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Research Paper

Input Demand and Substitution Effects in Upcountry Vegetable Cultivation in Sri Lanka

P.S.R. Premarathna[1]*, D.V. P. Prasada[2]

[1] *Socio Economics and Planning Centre, Department of Agriculture, Peradeniya, Sri Lanaka*
[2] *Department of Agricultural Economics and Business Management, Faculty of Agriculture, University of Peradeniya, Sri Lanaka*

**Corresponding author: shamikap82@gmail.com*

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Abstract

The objectives of the study are to estimate the input demand elasticities and compute elasticities of substitution among various inputs employed in upcountry vegetable cultivation in Sri Lanka. The research study is based on data from Cost of Cultivation (COC) surveys conducted by Department of Agriculture in Sri Lanka over 14 growing seasons from 2014/15 *Maha* to 2022/23 *Maha* for key upcountry vegetable crops namely pole bean, cabbage, and carrot. The total cost function and cost share equations were jointly estimated using Seemingly Unrelated Regressions while imposing cross-equation symmetry constraints to generate coefficients to calculate elasticities. Results revealed that both own-price and cross-price elasticities are inelastic, indicating limited responsiveness. The analysis of partial elasticities of substitution demonstrates that labor is complementary to chemical fertilizer and seed, while substituting for other inputs. Chemical fertilizer, in turn, shows a complementary relationship with seed but serves as a substitute for other inputs. Further, the complementarity between seed and both labor and fertilizer indicate a relatively fixed technological relationship among these inputs. The interdependencies among labor, fertilizer, seeds, and other inputs underscore the need for a holistic approach to input management.

Keywords: Cost function, Input demand elasticities, Partial elasticities of substitution, Upcountry vegetables

Introduction

Vegetable cultivation in Sri Lanka plays a crucial role in ensuring food security, driving economic development, and supporting livelihoods. In 2023, the combined annual vegetable production from both upcountry and low country cultivation areas reached a total of 1,168,785 mt. This significant production has been recorded from a total cultivated land area of 94,654 ha (Department of Census and Statistics, 2023). Vegetable cultivation contributed 0.8% to Sri Lanka's Gross Domestic Product (Central Bank of Sri Lanka, 2022). Despite the fact that the paddy has traditionally taken the attention in agricultural research (Weerahewa, 2004; Rajapaksha & Karunagoda, 2009; Wijetunga, 2016), it is essential to recognize the contributions of other crops grown in distinct regions. The trend in upcountry vegetable production consistently reveals a substantial contribution to the national output, accounting for nearly half of the total vegetable production (Department of Census and Statistics, 2023). Among the upcountry vegetables' carrot, cabbage, and bean emerged as pivotal crops, consistently contributing to the one-fourth of the annual vegetable production highlighting the significance in a broader agricultural context (Department of Census and Statistics, 2023). There is limited economic research on input responsiveness in upcountry vegetable farming. Therefore, the current study focused to examine the complex interplay among inputs in upcountry vegetable cultivation. Understanding these relationships is crucial for supporting the farmers in optimizing resource use and enhancing productivity. This study estimates the input demand and substitution elasticities of upcountry vegetable farming, serving as tools for resource allocation and ensuring the continued contributions of upcountry vegetable crops to agricultural development in Sri Lanka. In this connection the specific objectives of the current study were (i.) to examine temporal input price variations during the study period, (ii.) to examine the input demand elasticity for vegetables cultivated in upcountry regions and (iii.) to estimate the elasticities of substitution among various inputs employed in the cultivation of vegetable crops in the upcountry regions.

Materials and Methods

Extraction of data

This research is primarily reliant on data sourced from Cost of Cultivation (COC) surveys conducted by the Socio Economics and Planning Center (SEPC) of the Department of Agriculture in Sri Lanka. Raw data at the individual farmer level used in this study was extracted for 14 growing seasons from 2014/15 *Maha* to 2022/23 *Maha*. Pole bean, cabbage and carrot, which are predominantly cultivated in Nuwara Eliya and Badulla districts belong to upcountry, were the crop chosen (Department of Census and Statistics, 2023). The data were pooled to form a pseudo panel as survey participants varied from year to year. This approach involved pooling the data from all available years and seasons (excluding 2020/21 *Maha*, 2021

Yala and 2021/22 *Maha* seasons) resulting in a robust dataset comprising cross-sectional information of 1,207 individual farmers in specific season in the respective year. Total sample (1207) included 360 cabbage farmers, 423 pole bean farmers, and 424 carrot farmers. This pooled-cross section of data qualifies for statistical properties and reliability of the study's estimates followings Walisinghe *et al*. (2017). The GDP deflator index was used to convert the nominal values into real values. The real input prices were calculated based on the year 2010, with 2010 = 100

