Advances in Industrial Engineering, June 2023, 57(1): 21-33
DOI: 10.22059/AIE.2022.342621.1836

RESEARCH PAPER

The Analysis of Profit Distribution under Yield Uncertainty for an Agriculture Supply Chain

Hamid Mashreghi*, Mahdie Ghasemzadeh, Mohammad Mahdi Paydar

Industrial Engineering Department, Babol Noshirvani University of Technology, Babol, Iran.

Received: 6 May 2022, Revised: 09 August 2022, Accepted: 09 August 2022

Abstract

In the two last decades, the analysis of the agriculture supply chain (ASC) has been paid attention by academics and practitioners. However, the issue of coordinating ASC is not considered so much where weak collaborations make lower profits and efficiencies. In this research, the distribution of profits and coordination of a three-level ASC including a gardener, a major buyer, and a retailer are investigated. The problem has been developed for both centralized and decentralized models. The optimal strategies of ASC are obtained for both models. In this study, the wholesale price contractual mechanism is investigated where the buyer's and retailers' wholesale price and the farm size are decision variables to find win-win situations under coordination. The proposed models were solved and sufficient propositions were developed. The numerical study is illustrated. The results show that with increasing farm area, the optimal harvest amount per unit area decreases for the centralized model. Furthermore, with increasing farm size, the gardener harvest amount per unit area and the supply amount increase where the retail selling price is almost constant for both cases. At the same level, with increasing farm size, the supply chain profit increases. In decentralized analysis with a wholesale price contract, the gardener's harvest amount per unit area and the supply amount increase by increasing the gardener's wholesale price. Moreover, by increasing the gardener's wholesale price, its profit increases, and the profit of the buyer and the retailer decreases. For future studies, analyzing and comparing other coordinating contracts, such as revenue sharing and traditional ASCs contracts is proposed.

Keywords:
Agriculture Supply Chain (ASC);
Coordination;
Three-Echelon Chain;
Wholesale Price Contract

Introduction and Literature Review

Agriculture and farming have an old history from thousands of years ago. The first agricultural revolution happened in 10,000 BC, which is called the Neolithic Revolution when humans transitioned from hunting and gathering to settled agricultural farms [1]. Today, global consumption of agricultural and food products has increased dramatically due to population growth, changes in general food needs, and increasing economic income. This increase in consumption has increased the demand for agricultural production and distribution worldwide and has led to a serious need for economic and logistic networks that shape modern agriculture activities.

The modern forms of agriculture with the help of the Industrial Revolution provide new mechanisms to enrich these activities. From another viewpoint, agriculture-to-market activities should be simultaneously considered with their process of warehousing, logistics, wholesaling,

* Corresponding author: (H. Mashreghi)
Email: Mashreghi.h@nit.ac.ir

retailing, and end consumers. This idea can be followed in the modern term of supply chain (SC).

The philosophy of SC and its management has been considered by researchers and industry managers in the last three decades. Moreover, aligning the firm competitive advantage with SC competitive advantage is very strategic for modern firms. Shaikh et al. [2] pointed out that due to the highly competitive conditions, every business organization faces many shortcomings in smoothly running his/her own business. Therefore, to survive in the competition, different types of business policies are required. In addition, customer and supplier companies that form an SC have long-term economic relationships and influence each other. In competitive markets, such as some industrial and most agricultural markets, the issue of having a competitive advantage is vital for chain partners. Noorbakhsh et al. [3] analyzed the question of whether the past performance of the customer company (supplier) can predict the future performance of the supplier company (customer). To answer this question, the predictability of returns at the industry level in 10 supply chains of the Tehran Stock Exchange from 2015 to 2020 has been investigated using the vector autoregression model.

Thus, the uncoordinated decisions of independent and separate economic entities in the SC usually result in a deviation from the optimal performance of the whole system. Accordingly, the problem of finding win-win scenarios for both individual and whole systems i.e. supply chain coordination (SCC) is so important for both researchers [4] and managers [5]. To analyze the possibility of coordination in SC, there exist two approaches: the *Theory of Games* for coordination analysis and *Mathematical Programming* techniques to improve operational coordination. By the first approach, Hadi et al. [6] investigated a green SC with governmental acts including a supplier and a manufacturer. The government is considered the leader of the game and sets special tariffs (taxes and subsidies) for all products to control market demand. In this study, a game theory model is formulated in four scenarios by considering member cooperation in the chain. Mahmoudi et al. [7] modeled a two-channel SC including a green producer and two retailers along with a Third-Party Logistics (TPL) company where the government is also considered as the game leader. Mohabbatdar and Esmaeili [8] proposed a new inventory model for a seller who performs marketing efforts. They present an algorithm to find the optimal solution and develop the numerical study including sensitivity analysis to compare the demand responses based on optimal setting of ordering and marketing effort.

