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A Data Envelopment Analysis of Technical Efficiency with Determinants of Apple Growers: Evidence from the Indian Himalayan Region of Himachal Pradesh

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ABSTRACT

Background: Apple cultivation is a key component of the rural economy and ecological sustainability of Himachal Pradesh in the Western Himalayan region. Despite favorable agro-climatic conditions, the state continues to lag behind Jammu and Kashmir in productivity and efficiency, highlighting the need to evaluate orchard performance and identify the socio-economic and climatic factors influencing production efficiency.

Methods: The study evaluates the technical efficiency of apple growers using an input-oriented data envelopment analysis (DEA) under CRS and VRS assumptions. Primary data were collected from apple farmers across the major producing districts of Shimla, Kullu, Mandi and Kinnaur. The efficiency scores obtained from DEA were further analyzed using a tobit regression model to examine the influence of socio-economic, farm and climatic factors.

Result: The findings reveal that a majority of apple orchards operate below the optimal efficiency level, indicating considerable scope for improving resource utilization. Most farms exhibit increasing returns to scale, suggesting that small orchard sizes remain a major constraint. The results also highlight district-level variations in efficiency due to differences in productivity, orchard characteristics and climatic risks. The econometric analysis shows that productivity, land inequality and climatic instability reduce efficiency, while adoption of improved varieties and greater specialization in apple farming enhance production performance.

Key words: Apple growers, Data envelopment analysis (DEA), Technical efficiency, Tobit regression.

INTRODUCTION

Horticulture has become one of the most vibrant aspects of agricultural revolution in the developing economies, which has played a significant role in the rural livelihoods, diversification of income and also in providing nutritional security. The fruits and vegetables offer better economic benefits than the old cereal crops and are important in enhancing the quality of diets and employment in the countryside (NHB, 2024). Horticultural crops in the ecologically delicate mountainous areas also encourage sustainable land use, increase biodiversity and decrease soil erosion. As a result, horticulture is a significant source of rural development in some of the hill states in India, especially those in the Western Himalayan range which include Himachal Pradesh, Jammu and Kashmir and Uttarakhand.

The cultivation of apple (*Malus domestica*) takes a central place in the agricultural economy of the Western Himalayan region among the other horticultural crops. Apple farming is a primary source of income for a major source of revenues and of employment generation many farming households and it is a big source of revenues and generation of employment in the region. Apple farming is a primary source of income and a major contributor to revenue and employment generation for many farming households. The crop is also very adaptive to the agro-climatic conditions of the high-altitude regions that have temperate temperatures, good site conditions and sufficient chilling periods. Apple production is the keystone of the rural economy of Himachal Pradesh and a large portion of the horticultural output. Other than being economic, production of apples also leads to better intake of nutrition since apples are good sources of vital vitamins, minerals and carbohydrates that are used to supplement the diets of communities in the hills. However, apple production and marketing continue to face several constraints, including disease and pest incidence, high production and transportation costs, inadequate technical knowledge and weak marketing infrastructure (Ali and Kachroo, 2023).

Although, the region can be characterized by favorable agro-climatic conditions, the apple industry in Himachal Pradesh has a number of structural issues that curtail the

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productivity and profitability. The land distribution in small fragments, old orchards, rising cost of production and changes in climatic conditions have largely contributed to the inefficiency in the apple production systems. The productivity of the state is relatively lower than the other apple growing areas like Jammu and Kashmir implying that there is a lot of scope of increasing the efficiency of resources use. In this regard, the technical efficiency, which refers to the capacity of the producers to get the highest possible output using the available inputs, becomes very important in increasing farm productivity and sustainability (Farrell, 1957). Economic efficiency goes on to amalgamate both technical and allocative efficiency which measures the best utilization of available resources given the current conditions of production (Yotopoulos and Lau, 1973).

Data envelopment analysis (DEA) has extensively been used as a non-parametric tool to measure production efficiency by considering how efficient a decision-making unit is and this approach does not have restrictive functional assumptions on the production process (Charnes *et al*., 1978). With the adoption of variable returns to scale (VRS) in minimum DEA, by Banker *et al*. (1984), it was possible to differentiate between the pure technical efficiency and the scale efficiency, thus enhancing the performance of farms. DEA has since found extensive use in agricultural economics to assess both production efficiency and resource allocation and the value-chain performance.