Theoretical and Empirical Model

The econometric application of the production theory based on the duality relationship between production functions and variable cost function was the empirical approach adopted to estimate input demand and elasticities of substitutions following, Kumara *et al*. (2010), Meena, *et al*. (2010), Tian *et al*. (2019) and Lee *et al*. (2022). The cost functions exhibit homogeneity in prices, irrespective of the homogeneity properties of the production function (Binswanger, 1974). Cost functions typically employ input prices rather than input quantities as the latter are not suitable exogenous variables for econometric estimation (Felipe, 2021). On practical ground, farms and entrepreneurs base their decisions on input prices, which subsequently influence the quantity of inputs to be purchased or utilized. Estimating production functions can be problematic with high potential for multicollinearity among input variables, while cost functions typically face fewer challenges in this regard due to minimal multicollinearity among input prices, increasing the power of tests (Binswanger, 1974; Pang *et al*., 2021; Khanal *et al*., 2022). On the contrary in estimating production functions, inverting the matrix of coefficients to estimate elasticities of substitution and input demand, can introduce statistical errors, whereas cost function estimation prevent this step. Therefore, in the present study Trans-log cost function was used to derive all the cost dynamics discussed in the objectives.

Specification of the Cost Function

$$\text{Min C} = \sum_{i=1}^{n} X_i \, P_i \quad (i=1,2,3,\ldots,n) \qquad (1)$$

$$\text{Subject to, } Y = f(X_1, X_2, \ldots, X_n) \qquad (2)$$

The cost function was specified corresponding to the following cost minimization problem.

Where, X_i are input levels, P_i are input prices and Y are output

$$C^* = g(Y, P_i, \ldots, P_n) \qquad (3)$$

Function 3 that assigns to every combination of input prices the minimum cost corresponding to the cost minimizing input levels X_i^*. The C of (1) is the cost of production under any feasible factor combination, C^* refers to the cost of production when the cost minimizing input combination is used. Since the optimal input combination is a function of the factor prices, the minimum cost is also. C^* is homogeneous of degree one in prices.

Shephard's lemma holds for the cost function,

$$\frac{\partial C^*}{\partial P_i} = X_{i.} \quad (4)$$

Let f be the boarded Hessian Metrix of (2) and

$$f_i = \frac{\partial Y}{\partial X_i} \text{ and } f_{ij} = \frac{\partial^2 Y}{\partial X_i\ X_j}.$$

Partial elasticities of substitution are defined as,

$$\sigma_{ij} = \frac{\sum_{i=1}^{n} X_i f_i}{X_i X_j} (f^{-1})_{ij} \quad (5)$$

$$\sigma_{ij} = \sigma_{ji} \quad (6)$$

means that the degree to which input *i* can substitute for or complement input *j* is the same as the degree to which input *j* can substitute for or complement input *i*.

In the case of the cost function, estimates σ_{ij} can be obtained directly from the parameters of the function, because,

$$\sigma_{ij} = \frac{\sum_{i=1}^{n} X_i P_i}{X_i X_j} \frac{\partial^2 C^*}{\partial P_i\ \partial P_j} \quad (7)$$

The Trans-log version of the cost function, written as a logarithmic Taylor series expansion to the second term of a twice differentiable cost function, was used in this study. Rewriting (3) in natural logarithms.

$$ln C^* = f(lnY, lnP_i, \dots, lnP_n) \quad (8)$$

$$lnC^* = \beta_0 + \beta_y lnY + \sum_i \beta_i lnP_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij}\ lnP_i lnP_j + \sum_i \gamma_{iy} lnP_i\ lnY + u_t \quad (9)$$

Where, C^* is the total cost, P_i is the factor prices (p/P), Y is the output; β_0, β_y, β_i and γ_{ij} are coefficients of the cost function, and u_t is the error term.