In the second approach by using *Mathematical Programming*, there is less research for analyzing coordination. Alimohammadi Ardakani [9] discussed the transfer of petroleum products from supply points to consumption areas through the SC by a mathematical model. The model consists of two objectives: reducing the cost of transportation and reducing the number of loads. Khalili et al. [10] proposed an optimization model based on the modern portfolio theory, mean-variance analysis, and conditional value-at-risk (CVaR) for cost minimization and risk reduction in the electricity supply problem. The simulation was done based on the real data of Iran in 2018 and 2019. Abdolazimi et al. [11] developed a bi-objective mixed-integer linear programming model to minimize the total cost and maximize both usages of environmentally friendly materials and clean technology. This study evaluates the exact, heuristic, and meta-heuristic methods in solving the proposed model in both small and large sizes. Similarly, Arabi and Gholamian [12] developed a three-objective multi-product multi-period mixed integer quadratic programming problem to optimize a sustainable stone SC network design. Maximizing total profit, minimizing sound pollution and minimizing dust pollution are considered simultaneously as objective functions. In addition, a real case study in Iranian stone mines has been investigated to show the applicability of the model.

However, from real applications point of view, ASCs are different from other product SCs. This difference can be imagined as a continuous and significant change in the quality of agricultural and food products through the whole SC and its final consumption points.

Obviously, many consumers prefer the freshest product at a reasonable price, but the high vulnerability of agricultural and food products has led to waste and excessive destruction of products. In order to stay in a competitive environment, various products must be available to them according to changing customer's demand. Therefore, global rising in food demand enforces the food industries to identify new effective strategies for sourcing, production, distribution and collaboration. Accordingly, there exists rare research in the field of ASC coordination. Herein we attempt to address all our findings in this field which are the most relevant to our problem structure.

Nong and Pang [13] considered the problem of ASC coordination with stochastic yield based on price compensation strategy. They study a two-echelon SC with one supplier and one retailer by mathematical proof and numerical study. It is important to know that they utilize a relevant cost allocation model from agriculture economic studies which provides good linkage between ASC literature and SCC as we follow it in our model. Yang et al. [14] developed option contracts in a supplier-retailer ASC where market demand depends on sales effort. They examine a benchmark case of integrated SC with the loss rate and introduce three coordinating option contracts led by the supplier to reduce the retailer's risk. It is shown that the call option contract can reduce the shortage risk whereas the put option contract can reduce the inventory risk and the bidirectional option contract can reduce the bilateral risk.

In addition [15], Bai et al.a analyzed a two-echelon system including a manufacturer and a retailer for perishable items. Two coordination mechanisms including revenue sharing contract (RS) and improved revenue sharing contract (revenue and cost sharing or RCS) have been considered. They show that RCS mechanism is more powerful for coordinating SC. Van Bergen et al. [16] considered a three-echelon ASC with one farmer, one processor, and one manufacturer. They analyzed risks of demand, yield, quality, and price and compared conventional fixed price (soft tolling) contracts with two SC finance (SCF) schemes including hard tolling (HT) and contract farming (CF). Hu et al. [17] developed a four-echelon agri-food SC that consists of an agricultural producer, a processing company, a distributor and many consumers. Each actor's quality decision is analyzed based on Stackelberg game theory and combined multiple strategies (profit sharing, quality commitment and risk sharing) are considered for coordinating quality control in the agri-food SC. Anderson and Monjardino [18] considered yield risk in agriculture setting in a three-level SC including a small number of suppliers, large number of growers, and small number of buyers. Cereal growing is considered in this study. Peng and Pang [19] considered a three-level contract-farming SC with a risk-averse farmer, a risk-neutral supplier and a risk-neutral distributor in which the farmer faces yield uncertainty and the government offers agricultural subsidy to the farmer. The CVaR criterion is used to describe the risk-averse behavior of the farmer. In the research, the optimal strategies of the SC were derived and a restricted sensitivity analysis illustrated to investigate the effects of the government subsidy and other parametrical factors.

Lie et al. [20] investigated the issue of investment decision and coordination in a green ASC. They proposed a more appropriate SC structure based on a hybrid big data and blockchain application environment by combining it to the situation of China's agricultural development. A green agri-food SC with a producer and a retailer is considered and according to changes in the freshness and greenness of agri-food products, the producer and retailer profit functions were modeled before and after the use of big data and blockchain. Then, the implementation of cost-sharing and revenue-sharing contracts were analyzed to coordinate the SC.