A number of empirical tests have used DEA to analyze agricultural production and marketing productivity. Sexton and Lewis (2003) used two-stage DEA to measure the efficiency of production in complex systems and the study has demonstrated the applicability of DEA in the multi-stage production processes. On the same note, Lu (2006) used a value-chain DEA model to vegetable marketing systems and realized that direct marketing arrangements were somewhat less efficient compared to wholesale marketing channels. Ruben *et al*. (2003) proved that the high costs of transactions in supply chains might considerably decrease the efficiency of production and welfare of farmers. Similarly, Kumar (2021) studies on agricultural value chains have emphasized that value chain financing and stronger linkages among stakeholders improve value addition and supply chain efficiency, while Sah *et al*. (2024) highlighted that effective coordination among value chain actors is essential for improving value addition and market performance. Under Indian horticultural marketing, Guleria *et al*. (2022) found that some marketing channels are found to be more effective in enhancing the marketing performance of the apple growers in Himachal Pradesh. According to more recent research, technological adoption, institutional arrangements and market integration are also said to contribute to agricultural productivity and efficiency improvement (Afdhal and Heppi, 2024; Kweh *et al*., 2024).

Despite growing research on agricultural efficiency, empirical evidence on the technical and scale efficiency of apple orchards in the Western Himalayan region remains limited, particularly at the farm level. Most existing studies focus on production trends or marketing efficiency rather than the efficiency of orchard production systems. Moreover, the role of farm characteristics, socio-economic conditions and climatic risks in determining orchard efficiency has received relatively little attention.

The present study was undertaken with two major objectives. First, to estimate the technical and scale efficiency of apple orchards in Himachal Pradesh using data envelopment analysis (DEA) under constant returns to scale (CRS) and variable returns to scale (VRS) assumptions. Second, to examine the influence of socio-economic, farm-level and climatic factors on orchard efficiency through Tobit regression analysis. On the basis of these objectives, the study also attempts to suggest suitable policy implications for improving productivity, resource utilization and sustainability in apple cultivation in the Western Himalayan region.

MATERIALS AND METHODS

Sampling

The study was conducted during 2025 as part of the PhD work at the Central University of Himachal Pradesh. A multi-stage random sampling method was used to select respondents for the study on apple growers in Himachal Pradesh. In the first stage, four districts-Kinnaur, Kullu, Mandi and Shimla-were selected, as these districts accounted for nearly 96 per cent of the total apple production and 85 per cent of the total area under apple cultivation in Himachal Pradesh (Department of Economics and Statistics, 2022-23). In the second stage, two blocks were selected from each district based on apple-growing intensity and relevance to the study. In the third stage, villages were selected from each block and in the final stage, 15 farmers were selected randomly from each selected village. Overall, 240 farmers were surveyed from 16 villages and 8 blocks. The sample size was considered adequate as it represented the major apple-growing regions of the state and captured variations in production and marketing conditions, thereby ensuring the reliability and representativeness of the study findings.

DEA

Data envelopment analysis (DEA) is a non-parametric technique used to evaluate the relative efficiency of production units, referred to as decision-making units (DMUs). In an input-oriented approach, efficiency is improved by minimizing inputs while maintaining the same level of output, whereas the output-oriented approach focuses on maximizing output with given inputs (Ferdous *et al*., 2008). DEA commonly employs two models: Constant returns to scale (CRS) and variable returns to scale (VRS). The CRS model assumes that firms operate at an optimal scale, while the VRS model accounts for scale inefficiencies (Huguenin, 2012). In this study, input-oriented CRS and VRS models were applied to evaluate the technical efficiency of apple orchards.

In this study, each apple orchard is treated as a decision-making unit (DMU). Let there be n DMUs, each using m inputs to produce s outputs. The notation used in the DEA models is defined as follows:

- x_{ij}= Quantity of input i used by DMU j.
- y_{rj}= Quantity of output r produced by DMU j.
- λ_j= Intensity variable or weight assigned to DMU j.
- θ= Technical efficiency score.
- S_i^-= Input slack variable.
- S_r^+= Output slack variable.
- ε= Non-archimedean infinitesimal constant.

CRS input-oriented DEA model:

$$\text{Min } \theta - \varepsilon \left[\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+ \right]$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j + S_i^- = \theta\, x_{10},\ i = 1,2,....,m$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - S_r^+ = y\, r_0,\ r = 1,2,....,s$$

$$\lambda_j,\ S_i^-,\ S_r^+, \geq 0,\ j = 1,2,...,n$$

The CRS model measures the overall technical efficiency of each DMU under the assumption that farms operate at an optimal production scale.

