Measuring the Overall Efficiency of the Sugar Supply Chain in Iran

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ABSTRACT

The sugar industry has many backward and forward linkages in the supply chain. In this industry, a chain of agricultural, industrial, oil, transportation, and commerce sectors is engaged to transform raw materials into product and shipping it to consumers. In this research, the efficiency of decision-making units in Iran's sugar supply chain is evaluated using network and simple Data Envelopment Analysis methods. Results of the first level of decentralized sugar supply chain in Iran (extraction of sugar from sugar beets) indicate that the average technical efficiency in terms of a constant return to scale and the allocation, economic, and scale efficiency are not at appropriate levels. In the second level of supply chain, weakness was observed in allocative and economic efficiency. The results showed that the Provinces of West Azerbaijan and Khorasan-e Razavi offer desirable conditions for sugar beet production in terms of efficiency. Supply chain management has been used as a tool for timely delivery of the product to market at a lower cost to increase the efficiency of the entire sugar supply chain. A move toward vertical integration in sugar production is also proposed to benefit integration.

INTRODUCTION

Sugar beets and sugar cane are the main raw materials of sugar production. The varied climates of Iran are appropriate for both sugar beet and sugar cane cultivation. After cereals, most global agricultural trades involve sugar, which is a basic and strategic product (Al-Nabi Amelishi *et al.*, 2013).

The raw materials of the supply chain are provided by the agricultural and import sectors. The most important step in the production of sugar is the provision of its initial inputs (sugarcane and sugar beets). Thus, the sugar industry is strongly dependent on the agricultural sector. Other products are also obtained from the sugar industry. Molasses and pulp have been introduced as inputs for animal feed and alcohol and bagasse production as inputs for MDF, paper, and feed production (Toloui *et al.*, 2013).

Sugar production in 2018 was 1,403,145 tons in Iran, while consumption was 1,684,145 tons per year. Iran's per capita sugar consumption is 6 times more than the world average (28 kg yr^{-1}), which indicates that domestic production cannot provide all of the country's need, and the rest should be provided by 823,000 tons of imports (Iranian Sugar Association, 2018).

This industry, with 100 years of experience and presence of 35 units of sugar factory (26 units using sugar beet and 9 units using sugarcane), has a significant part of the workforce in the agriculture, industry, commerce and services sectors. Sugar production has a special place in political and economic issues and has a particular

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importance in the consumer basket of households and industries in different countries (Toloui *et al.*, 2013).

Sugar beets, sugar cane and sugar production can be defined in the supply chain. In the first ring of this chain, the sugar cane and beets are supplied by the agriculture sector. In the second ring, the sugar is extracted and the raw sugar is refined.

The objective of supply chain management is to minimize costs throughout the chain and satisfy customer needs. Performance evaluation of supply chain system is the objective. Chain systems can be considered as an input-output system where every member of the chain provides inputs to the product. Consequently, performance-measuring criteria can be divided into inputs and outputs. The classification of outputs and inputs should be done accurately because incorrect classification can create bias in performance evaluation (Chen *et al.*, 2011).

Among many evaluation methods, Data Envelopment Analysis (DEA) has been widely used to calculate the relative performance of a set of producers or processors called Decision Making Units (DMU). DEA is an effective method for estimating trade off curves and measuring the relative efficiency of producing pairs when there are multiple performance criteria. Methods for accurate estimation of the performance of a chain have been developed and are called DEA (Cheung and Hansman, 2000).

Improving the performance of chain-members is the most efficient way to provide cost-competitive production of vegetable oil. However, the lack of an appropriate performance measurement system is a major barrier to effective supply chain management (Lee and Billington, 1992).

In general, decisions in the supply chain take place in a centralized and decentralized manner. In a centralized control system, the supply chain is supervised by a single decision-maker who can arrange both supplier and manufacturer operations to maximize the efficiency of the whole supply chain. In a decentralized control system, there is no "super" decision-maker to control all the divisions. Each division has its own incentives and strategies and tends to pursue its own interests (Chizari and Fehresti-Sani, 2018).

The decision-making units in the Iranian sugar supply chain are managed by decentralized (sugar beet sector) and centralized (sugarcane sector) mechanisms. Producers of sugar beet in different provinces focus on their own goals and policies and either is not controlled or is controlled by a general ledger system. Therefore, the supply chain flows from sugar beet harvesting to sugar beets as a decentralized supply chain.

In the economic literature, over the past decade, a number of studies have developed different conceptualizations and research methods to investigate supply chains. Some of the optimization techniques employed in different studies were based on different criteria including cost minimization (Camm *et al.*, 1997), inventory levels (Altiok and Ranjan, 1995), profit maximization (Cohen and Lee, 1989), fill rate (Lee and Billington, 1993), product demand variance (Newhart *et al.*, 1993), and system capacity (Voudouris, 1996).