Kang et al. [21] considered the impact of government subsidies and fairness concerns on decisions and coordination in the Poverty Alleviation SC (PASC) including an agricultural company and a core company. In addition, the reasonable range of government subsidies is investigated and the impact of agricultural companies' fair concerns on corporate social responsibility (CSR) level, price, and quantity of agricultural production are investigated by coordination mechanisms. Nematollahi et al. [22] analytically examined the scenarios based on competition and coordination that drive conventional and organic markets under contract farming mechanisms. In their study, a three-party ASC including an agricultural company, an organic farmer and a conventional farmer has been investigated. Moreover, numerical study and sensitivity analysis of some important parameters are presented.

Regarding the literature, the focus of analyzing coordination in ASCs has been mainly concentrated based on downstream concerns of production and distribution [14, 17, 18, 20, 21, 22]. There is also a main stream in analyzing ASC as part of an agri-food SC which focuses on tackling transportation and warehousing issues concerning to freshness of products. However, for considering upstream coordination issues in ASC there is necessary to link farming activities to distribution and sales activities by some cost functions. Nong and Pang [13] and Peng and Pang [19] started this trend well where they concentrated merely on risk issues of ASC and analyzing the government's policies.

In this paper, based on the cost function of [19], we model a three-echelon ASC including a general gardener, a major buyer (wholesaler, large distributor or traditional warehouser) and a general retailer. Thus, by considering perfect market and wholesale price contractual mechanisms through the channel, we attempt to find optimal decisions for SC and its partners in terms of production, ordering, and the production quantity per farm size. Moreover, we analyze the coordination possibilities and develop comprehensively numerical studies to conclude managerial results. The remainder of this paper is organized as follows. After introducing the research and its background, Section 2 describes the centralized model of ASC. Section 3 presents a numerical example to illustrate further insights. Finally, conclusions are presented in Section 4.

Model Formulation

In this study, we model a three-echelon ASC including a gardener, a major buyer (wholesaler or large distributor) and a general retailer. The notations and assumptions of the model are presented in the following sections. After that, we demonstrate the SC profits and analyze centralized and decentralized models.

Notations

In Table 1, the notations related to the SC model including indices, parameters, and decision variables are described.

Assumptions

The assumptions of the model are as what follows:

Assumption (1). The selling price function, the supply function, and the cost function of ASC are assumed respectively as follows based on Peng and Pang [19]:

$$p = a - bS(y,\varepsilon) \tag{1}$$

$$S(y,\varepsilon) = ny\varepsilon \tag{2}$$

$$c_g(y,n) = cn + c_n(n-n_0)^2 + c_y(n(y-y_0))^2 \tag{3}$$

where ε is the farmer's production yield random variable with probability density, $f(.)$, and cumulative distribution, $F(.)$. Moreover, it can be seen that

$$\frac{\partial c_g(y,n)}{\partial n} = c + 2c_n(n-n_0) + 2c_y n(y-y_0)^2$$
$$\frac{\partial c_g(y,n)}{\partial y} = 2n^2 c_y(y-y_0)$$

Table 1. The notations of the model

Indices		Decision variables	
g	The gardener	n	The farm size in terms of acres
b	The major buyer	y	The agricultural yield per unit area
r	The retailer	w_b	Wholesale price of major buyer
SC	The retailer	w_g	Wholesale price of gardener
Parameters			
c_g	Cost of production of gardener per acre per unit		
c_b	Cost of supplying major buyer for each unit of product		
c_r	Retailing cost per unit		
c_n, c_y	The endeavor cost coefficients of the gardener		
c	The cost of agricultural materials (per acre)		
p	Retail selling price		
q	Retail order quantity		
a	The highest level of market price		
b	Price reduction coefficient based on market supply increase		
ε	The farmer's yield random variable with PDF, $f(.)$, and CDF, $F(.)$		
T_1	Transfer payment from major buyer to gardener		
T_2	Transfer payment from retailer to major buyer		

Agricultural supply chain model

According to the assumptions, the profit of the gardener, π_g, the profit of the major buyer, $\boldsymbol{\pi_b}$, and the profit of the retailer, π_r are as follow [4]:

$$\pi_g(n,y) = T_1 - c_g(y,n) \tag{4}$$
$$\pi_b(w_b) = T_2 - T_1 - c_b S(y,\varepsilon) \tag{5}$$
$$\pi_r(q) = (p-c_r)S(y,\varepsilon) - T_2 \tag{6}$$

where $T_1 = w_g S(y,\varepsilon)$ and $T_2 = w_b S(y,\varepsilon)$ are the transactions of the contracts in ASC. Accordingly, the total SC profit function can be calculated as follows:

$$\pi_{SC}(n,y,p) = \pi_g + \pi_b + \pi_r = (p - c_b - c_r)S(y,\varepsilon) - c_g(y,n) \tag{7}$$