The model is based on several key constraints and assumptions. Firstly, symmetry constraints hold, meaning there is equality of cross derivatives, denoted as ($\gamma_{ij}=\gamma_{ji}$ for all *i,j*; *i≠j*). Secondly, the model assumes linear homogeneity in prices which is defined as $\Lambda g(Y, P_i, \dots, P_n) = g(\Lambda Y, \Lambda P_i, \dots, \Lambda P_n)$. This implies $\sum_i \beta_i = 1$, $\sum_i \gamma_{ij} = 0$ and $\sum_i \gamma_{ji} = 0$. for all *i, j*. An easier way to impose the price homogeneity condition is to use for an arbitrary choice of an input (P_1) and normalize the other input prices ($P_2, \dots, P_n$) and total cost (C^*) by it. Thirdly, the model requires monotonicity, meaning the function must be an increasing function of input prices. This is expressed as,

$$\frac{\partial lnC}{\partial lnP_i} = \beta_0 + \sum_j \gamma_{ij} lnP_i \geq 0 \qquad i = 1, \dots, n.$$

Finally, concavity in input prices is required, implying that the matrix $\frac{\partial^2 C}{\partial P_i\ P_j}$ must be negative semi-definite within the range of input prices. Using Shepherd's duality theorem, that the first derivative of equation (9) with respect to logarithms of the input prices are equal to the respective input share in the total cost. The input share equations can be written as equation 10.

$$\frac{\partial lnC*}{\partial lnP_i} = S_i = \beta_i + \sum_i \gamma_{ij}\ lnP_j + \gamma_{iy} lnY + \varepsilon \ \text{(for } \dots, \text{n)} \quad (10)$$

S_i is share of the i[th] input in total cost, P_i is price of the i[th] input (p_j /P), β_i ,γ_{ij} ,γ_{iy} are parameters of the share equation and ε is the error-term. In their own, the γ_{ij} parameters could not be used directly for economic interpretation and if the γ_{ij} parameters are estimated and all the factor shares (S_i and S_j) are found, all elasticities can be estimated. These parameters are related to elasticities of factor demand (μ_{ij} and μ_{ii}) and elasticities of substitution (σ_{ij} and σ_{ii}) as mentioned in 11, 12, 13 and 14 equations.

$$\mu_{ij} = \frac{\gamma_{ij}}{s_i} + S_j \qquad \text{for all } i, j;\ i \neq j. \tag{11}$$

$$\mu_{ii} = \frac{\gamma_{ii}}{s_i} + S_i - 1 \qquad \text{for all } i. \tag{12}$$

$$\sigma_{ij} = \frac{1}{s_i s_j}\gamma_{ij} + 1 \qquad \text{for all } i, j;\ i \neq j. \tag{13}$$

$$\sigma_{ii} = \frac{1}{s_i^2}(\gamma_{ii} + S_i^2 - S_i) \text{ for all } i. \tag{14}$$

From the general function (9), the cost function for the i[th] farms who have grown upcountry vegetables in Sri Lanka can be specified as in equation 15;

Price homogeneity in the cost function was achieved by arbitrarily dividing the total cost and input prices by the seed price of individual farms.

The table 1 reports the descriptive statistics of the variables used in the empirical model. It is followed by a brief description of the variables and the notation used in the study.

The total cost (Cost) associated with vegetable cultivation on an individual farm, denoted as C^*, is determined by aggregating the total variable expenses. These variable costs encompass various inputs such as labour, fertilizers (chemical and organic), seeds, pesticides, machinery and other expenditures (trellis cost, lime, liquid fertilizer and other miscellaneous cost items) essential for the cultivation process. The wage rate (P_l) define as the average daily wage rate per man day. Labour input considered inclusive of both family and hired labour. To express this in monetary terms, we incorporate the imputed cost of family labour by adding it to the cost of hired labour specific to the region. Additionally, the female labour days were converted into equivalent man days through appropriate conversion ratios (Socio Economics and Planning Center, 2020).

$$\begin{aligned} lnC_i^* = {} & \beta_0 + \beta_y lnY_i + \beta_l lnP_{l,i} + \beta_f lnP_{f,i} + \beta_s lnP_{s,i} + \beta_o lnP_{o,i} + \tfrac{1}{2}\gamma_{ll} lnP_{l,i} lnP_{l,i} + \\ & \tfrac{1}{2}\gamma_{ff} lnP_{f,i} lnP_{f,i} + \tfrac{1}{2}\gamma_{ss} lnP_{s,i} lnP_{s,i} + \tfrac{1}{2}\gamma_{oo} lnP_{o,i} lnP_{o,i} + \tfrac{1}{2}\beta_{yy} lnY_i lnY_i + \\ & \gamma_{lf} lnP_{l,i} lnP_{f,i} + \gamma_{ls} lnP_{l,i} lnP_{s,i} + \gamma_{lo} lnP_{l,i} lnP_{o,i} + \gamma_{lf} lnP_{l,i} lnP_{f,i} + \gamma_{fs} lnP_{f,i} lnP_{s,i} + \\ & \gamma_{fo} lnP_{f,i} lnP_{o,i} + \gamma_{ly} lnP_{l,i} lnY_i + \gamma_{fy}\, lnP_{f,i} lnY_i + \gamma_{oy}\, lnP_{f,i} lnY_i + \gamma_{sy}\, lnP_{s,i} lnY_i + \\ & \gamma_{oy}\, lnP_o lnY_i + \alpha_1 D_v + \alpha_2 D_s + \alpha_3 D_{yr} + u_i \end{aligned} \tag{15}$$