Many studies have done Network Data Envelopment Analysis (NDEA) on the supply chain to measure overall efficiency. It can be seen that most studies in the supply chain and the application of DEA to the supply chain have been conducted in the industrial sector and few have been conducted on the agricultural sector. Most studies on the application of the DEA in the supply chain provide only a numerical sample of the model results, such as in Chen and Yan (2011), Kao and Hwang (2008), Mishra (2012) and Krmac and Djordjević (2019). However, a few studies have gathered and analyzed real data in the supply chain (using Network DEA in supply chain), e.g. efficiency for export of frozen vegetables (Chaowarat and Shi, 2013),

performance evaluation of supply chain in the Iranian Pharmaceutical Industry (Ebrahimpour Azbari *et al.*, 2014), in the vegetable oil supply chain (Chizari and Fehresti-Sani, 2018), and Public Pharmaceutical Products Supply chains (Berrado and Benabbou, 2019).

A review of the literature shows that no research has been done to measure the overall efficiency of the sugar supply chain. Considering the importance of the agricultural sector and importance of sugar products in the consumer basket of Iranian households, the present study used real sugar beet data in the agricultural and industrial sector to evaluate single-level and two-level efficiency in the sugar supply chain.

MATERIALS AND METHODS

Methods

One common nonparametric method for measuring efficiency is DEA, which was first proposed by Farrell (1957). Charnes *et al.* (1978) provided supplementary content on this approach (Silva *et al.*, 2017). Technical efficiency based on DEA, which is a linear programming method, is calculated as follows:

$$\theta^* = \min \theta \tag{1}$$

$$s.t. \quad \sum_{j=1}^{j} \lambda_j x_{ij} \leq \theta \, x_{ij0} \tag{2}$$

$$\sum_{j=1}^{j} \lambda_j y_{rj} \geq y_{rj0} \tag{3}$$

Where, x_{ij} is amount of input i, y_{rj} is amount of output r and λ_j is Weight of reference set of output in DMUj. The y_{rj0}'s, x_{ij0}'s and θ are the observed output and input values and efficiency index of DMU_0 (the DMU to be evaluated) respectively.

If $\theta^* = 1$, according to Farrell's theory, the firm has a relative efficiency of 100% (Elhendy and Alkahtani, 2013). For variable returns to scale, technical efficiency can be divided into scale and management efficiency. The Variable Returns to Scale (VRS) model can be derived by adding constraint of Equation (7) to the Constant Returns to Scale (CRS) model (Equations 4 to 7).

$$\theta^* = \min \theta \tag{4}$$

$$s.t. \quad \sum_{j=1}^{j} \lambda_j x_{ij} \leq \theta \, x_{ij0} \tag{5}$$

$$\sum_{j=1}^{j} \lambda_j y_{rj} \geq y_{rj0} \tag{6}$$

$$\sum_{j=1}^{j} \lambda_j = 1 \tag{7}$$

If there is a difference between the technical efficiency values for constants and variables, there is inefficiency in the scale. Scale efficiency can be obtained as follows:

$$SE = \frac{TE_{CRS}}{TR_{VRS}} \tag{8}$$

Where, SE is the Scale Efficiency, TE_{CRS} and TR_{VRS} are the Technical Efficiency derived from the CRS efficiency model and from the VRS efficiency model, respectively.

The scale efficiency denotes the correct utilization of each input as derived from the technical efficiency ratio in the CRS state divided by the management efficiency (net technical efficiency) in terms of the VRS (Elhendy and Alkahtani, 2013). If price information is also available and the goal of the firm is to maximize profits, measurement of the allocative efficiency in addition to measurement of technical efficiency is possible. In order to measure the allocative efficiency in the DEA, the model first should be implemented as follows:

$$\min \sum_{i=1}^{m} c_{ij0} x_i \tag{9}$$

$$s.t. \quad x_i \geq \sum_{j=1}^{n} x_{ij} \lambda_j \quad i = 1,2,3,...,m \tag{10}$$

$$y_{rjo} \leq \sum_{j=1}^{n} y_{rj}\lambda_j$$
$$\lambda_j \geq 0 \qquad j = 1,2,3,...,t \qquad (11)$$

Where, c_{ij0} is the cost of each unit of the ith input of the DMU_{j0}. The economic efficiency of DMU_{j0} is calculated as Equation (12):

$$EE = \frac{C_{ij0}x'_{ij0}}{C_{ij0}x_{ij0}} \qquad (12)$$

This ratio represents the minimum cost per observed cost. In order to calculate the Allocative Efficiency (AE), Economic Efficiency (EE) can be divided by the Technical Efficiency (TE) as in Equation (13):

$$AE = \frac{EE}{TE} \qquad (13)$$

The allocative efficiency criterion reflects the shortcomings that result from inappropriate allocation of the inefficient input costs (Emami Meybodi, 2000). Most of the time, DEA compares single-level decision-making units in the supply chain with the chain operation of the decision-making units as its basis. The output of and input to the lower level in the supply chain affects the performance of the higher level. In this regard, studies related to the efficiency of the supply chain have introduced Network Data Envelopment Analysis (NDEA). One objective of the current research is to measure the overall supply chain efficiency of sugar in Iran using the NDEA. Appropriate efficiency measurement for the supply chain should be designed to take into account network characteristics and internal relationships (Chen and Yan, 2011). This model predicts intermediate relations between decision-making units and allows consideration of the complex decision-making unit with multiple nodes (Bogetoft *et al.*, 2009).