It is clear that the total SC profit does not depend on the different types of contracts. According to Eq. 4, the expected total profit of the SC can be calculated as follows:

$$E(\pi_{SC}) = E\left\{(p - c_b - c_r)S(y,\varepsilon) - c_g(y,n)\right\} = E\left\{\left(a - bny\varepsilon - c_b - c_r\right)ny\varepsilon - c_g(y,n)\right\}$$
$$= (ny\int_A^B \left(a - bnyu - c_b - c_r\right)uf(u)du) - c_g(y,n) = ny\left\{\int_A^B \left(a - c_b - c_r\right)uf(u)du\right\} - bn^2y^2\int_A^B u^2 f(u)du - c_g(y,n)$$

where $\int_A^B u^2 f(u)\, du = \sigma^2 + \mu^2$. Therefore, the expected profit function of the SC becomes:

$$E(\pi_{SC}) = ny\left\{a - c_b - c_r - bny(\sigma^2 + 1)\right\} - c_g(y,n) \tag{8}$$

Centralized supply chain optimization

In this section, it is assumed that the farm size, n, is constant. Proposition 1 provides the optimal solution for the SC harvest amount per unit area which is a function of firm size to farm $y^*(n)$.

Proposition 1. With the constant farm size, n, the optimal harvest amount per unit area, y, to maximize the total SC profit is obtained from the following equation:

$$y_{SC}^*(n) = \frac{M_2}{M_1} \tag{9}$$

where $M_1 = 2n(b(\sigma^2 + 1) + c_y)$ and $M_2 = \left(a - c_b - c_r\right) + 2c_y y_0 n$.

Proof. To maximize profit functions with respect to y, the first optimality condition can be developed as follows:

$$\frac{\partial E(\pi_{SC})}{\partial y} = n\left\{a - c_b - c_r - bny(\sigma^2 + 1)\right\} - bn^2(\sigma^2 + 1)y - 2n^2 c_y(y - y_0)$$
$$= n\left\{a - c_b - c_r - bny(\sigma^2 + 1) - bny(\sigma^2 + 1) - 2nc_y(y - y_0)\right\}$$
$$= n\left\{\left\{-2bn(\sigma^2 + 1) - 2nc_y\right\}y + \left(a - c_b - c_r + 2nc_y y_0\right)\right\}$$
$$= n\left\{\left\{-2n(b(\sigma^2 + 1) + c_y)\right\}y + \left(a - c_b - c_r\right) + 2nc_y y_0\right\} = 0$$

Accordingly, the Eq. 9 is obtained. Moreover, since $M_1 > 0$, the optimal solution for the farm harvest amount per unit area is unique because:

$$\frac{\partial^2 E(\pi_{SC})}{\partial y^2} = -2bn^2(\sigma^2 + 1) - 2n^2 c_y = -M_1 < 0$$

Result 1. The optimal harvest amount per unit area, y^*, for the SC decreases by increasing the farm size, n.

Proof. According to Eq. 9 it is observed that

$$\frac{\partial y_{SC}^*(n)}{\partial n} = \frac{4c_y y_0 b(\sigma^2 + 1) + c_y n - 2b(\sigma^2 + 1) + c_y(\left(a - c_b - c_r\right) + 2c_y y_0 n)}{(2nb(\sigma^2 + 1) + c_y)^2}$$
$$= \frac{-2b(\sigma^2 + 1) + c_y\left(a - c_b - c_r\right)}{(2nb(\sigma^2 + 1) + c_y)^2} < 0$$

As a result, by increasing farm size, n, the optimal harvest amount per unit area, y, decreases for centralized SC.

Decentralized supply chain analysis with fixed farm size and wholesale price contract

According to the Eqs. 4 to 6 and considering the wholesale price contract, it can be seen that $T_1^W = w_g S^W(y,\varepsilon)$ can be considered as the transfer payment from the buyer to the farmer and $T_2^W = w_b S^W(y,\varepsilon)$ as the transfer payment from the retailer to the buyer. Therefore, the gardener's profit, $\pi_g^W(n,y)$, the buyer's profit, $\pi_b^W(w_b)$, and the retailer's profit, $\pi_r^W(p)$, are obtained as follows:

$$\pi_g^W(n,y) = w_g S^W(y,\varepsilon) - c_g(y,n) \tag{10}$$

$$\pi_b^W(w_b) = (w_b - w_g - c_b) S^W(y,\varepsilon) \tag{11}$$

$$\pi_r^W(p) = (p^W - w_b - c_r) S^W(y,\varepsilon) \tag{12}$$

It is assumed that the gardener determines its optimal harvest amount per unit area y_g^{*W} after determining the wholesale price by the buyer. Therefore, the gardener will follow the buyer's pricing decision.

