy}[\ln Y_i]^2 + \frac{1}{2}\sum_{i=1}^{n} \alpha_{ij} \, ln\left[\frac{P_i}{P_4}\right] \cdot ln\left[\frac{P_i}{P_4}\right] + \sum_i \delta_{iy} \ln\left[\frac{P_i}{P_4}\right] \cdot \ln Y_i \text{..........................Eq. 04}$$

In equation (04), (ln) represents the natural logarithm, (C_i) represents the total input cost, (P_{ij}) is the input price and (Y_i) is the output adjusted for statistical noise. The inefficiency model is estimated from the equation shown below;

$$\mu_i = \delta_0 + \sum_{n=1}^{9} \delta_n \, Z_{ni} \text{ ....Eq. 05}$$

Where, (Z_i) represents farm-specific variables that may have an impact on the inefficiency and (δ_i) is an unknown parameter to be estimated. Several previous studies have concentrated on assessing the productivity and technical efficiency of dairy farms in Sri Lanka using advanced methodologies. For example, Thiwyadharsan et al., (2013), utilized a stochastic frontier approach to examine cattle farming in the Moneragala veterinary region. Their research incorporated variables such as farmer gender, age, innovativeness, education level, income, extension services, and experience to evaluate technical efficiency. Similarly, Basnayake and Gunaratne (2002), employed a stochastic frontier analysis alongside the Cobb-Douglas production function to investigate technical efficiency in tea smallholdings within the mid-country wet zone, with occupation being a key variable. Additionally, Bandara and Weligamage (2018) studied dairy production in the Eastern dry zone, focusing on farmer organization membership, herd size, and the use of artificial insemination as determinants of technical efficiency. These studies collectively contribute to understanding the factors that influence productivity in Sri Lanka's agricultural sectors and provide insights into optimizing dairy farming practices.

2.4 The Analytical Framework

2.4.1 The Econometric model of Stochastic Production Frontier

The Stochastic Frontier Normal/ Half-Normal Model analysis was used to identify determinants of technical inefficiency, since the technical inefficiency scores (index) range between zero and one, representing the upper and lower limits. It captures factors that lead to deviations from the optimal production level. Technical inefficiency scores obtained from SFA model above were regressed against selected input and milk producer characteristics variables to establish their influence on technical inefficiency. The Cobb-Douglas Stochastic Production function is defined in logarithmic form as follows;

$$\boldsymbol{Ln\ Y_i = \beta_0 + \beta_1 LnX_{i1} + \beta_2 LnX_{i2} + + \beta_3 LnX_{i3} + \beta_4 LnX_{i4} + \nu_i - u_i} \text{..........................Eq 06}$$

$\boldsymbol{Y_i}$ = Milk production of each farm (Liters/Day)
$\boldsymbol{\beta}_n$ = Partial elasticities of each independent variable

$\boldsymbol{X_{i1}}$ = Concentrate feed amount (kilograms/Day)
$\boldsymbol{X_{i2}}$ = Labor usage (hours/Day)
$\boldsymbol{X_{i3}}$ = Capital (Rupees)
$\boldsymbol{X_{i4}}$ = Number of cows per farmer
$\boldsymbol{v_i}$ = Random error
$\boldsymbol{u_i}$ = Non-negative error term

2.4.2 Factors associated with Technical Efficiency

The model for the technical inefficiency effects in the Stochastic Frontier of equation is defined as;

$$\boldsymbol{U_i} = \boldsymbol{\delta_0} + \boldsymbol{\delta_1} + \boldsymbol{\delta_2} + \boldsymbol{\delta_3} + \boldsymbol{\delta_4} + \boldsymbol{\delta_5} + \boldsymbol{\delta_6} + \boldsymbol{\delta_7} + \boldsymbol{\delta_8} + \boldsymbol{\delta_9} + \boldsymbol{\delta_{10}} + \mathbf{W}_i \text{......Eq. 07}$$

(07)