Decision-making units can also have a two-stage structure in which decision-making is a two-stage process with middle values. By using inputs in the first step of chain, the outputs of the first stage, called intermediate values, are obtained. The middle values are used in the second process to produce outputs. The main characteristics of this structure are that the outputs of the first stage are only the inputs of the second stage (Kao and Hwang, 2008). Figure 1 shows a simple supply chain.

The supply chain shown in Figure 1 consists of one manufacturer and supplier of raw materials with initial input (X), final output (Z) and intermediate value (Y) in the supply chain.

Figure 2 shows the two-stage supply chain (supplier-producer), where S and M are the supplier and manufacturer, respectively, of the supply chain, X is the input vector and Y^1 and Y^2 are the output vectors of the supplier and also are input vectors of the manufacturing stage. Z^1 and Z^2 are output vectors of M1 and M2, respectively. For intermediate values, it should be ensured that the surface taken as input from manufacturer M must not be larger than the output of section S.

Decision-making in the supply chain should either be centralized or decentralized mechanisms in which the difference in how the management affects chain efficiency and the method for calculating and comparing the performance of the chain members
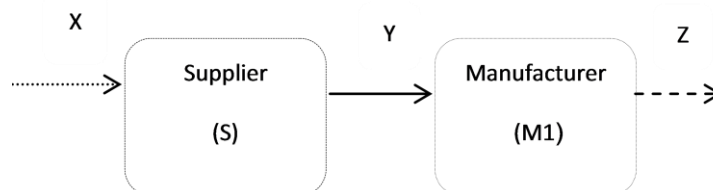

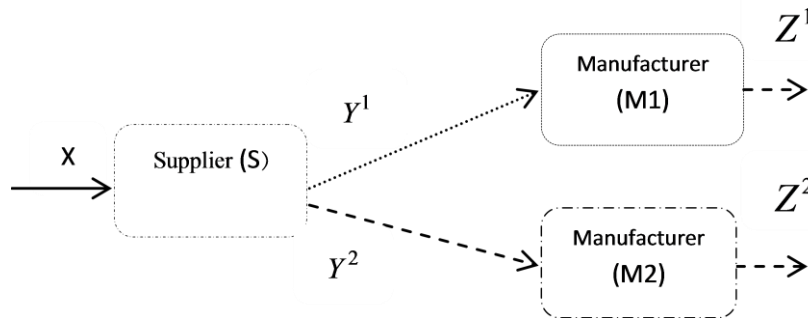**Figure 1.** Simple supplier–manufacturer supply chain.

Figure 2. Two steps supplier–manufacturer supply chain.

differs (Chen and Yan, 2011).

The most important step in the production of sugar is the provision of the initial inputs (sugar beets or cane). The sugar industry strongly depends on the agricultural sector, and the factors effecting the cultivation of these products directly affect the industry and related sectors. In the sugar supply chain, the direct outputs include sugar, molasses and bagasse. Sugar production from sugar beets in Iran is done by 26 factories that operate in different provinces. Each has its own goals and desires to optimize and maximize efficiency to make a profit. The current study, evaluates the industry using a decentralized supply chain based on the data and information gathered from the Statistics Center of Iran.

The efficiency of the supply chain in a two-stage situation has been examined when raw sugar produced from sugar beet extraction is transformed into sugar in factories. Figure 3 shows the relationship between the sugar beet producer and two sugar factories of a model of the two-level supply chain. The figure shows that, in the first level of the sugar supply chain, direct inputs of labor, land, chemical fertilizer, chemical pesticides, and seed are used to produce sugar beet. Sugar beets produced in each province are delivered to one of the two sugar refineries. At this level, sugar beets delivered to sugar refineries are considered to be the intermediate input.

Sugar refineries use this intermediate input by the use of the direct inputs of labor and capital to extract and refine sugar. These factories will eventually provide sugar to the consumer market and molasses and pulp to the timber industry, animal feed, and other industries as needed. Accordingly, the model of technical efficiency of the two-level
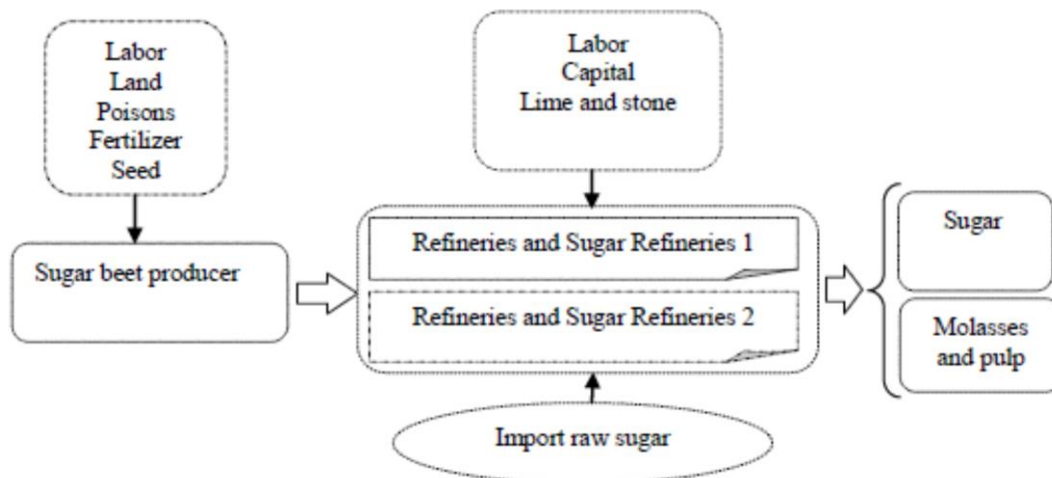

