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A Mathematical Model for Resource Sharing with Bilateral Contracts in a Supply Chain with Government Intervention under a Game Theory Approach

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A B S T R A C T

Contracts have been used for coordination in many supply chain alliances among businesses. Because bilateral contracts are significantly more successful and profitable than uni-contracts, In this article, the issues of implementing bilateral contracts are investigated with the approach of game theory and government intervention to increase bilateral interaction between members of co-production and co-distribution in the supply chain. By adopting the game theory model between these two members of the chain and intervention government, this research seeks to increase production and distribution by making maximum use of the excess capacity of production and distribution in the chain. In this way, the producer uses his surplus capacity in two ways: one is produced directly by the producer and enters the market by the distributor, and the other is an order that the distributor gives to the producer, which is different from the product that the producer produces. It is produced directly and given by the distributor. The purpose of this research is to investigate and analyze the amounts and profits resulting from the participation of production and distribution with government intervention in the supply chain. According to this research, governments should provide an environment for supply chain members to have more cooperation with each other because, in the case of cooperation among supply chain members, the profits of the chain and the members will increase.

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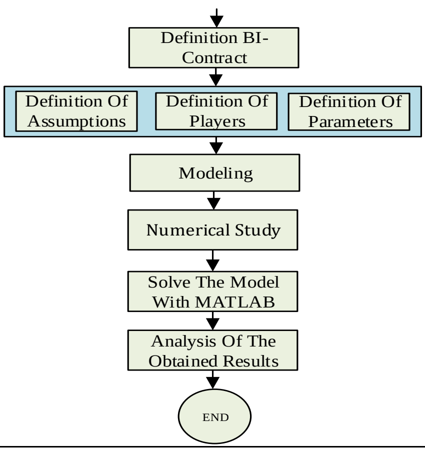
Graphical Abstract

Context	Methodology
	

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1. INTRODUCTION

In today's world, many companies, to maintain their growth in the consumer goods market, try to develop their product share on the one hand and reduce their operational costs on the other; however unfortunately, nowadays, issues (e.g., increasing customer tastes, competitiveness, and a variety of products in business markets) that increase the operating costs of companies have become a common concern of all manufacturing companies to reduce this operating cost in the supply chain (SC) (1). In this regard, companies have turned to coordination in the SC to integrate and coordinate the SC to increase profits, reduce costs and shortages, and share the amount of risk among the players and partners of the SC (2).

Coordination in the SC is done through mechanisms in the chain. One of these mechanisms is a contract. SC contracts are useful tools for multiple SC members to behave in a coordinated manner in a non-integrated chain (3). A contract is a set of terms and conditions that provide appropriate information and incentive mechanisms such as risk sharing among chain members as well as rewards that ensure all parts of the SC coordinate and share the optimal amount of profit. Due to their positive impact on the chain, coordination contracts have significantly been considered by researchers and executives over the last few decades (4). There are different contracts in the SC, which are called uni-contracts. However, this article deals with a type of contract, called a bilateral contract.

In bilateral contracts, one company shares a part of its surplus capacity, for example, its production capacity, with another company, and the other company shares a part of its surplus capacity, such as its distribution capacity, with this company (5). It should be noted that in such cases, each of the companies is both a producer and a distributor; the only issue is the excess capacity of these companies.

As an example, Nestlé and Spray Ocean in America have developed a long-term strategic operation contract to increase production and efficiency in the chain. Under this contract, Spray Ocean is responsible for charging bottles for two companies "for fruit juice drinks," while Nestlé is in charge of the supply and distribution process of Ocean Spray Company (6). An example of these contracts can be mentioned regarding Fiat and Tata Company in India regarding engine manufacturing. In this cooperation, Fiat produces its engines, and Tata Company shares its agencies and marketing management networks for Fiat in India. This type of contract can also refer to the contract for both the distribution and production of Bosch and Panasonic companies (7).