Table 1. Descriptive statistics of the variables

Variable	Mean	SE
Total cost (LKR)*	115,836.10	4,211.60
Wage rate (LKR/ man day)	807.44	6.41
Chemical fertilizer price (LKR kg^{-1})	61.38	2.73
Other input price (LKR per one kg of output)	9.25	0.33
Output (kg)	2,388.36	59.98
Labour share (SL)	0.583	0.003
Fertilizer share (SF)	0.109	0.002
Other input share (SO)	0.227	0.002
Land extent (acre)	0.445	0.012

LKR- Sri Lankan Rupees, Number of observations = 1207, SE = Standard error*

The weighted average of the daily wage rate, was calculated by dividing the total labour cost by the total number of man-days worked on the farm during the season. Fertilizer price (P_f) is the weighted average price for one kilogram, reflecting different types and quantities used by upcountry vegetable farmers, including both straight namely Urea, Triple Superphosphate and Muriate of Potash and mixed fertilizers. This weighted average price provides an accurate cost representation. Seed price (P_s) is the price of one kg of seeds used by individual farmer. Other input price (P_o) is the other material cost component comprises a composite cost, encompassing expenses related to agrochemical price, liquid fertilizer, lime, organic matter, machinery, and other miscellaneous cost items that cannot be precisely allocated to the primary cost components. Since unit prices for these inputs cannot be determined, a proxy was used by dividing the total other input cost by the crop output. Wage rate, fertilizer price, seeds price and other input price significantly influence the overall cost of vegetable cultivation, with a positive relationship hypothesized. D_v represents a factor variable included three types of vegetables cultivated in upcountry regions: cabbage, carrot, and pole bean. Cabbage was chosen randomly as the base crop. This variable is utilized to investigate the impact of distinct crops on total cost and input share equations in comparison to the base case. D_s is the dummy variable to capture the variation among crop growing seasons namely *Maha* and *Yala* and it serves as a binary indicator, taking a value of 1 for *Maha* and 0 for the *Yala*. The dummy, D_{yr} served as a year dummy introduced as a factor variable with the base year being 2015.

S_i is the function for labour, fertilizer and other input's cost share equations which were derived by differentiating the normalized Trans-log cost function (15) as follows, The share of labour cost (S_L) defines as:

$$S_L = \frac{P_l^* X_l}{C^*} = \alpha_l + \gamma_{ll} lnP_l^* + \gamma_{lf} lnP_f^* + \gamma_{lo} lnP_o^* + \alpha_1 D_v + \alpha_2 D_s + \alpha_3 D_{yr} \quad (16)$$

The share of fertilizer cost (S_F) defines as,

$$S_F = \frac{P_f^* X_f}{C^*} = \alpha_f + \gamma_{ff} lnP_f^* + \gamma_{fl} lnP_L^* + \gamma_{fo} lnP_o^* + \alpha_1 D_v + \alpha_2 D_s + \alpha_3 D_{yr} \quad (17)$$

The share of other input (S_O) defines as,

$$S_O = \frac{P_o^* X_o}{C^*} = \alpha_o + \gamma_{oo} lnP_o^* + \gamma_{ol} lnP_l^* + \gamma_{of} lnP_f^* + \alpha_1 D_v + \alpha_2 D_s + \alpha_3 D_{yr} \quad (18)$$

Where, X_l, X_f and X_0 are the quantities of variable inputs of fertilizer, labour, and other inputs respectively. As noted earlier, the elasiticities are functions of variable input ratios, variable input prices and the parameter estimates of the Trans-log cost function. These elasticities were evaluated at simple averages of the S_i (input cost shares) of the variable input prices. The research adopted Seemingly Unrelated Regressions (SUR), a statistical approach, to analyze data with multiple related but not identical regression models, offering advantages such as increased efficiency, accounting for correlation among error terms, addressing endogeneity and consistency in estimators under certain assumptions (Zellner, 1962). The above model represented by total cost (equation 15), input cost shares (equations 16, 17 and 18) were jointly estimated. The error terms were assumed to be satisfied all the classical assumptions and should be correlated across the equations. The input cost shares (equations 16, 17 and 18) have been imposed cross-equation symmetry constraints (γ_{ih}=$\gamma_{hi}$where i, h = 1, 2,..., n, but i≠h) with total cost function, and estimated jointly to generate meaningful coefficients for calculation of elasticities. The coefficients related to seed in the input cost shares were derived by applying homogeneity restrictions, namely $\sum_i \beta_i$=1, $\sum_i \gamma_{ij}$ =0, $\sum_i \gamma_{ji}$ =0 for all *i* and *j*.