Figure 3. Decentralized supply chain of Iran (sugar beet).

decentralized supply chain can be written as a model. In this model:

$$\theta_{decentralized}^{*} = \min \theta_{decentralized} \quad (14)$$

$$s.t. \quad \sum_{j=1}^{j} \alpha_j x_{ij} \leq \theta_{discentral} x_{ij0} \quad (15)$$

$$\sum_{j=1}^{j} \beta_{\alpha_j} y_{ij} \leq \theta_{discentral} y_{ij0} \quad (16)$$

$$\sum_{j=1}^{j} \beta_{bj} Z_{ij} \leq \theta_{discentral} Z_{ij0} \quad (17)$$

$$\sum_{j=1}^{j} \beta_{\alpha_j} \omega_{ah} \geq \omega_{a_h0} \quad (18)$$

$$\sum_{j=1}^{j} \beta_{b_j} \omega_{b_{hj}} \geq \omega_{b_{hj0}} \quad (19)$$

$$\sum_{j=1}^{j} \alpha_j F_j \geq \sum_{j=1}^{j} \beta_{\alpha_j} F_{j0} \quad (20)$$

$$\sum_{j=1}^{j} \alpha_j L_j \geq \sum_{j=1}^{j} \beta_{b_j} L_j \quad (21)$$

$$\sum_{j=1}^{j} \beta_{\alpha_j} F_j \leq F_{j0} \quad (22)$$

$$\sum_{j=1}^{j} \beta_{b_j} L_j \leq L_{j_0} \quad (23)$$

$$\alpha_{j_0}, \beta_{\alpha_j}, \beta_{b_j} \geq 0 \quad j = 1, 2, ..., n \quad (24)$$

In this model:
Where,

$\theta_{central}, \theta_{discentral}$ Efficiency of centralized and decentralized supply chain.

x_{ij}, x_{ij0} Amount of ith input of sugar beet production units in chain j and actual amount in investigation chain.

y_{ij}, y_{ij0} Amount of ith direct input of first sugar refining plant in chain j and actual amount in investigation chain.

z_{ij}, z_{ij0} Amount of ith direct input of second sugar refining plant in chain j and actual amount in investigation chain.

$\omega_{\alpha_h}, \omega_{\alpha_{h0}}$ Amount of hth direct output of first sugar refining plant in chain j and actual amount in investigation chain.

$\omega_{b_{hj}}, \omega_{b_{hj0}}$ Amount of hth direct output of second sugar refining plant in chain j and actual amount in investigation chain.

F_j, F_{j0} Amount of sugar beet delivered to first sugar refining plant in chain j and actual value in target chain.

L_j, L_{j0} Amount of sugar beet delivered to second sugar refining plant in chain j and actual value in target chain.

$\alpha_j, \beta_{\alpha_j}, \beta_{b_j}$ Weights of reference set of sugar beet production units and sugar refining plants.

All assumptions that are considered in the data envelopment analysis method for decision-maker units are also dominant for NDEA method. Indeed, DEA is a powerful performance measurement and benchmarking tool for applications where the evaluated "Decision-Making Units" (DMUs) are described by activities representing real processes that generate products or services and are based on a convex (or even linear) technology. The first to third constraints (inequalities 15 to 17) are considered to be input restrictions, the fourth and fifth constraints (inequalities 18 and 19) are considered to be output constraints, and the sixth to ninth constraints (inequalities 20 and 23) are considered to be the intermediate input-output constraints in the calculation of supply chain efficiency.

Constraints 15 to 19 in the set of model constraints ensure the inputs of sugar beet production units and sugar refining units in the supply chain. By assigning the weight of the reference set to all inputs and outputs in all chains for the specified output quantities, the inputs in the investigated chain are minimized. Constraints 20 and 21 are common to both centralized and decentralized control models. For example, constraint 20 guarantees that modifications in the amount of sugar beets supplied to the first refining and processing plant (F) based

on the weight of the reference set allocated to sugar refineries is not greater than the adjustments based on the weight of the reference set associated with the sugar beet production unit.

Constraints 22 and 23 relate to the decentralized model and consider real value F_j, L_j as a limitation. For example, constraint 22 ensures that the total amount of sugar beets transferred from the sugar beet production units to the first refining and processing plant (F) is less than or equal to its actual amount in the chain. In this model, the initial value of the inputs used along the chain is minimized to fit the final product level and determines the weights of reference sets $\alpha_j, \beta_{\alpha_j}, \beta_{b_j}$, which are the limits related to intermediate products. Using this template, the decentralized technical efficiency of the supply chain is calculated.