In this research, bilateral contracts in the SC have been investigated and modeled so that each member of the chain provides production-distribution of its surplus capacity to the other. In this research, there are three players: the producer, the distributor, and the government. The producer gives two types of products to the distributor for distribution in the market: one is his production, and the other is the production that he gives to the producer on the order of the distributor. In the same way, distributors distribute two types of products: one is produced by the manufacturer, and the other is ordered by themselves. The types of these two products are not similar. In this research, mathematical modeling is first carried out for each member of the supply chain, and then their profit values are calculated based on random numbers for each player. Finally, charts are drawn by changing the parameters. Also, the government's goal as the third player in this model is to increase cooperation among members, cooperation, social welfare, price reduction, maximum use of companies' capacity

2. LITERATURE REVIEW

In general, there are two types of structures in the SC: centralized and decentralized SCs. In a centralized SC, decisions are made centrally for the entire chain, and the profit of the entire chain is considered (8). However, in a decentralized SC, every one of the members decides in a decentralized manner, independently from other members, and based on his knowledge. The coordination mechanism in the SC is one of the most important issues in the decentralized SC (9). In the research literature, the issue of contracts and the SC coordination with the intervention of the government has been investigated with the approach of game theory.

About emission of carbon reduction in an SC focused on retailers in which consumer awareness of such issues as environment and tax, Revenue-sharing against cost-sharing is studied in the context. They design some incentive schemes and show their effectiveness and perfect consistency for both retailers and manufacturers (10).

Asghari et al. (11) discussed developing an improved Particle Swarm Optimization (PSO) algorithm using crowd-learning theory to solve complex optimization problems involving pricing and advertising decisions in closed-loop supply chain networks. The proposed algorithm is validated through testing and shown to perform better than existing algorithms in terms of computational time and solution quality. Heydari et al. (12) studied reverse and closed-loop SC coordination with government roles. They showed that government-sponsored incentives for the manufacturer are preferred by the retailer. In an SC, the final product is distributed in multiple channels. Zheng et al. (13) studied the effects of government subsidies for green products. They show that the social welfare under the high replacement subsidy is not always superior to the low subsidy. Cao et al. (14) considered an optimization problem, in which two important decision variables are regarded: 1. Production level, 2. Carbon level enhancement. They also consider cap-and-trade and low-carbon subsidy policies in their analysis. They show that a low-carbon subsidy policy is more beneficial to society when the environmental damage coefficient is less than a threshold; however, otherwise, cap-and-trade policy is more beneficial. Xu et al. (15) investigated joint production and pricing decisions for multiple products with cap-and-trade and carbon tax regulations. They demonstrate that the social welfare under carbon tax regulation is not less than that under cap-and-trade regulation. Despite this, no one regulation always generates more profit and has advantages in curbing carbon emissions than the other one.

Fathollahi-Fard et al. (16) proposed a bi-level programming model for home healthcare supply chain (HHSC) planning considering demand outsourcing. The paper develops mathematical formulations for the bi-level model and proposes several meta-heuristic algorithms to solve it. A hybrid heuristic-exact method is also presented to validate the meta-heuristics on small instances. Hafezalkotob et al. (17) adopted a multi-level game theory approach to study government financial intervention in regular and green SCs. They stress the impact of budgetary limitations of the government on efficiency decisions for the decrease of pollution of the products. Hafezalkotob (18) studied competition to improve sustainability stressed and emphasized by the government. They consider two players: 1. Internal suppliers, 2. External suppliers. The study concludes that limitations imposed by the government are effective on stability, competitivity, or monopoly of the market. Mahmoudi and Rasti-Barzoki (19) adopted an evolutionary game theoretic approach to study sustainable SCs under government intervention. They find that government policy impacts producers' activity, competitive markets, and emissions.

Fathalikhani et al. (20) studied the impact of government intervention on cooperation, competition, and cooperation of humanitarian SCs and found that the cooperation of donors increases the donors' utility. Javadi et al. (21) studied a setting with the distribution of products in multiple channels in which the policy of the SC is determined directly by two factors: 1. Return regulations that focus on flexibility, and 2. Regulation that intensifies saving of energy. They discovered that the revenue-seeking policy does not necessarily lead to a higher energy-saving level and better social welfare unless the government's budget is increased. Hadi et al. (22) investigated an optimization problem that assumes production is hybrid and the intervention of government is allowed. They also assumed the policies of SC support the protection of the environment and revenue goals. The study leads to the finding that players of SC and the government experience improved the profit performance when they decide together. Hafezalkotob (23) modeled intervention policies of the government in the price-energy-saving competition of green SCs. They find that when the government intervenes, the utility of society improves in all cases. Yet, the environment, SCs with green strategy, and consumers must not be ignored in designing the policies of the SC.