$\boldsymbol{U_i}$ = Non-negative error term
$\boldsymbol{\delta_0}$ = Constant
$\boldsymbol{\delta_1}$ = Age of the farmer (years)
$\boldsymbol{\delta_2}$ = Gender of the farmer (male=1, female=0)
$\boldsymbol{\delta_3}$ = Education level (Grade)
$\boldsymbol{\delta_4}$ = Household size (number of family members)
$\boldsymbol{\delta_5}$ = Availability of purebred cows (yes=1, no=0)
$\boldsymbol{\delta_6}$ = De-wormers (Rs./Day)
$\boldsymbol{\delta_7}$ = Grazing time (hours/Day)
$\boldsymbol{\delta_8}$ = Vitamins (Rs./Day)
$\boldsymbol{\delta_9}$ = Experience in dairy farming (years)
$\boldsymbol{\delta_{10}}$ = Participation in training programs (yes=1, no=0)
$\mathbf{W}_i$ = Unobservable random variables

The i^{th} farm's technical efficiency (TE_{i}) measure is given by the ratio of the realized output (Y_i) given the value of its inputs and inefficiency effects to corresponding maximum potential output (Y_i^*) assuming there were no inefficiencies arising from the production process. Thus, the technical efficiency of the i^{th} farm is given as;

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(X_i; \beta),\ exp\ (V_i - U_i)}{f(X_i; \beta),\ exp\ (V_i)} = exp(-U_i) \text{..............................Eq. 08}$$

The (TE_i) ranges between 0 and 1. The equation (08) displays that the difference between (Y_i) and (Y_i^*) is captured by (U_i). And if ($U_i = 0$), then ($Y_i = Y_i^*$) denoting that the output lies on the frontier and thus the farm is technically efficient and obtain its maximum potential output given the level of inputs. Nevertheless, if ($U_i > 0$), the production lies below the frontier and the farm is technically inefficient. Finally, the technical efficiency of i^{th} farm is calculated as follows;

$$TE_i = exp(-U_i) \text{..Eq. 09}$$

3. Results

Descriptive analysis was carried out to determine the socio-economic conditions of the study sample. The Table 2. showcases the results and descriptive statistics of the study.

Table 2. Descriptive statistics of socio-economic conditions of the small scale dairy farmers in the Kurunegala District of Sri Lanka

Variable Name	**Mean**	**Minimum**	**Maximum**	**Std. Deviation**
Milk output (Liters/day)	12.25	2	47.5	7.75
Feed (Kilograms/day)	8.14	1	45	5.86
Labor (Hours/day)	7.34	2	10	1.65
Capital (Rs.)	116,520	5,000	650,000	129,227
Cows (Number/farmer)	2.67	1	10	1.45
Age (Years)	50.08	28	72	10.03
Gender (Male/ Female)	0.80	0	1	0.40
Education (Grade)	8.42	1	13	2.29
Household Size (Number)	3.71	1	6	1.06
Pure-bred (yes/ No)	0.56	0	1	0.49
Dewormers (Rs./day)	7.20	0	130	20.15
Grazing time (Hours)	8.89	5	12	1.26
Vitamins (Rs./day)	87.69	0	5220	537.09
Experience (Years)	9.05	1	19	4.64
Training (Yes/ No)	0.66	0	1	0.47

Source: Survey data, 2023

On average, a typical dairy farmer in the sample was fifty years old with an average of eight years of education and nine years of experience. Further, the average farmer uses very little amounts on vitamins and dewormers. The table also shows that an average dairy producer farmer in Kurunegala district in Sri Lanka employed seven hours of labor per day and produced an output of 12.25 liters of milk per farmer. These results show that most of the producers, although they were with good experience and middle age, they are not well educated, not hiring enough labor power for their activity, providing less nutrition quantities for dairy cows. These factors may be the main reasons for the low level of fresh milk production of their farms (4.6 liters per cow). In the meantime, the majority (eighty percent) of the study sample were male and only twenty percent were female. This can be since handling and maintaining cattle is quite difficult for a female than a male. In the sample of small-scale dairy farmers in the Kurunegala district in Sri Lanka, which was selected for the study, seventy three percent of farmers engaged in dairy production as an extra income source while engaging in crop production, especially in paddy cultivation. Only three percent of farmers are engaged in the private sector and only three percent of farmers engage in the dairy industry alone as their only income source is dairy farming.