VRS input-oriented DEA model:

$$\text{Min } \theta - \varepsilon \left[\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+ \right]$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j + S_i^- = \theta\, x_{10},\ i = 1,2,....,m$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - S_r^+ = y\, r_0,\ r = 1,2,....,s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j,\ S_i^-,\ S_r^+, \geq 0,\ j = 1,2,...,n$$

The additional convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$. The additional convexity constraint allows the VRS model to account for scale inefficiencies and estimate pure technical efficiency independently of farm size.

Scale efficiency

Scale efficiency (SE) was estimated to determine whether inefficiency arises from managerial performance or from operating at a non-optimal scale. Scale efficiency is calculated as:

$$SE = \frac{TE_{CRS}}{TE_{VRS}} \quad ....(1)$$

Where,

- TE_{CRS}= Technical efficiency under CRS assumptions.
- TE_{VRS}= Technical efficiency under VRS assumptions.

A firm operates at the optimal scale when scale efficiency equals one; otherwise, it indicates scale inefficiency (Altaie, 2022).

Table 1 presents the input and output variables used in the data envelopment analysis (DEA) to measure the efficiency of apple orchards. The input variables include land size, pre-harvesting cost, age of trees, post-harvesting cost, total number of trees and sale rate, while the outputs are the quantity of apple produced and the total value of apples sold.

A second-stage tobit regression analysis was conducted to examine the influence of socioeconomic and farm-specific factors on technical efficiency. The efficiency scores obtained from the first-stage DEA (CRS and VRS models) were regressed against farm and farmer characteristics. Such two-stage approaches are widely used to understand how demographic and institutional variables affect efficiency outcomes (Hoff, 2007; Simar and Wilson, 2007). Among the available methods, Tobit regression is considered more appropriate than OLS because efficiency scores are bounded between 0 and 1 and exhibit censored characteristics (Tobin, 1958; Wooldridge, 2012). Therefore, in this study, Tobit regression was employed to identify the socioeconomic determinants influencing the technical efficiency of apple orchards, following the approach used in previous efficiency studies (Zongli *et al*., 2017).

$$TE_{CRS} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... + \beta_{12} X_{12} + \varepsilon_i \quad ...(2)$$

$$TE_{VRS} = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + ... + \alpha_{12} X_{12} + \varepsilon_i \quad ...(3)$$

$$TE_{SE} = \mu_0 + \mu_1 X_1 + \mu_2 X_2 + \mu_3 X_3 + ... + \mu_{12} X_{12} + \varepsilon_i \quad ...(4)$$

Equations (2)-(4) represent the tobit regression models used to examine the determinants of efficiency. Here, TE_{CRS}, TE_{VRS} and TE_{SE} denote the technical efficiency scores under constant returns to scale (CRS), variable returns to scale (VRS) and scale efficiency (SE), respectively. Each efficiency score is modelled as a function of 12 explanatory variables (X_1-X_{12}) with corresponding coefficients and an intercept term. Since efficiency scores are bounded between 0 and 1, tobit regression is applied to estimate the effect of these variables on the efficiency levels of apple orchards.

Table 2 shows the description of variables used in tobit regression models for technical efficiency analysis. It also explains variety of apple the measurement and unit of the variables.

RESULTS AND DISCUSSION

Efficiency estimation

Table 3 shows the technical efficiency of the apple orchards in the CRS and VRS assumptions and scale efficiency within the selected districts of Himachal Pradesh. The findings indicate that there exists a great deal of differences in the efficiency levels across districts.

Kinnaur shows the best results of all efficiencies with mean CRS, VRS and scale efficiency scores of 0.92, are near the production frontier 0.95 and 0.97 respectively and low variability. It means that most orchards in Kinnaur are near the production frontier and near-optimal scale, possibly due to a favourable agro-climatic environment, a comparatively large size of orchards and superior resource management.

Conversely, Shimla has the least CRS (0.69) and scale efficiency (0.77) with a high degree of variability, indicating that there are high levels of inefficiency between orchards. Such inefficiencies can be linked with increased input expenses, old age orchards and being prone to climatic hazards. The degree of efficiency in Kullu and Mandi is moderate and the VRS scores are much higher than the CRS scores, which means that the managerial practices are relatively efficient, but orchards do not work in full scale.