Liu et al. (24) used a three-level game theory model with government intervention. The outputs showed that excess costs play a key role in reducing carbon in the chain, and the government also plays a very important role in this regard. The outputs through numerical values were also confirmed. This article examines a comprehensive approach to determining the quantity of coordination in the SC to effectively evaluate the performance of the SC in the 4th industrial age, It was observed that senior management focuses more on organizational issues (e.g., lean structure, organizational culture, and accountability factors) for improving coordination in the SC than on technology in the Industry 4.0. Ghozatfar et al. (25) focused on waste management, with waste being converted into energy and compost, using a game theory approach with the government intervening in municipal management. The government intervenes by determining the level of subsidy for the purchase of recyclable waste and imposing penalties for the emission of greenhouse gases and effluents, within a set of policy choices between income generation, environmental efforts, and social welfare.

3. PROBLEM STATEMENT

As mentioned, in this case, it is assumed that the goods produced by the manufacturer in two ways (i.e., direct production by the manufacturer and custom production given to the manufacturer by the distributor) are not the same. In this case, the assumption is that the price of the goods imported into the market, where the value of A and A' is the base price of these two products, and according to the famous economist Smith's rule, by producing as much as possible by the manufacturer, whether in the mode of sending by the distributor or in the mode of ordering production from the distributor, this base amount will be reduced. The production and distribution model with the game theory approach and government intervention is shown in Figure 1.

3. 1. Definition of Parameters

The model parameters are as follows:

A : The basic price of the product that the manufacturer produces directly and distributes to the distributor.

$\acute{A}$: The base price of the custom product that the distributor orders from the manufacturer and is distributed by the distributor.

α: The base price of the product ordered by the distributor for the manufacturer.

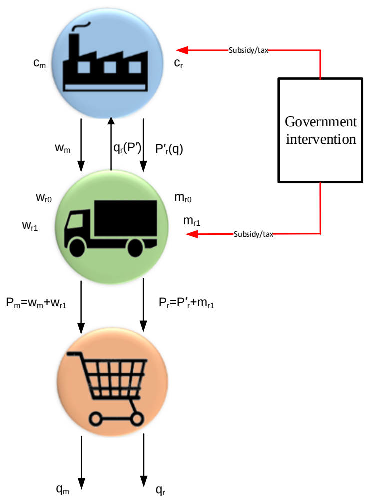

Figure 1. Game theory model with the government intervention in the supply chain

γ: The coefficient that is deducted from the base price of the product by the distributor to the manufacturer for each order unit

β: The coefficient that is deducted by the manufacturer from the price of the base product for each unit of product production

$\acute{\beta}$: The coefficient that is deducted by the distributor from the price of the base product for each custom product production unit.

c_m: The cost of each unit of product production by the manufacturer

c_r: The cost per unit of production of the product ordered by the distributor and produced by the manufacturer.

w_{r0}: Cost per unit of handling by the distributor from each unit of product produced by the manufacturer

w_{r1}: The amount received by each distribution unit from the manufacturer's products by the distributor

w_m: The amount that the manufacturer receives from the distributor for each product.

m_{r0}: Cost per unit of handling by the distributor of each unit of product ordered by the distributor

m_{r1}: The amount received by the distributor for each unit of ordered product per distribution unit

LS: It is a proportion of the subsidy that the government allocates for greater use of the power and capacity of both production and distribution companies.

Pm: The price that is offered to the market by the distributor for each unit of product production

Pr: The price that is offered to the market by the distributor for each unit of production of the customized product.

3. 2. Definition of Decision Variables Modelling variations are as follows:

q_m: The amount of production that the producer produces from her excess capacity and is distributed by the distributor

q_r: The order quantity is distributed to the manufacturer by the distributor, which is distributed by the distributor

s: It is the amount that is deducted by the government for each production unit from the production and added to the producer for each unit of order for production.