Proposition 2. Assuming constant firm size, n, the optimal harvest amount per unit area of the gardener to maximize the total profit of the gardener is obtained from the following equation:

$$y_g^{*W} = y_0 + \frac{w_g}{2nc_y} \tag{13}$$

Proof. According to Eq. 10, the expected profit function of the gardener can be calculated as follows:

$$E(\pi_g^W) = E\{w_g ny\varepsilon - c_g(y,n)\} = \int_A^B \left(w_g nyu - c_g(y,n)\right) f(u)du$$

$$= w_g ny \int_A^B uf(u)du - c_g(y,n)\int_A^B f(u)du = w_g ny\mu - c_g(y,n) = w_g ny - c_g(y,n)$$

Thus, to maximize the gardners's profit function with respect to y_g^W, it can be concluded that:

$$\frac{\partial E(\pi_g^W)}{\partial y_g^W} = w_g n - 2n^2 c_y (y - y_0) = 0 \Rightarrow y_g^{*W} = \frac{2n^2 c_y y_0 + w_g n}{2n^2 c_y} = y_0 + \frac{w_g}{2nc_y}$$

Result 2. The optimal amount of harvest for the gardener, y_g^{*W}, is decreasing by increasing the farm size n when the buyers' wholesale price is constant.

Proof. According to Eq. 13, it is observed that $\frac{\partial y_g^{*W}}{\partial n} = \frac{-w_g}{2c_y n^2} < 0$. Therefore, the result can be observed.

Coordination analysis

According to the optimal values of harvest amount per unit area for the gardener and SC from Propositions 1 and 2, we know that coordination occurs when these two levels would be equal in a constant amount of farm. To evaluate this possibility, the difference between the SC and the gardner optimal decisions so called productivity difference, $\Delta(y)$, is defined as follows:

$$\begin{aligned}
\Delta(y) &= y^*_{SC}(n) - y^{*W}_g(n) \\
&= \frac{(a-c_b-c_r)+2c_y y_0 n}{2(b(\sigma^2+1)+c_y)n} - \frac{2c_y y_0 n + w_g}{2c_y n} \\
&= \frac{\left((a-c_b-c_r)+2c_y y_0 n\right)c_y - \left(2c_y y_0 n + w_g\right)(b(\sigma^2+1)+c_y)}{2c_y(b(\sigma^2+1)+c_y)n} \\
&= \frac{(a-c_b-c_r-w_g)c_y - b(\sigma^2+1)\left(2c_y y_0 n + w_g\right)}{2c_y(b(\sigma^2+1)+c_y)n} \\
&= \frac{(a-c_b-c_r)c_y - 2c_y y_0 b(\sigma^2+1)n - (b(\sigma^2+1)+c_y)w_g}{2c_y(b(\sigma^2+1)+c_y)n} \\
&= \frac{a-c_b-c_r}{2(b(\sigma^2+1)+c_y)n} - \frac{y_0 b(\sigma^2+1)}{b(\sigma^2+1)+c_y} - \frac{w_g}{2c_y n}
\end{aligned}$$

Therefore $\Delta(y)$ can be simplified as follows:

$$\Delta(y) = y^*_{SC}(n) - y^{*W}_g(n) = L_1 + \frac{L_2 - L_3 w_g}{n} \tag{14}$$

where $L_1 = -\frac{y_0 b(\sigma^2+1)}{b(\sigma^2+1)+c_y} < 0$, $L_2 = \frac{(a-c_b-c_r)}{2(b(\sigma^2+1)+c_y)} > 0$, and $L_3 = \frac{1}{2c_y} > 0$.

Result 3. The productivity difference, $\Delta(y)$, at a fixed farm size, n, decreases by increasing wholesale price w_g.

Proof. According to Eq. 14, it is observed that

$$\frac{\partial \Delta(y)}{\partial w_g} = -\frac{L_3}{n}$$

Therefore, as L_3 is positive, where the wholesale price increases, the productivity difference at the fixed farm size decreases.

Result 4. The productivity difference $\Delta(y)$ at a fixed level of wholesale price w_g, decreases by the farm size, n.

Proof. According to Propositions (1) and (2), it can be seen that

$$\frac{\partial \Delta(y)}{\partial n} = \frac{-2\left(b(\sigma^2+1)+c_y\right)(a-c_b-c_r)}{(2n\left(b(\sigma^2+1)+c_y\right))^2} - \frac{-w_g}{2c_y n^2} = \frac{c_b+c_r-a}{2n^2\left(b(\sigma^2+1)+c_y\right)} + \frac{w_g}{2c_y n^2}$$

Therefore, by increasing the farm size, n, the productivity difference, $\Delta(y)$, decreases.