Table 3. Results of the Stochastic Frontier Analysis

Variable type	Description	Notation	Coefficient	Standard error
Input Variables	Constant	β_0	-3.1007***	1.5857
	Feed (Kilograms/day)	β_1	0.4867***	0.0931
	Labour (Hours/day)	β_2	0.7346***	0.2517
	Capital (Rs.)	β_3	-0.0085	0.0395
	Cows (Number/farmer)	β_4	0.2830***	0.1016
Inefficiency Variables	Constant	δ_0	-1.4454	1.8293
	Age (Years)	δ_1	0.0037	0.0208
	Gender (Male/ Female)	δ_2	-0.1094	0.4472
	Education (Grade)	δ_3	-0.1153	0.0967
	Household size (Number)	δ_4	-0.1795	0.1919
	Pure-bred (yes/ No)	δ_5	-0.2859	0.3710
	De-wormers (Rs./day)	δ_6	-0.0113	0.0131
	Grazing time (Hours)	δ_7	0.2925*	0.1702
	Vitamins (Rs./day)	δ_8	-0.0010	0.0008
	Experience (Years)	δ_9	-0.0749*	0.0446
	Training (Yes/ No)	δ_{10}	0.1518	0.4011

$\gamma = \sigma u\ 2 / \sigma 2$: 0.2138; MT Efficiency: 0.6772;

Table 3. shows that number of labourers, and feed cost coefficients are with positive signs and are statistically significant at 0.01 level, showing direct relationship with milk production. This implies that any one percent increase in

*** Significant at P=0.05, * Significant at P=0.1

feed intake and number of labourers would increase milk production by 0.48 % and 0.73% for each of these variables respectively. The coefficient for capital cost was a negative sign, indicating an indirect relationship of this variable with milk production. This implies that a one percent increase in capital costs will lead to a 0.008% decrease in milk production. Interestingly, according to the Cobbs Douglas production function, for every additional cow, there is an increase of 0.4867 liters in the milk output. This means that, on average, each additional cow contributes about 0.4867 liters of milk to the total milk output, assuming that other factors remain constant. It's a positive correlation, and it indicates the productivity of each cow in terms of milk production.

When the inefficiency variables are considered, grazing time and experience of the farmer are significant determinants of the efficiency of dairy farmers in the study area. Interestingly, in the inefficiency model, a negative relationship indicates that the particular variable affects the inefficiency negatively, implying that it has a positive effect on the efficiency and vice versa. The table 3 shows that, when the education level of a farmer increases by one grade, the efficiency of the farmer increases by 0.11 percent, showing that there is a positive relationship between a farmer’s education level and their efficiency in milk production, although the effect is insignificant. This positive effect can be due to higher education levels often resulting in increased knowledge and skills that can be applied to farming practices. Farmers with higher education levels may be more likely to adopt modern and efficient agricultural practices and technologies. Further, educated farmers may have better access to information, resources, and networks that can enhance their farming efficiency. Moreover, Education can improve a farmer’s ability to analyze data and make data-driven decisions, leading to improved resource management. This argument is further clarified by the study done by Bandara and Weligamage (2018). In addition, the experience of the farmer is also affecting the efficiency of the farmer in dairy production in the study area. As shown in the table 3, when the experience of the farmer increases by one year, the efficiency of the farmer increases by 0.07 percent showing a positive relationship between the years of experience of the farmer and technical efficiency. This can be a result of an accumulation of the greater knowledge of farming practices with more years of experience, which can lead to improved decision-making, better skills in problem-solving, and overall efficiency in farming.