3. 3. Definition of Auxiliary Variables Modelling auxiliary variables are as follows:

$\acute{p}_r(q)$: The price per unit of the product produced by the manufacturer that is ordered by the distributor.

π_m: Producer's profit function

π_r: Distributor profit function

π_G: Subject to the government's goal

Note: the price distribution function $\acute{p}_r(q)$ can be considered as follows:

$$\acute{p}_R(q) = \alpha - \gamma q_r \tag{1}$$

3. 4. Manufacture The goal of the manufacturer is to make the most of the surplus capacity that they produce from this capacity for themselves as well as for customized products ordered by the distributor. The manufacturer's model is as follows:

$$\max_{q_M} \pi_m = (A - \beta q_m - w_{r1} - 2c_m)q_m + \\ +(\alpha - \gamma q_r - c_r)q_r - (q_m - q_r)s(1 - ls) \tag{2}$$

s.t.

$$q_m + q_r \leq CAP_m \tag{3}$$

$$q_r \leq \frac{(\alpha - c_r)}{\gamma} \tag{4}$$

$$A - \beta q_m - w_{r1} - c_m \geq 0 \tag{5}$$

$$A - \beta q_m \leq ld \tag{6}$$

$$\acute{A} - \acute{\beta} q_r \leq \acute{l}d \tag{7}$$

$$q_m s(1 - ls) - q_r s(ls) \geq \lambda \tag{8}$$

$$q_{m\geq 0}\ ; q_{r\geq 0} \tag{9}$$

3. 5. Distributor The distributor earns profits in two ways: one by selling the products it gives and distributes to the producer, and the other by distributing the products of the manufacturer. The distributor model is as follows:

$$\max_{q_R} \pi_R = (\acute{A} - \acute{\beta} q_r)q_r - (\alpha - \gamma q_r)q_r - m_r.q_r \\ +\left(q_{m(w_{r1} - w_{r.})}\right) + q_r s(ls) \tag{10}$$

s.t.

$$q_m + q_r \leq CAP_m \tag{11}$$

$$q_r \leq \frac{(\alpha - c_r)}{\gamma} \tag{12}$$

$$\acute{A} - \acute{\beta} q_r - (\alpha - \gamma q_r) - m_{r.} \geq 0 \tag{13}$$

$$A - \beta q_m \leq ld \tag{14}$$

$$\acute{A} - \acute{\beta} q_r \leq \acute{l}d \tag{15}$$

$$-q_m s(1 - ls) + q_r s(ls) \geq \lambda \tag{16}$$

$$q_{m\geq 0} \tag{17}$$

$$q_{r\geq 0} \tag{18}$$

3. 6. Government The goal of the government is to maximize the use of capacities and increase the amount of production:

$$max\ \pi_G = q_m + q_r \tag{19}$$

s.t.

$$q_m + q_r \leq CAP_m \tag{20}$$

$$A - \beta q_m \leq ld \tag{21}$$

$$\acute{A} - \acute{\beta} q_r \leq \acute{l}d \tag{22}$$

$$-q_m s(1 - ls) + q_r s(ls) \geq \lambda \tag{23}$$

$$q_{m\geq 0} \tag{24}$$

$$q_{r\geq 0} \tag{25}$$

4. NUMERICAL STUDY

In this section, by providing a numerical example of the parameters of the model for the three players (i.e., producer, distributor, and government), it is shown that the product produced by the producer and the distributor is it, and the government in this model, by providing subsidies and taxation, encourages two actors to cooperate more and produce more. In this part, the effect of parameter changes on the performance of the chain and decision variables, i.e., production values by two actors, as well as the profit of the actors in this model, will be analyzed along with the presentation of the diagram. In this regard, numerical values have been assigned to the parameters of the model. It should be noted that these values must be reasonable for the model to be solvable; otherwise, the model will not be solvable.

The parameters of the model in this problem are as follows:

capm=3500	*gama*=0.01	*alpha*=1500	*wr0*=100
A=3400	*beta*=0.08	*AP*=2250	*betap*=0.08
ld=3500	*ldp*=2300	*wr*1=150	*cm*=1000
mr0=150	*ls*=0.4	*cr*=280	*landa*=100

According to the given data, the decision variables or the Nash equilibrium, which are the same production values as well as the profit function for the producer (π_m), distributor (π_r) and government profit in the SC are shown in Table 1. After solving this model by MATLAB software, the results are listed in Table 1.