According to Result 3, it is clear that the productivity difference goes from a high limit with the lowest wholesale price level to lower values to zero. In this area, the harvest amount per unit area is lower than the optimal level for the SC, which leads to ncoordination. After that, it is possible to achieve coordination at a fixed level of wholesale price. This price level is presented in Theorem 1. In addition, due to the supply structure and the possibility of increasing the level of achievement of gardener with lower costs than SC, it is possible to increase the achievement of farm (productivity management) more than its optimal level of SC. Therefore, it is possible to reach the conditions of *Supercoordination* as Yan et al. [23] introduced it. They developed this concept for the first time when reducing financial risks provides higher possible potential markets which enables the supply chain partners to enrich efficiencies greater than 100% compared to benchmark markets.

Theorem 1. (*Coordination analysis*) Considering fixed size of the land, the efficiency of the ASC, to find the coordination situation of the gardener and the SC, there exist three cases where $\bar{w}_g^W = \frac{L_1 n + L_2}{L_3}$ is the coordinating threshold of the wholesale price and EF is the channel efficiency:

A) (*Incoordination*) If $w_g < \bar{w}_g^W$ then $y_g^{*W} < y_{SC}^*$ and therefore $EF < 1$.

B) (*Coordination*) If $w_g = \bar{w}_g^W$ then $y_g^{*W} = y_{SC}^*$ and therefore $EF = 1$.

C) (*Supercoordination*) If $w_g > \bar{w}_g^W$ then $y_g^{*W} > y_{SC}^*$ and therefore $EF > 1$.

Proof. If $\Delta(y) = y_{SC}^*(n) - y_g^{*W}(n) = L_1 + \frac{L_2 - L_3 w_g}{n} = 0$ we have $\bar{w}_g^W = \frac{L_1 n + L_2}{L_3}$ where enables the partners to achieve coordination. Moreover, regarding Result 3, lower wholesale prices than $\bar{w}_g^W$ provides higher productivity difference which results in less efficiency (Case A). On the other hand, higher wholesale prices than $\bar{w}_g^W$ provides less productivity difference which results in higher efficiency (Case C).

Observation 1. Concerning Yan et al. [23], the concept of *Supercoordination* refers to additionally potential market compared to sales baseline which provides higher profits under individualized decision making. Although this phenomenon appears in [23] where financial risks decrease, in this paper, the opportunity of maximizing yield production per area by the isolated gardener makes similar adding potential market for selling agricultural products. Thus, the similar structure for appearing *Supercoordination* enables SC partners to achieve higher efficiencies than 1.

Numerical Study

In this section, for illustration purpose, we present a numerical study. Assume that the yield random variable, ε, follows a Uniform probability with $\mu = 1$ and $\sigma = 0$. In addition, the other parameters of the problem concerning the fixed size of the farm n are $a = 5$, $b = 1 \times 10^{-7}$, $c_r = 0.5$, $c_b = 0.5$, $c_n = 2$, $c = 400$, $c_y = 5 \times 10^{-8}$, $y_0 = 600$, $w_b = 2$, $w_g = 1$, $n_0 = 50$.

The numerical study has been performed in two sections of centralized and decentralized ASC analysis. The problem model is solved in both cases and considering the wholesale price contract using MATLAB software and the results are presented in the form of a table in the next sections.

Centralized supply chain analysis

According to the SC problem in the case of constant farm size, a numerical study has been conducted using MATLAB software and the results are presented in Table 2. The results are shown in Table 2 are based on the equations of Section 2.4, i.e. the optimization of the centralized SC with the constant size of the farm.

Table 2. Numerical results of centralized SC

n	y^*_{SC}	S	p	π^*_{SC}
60	222422.22	13345333	3.67	35399725.86
110	121412.12	13355333	3.66	35453364.86
160	83533.33	13365333	3.66	35454896.32
210	63692.06	13375333	3.66	35434382.77

In Table 2, the changes in different components of the centralized model based on the change of farm size are investigated. It can be seen that (as we proved it previously) by increasing *n*, the amount of gardener harvest per unit area, y^*_{SC}, decreases. The supply quantity, *S*, is increasing with increasing *n*. In addition, it is observed that by increasing n, the retail selling price, *p*, is almost constant. Moreover, optimal centralized SC profit, π^*_{SC}, increases by increasing *n* but decreases at $n = 210$.

Decentralized supply chain analysis and coordination analysis

According to the wholesale price contract and considering the fixed size of the farm, a numerical study has been conducted in the case of decentralized ASC. The problem was analyzed using MATLAB software and the results are presented in Table 3.