On the state level, the CRS efficiency (0.67) is significantly low compared to the VRS efficiency (0.88), which gives a scale efficiency of 0.75. Such a significant

Table 1: Input and output variables for DEA.

Input/output	Variables	Measurement
Input	land size	in ha
	Pre-harvesting cost	in Rs
	Age of trees	in years
	Post harvesting cost	in Rs
	Total number of trees	in numbers
	Sale rate	Rs per boxes
Output	Quantity of apple produce	in boxes.
	Total value of sold apple	in Rs

Source: Author's compilation.

Table 2: Description of variables used in tobit regression models for technical efficiency analysis.

Variable	Description	Measurement	Unit
X1	Occupation	0 = Self-employed (Non-farm), 1 = Apple farming, 2 = Government service, 3 = Retired/pensioner, 4 = Mixed farming	Categorical
X2	Average age of trees	Average age of apple trees in the orchard	In years
X3	Total area under apple cultivation	Total cultivated area under apple orchards	Hectares
X4	Variety of apple	1 = Traditional, 2 = Average (Royal), 3 = Hybrid (Spur)	Categorical
X5	Harvesting period (related to altitude)	1 = Jul-Aug (Low Altitude), 2 = Aug-Sep (Mid altitude), 3 = Sep-Oct (Semi-high altitude), Oct-Nov (High altitude)	Categorical
X6	Productivity	Orchard productivity level	Boxes per hectare
X7	Age of grower	Age of orchard owner	In years
X8	Family members	Total number of family members	In numbers
X9	Type of family	0 = Joint family, 1 = Nuclear family	Binary
X10	Education	Educational attainment of farmer	Years of schooling
X11	Chilling hours	Total winter chilling hours below 7°C	Number of hours
X12	Hailstorm occurrence	Occurrence of hailstorm during production season	0 = No, 1 = Yes

Source: Author's compilation.

Table 3: Technical and scale efficiency of apple orchards in selected districts of Himachal Pradesh.

District	CRS		VRS		Scale	
	Mean (SD)	Minimum	Mean (SD)	Minimum	Mean (SD)	Minimum
Kinnaur	0.92 (0.06)	0.81	0.95 (0.05)	0.83	0.97 (0.02)	0.88
Kullu	0.77 (0.17)	0.44	0.90 (0.10)	0.65	0.86 (0.14)	0.44
Mandi	0.78 (0.13)	0.46	0.93 (0.08)	0.73	0.83 (0.13)	0.46
Shimla	0.69 (0.18)	0.41	0.89 (0.10)	0.64	0.77 (0.15)	0.51
Overall (State average)	0.67 (0.21)	0.3	0.88 (0.10)	0.61	0.75 (0.19)	0.35

Source: Author's compilation.

difference in CRS and VRS efficiency implies that scale inefficiency is one of the prevailing channels of productivity losses in the production of apples in Himachal Pradesh. The large variation of the efficiency scores also shows that a lot can be done in enhancing the resource use especially through increasing the size of the orchard enterprise and making the farms more organized.

Table 4 shows the district wise comparison of efficiency estimation. These results show significant regional variations in efficiency and scale performance. Mandi has the largest proportion of orchards operating under increasing returns to scale (82%), which means the fact that it has a strong management and can gain by increasing the production scale. Kinnaur is also an efficient performer and most orchards have a high level of CRS and VRS efficiency, indicating the good use of resources and working at the optimum scale. On the other hand, Kullu has medium technical efficiency and low scale efficiency, which could be improved by means of improved resource allocation and extension of orchards. Shimla has the worst efficiency with most orchards working below the optimum scale despite the good management of inputs.

Determinants of efficiency

Table 5 presents the tobit regression estimates for the determinants of apple orchard efficiency under constant returns to scale (TE_{CRS}), variable returns to scale (TE_{VRS}) and scale efficiency (TE_{SE}). The coefficient indicates the effect on the underlying efficiency score, while the marginal effect represents the change in the observed efficiency level and is therefore easier to interpret. A positive and statistically significant coefficient implies that the variable increases orchard efficiency, whereas a negative coefficient indicates a reduction in efficiency. Tobit regression is particularly suitable in this context because the efficiency scores are bounded between zero and one.