5. SENSITIVITY ANALYSIS

As shown in Table 1, with the given parameters, the amount of production by the manufacturer with the production of 1813 units reaches a profit of 3,998,241, and also the distributor's orders of 1687 units of the product, which is a profit of 1,217,394 units. Finally, the government also gets a profit of 191,648 units with the amount of 464 units of tax and subsidy. The changes of variables based on some parameters are depicted in Figure 2. As shown in this figure, with an increase in the base price by the producer, the amount ordered by the distributor decreases, and the producer uses her/his excess capacity to produce her/his product.

As shown in Figure 3, with the increase in the price of the producer's product in the market, the amount of production by the producer will increase, and her desire to produce a customized product by the distributor will decrease.

As shown in Figure 4, with an increase in the price of the manufacturer's customized product in the market, the amount of production by the manufacturer will decrease and the desire to produce the customized product by the distributor will increase.

TABLE 1. Values of the decision variables and functions of profiteers

q_m	q_r	s	Profit/ Manufacture (π_m)	Profit/ distributor (π_r)	Profit/ Government (π_G)
1813	1687	464	3,998,241	1,217,394	191,648

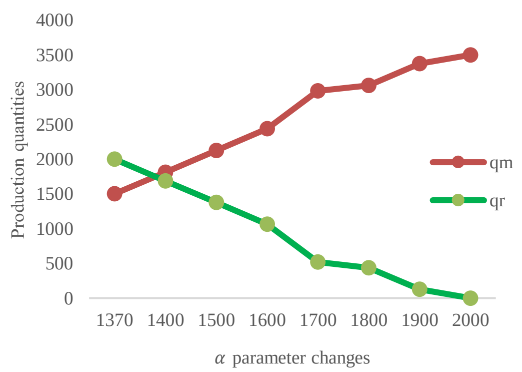

Figure 2. Changes in alpha value on decision variables

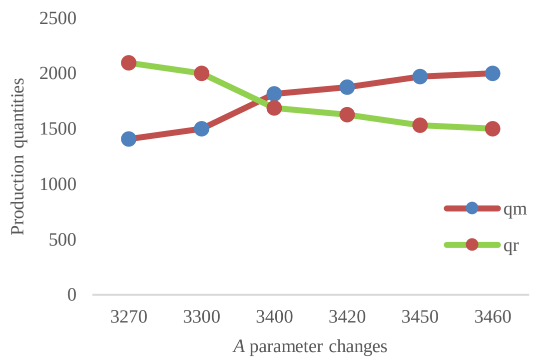

Figure 3. Changes in producer's product price value on decision variables

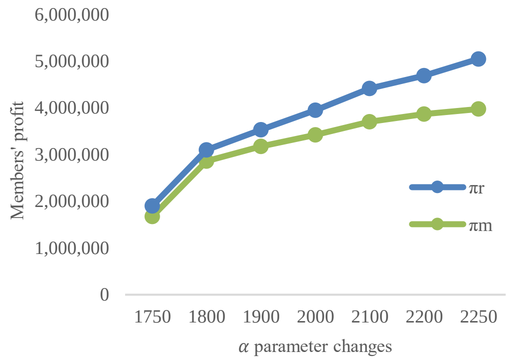

Figure 5. Changes in alpha value on decision variables

Figure 4. Changes in the ordered product price value on decision variables

In Figure 4, when the manufacturer produces the distributor's customized product, the profit of both members of the chain increases as depicted in Figure 5. It means that when the members of the supply chain cooperate with each other, the profit of the entire chain and, as a result, the profit of all members will increase.

6. RESEARCH GAP

Similarly, an extensive research has been conducted on types of coordination as well as types of contracts in the SC, along with the presentation of mathematical models. Unfortunately, it should be noted that on bilateral contracts in general, not much research has been done in this area of research attempting to examine the subject of bilateral agreements with view of theory of the game as well as the government as a player in the game that is known as government intervention. Bilateral contracts are the sharing of resources and excess capacity of each other, while uni-contracts are a kind of delivery (i.e., part of their work is transferred to another); however, in bilateral agreements, this is not the case; the action of each of the parties affects the other. In this study, the subject of bilateral contracts is analyzed and examined with theory of the game approach and government intervention.