In this study, in order to calculate the overall efficiency of the sugar supply chain of Iran, data and information on the agricultural production costs statistics from the Statistics Center of Iran and Sugar Association of Iran for the whole country were analyzed using GAMS software.

RESULTS AND DISCUSSION

In the first level of the sugar supply chain, ten provinces that produce sugar beet were studied. The Provinces of West Azerbaijan, Khorasan-e Razavi, Fars, Kermanshah and Khuzestan produced the most sugar beets at 1,853,867, 920,004, 659,002, 624,999 and 30,9046 tons, respectively, in 2014. Table 1 shows the sugar beet efficiency of major production centers in 2014.

A value of "1" in Table 1 denotes an efficient decision-making unit. West Azerbaijan, Kermanshah, and Khuzestan Provinces ranked as technically efficient with constant returns to scale. The Provinces of Ilam and South Khorasan ranked the lowest for technical efficiency. The highest and lowest CRS efficiencies among the studied provinces were 1 and 0.25, respectively. This 75% difference in technical efficiency of the sugar beet producers shows that there was great potential for increasing technical efficiency and reaching a maximum product according to the fixed set of production factors used.

For VRS, the technical efficiency of West Azerbaijan, Kermanshah, Khuzestan, Fars, Chaharmahal-Bakhtiari, Ilam, Semnan, South Khorasan and Khorasan-e Razavi Provinces was suitable. The efficiency of West Azerbaijan and Hamedan were suitable for allocative efficiency. Qazvin and

Table 1. Results of calculation of technical efficiency in CRS and VRS conditions, allocation efficiency, economic efficiency, scale efficiency and management efficiency of Iranian sugar beet producers. [a]

Provinces	CRS	VRS	Allocation efficiency	Economic efficiency	Scale efficiency	Management efficiency
West Azerbaijan	1.00	1.00	1.00	1.00	1.00	1.00
Kermanshah	1.00	1.00	0.52	0.52	1.00	1.00
Khuzestan	1.00	1.00	0.47	0.47	1.00	1.00
Fars	0.72	1.00	0.86	0.62	0.72	1.00
Hamadan	0.38	0.78	1.00	0.38	0.49	0.78
Chaharmahal - Bakhtiari	0.63	1.00	0.49	0.31	0.63	1.00
Lorestan	0.61	0.88	0.57	0.35	0.69	0.88
Ilam	0.25	1.00	0.84	0.21	0.25	1.00
Semnan	0.27	1.00	0.85	0.23	0.27	1.00
Qazvin	0.49	0.90	0.45	0.22	0.54	0.90
South Khorasan	0.25	1.00	0.88	0.22	0.25	1.00
Khorasan –e Razavi	0.88	0.99	0.82	0.72	0.89	0.99
North Khorasan	0.45	0.92	0.64	0.29	0.49	0.92

[a] Source: Research findings.

Chaharmahal-Bakhtiari had the lowest allocative efficiency. The results show that the difference between the best and the worst producer in terms of allocative efficiency was 45%, which demonstrates a large difference between sugar beet producers in terms of optimal allocation of resources according to price.

The economic efficiency of West Azerbaijan and Khorasan-e Razavi was suitable. Ilam, Semnan, Qazvin and South Khorasan had the lowest economic efficiency. The change in economic efficiency between the best and worst production units was 79% due to the difference in production costs and shows that there is a wide difference in profitability among sugar beet farmers.

The scale efficiency of West Azerbaijan, Kermanshah, and Khuzestan Provinces was appropriate. South Khorasan and Ilam Provinces had the lowest scale efficiency. Most provinces ranked acceptable in terms of management efficiency.

The average technical efficiency for CRS, VRS and allocative, economic, scale and management efficiency of sugar beet production in 2014 was 0.61, 72.0, 96.0, 43.4, 0.63, and 0.69, respectively. The average technical efficiency of sugar beet growers was 61%. That is, on average, the units showed a 39% technical inefficiency in terms of CRS.

The average allocative efficiency of sugar beet growers was 72%. This means that the units studied had a 28% allocative inefficiency. The average economic efficiency of Iranian beet growers was 43%, which indicates that 57% of the units showed economic inefficiency. These findings indicate that sugar beet growers do not exhibit good profitability.

A review of the management efficiency shows that the average efficiency of sugar beet management was 96% and the average efficiency to scale was 63%. In the sugar refining industry, which is the second ring of the sugar supply chain, 24 units are active. These factories use the inputs of capital, labor and sugar beets (as the intermediate input) to refine raw sugar to obtain sugar and molasses with pulp. The results of technical efficiency for CRS, VRS and allocative, economic, scale and management efficiency for sugar refining plants are presented in Table 2. As shown, the value for these in 2014 were 0.87, 0.91, 0.44, 0.49, and 0.91, respectively.

The average technical efficiency for CRS of Iranian sugar factories was 87%, which means 13% technical inefficiency in terms of CRS. The average technical efficiency for VRS of the sugar factories was 91%, meaning an average of 9% technical inefficiency in terms of VRS.