The grazing time refers to the period of time cows spend feeding on fresh grass, forage or pasture. The coefficient of grazing time indicates that if grazing time increases by one hour, there is an associated decrease in milk production efficiency by 0.29 as a percentage. This suggests that, on average, longer grazing time tends to result in less efficient milk production. It can be explained that spending too much time grazing may not necessarily result in higher nutrition if the quality of forage is poor or if cows overgraze and consume less nutritious vegetation. And longer grazing time may reduce the time cows spend resting or being more efficiently managed, potentially impacting overall milk production. Furthermore, the typical weather conditions of the district are quite harsh with high temperatures. Prolonged exposure to harsh weather conditions during extended grazing periods might adversely affect cow health and milk production efficiency. This explains that longer grazing time does not promise a more efficient milk production. It is shown that the unit increase in the variables, including age, gender, household size, availability of pure-bred cows, and participation in training programs do not significantly affect the efficiency of milk production in the Kurunegala district.

The mean technical efficiency of the small-scale dairy farmers in the Kurunegala district is sixty eight percent, which is a higher percentage when compared with the study carried out in the Eastern dry zone in Sri Lanka by Bandara and Weligamage, (2018), in which the mean technical efficiency is fifty percent. Still, the efficiency in the area of our study can be increased by thirty two percent without increasing the level of inputs for the milk production.

Table 4. Technical efficiency levels of the small-scale dairy farmers in the Kurunegala district

Efficiency % group	**Frequency**	**Percentage %**	**Cumulative %**
00 – 19	2	2.04	2.04
20 – 39	9	9.18	11.22
40 – 59	18	18.37	29.59
60 – 79	40	40.82	70.41
80 – 100	29	29.59	100.00
Total	98	100.00	

Source: Survey data, 2023

The majority of the farmers (fourty) in the selected sample of small-scale dairy farmers in the Kurunegala district lie at an efficiency level between sixty – seventy nine percent as indicated in the Table 4. And between zero – nineteen percent there are only two farmers out of ninety-eight farmers and there are nine farmers in the twenty – thirty nine percent efficiency level. And there are eighteen farmers who have an efficiency level between fourty – fifty nine percent whereas, twenty-nine farmers belong to eighty – hundred efficiency level. From the sample of hundred small-scale dairy farmers, only ninety-eight farmers were counted for the estimation of technical efficiency and two farmers were omitted in the analysis.

Table 5. The mean milk production levels at different technical efficiency percentages.

Efficiency % group	Mean milk output (Liters/day)
00 – 19	3.00
20 – 39	4.56
40 – 59	8.61
60 – 79	10.89
80 – 100	19.16

Source: Survey data, 2023

According to the results presented in Table 5, the mean milk production of dairy farmers who have an efficiency level between eighty percent and hundred percent is 19.16 liters per day. The majority of the farmers have an efficiency level between fifty and seventy nine percent, and the mean milk production of such farmers was estimated to be around 10.89 liters per day, while the farmers who have an efficiency level between zero to nineteen percent were reported to be around three liters per day. 4.56 liters and 8.61 liters are obtained by the dairy farmers who belong to the twenty – thirty-nine and fourty – fifty nine efficiency levels.

The analysis of efficiency levels showed that most dairy farmers fell within the sixty-seventy nine percent efficiency range, indicating that many had optimized their milk production processes. Farmer's experience and number of grazing hours were identified as influential factors affecting efficiency. The analysis emphasized the significant impact of education on production efficiency, suggesting that investing in training programs and workshops covering animal care, nutrition, and advanced farming methods can greatly enhance farmers' ability to manage their operations effectively. Moreover, encouraging the farming community to engage in education will enhance the efficiency of milk production in the future. In addition, implementing effective grazing management practices, such as rotational grazing systems, can optimize pasture resource utilization and enhance milk production.