7. MANAGERIAL INSIGHTS

In this model, all three players in the SC (i.e., producer, distributor, and government) seek to reach an equilibrium point based on the parameters that are assigned, and with each change in the parameter, a new Nash equilibrium point is obtained. For example, based on the existing parameters, by changing the price of the producer's product in the market, the producer has more incentive to produce, even though he has to pay taxes to the government. In this model, the government, in addition to trying to increase the amount of production and cooperation between the producer and distributor by giving subsidies and charging taxes. In the real world, in addition to subsidies and taxes, the government tries to create information infrastructure, laws, and regulations, provide facilities, etc., so that players in the SC can, buy sharing excess capacity in the direction of social welfare, reduce prices, etc., make maximum use of resources. In general, it can be said that the basis of the government's intervention is that incentives such as increasing social welfare, reducing prices, maximizing the use of companies' capacity, and finally making money in the SC can increase motivation and encouragement for members in different SCs to use the maximum amount of excess capacity.

The government should encourage the supply chain members to collaborate and cooperate more for the general well-being of society, reduce prices, distribute profits justly, and share risk among members by creating appropriate infrastructures.

8. CONCLUSION AND FUTURE STUDIES

The modeling in this research is in a three-level SC, producer, and distributor, with the intervention of the government, where all three members of this chain try to reach the Nash equilibrium point in this game based on the parameters that have been defined. These parameters apply within the limitations of the model.

As it has been observed with changes in parameters, players' strategies change because each of the players seeks to maximize their profits, As seen in the model, by changing the parameters, the decision variables are also changed, and the new Nash equilibrium point is reached.

It is important to state this point that in defining the parameters it must be done very carefully that the model must have an optimal response.

This paper may be extended in several directions; for example, using the Nash equilibrium with the bargaining power approach, without complete information, using advanced optimization algorithms (e.g., hybrid heuristics and meta-heuristics), relaxing some assumptions of the model and re-formulating the model again. Modeling in probabilistic mode with a game theory approach, increasing the number of SC levels; for example, a multi-level SC, using the Stackelberg approach or another method, different functions to use the changes in the amount of the production order that the distributor gives to the manufacturer.

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Persian Abstract

چکیده

امروزه در بسیاری از ائتلاف‌ها، شرکت‌ها در زنجیره تامین هماهنگی‌های خود را از طریق قراردادها انجام می‌دهند. از آنجائیکه موفقیت و عایدی قراردادهای دو طرفه نسبت به قراردادهای یک طرفه بسیار زیاد می‌باشد. در این مقاله مسائل پیاده‌سازی قراردادهای دو طرفه را با رویکرد تئوری بازی‌ها و مداخله دولت جهت افزایش تعامل دو سویه بین اعضای هم تولید و هم توزیع در زنجیره تامین مورد بررسی قرار گرفته است. در این تحقیق با اتخاذ مدل تئوری بازی‌ها بین این دو عضو زنجیره، با مداخله دولت به دنبال افزایش تولید و توزیع با استفاده حداکثری از ظرفیت مازاد تولید و توزیع در زنجیره است. بدین صورت تولید کننده به دو صورت از ظرفیت مازاد خود استفاده می‌نماید یکی بصورت مستقیم توسط تولید کننده، تولید و توسط توزیع کننده وارد بازار می‌شود. و دیگری سفارشی است که از طرف توزیع کننده به تولید کننده داده می‌شود که متفاوت با کالایی است که تولید کننده بطور مستقیم تولید می‌کند. هدف این تحقیق بررسی و تحلیل مقادیر و سود حاصله از مشارکت تولید و توزیع با مداخله دولت در زنجیره تامین می باشد. بر اساس این تحقیق، دولت‌ها باید محیطی را فراهم کنند تا اعضای زنجیره تامین همکاری بیشتری با یکدیگر داشته باشند. زیرا در صورت همکاری بین اعضای زنجیره تامین، سود کل زنجیره و در نتیجه سود اعضا افزایش می‌یابد.