Table 3. Numerical results of decentralized SC with wholesale price contract and n = 160

w_g	y_g^{*W}	S^W	p^W	π_g^W	π_b^W	π_r^W	π_{SCR}^W	EF^W
1.00	63100	10096000	3.99	9976550 (0.33)	5048000 (0.17)	15047078.4 (0.50)	30071628.4	0.85
1.05	66225	10596000	3.94	11003146.88 (0.35)	4768200 (0.15)	15262478.4 (0.49)	31033825.28	0.88
1.10	69350	11096000	3.89	12079587.5 (0.38)	4438400 (0.14)	15427878.4 (0.48)	31945865.9	0.90
1.15	72475	11596000	3.84	13205871.88 (0.40)	4058600 (0.12)	15543278.4 (0.47)	32807750.28	0.93
1.20	75600	12096000	3.79	14382000 (0.43)	3628800 (0.11)	15608678.4 (0.46)	33619478.4	0.95
1.25	78725	12596000	3.74	15607971.88 (0.45)	3149000 (0.09)	15624078.4 (0.45)	34381050.28	0.97
1.30	81850	13096000	3.69	16883787.5 (0.48)	2619200 (0.07)	15589478.4 (0.44)	35092465.9	0.99
1.35	84975	13596000	3.64	18209446.88 (0.51)	2039400 (0.06)	15504878.4 (0.43)	35753725.28	1.01
1.40	88100	14096000	3.59	19584950 (0.54)	1409600 (0.04)	15370278.4 (0.42)	36364828.4	1.03
1.45	91225	14596000	3.54	21010296.88 0.57	729800 0.02	15185678.4 (0.41)	36925775.28	1.04
1.50	94350	15096000	3.49	22485487.5 (0.60)	0 (0.00)	14951078.4 (0.40)	37436565.9	1.06

According to Theorem 1, it has been proved that in $w_g = \bar{w}_g^W$ it is possible to achieve coordination, where this level for the numerical study becomes $w_g = \bar{w}_g^W = 1.33$. The results obtained in Table 3 are based on the equations of Section 2.5 i.e. the analysis of the decentralized SC with fixed farm size and the wholesale price contract.

Table 3 investigates the effect of changing the wholesale price of the gardener on different components of the decentralized SC model for fixed $n = 160$. According to the table, with increasing w_g, the amount of gardener harvest per unit area in the mode of the wholesale price contract, y_g^{*W}, increases. By increasing w_g, the supply quantity, S^w, increases and the retail selling price, P^w, decreases. In addition, the expected profit of the gardener, π_g^W, increase and the expected profit of the buyer, π_b^W, decrease. Meanwhile, the expected profit of the retailer, π_r^W, has an increasing trend before $w_g = 1.25$, and decreasing after that. Moreover, by increasing w_g, the real SC profit, π_{SCR}^W, increases.

Regarding the profit shares of the partners as illustrated in columns of Table 3, by increasing w_g, the profit share of the buyer and the retailer decreases but the profit share of the gardener increases. Therefore, the efficiency of the wholesale price contract, EF, increases by greater w_g. According to the table, the results of Theorem 1, can be observed for incoordination ($w_g < \bar{w}_g^W = 1.33$), coordination at $w_g = \bar{w}_g^W = 1.33$, and supercoordination, ($w_g > \bar{w}_g^W = 1.33$).

Conclusion and Future Research

Reviewing the rich history of SCC literature, it is observed that implementation of coordination analysis approach in the field of ASCs are so rare and limited. In this study, we reviewed this field and modeled a three-level ASC including a gardener, a major buyer, and a retailer. The model formulation is developed for two modes of centralized and decentralized SC. The general SC model is stated and the profit functions of the ASC partners are written based on the assumptions. Centralized SC optimization has been performed in the conditions of constant farm size. In this study, a wholesale price contract is developed through all contractual agreements and coordination analysis. The results of centralized SC optimization show that by increasing farm size, the optimal harvest amount per unit area decreases.

In the case of decentralized SC by increasing farm size, the gardener's harvest amount per unit area and the supply quantity increase. However, the retail selling price remains almost constant. In addition, the profit of the SC increases.

Moreover, in order to find coordination possibilities, a productivity difference measure is defined based on the difference in harvest amount area per unit for the SC and the gardener. Therefore, by analyzing this measure, three cases of incoordination, coordination, and super coordination were extracted based on changes of wholesale prices. Finally, by a numerical study, different optimal values in centralized and decentralized models were illustrated. The numerical analysis shows that under wholesale price contracts, with the increase of the gardener's wholesale price, the gardener's harvest amount per unit area and the supply amount increase. Moreover, with the increase of the gardener's wholesale price, the profit of the gardener increases, and the profit of the buyer and the retailer decreases.

This study provides a novel benchmark for classic ASCs and typical contractual analysis which is the base of most actual fruit and vegetable SCs. Thus, for future studies, we can study other SC coordination contracts in particular traditional ASCs contracts to evaluate the productivity and efficiency level in ASCs. Moreover, a novel mechanism such as revenue sharing or option contracts can be developed and analyzed to improve the traditional views of ASC partners and make collaborative environment for them.