Results and Discussion

The temporal variations of real input prices during the study period (2015-2023) are depicted in Figures 1-3.

From 2015 to 2023, the average price of chemical fertilizer in upcountry vegetable farms experienced significant fluctuations influenced by policy interventions. Stable prices until 2016 have paved way to a slight increase with the introduction of cash grants to paddy farmers in place of the price subsidy (Central Bank of Sri Lanka, 2016). A significant rise in prices occurred in 2021 as a result of the chemical fertilizer import ban, spiking average real price of chemical fertilizer from 24 LKR/ kg in the

2021 *Yala* to 109 LKR kg^{-1} in the 2021/22 *Maha* season, with further fluctuations due to economic crisis.

Concurrently, the substantial increase in nominal wages in upcountry vegetable farms between 2022 and 2023 (see figure 2) can be attributed to the prevailing higher inflationary environment during the economic crisis period. The increase in nominal wages in the informal private sector was mainly due to the demand for higher wages by daily wage earners, driven by the rising cost of living and a shortage of labour supply.

Trends in input prices in upcountry vegetable farms

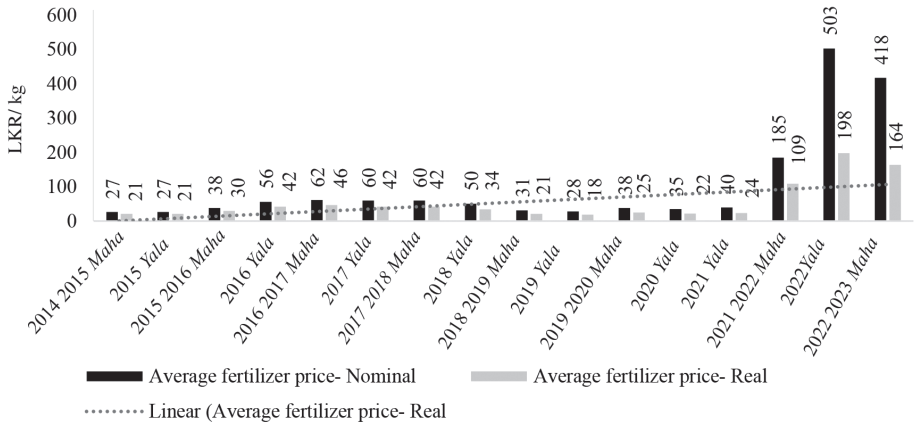

Figure 1. Average price of chemical fertilizer used in upcountry vegetable farms: 2015 - 2023 (Base 2010 = 100)

Note: Data for the 2020/2021 Maha, was not available for the selected crops in the study

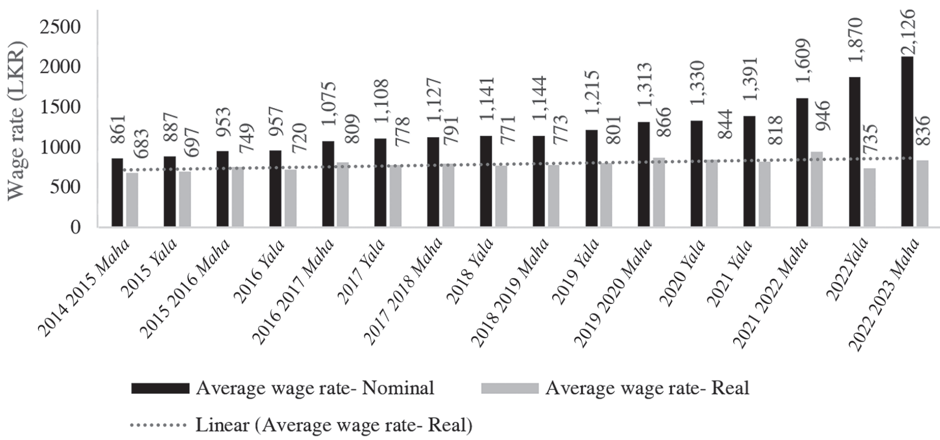

Figure 2. Average wage rate for labour employed in upcountry vegetable farms: 2015-2023 (Base 2010 = 100)

The average unit cost of other inputs (see Figure 3) also surged post-2021. This increase was driven by the implementation of policies encouraging organicagriculture, restrictions on importation of agrochemicals, and the rising costs of both agrochemicals and organic materials. The situation was exacerbated the rising petroleum prices in 2022, which affected cost of power and cost of other related inputs for vegetable farming.