The findings of this study are consistent with certain previous research on the agricultural efficiency particularly in dairy and tea smallholder production in Sri Lanka. For instance, Bandara and Weligamage (2018) also indicated that Sri Lanka's Eastern Dry Zone dairy farmers whose technical efficiency is greater were able to produce more milk, as can be noted from the 19.16 liters per day recorded in this study for farmers in the eighty percent – hundred percent efficiency category. As with Basnayake and Gunaratne (2002), where the technical efficiency of tea smallholdings in Sri Lanka's Wet Zone Mid

Country was heavily dependent on experience and farm management practices, the same rate of experience among farmers and hours of grazing, as revealed here, influenced the latter. The focus on education as a key to efficiency also relates to Damunupola et al. (2022), with those researchers identifying the transmission of knowledge through training as a means to enhance the productivity of the dairy sector. These consistencies confirm that experience, education, and optimally utilized resources are imperative in different scenarios of agriculture in Sri Lanka, which serves as a validation of the robustness of the available results.

While the results of the current study are largely consistent with the current literature, variations do exist. And they can be explained by contextual factors, differences in methodology, and explanations related to data. For example, Dharmadasa and Wijethilaka (2014) concluded that out-migration of labour negatively affected the technical efficiency of Sri Lanka's Low Country Wet Zone tea smallholders, a concern not separately addressed in this dairy-focused research. This difference might be attributed to the varying labour realities in dairy versus tea farming, where dairy farms employ family labour or local workers, negating the effects of migration. Second, the study's focus on grazing times as an explanatory variable for efficiency is alternative to Bandara and Weligamage (2018), where feed quality was considered paramount over grazing habits in the Eastern Dry Zone. This heterogeneity can be attributed to differences in the availability of grasslands across regions since the Eastern Dry Zone receives less dependable rainfall and, thus, has more limited opportunities for grazing compared to other regions. Methodologically, this study's employment of a specific efficiency range (sixty percent–seventy nine percent) could be different from more general efficiency classifications applied by other studies, potentially affecting comparative estimates of milk yields. These differences underscore the importance of context-specific variables such as area climate, labour availability, and data granularity in accounting for efficiency outcomes.

4. Conclusions

The paper aimed to evaluate the technical efficiency of dairy farmers in the Kurunegala district in Sri Lanka using stochastic frontier analysis and to analyse the impact of different factors on technical efficiency using a hundred dairy farmers. The results of this study indicate that technical efficiency of milk production by most of dairy farmers are on average of sixty eight percent. And it indicates that there is a possibility of improving technical efficiency by thirty two percent in the study area without any additional input. The results further show that there is a substantial technical efficiency on dairy farms in Kurunegala, Sri Lanka suggesting relatively efficient production. Farmer’s level of education, farmer’s farming experience, grazing time are the main determinants associated with TE in the sampled dairy farmers. The study shows that, technical efficiency can be further improved through provision of education and experience toward dairy farming practices. More education will be crucial in increasing technical efficiency. Holding workshops and awareness programs which will enhance the education level of the farmers might result in improved efficiency levels in dairy farming.

Additionally, one of the limitations of the study is that it does not consider the climatic changes as variable. Thus, future studies may investigate the impact of climate variability and climate change on dairy production efficiency and socio-economic conditions. A future research endeavour could explore how climatic shifts, including prolonged droughts, increased temperatures, and irregular rainfall, affect key aspects of dairy farming. This could encompass examining how changing weather patterns influence feed availability and quality, impact cattle health and milk yields, and disrupt grazing patterns.

Moreover, such a study could assess how farmers adapt their practices and resource management strategies in response to changing climatic conditions. By integrating climate-related variables into the analysis, researchers could better understand the interplay between internal and external factors that shape dairy production efficiency and socio-economic conditions. This would contribute to a more comprehensive understanding of the challenges faced by small-scale dairy farmers in the Kurunegala district and provide insights into potential adaptation and mitigation strategies. Additionally, it recommends employing panel data spanning several years for a comprehensive analysis of how climate variations impact dairy farming practices and the socio-economic well-being of farmers. This longitudinal approach is expected to facilitate more informed policy decisions for sustainable agricultural practices in the face of evolving climate conditions.

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