References

[1] Routroy, S. and A. Behera, *Agriculture supply chain: A systematic review of literature and implications for future research.* Journal of Agribusiness in Developing and Emerging Economies, 2017.

[2] Shaikh, A.A., et al., *Analysis of a Two-Storage System for Advance Payment Policies with the Partial Backlogged Shortage.* Advances in Industrial Engineering, 2020. 54(3): p. 221-242.

[3] Noorbakhsh, A., R. Soltani, and M. Asadi Mafi, *Supply Chain and Predictability of Return.* Advances in Industrial Engineering, 2021. 55(4): p. 323-333.

[4] Arshinder, Kanda,A., Deshmukh, S.G.,2008. *Supply chain coordination: Perspectives, empirical studies and research directions*. International Journal of Production Economics 115 (2008) 316– 335.

[5] Sluis, S., Giovanni, P.D, *The selection of contracts in supply chains: An empirical analysis*. Journal of Operations Management 41 (2016) 1-11.

[6] Hadi, T., M. Sheikhmohammady, and S.K. Chaharsooghi, *A Game Theoretical Approach to Competition Between Members of a Green Supply Chain with Hybrid Products.* Advances in Industrial Engineering, 2020. 54(4): p. 381-399.

[7] Mahmoudi, A., M. Abedian, and D. Shishebori, *The dual-channel green supply chain performance under government monitoring: A Game theoretic approach.* Advances in Industrial Engineering, 2020. 54(4): p. 423-446.

[8] Mohabbatdar, S. and M. Esmaeili, *Optimal Selling Price, Marketing Expenditure and Order Quantity with Backordering.* 2011. Journal of Industrial Engineering, University of Tehran, Special Issue, 2011, PP. 103-112.

[9] Alimohammadi Ardekani, M., *A Multi-Objective Supply Chain Configuration for the Oil Industry under Uncertainty.* Advances in Industrial Engineering, 2022. 56(1): p. 15-41.

[10] Khalili, S., et al., *Proposing a New Mathematical Model for Optimizing the Purchase of Electricity Required by Large Consumers Based on Modern Portfolio Theory: A Case Study of the Iranian Electricity Market.* Advances in Industrial Engineering, 2022. 56(1): p. 87-113.

[11] Abdolazimi, O., et al., *A comparison of solution methods for the multi-objective closed loop supply chains.* Advances in Industrial Engineering, 2020. 54(1): p. 75-98.

[12] Arabi, M. and M.R. Gholamian, *Sustainable Supply Chain Network Design with Price-Based Demand Considering Sound and Dust Pollutions: A Case Study.* Advances in Industrial Engineering, 2021. 55(3): p. 285-306.

[13] Nong, G. and S. Pang, *Coordination of agricultural products supply chain with stochastic yield by price compensation.* IERI Procedia, 2013. 5: p. 118-125.

[14] Yang, L., R. Tang, and K. Chen, *Call, put and bidirectional option contracts in agricultural supply chains with sales effort.* Applied Mathematical Modelling, 2017. 47: p. 1-16.

[15] Bai, Q.-G., et al., *A two-echelon supply chain coordination for deteriorating item with a multi-variable continuous demand function.* International Journal of Systems Science: Operations & Logistics, 2015. 2(1): p. 49.

[16] Van Bergen, M., et al., *Supply chain finance schemes in the procurement of agricultural products.* Journal of Purchasing and Supply Management, 2019. 25(2): p. 172-184.

[17] Hu, J.-y., et al., *Quality control of a four-echelon agri-food supply chain with multiple strategies.* Information Processing in Agriculture, 2019. 6(4): p. 425-437.

[18] Anderson, E. and M. Monjardino, *Contract design in agriculture supply chains with random yield.* European Journal of Operational Research, 2019. 277(3): p. 1072-1082.

[19] Peng, H. and T. Pang, *Optimal strategies for a three-level contract-farming supply chain with subsidy.* International Journal of Production Economics, 2019. 216: p. 274-286.

[20] Liu, P., et al., *Investment decision and coordination of green agri-food supply chain considering information service based on blockchain and big data*. Journal of Cleaner Production, 2020. 277: p. 123646.
[21] Kang, K., M. Wang, and X. Luan, *Decision-making and coordination with government subsidies and fairness concerns in the poverty alleviation supply chain*. Computers & Industrial Engineering, 2021. 152: p. 107058.
[22] Nematollahi, M., A. Tajbakhsh, and B.M. Sedghy, *The reflection of competition and coordination on organic agribusiness supply chains*. Transportation Research Part E: Logistics and Transportation Review, 2021. 154: p. 102462.
[23] Yan, N., et al., *A partial credit guarantee contract in a capital-constrained supply chain: Financing equilibrium and coordinating strategy*. International journal of production economics, 2016. 173: p. 122-133.