For TE_{CRS}, the significant positive determinants include apple farming (at 10%), total area under apple cultivation (at 1%), hybrid/spur variety (at 5%), productivity (at 1%) and chilling hours (at 10%). This indicates that larger orchard size, higher productivity, improved apple varieties and favorable chilling conditions contribute positively to constant-returns technical efficiency. In contrast, hailstorm occurrence has a negative and strongly significant effect, suggesting that hail damage substantially reduces orchard efficiency.

For TE_{VRS}, the important positive determinants are government service (at 10%), productivity (at 1%), age of grower (at 1%) and chilling hours (at 5%). The positive effect of grower age may reflect greater farming experience and managerial capability among older orchardists. On the other hand, the average age of trees has a significant negative effect, implying that older orchards tend to be less efficient under VRS. Similarly, the harvesting periods Jul-Aug, Aug-Sep and Sep-Oct show negative and significant coefficients compared to the base category of Oct-Nov high-altitude harvesting, indicating lower efficiency among orchards harvesting earlier than the main harvesting period. The harvesting period is closely associated with climatic conditions, as temperature variations affect flowering and fruit maturity, resulting in either earlier or delayed harvesting. Hailstorm occurrence also has a negative and statistically significant effect on TE_{VRS} efficiency.

For TE_{SE}, the strongly positive determinants are average (Royal) variety, hybrid (Spur) variety, total area under apple cultivation and productivity, all of which improve scale efficiency compared to traditional varieties and smaller orchards. In contrast, age of grower and hailstorm occurrence are significantly negative, implying that older growers and orchards affected by hailstorms tend to be less scale-efficient. The harvesting-period variables for Aug-Sep and Sep-Oct are also strongly negative compared to the base category, indicating lower scale efficiency among orchards harvesting outside the Oct-Nov high-altitude harvesting period.

Overall, the findings suggest that productivity, larger orchard area, improved apple varieties and adequate

Table 4: Comparison of efficiency and returns-to-scale across districts.

Indicator	Kinnaur	Kullu	Mandi	Shimla
Increasing returns to scale	57%	72%	82% (Highest)	78%
Decreasing returns to scale	3%	5%	1%	0%
CRS efficiency-majority range	0.91-0.99	0.71-0.90	0.71-0.90	0.51-0.70
CRS fully efficient (=1)	Moderate	Moderate	Good	Good
VRS efficiency-majority range	0.91-0.99	0.71-0.90	0.91-0.99	0.71-0.90
VRS fully efficient (=1)	High	Moderate	High	High
Scale efficiency-majority range	0.91-0.99	0.71-0.90	0.71-0.90	0.50-0.70
Scale efficiency (=1)	High	Moderate	Good	Moderate
Overall interpretation	Strong technical and scale performance with high near-efficiency	Moderate efficiency, more variation, scope to improve scale	Strongest efficiency overall (VRS+scale + IRS%)	Good technical performance, but larger proportion in mid-efficiency scale categories

Source: Author's compilation.

Table 5: Determinants of apple orchard efficiency in Himachal Pradesh: Tobit regression results.