Input demand elasticities and elasticities of substitution in inputs

Table 2 presents the model fit statistics, along with the coefficient estimates for the Trans-log cost function and the input cost share equations, estimated through SUR. All models were statistically significant (p< 0.01) with high chi-square statistics.

The table 2 depicts the SUR estimation results highlight several important relationships within the total cost and factor cost share equations. The labour cost share is positively influenced by wage rate (0.1752) but negatively affected by fertilizer (-0.0786), other input prices (-0.0314) and seed prices (-0.0652). Similarly, the fertilizer cost share is positively related to fertilizer price (0.0752) and other prices (0.0383) but inversely related to, wage rate (-0.0786). Other input cost share shows a mixed response, positively related to fertilizer price (0.0383) and seed price (0.0258), but negatively to other input prices. The output variable shows mixed effects across shares, with labour and fertilizer input shares showing small negative impacts, while other input shares show a slight positive impact. Seasonal effects are minimal, while the crop dummies reveal variability in cost shares, particularly for fertilizer and other input, indicating differences in input cost structures across crops like carrot and pole bean compared to the base crop (cabbage).

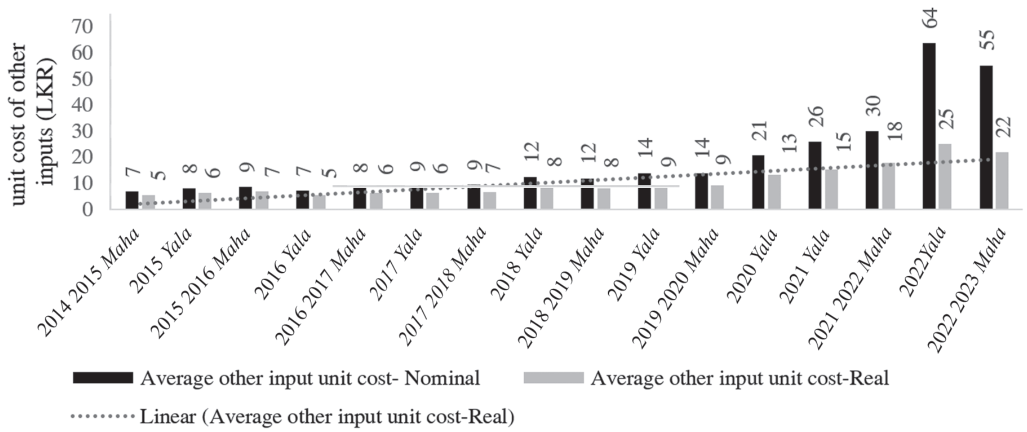

Figure 3. Average other input unit cost in upcountry vegetable farms: 2015-2023 (Base Year 2010 = 100)

Table 2. Restricted estimates of the coefficients of the Trans-log cost function derived from SUR

Equation	RMSE	R^2	chi^2	p value
Cost	0.22148	0.9246	283075	0.000
Labour share	0.06825	0.6017	4969.28	0.000
Fertilizer share	0.05046	0.5252	1643.76	0.000
Other input cost share	0.05751	0.4604	14934.9	0.000

Notes: n=1207, RMSC=Root mean square error

Factor share	Wage rate (PL)	Fertilizer price (PF)	Other input price (PO)	Seed Price (PS)+	Output (Y)	Season (*Maha*=1, *Yala*=0)	Crop dummy (base= Cabbage)		Intercept
							Carrot	Pole bean	
Labour cost share	0.1752**	-0.0786**	-0.0314**	-0.0652	-0.0368**	0.0096*	-0.0163	-0.0254	0.2114**
	(0.031)	(0.004)	(0.045)		(0.004)	(0.004)	(0.105)	(0.015)	(0.032)
Fertilizer cost share	-0.0786**	0.0752**	0.0383**	-0.0349	-0.0108**	-0.0039*	0.0220**	-0.0258**	0.2457**
	(0.004)	(0.011)	(0.011)		(0.002)	(0.002)	(-0.026)	(0.008)	(0.021)
Other input cost share	-0.0314*	0.0383**	-0.0327**	0.0258	0.0470**	-0.0049*	-0.0731**	-0.1040**	0.5250**
	(0.015)	(0.011)	(0.011)		(0.003)	(0.004)	(0.005)	(0.006)	(0.023)
Seed cost share ++	-0.0652	-0.0349	0.0258	0.0743					0.0179

*Notes: ** significant at 1% and * significant at 5%, Standard errors are reported in parentheses*

+ and ++ - The coefficients related to seed in the input cost shares were derived by applying homogeneity restrictions, specifically ($\sum_i \beta_i$=1, $\sum_i \gamma_{ij}$ =0 and $\sum_i \gamma_{ji}$ =0. for all i, j).