The average allocative efficiency of Iranian sugar factories was 53% and the average economic efficiency was 44%. These findings indicate that the sugar factories lack profitability, though the management and scale efficiency of the sugar factories is good. These plants show good technical efficiency, but show allocative and economic inefficiency.

The relationship between the sugar beet production areas and sugar factories (the two levels of the sugar supply chain) is shown in Figure 4 for the ten provinces supplying sugar beets. In West Azerbaijan Province, sugar beet production does not meet the needs of the factories in this province. The remaining supply is obtained from Kermanshah, Lorestan, Chaharmahal-Bakhtiari, Fars, Khuzestan (544,518, 33,295, 39,372, 354,610, 293,819 tons, respectively). Also, the sugar beets produced in Qazvin do not meet the needs of this province's factories. The rest is provided by Semnan, Lorestan and Khorasan-e Razavi Provinces. The requirements of the factories in North Khorasan are supplemented by sugar beets from Khorasan-e Razavi.

The provinces that sell sugar beets to factories form a supply chain and the factories form a chain with the sugar beet producing provinces that supply them. Table 3 shows the calculated overall technical efficiency of the two-level sugar chains for sugar beet production centers and sugar factories. The second column of the table shows how the members of each chain communicate (Figure 4).

Table 2. Results of calculation of technical efficiency in CRS and VRS conditions, allocative efficiency, economic efficiency, scale efficiency and management efficiency of sugar refining plants.

Sugar factories	CRS	VRS	Allocation efficiency	Economic efficiency	Scale efficiency	Management efficiency
P1	0.16	0.18	0.87	0.14	0.86	0.18
P2	1.00	1.00	0.45	0.45	1.00	1.00
P3	0.70	0.72	0.52	0.36	0.97	0.72
P4	0.88	1.00	0.26	0.22	0.88	1.00
P5	0.88	1.00	0.40	0.35	0.88	1.00
P6	1.00	1.00	0.34	0.34	1.00	1.00
P7	0.72	1.00	0.33	0.24	0.72	1.00
P8	1.00	1.00	0.20	0.20	1.00	1.00
P9	1.00	1.00	0.20	0.20	1.00	1.00
P10	0.21	0.23	1.00	0.21	0.90	0.23
P11	0.90	0.91	0.48	0.44	0.99	0.91
P12	1.00	1.00	1.00	1.00	1.00	1.00
P13	1.00	1.00	1.00	1.00	1.00	1.00
P14	0.70	1.00	0.76	0.53	0.70	1.00
P15	1.00	1.00	0.53	0.53	1.00	1.00
P16	1.00	1.00	0.50	0.50	1.00	1.00
P17	1.00	1.00	1.00	1.00	1.00	1.00
P18	1.00	1.00	0.35	0.35	1.00	1.00
P19	0.79	1.00	0.58	0.46	0.79	1.00
P20	1.00	1.00	0.29	0.29	1.00	1.00
P21	1.00	1.00	1.00	1.00	1.00	1.00
P22	1.00	1.00	0.21	0.21	1.00	1.00
P23	1.00	1.00	0.33	0.33	1.00	1.00
P24	1.00	1.00	0.24	0.24	1.00	1.00

Table 3 also shows the results of the technical efficiency of sugar factories in 2014 based on the relationship of chain members shown in Figure 4. Each chain is considered a decision-making unit for efficiency calculation for a total of 33 decision-making units in the two-level sugar supply chain. The average technical efficiency of the members of the chain was 0.9. Active chains in West Azerbaijan, Chaharmahal-Bakhtiari, Lorestan, Kermanshah, Khuzestan, and North Khorasan Provinces show good technical efficiency, but the active chains in Fars and Semnan Provinces do not. Training is needed in these locations to improve the technical efficiency of the provinces in order to increase the efficiency of the whole chain.

CONCLUSIONS

The results for the first level of the sugar supply chain show an inadequate average technical efficiency for CRS and allocative, economic, and scale efficiency, and a good average technical efficiency for VRS and management efficiency. Measurement of technical efficiency for CRS shows large differences in input allocations for sugar beet production in the country. It was observed that farmers were not fully aware of the correct production techniques or did not use them at the right times or in optimum amounts. This means that there is good potential for increasing technical efficiency and achieving maximum production for the fixed set of production factors used.