Dependent variable	TE_{CRS}		TE_{VRS}		TE_{SE}	
Independent variables	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient	Marginal effect
Occupation (Base: Non-farm self-employment)						
Apple farming	0.066* (0.038)	0.057* (0.033)	0.039 (0.031)	0.031 (0.026)	0.055 (0.036)	0.047 (0.031)
Government service	0.051 (0.044)	0.044 (0.038)	0.081* (0.043)	0.060* (0.032)	0.019 (0.041)	0.016 (0.036)
Retired/pensioner	0.042 (0.072)	0.036 (0.063)	0.012 (0.052)	0.010 (0.042)	0.049 (0.066)	0.042 (0.057)
Mixed farming	0.049 (0.044)	0.043 (0.038)	0.048 (0.040)	0.038 (0.031)	0.044 (0.039)	0.038 (0.034)
Occupation category 5	0.089 (0.072)	0.077 (0.062)	0.048 (0.058)	0.037 (0.044)	0.088 (0.075)	0.075 (0.062)
Average age of trees	0.001 (0.001)	0.001 (0.001)	-0.003*** (0.001)	-0.003*** (0.001)	0.003*** (0.001)	0.003*** (0.001)
Total area under apple cultivation	0.003*** (0.001)	0.003*** (0.001)	-0.001 (0.001)	-0.001 (0.001)	0.004*** (0.001)	0.004*** (0.001)
Variety (Base: Traditional)						
Average (Royal)	0.035 (0.030)	0.031 (0.026)	-0.011 (0.024)	-0.009 (0.018)	0.055** (0.026)	0.048**(0.023)
Hybrid (Spur)	0.067** (0.032)	0.058** (0.028)	0.002 (0.029)	0.001 (0.021)	0.091*** (0.028)	0.078*** (0.025)
Harvesting period (Base: Oct-Nov high altitude)						
Jul-Aug (Low altitude)	-0.043 (0.036)	-0.036 (0.030)	-0.062** (0.028)	-0.036** (0.016)	0.006 (0.030)	0.004 (0.023)
Aug-Sep (Mid altitude)	-0.240*** (0.034)	-0.213*** (0.030)	-0.163*** (0.028)	-0.115*** (0.018)	-0.160*** (0.030)	-0.139*** (0.025)
Sep-Oct (Semi-high altitude)	-0.264*** (0.038)	-0.234*** (0.034)	-0.141*** (0.031)	-0.097*** (0.022)	-0.196*** (0.032)	-0.173*** (0.028)
Productivity	0.004*** (0.0004)	0.003*** (0.0003)	0.002*** (0.0003)	0.001*** (0.0002)	0.003*** (0.0003)	0.003*** (0.0003)
Age of grower	-0.001 (0.001)	-0.001 (0.001)	0.002*** (0.001)	0.001*** (0.001)	-0.002** (0.001)	-0.002** (0.001)
Family members	-0.001 (0.005)	-0.001 (0.004)	0.001 (0.004)	0.001 (0.003)	0.001 (0.004)	0.001 (0.004)
Type of family	-0.035 (0.028)	-0.030 (0.024)	-0.005 (0.024)	-0.004 (0.020)	-0.022 (0.024)	-0.019 (0.020)
Education	0.008 (0.024)	0.007 (0.020)	0.014 (0.022)	0.010 (0.016)	0.000 (0.020)	0.001 (0.017)
Chilling hours	0.028* (0.016)	0.024* (0.013)	0.029** (0.013)	0.022** (0.010)	0.017 (0.013)	0.014 (0.011)
Hailstorm occurrence	-0.083*** (0.026)	-0.071*** (0.022)	-0.034* (0.020)	-0.025* (0.015)	-0.057*** (0.022)	-0.048*** (0.018)

***; ** and * Significant at 1%, 5% and 10%.

Source: Author's compilation.

chilling hours enhance orchard efficiency, whereas hailstorm incidence, older orchards and harvesting outside the usual harvesting period reduce efficiency.

CONCLUSION AND POLICY IMPLICATION

The findings indicate that scale inefficiency is the primary limitation in apple production in Himachal Pradesh since the difference between CRS (0.67) and VRS (0.88) efficiency scores is very wide and therefore, most of the orchards are working below the optimal scale. Kinnaur has the highest efficiency which is backed by the bigger size of orchard, less land inequality, constant chilling hours and reduced cost of inputs, as Shimla exhibits the least efficiency in terms of old-fashioned orchards, high cost of inputs and high risks of climate. Further results of the DEA indicate that 80 per cent of the farmers are experiencing the increasing returns to scale, which implies that there is a good prospect of high gains on the growth size of orchard. The findings of the Tobit regression prove that adoption of hybrid variety and full-time farming positively affect efficiency whereas excess input costs, land inequality and climatic instability have negative effects on efficiency.

These conclusions also suggest that the optimal way of enhancing efficiency is through policies that aim at reducing costs, increasing scale and adapting to the climate. The input subsidies, cooperative farming, land-pooling and a stronger farmer producer organizations (FPO) can all contribute to the decrease in the cost of production and economies of scale. High-density and hybrid varieties, climate-resistant practices, hail nets, micro-irrigation and crop insurance can be encouraged to overcome the challenges of climate change. Income of farmers can be increased by strengthening marketing channel, decreasing reliance on commission agent and value addition by grading, storage and processing. Also, orchard management and decision-making are possible through training programs and computerized advisory systems. The combination of these will help achieve a more sustainable, competitive and resilient apple economy in Himachal Pradesh.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript. All authors have read and approved the final version of the manuscript and agree with its submission for publication.

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