Breusch-Pagan test of independence was performed to find the correlation matrix of residuals of SUR. Test results indicated correlated error terms in the system equations (chi^2 (6) = 2313.78 and p = 0. 000), that supporting the appropriateness of applying SUR.

Elasticity of input demands in upcountry vegetable production

The findings evidenced the own-price elasticities for labour, chemical fertilizer, other inputs and seeds appear to be inelastic (see Table 3). It was found that the own price elasticity value of -0.116 which depicted inelastic labour demand in upcountry vegetable producers may have limited flexibility in adjusting the quantity of labour in response to changes in wage rate (Chaudhary *et al*., 1998; Goyal & Berg, 2003; Kumara *et al*., 2010; Meena *et al*., 2010; Wijetunga, 2016). This could be due to the reliance on family labour, especially when labour prices increase. Small-scale farmers often turn to family labour to manage their small landholdings, whereas larger farms might attempt to mechanize their farming activities.

However, the challenging terrains and the diverse nature of these vegetable crops in the region further complicate the adoption of mechanized equipment. The negative elasticity of labour demand with respect to the fertilizer price (-0.026) suggests complementary relationship but highly inelastic response. It is important to note that several factors contribute to this, including the perceived indispensability of chemical fertilizer in promoting crop growth, limited availability of substitutes and exhibiting inertia in response to price changes. The cross-price elasticity of labour demand respect to other inputs unit price (composite cost of machinery, organic matters, chemical cost of pest and disease management and other related cost items: 0.174), suggest a substitutable with not extremely pronounced. However, there is a possibility to increase labour demand while increase of cost of machinery cost, agrochemical cost for pest and disease management, organic matter and other input cost to keep the production at optimum but that is not pronounced by the study findings.

Table 3. Input demand and cross-demand elasticities

Input	Labour (Price)	Chemical fertilizer (Price)	Other inputs (Price)	Seed (Price)
Labour demand	-0.116[b]	-0.026	0.174	-0.031
SE[a]	0.053	0.007	0.077	
t statistics	-2.190	-3.761	2.250	
Chemical fertilizer demand	-0.138	-0.201	0.579	-0.240
SE	0.037	0.101	0.101	
t statistics	-3.761	-1.991	5.735	
Other inputs demand	0.445	0.277	-0.916	0.194
SE	0.067	0.048	0.048	
t statistics	6.750	5.735	-18.948	
Seed demand	-0.227	-0.325	0.548	0.00421

Notes: [a] *Standard error:* $SE(\mu_{ij}) = SE(\gamma_{ij})/S_i$.

[b] *Highlighted elasticity values are own price elasticities of the farm input.*

It's crucial to note that these elasticities are not symmetrical.

The cross-price elasticity of labour demand with respect to seed price is -0.013, indicating a minimal decrease in labour demand as seed prices rise. The negative own price elasticity of chemical fertilizer (-0.201) indicates an inelastic response, reflecting low sensitivity to changes in its own price. This suggests that the demand for chemical fertilizers is relatively unresponsive to price changes, since the high sensitivity of upcountry-grown hybrid vegetable planting materials to chemical fertilizers (Goyal & Berg, 2003; Meena *et al*., 2010; Kumara *et al*., 2010; Wijetunga, 2016; Ashrit, 2021). The complementary relationship of chemical fertilizer demand respects to the labour price depicted inelastic response (-0.138) (Binswanger, 1974; Meena *et al*., 2010). Further, the negative elasticities of chemical fertilizer demand respect to the seed prices (-0.240) portray the complementary relationship (Wijetunga, 2016). With other input prices, the chemical fertilizer demand indicates inelastic (0.579) substitute relationships, evidenced by Kumara *et al*. (2010). This could be explained that while cost of organic matter farmer tend to increase the use of chemical fertilizer to keep the crop performance. However, Chaudhary *et al*. (1998), Goyal and Berg (2003), Wijetunga (2016), and Ashrit (2021) have revealed a complementary relationship between chemical fertilizer demand and the other input prices. The own price elasticity for other input reflects comparatively higher responsiveness (-0.916) compared to the labour, fertilizer and seeds. A positive cross-price elasticity of other input demand with respect to wage rate (0.445) and fertilizer price (0.277) indicates substitute relationships. As the wage rate increases, farmers tend to use machinery to substitute labour-intensive activities such as land preparation, weeding and etc. Farmer might apply agrochemicals to manage pests and diseases, thereby reducing the need for manual weeding. Similarly, when the price of chemical fertilizers rises, farmers may seek alternatives like organic compounds to maintain crop productivity. However, finding perfectly substitutable inputs can be challenging, as these alternatives may not fully replicate the effectiveness or ease of use of the original inputs. The cross-price elasticities involving seeds demand has shown complementary relationship with labour and chemical fertilizer price whereas substitutive relationship with other input prices.