The limitations of this study were the collection of required data and the adaptation of the relevant theory and methodology using the available data. Due to the need for large volumes of data related to sugar companies in different provinces, collection of the required data was difficult
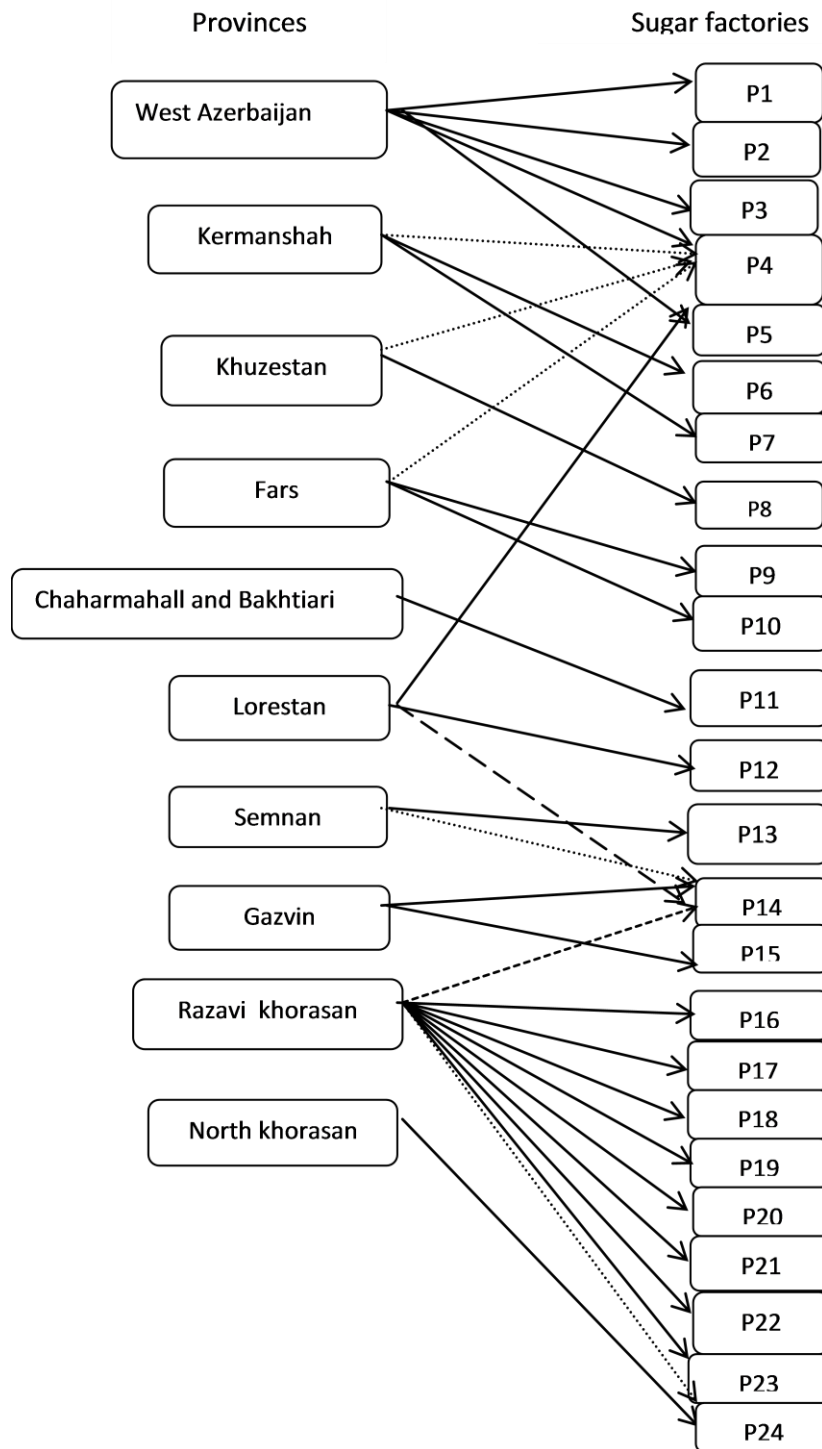
Figure 4. Relationship between members in two-level sugar supply chain in Iran (Source: Iranian Sugar Factories Syndicate).

Table 3. The calculated results of the overall efficiency of sugar supply chains.

Decision Making Unit	Chain members relationship	Efficiency
DMU1	R1-P1	1.00
DMU2	R1-P2	1.00
DMU3	R1-P3	1.00
DMU4	R1-P4	1.00
DMU5	R1-P5	1.00
DMU6	R1-P6	1.00
DMU7	R1-P8	1.00
DMU8	R1-P9	0.88
DMU9	R1-P11	0.88
DMU10	R1-P12	0.88
DMU11	R2-P6	1.00
DMU12	R2-P7	1.00
DMU13	R3-P8	1.00
DMU14	R4-P9	0.55
DMU15	R4-P10	0.55
DMU16	R5-P11	1.00
DMU17	R6-P12	1.00
DMU18	R7-P13	0.54
DMU19	R8-P14	1.00
DMU20	R8-P15	1.00
DMU21	R8-P13	1.00
DMU22	R8-P12	1.00
DMU23	R8-P20	1.00
DMU24	R9-P16	1.00
DMU25	R9-P17	0.77
DMU26	R9-P18	0.75
DMU27	R9-P19	0.73
DMU28	R9-P20	0.71
DMU29	R9-P21	0.97
DMU30	R9-P22	0.76
DMU31	R9-P23	1.00
DMU32	R10-P24	1.00
DMU33	R10-P20	1.00

[a] Source: Research findings.

and reduced the scope in the present study. In fact, it seems necessary to develop a system in the country in which companies that are present in the sugar supply chain are required to record information and data about their production and distribution, prices and costs. This would eliminate limitation of data and facilitate the development of related research. A large difference in allocative efficiency between production units was observed in optimal allocation of resources according to price. Most sugar beet producing provinces studied in 2014, except for West Azerbaijan and Khorasan-e Razavi, showed inadequate economic efficiency. The results indicate that the profitability of the production units was low. This indicates that farmers are unsuccessful in recouping at least the costs of production. With improvement of activities and elimination of potential market constraints for inputs, they can increase their allocative and economic efficiency, thereby increasing their income.

The results showed that scale efficiency was low, which can be due to the conservative behavior of sugar beet growers when using production inputs. Hence, the government can reduce the risk of

production by increasing support for this product. The management efficiency was found to be desirable. This high level of managerial efficiency indicates that technical knowledge has had a significant effect on the use of outdated technologies on existing resources.

On the second level of supply chain, the average technical efficiency under constant and variable returns to scale and allocative, economic, scale and management efficiency of sugar beet sugar factories were 0.87, 0.91, 0.53, 0.44, 0.94 and 0.91, respectively. The average technical efficiency of sugar factories in terms of CRS and VRS was relatively favorable, but the average allocative efficiency of sugar factories was not good. The results indicate a large gap between the most efficient and inefficient plants, which indicates a difference in resource prices. The government can address this by expanding private sector ownership, breaking up monopolies, and improving competition to increase efficiency and optimal allocation of resources.

The average economic efficiency of sugar factories was not satisfactory, which indicates uneconomical allocation in the extraction and refining process for sugar. The results show a large gap between the most efficient and most inefficient plants, indicating a wide difference in their profitability. A major reason for uneconomical production of sugar is the fact that factories only extract sugar, pulp, and molasses from sugar beets, while they could also produce raw materials for chemical plants and livestock feed.

The average scale of factories was good and indicated efficient use of inputs. Also, the average result for factory management efficiency was good, indicating the importance of technical knowledge among managers to improve existing technology and resources. This has had a good effect on technical efficiency. In order to increase the efficiency of the entire Iranian supply chain of sugar, measures must be taken in the first and second levels of the supply chain to increase the efficiency of the units, which

will increase the overall efficiency of the chain.

In general, since maximizing the welfare of sugar beet producers as one of the suppliers and the final consumer welfare of the processed product (sugar) in the sugar supply chain is considered by economic planners, planning and decision making with a systemic and chain view in the sugar supply chain is inevitable. What has happened in the sugar supply chain in Iran is the low efficiency of some producers present in the first ring of the chain, which also has technical and allocation effects on the next rings. Also, according to the results obtained, some companies in the next rings of the chain are not working at maximum capacity (for reasons such as the existing sanctions or instability in decisions and economic conditions of the country), so, this inefficiency is shifted to the previous and the next ring in the supply chain. Therefore, the efficiency of system and the effect of market adjustment policies (such as cross-sectional import of sugar from abroad) decreases.

Therefore, to increase the efficiency of the whole sugar supply chain, we recommend the following actions: (1) Development of the production technical knowledge and its transfer from leading farmers to other farmers in the first ring of the chain, (2) Providing facilities and infrastructure necessary to streamline production for companies in the second ring of the chain, and (3) Decision-making in the chain based on different impact assessment studies.

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اندازه‌گیری کارایی کل زنجیره‌تامین قند و شکر

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چکیده

صنعت قند و شکر از جمله صنایعی است که بیش‌ترین ارتباط را با حلقه‌های پیشین و پسین در زنجیره تولید دارد. در این صنعت، زنجیره‌ای از بخش‌های کشاورزی، صنعت، نفت، حمل و نقل و بازرگانی از تأمین مواد اولیه تا رسیدن کالای نهایی به دست مصرف‌کننده، درگیر فعالیت‌اند. در این پژوهش، به ارزیابی شاخص‌های کارایی و رتبه‌بندی واحدهای تصمیم‌گیرنده در زنجیره تأمین شکر ایران براساس روش تحلیل پوششی داده‌ها در حالت‌های ساده و شبکه‌ای پرداخته شد. بر اساس نتایج گرفته شده در سطح اول زنجیره تأمین غیرمتمرکز شکر ایران (بخش استحصال قند و شکر از چغندرقند)، میانگین کارایی فنی در شرایط بازدهی ثابت نسبت به مقیاس، کارایی تخصیصی، کارایی اقتصادی و کارایی مقیاس، در وضعیت مناسبی قرار ندارد. لیکن در سطح دوم زنجیره تأمین مذکور، تنها ضعف در کارایی تخصیصی و در نتیجه کارایی اقتصادی دیده می‌شود. نتایج نشان داد، استان‌های آذربایجان غربی و خراسان رضوی در تولید چغندرقند از نظر انواع کارایی در وضعیت مطلوبی به سر می‌برند. مدیریت زنجیره تأمین به عنوان ابزاری برای تحویل به موقع محصول به بازار با هزینه کمتر و درنتیجه افزایش کارایی کل زنجیره تأمین شکر به کار برده می‌شود. همچنین حرکت به سمت ادغام عمودی در تولید شکر چغندرقندی به دلیل استفاده از منافع حاصل از یکپارچگی، پیشنهاد می‌شود.