Partial elasticities of substitution among farm inputs in upcountry vegetable farms

The findings in Table 4 revealed that the negative elasticity of substitution is -0.2367 between labour and chemical fertilizer and being complementary relationship and statistically significant. This potential complementary relationship implies that farmers may adjust their use of labour in response to changes in the availability or price of chemical fertilizer aligned with Meena *et al*. (2010).

Table 4. Estimates of the partial elasticities of substitution

	Labour	Chemical fertilizer	Other inputs	Seed
Labour	-0.1996	-0.2367	0.7633	-0.3901
SE[a]	0.0912	0.0629	0.3392	
t statistics	-2.1898	-3.7613	2.2501	
Chemical fertilizer		-1.8443	2.5450	-2.9815
SE		0.9261	0.4437	
t statistics		-1.9914	5.7355	
Other inputs			-4.0282	2.4102
SE		Symmetric	0.2126	
t statistics			-18.9479	
Seed				0.0523

[a] *Standard error (se) SE (σ_{ij})= SE (γ_{ij})/$S_i S_j$*

Note: The elasticities of substitution are symmetric. The own elasticity of substitution holds minimal economic significance. Table 4 depicted that the calculated t-values are greater than the critical t-values from the T tables, indicating that all the partial elasticities of substitution are statistically significant.

Further, the findings reveals that the substitution elasticity of 0.7633 between labour and other inputs (organic matter, agrochemicals for pest and disease management, machinery costs, and other related costs) which indicates a significant and complementary connection. The organic matter improves soil health, potentially reducing the need for labour-intensive soil amendments. Agrochemicals enhance pest and disease management, diminishing the necessity for manual pest control. Investment in machinery can replace manual labour for soil preparation tasks and manual weeding. These practical implications indicate that increasing investment in these inputs can significantly reduce the demand for manual labour, leading to cost efficiency by lowering labour expenses. Though the absence of standard error and t-statistic details regarding seed related partial elasticities of substitution, potential reasons were mentioned in the paper. The negative partial elasticity of substitution of -0.3901 between labour and seed indicates a complementary relationship between the two inputs. The complementary relationship between labour and vegetable seeds is a result of the involved interplay between crop characteristics, cultivation practices, farm size, market dynamics and etc. The analysis of elasticity of substitution between chemical fertilizer and seeds indicates complementary relationship (Wijetunga, 2016). The elasticity of substitution between chemical fertilizer and other inputs is positive, elastic and significant (2.5450), indicating a substitutable relationship between the two inputs. This means that an increase in the price of chemical fertilizer leads to an increased use of other inputs as substitutes, such as organic matter. Further, the results of the analysis revealed a positive and relatively elastic (2.4102) substitutable relationship between other inputs (organic matter, agrochemicals for pest and disease management, machinery costs and other related costs) and seeds. This suggests that as the price of seeds increases, farmers increase their use of these other inputs to adjust input mix efficiently, when seeds become more expensive, to sustain crop yields and manage costs.

Conclusions

In conclusion, the factor demand elasticity has revealed distinct relationships among inputs, showing varying degrees of responsiveness to changes in input prices in upcountry vegetable cultivation in Sri Lanka. Labour, fertilizer, other inputs, and seeds were found to exhibit differing levels of elasticity, highlighting their unique roles within the production process. Notably, the farm inputs demonstrated an inelastic response, signifying limited responsiveness to price changes. Furthermore, the analysis of partial elasticities of substitution demonstrates that labour is complementary to fertilizer and seed, while substituting for other inputs. Fertilizer, in turn, shows a complementary relationship with seed but serves as a substitute for other inputs. The complementarity between seed and both labour and fertilizer indicate a relatively fixed technological relationship among these inputs. Therefore, the relationships among labour, fertilizer, seeds and other inputs necessitate an integrated approach to input management. This involves ensuring access to improved inputs (for example seeds, fertilizer, agrochemicals and other inputs) which insist labour-saving. Furthermore, the potential for substituting inputs depends on their availability, efficiency and cost- effectiveness.

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