Developing a pricing model for brand-generic medicines

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Abstract

The pharmaceutical sector's pricing impacts healthcare costs and services significantly. Improper medicine pricing profoundly affects public health and healthcare services. Pricing is a key factor in the profitability of the pharmaceutical supply chain. The optimal supply chain maximizes satisfaction and aligns with economic and social goals. The main challenge for the pharmaceutical supply chain is balancing pricing with drug quality and innovation. Stakeholder satisfaction in pricing negotiations has declined in recent years. Pharmaceutical manufacturers face pressure due to inappropriate pricing, competition, and legal restrictions. Unilateral stress on one component affects the entire chain's performance and industry development. I.R. Iran’s pharmaceutical industry has embraced branding to support manufacturers and industry growth. This paper provides model of Iran's pharmaceutical supply chain, focusing on domestic brand generics. Using game theory, Optimal wholesale and retail prices have been calculated in a competitive market setting to achieve maximum profit under three scenarios. the optimal price of the brand-generic product is about 300% higher than the price of the generic product. The positive impact of brand-generic supply chain coordination on customer surplus and social welfare is 10% and 45%. Subsidies impact on the optimal prices by 3-5% reduction, customer surplus improves 3% and social welfare has a significant increase of 43%.

Keywords: Pharmaceutical Supply Chain Management; Domestic Product Pricing; Medicine; Subsidy; Game Theory.

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1. Introduction

During and after the Covid-19 pandemic, healthcare systems, services, and their costs became the more challenging topic of discussion [1-2]. Today, business environments are aggressive, unstable, competitive, and dynamic. Due to globalization, technology's fast growth, product life cycles shortening, profit margins, and economic markets shrinking. Also, with the awareness and unique customers' needs, organizations must provide high-quality products in the shortest possible time and improve their dynamic capabilities [2-3-4]. Productive supply chain management (SCM) plays a vital in all operational and strategic decisions at the organizational level that are transferred to the supply chain level. In recent years, SCM has been accepted as a critical factor for organizational presentation and achieving competitive advantage to gain more market share [5-6].

A supply chain is a set of independent organizations connected with mutual products, information, and financial flows. The supply chain is the path that a product takes from the first point of production to distribution and reaching the final consumer/customers [7-8]. The upstream flow of the supply chain is also known as the supply flow, and the downstream flow is also known as the distribution flow [9-10]. The five dimensions of competitive advantage introduced in the supply chain are price/cost, quality, product innovation, delivery reliability, and time to market [11]. Generally, in industries, price is used as a tool for profitability. Since the food and pharmaceutical drug industries' products are perishable and have a shorter shelf life, the discussion of price and pricing becomes more important. Price is known as a demand and cost control tool in the mentioned industries, besides profitability [12-13-14]. The pharmaceutical product price is a controversial topic worldwide [15]. The complex, competitive conditions of the pharmaceutical drug market have made the possibility of an agreement in the negotiations between the components of the pharmaceutical supply chain to achieve an optimal price that provides the interest of all the components decreasing day by day [15-16-17]. Price and pricing remain challenging issues in the supply chain. In the pharmaceutical drug market, pricing is crucial, as demand may be affected by the reduction of affordability of customers [18]. In economic terms, medicine price is the amount of money needed to buy and prepare a medicine, but in reality, the price that customers pay for pharmaceutical drugs results from the complex interaction of components, stakeholders of the supply chain, and the market environment of the pharmaceutical drug [19-20].In recent years, due to conflicting interests and objectives, the agreement between the components and stakeholders of the supply chain has decreased in determining the price of medicines [16]. In addition to imposing economic pressure on customers due to increased patients' out-of-pocket payments, inappropriate medicine pricing has placed governments under unprecedented socio-political pressures for medicine price monitoring and transparency [18-19]. Medicine costs are determined through price levels, and based on international experiences, one of the ways to curb medicine costs is to determine the optimal price of medicines [21]. Determining and controlling the price of medicines is the main challenge for pharmaceutical supply chain managers and governments [18]. These factors have led governments to adopt strict policies and regulations for pharmaceutical drug pricing to meet the medicinal needs of patients and reduce government expenses [22].

In the complex decision-making environment of decentralized systems, this research examines the complex choices made by manufacturers and distributors. Using a game theory approach, a model is presented in the Stackelberg-Stackelberg supply chain network structure with regard to the impact of competition on pricing and quality of brand between homogeneous products. This study focuses on the complex dynamics of pricing and brand quality in pharmaceutical supply chains, critical components of a competitive pharmaceutical market. Its main objective is to develop a quantitative model to optimize the prices of brand-generic pharmaceutical products while effectively managing quality-related and brand promotion costs. To closely mirror the actual conditions prevalent in the pharmaceutical industry in Iran, this study examines three scenarios: vertical integration, coordination in the brand-generic supply chain, and the impact of government subsidies on brand quality. This research evaluates the multifaceted effects of these scenarios on the supply chain by using numerical analysis, using experimental data from a medicine with the generic name of losartan. This analytical study aims to provide valuable insights to industry executives and policy makers, facilitating informed decision-making and strategic actions in the ever-evolving pharmaceutical landscape. As the main contribution, this research has addressed the critical issue of pricing and achieving a practical solution. First of all, in this research, the optimal wholesale and retail prices in a competitive environment including two chains have been calculated by considering the price and quality of the brand, and then the conventional pricing approach in which producers passively accept the prices has been challenged. Furthermore, it calculates optimal wholesale and retail prices for an active pharmaceutical supply chain, based on real-world dynamics. The findings provide valuable managerial and practical insights and provide guidance for strategic decision-making regarding pricing and quality in the pharmaceutical supply chain.

In addition to competition, development is also affected by the decision-makers' priorities and governments' application of laws and regulations [23]. This paper follows the following sections: Literature Review, which surveys previous works in this field. Then, the Methods section provides a model for pricing brand-generic drugs. The results section provides the results of the mentioned model. Finally, discuss, conclude and managerial implications section furnished model and achievements.

2. Literature Review

In this section, the text discusses the four main streams of literature related to the pharmaceutical industry. The first stream focuses on the general overview of thematic literature, specifically regarding pharmaceutical drug pricing and pricing strategies in the supply chain. The second stream examines competition structures among different supply chains. The third-stream reviews research literature from the past decade, highlighting the development of quantitative models for pharmaceutical supply chains. Finally, the text introduces the game theory approach as the primary methodology used in research and explores its significance in supply chain management.

2.1. The Position and Importance of Pharmaceutical Drug Pricing and Pricing Mechanisms

In the early 20th century, studies related to pharmaceutical markets were published in the form of books. The initial research primarily focused on the economic aspects of drug pricing and its direct relation to profitability in the context of pharmaceutical pricing behavior, focusing on the general economic characteristics of industrial development [24]. In 1959, the price increase of certain pharmaceutical products and suspicious claims made by manufacturers regarding value creation in the pharmaceutical industry led to the formation of the Keefauver Senate Subcommittee committee for future investigations in the United States [25-26].

The Keefauver hearings can be considered a turning point in the history of the pharmaceutical industry and related research [26]. The main focus of these hearings was examining pharmaceutical drug prices and the pharmaceutical industry's profits. Consequently, for the first time, drug companies were held accountable for the level of innovation and effectiveness of their products. Industry representatives defended themselves by citing the high research and development costs for drug production and the unique conditions of the pharmaceutical industry. Another topic was the issue of advertising and its impact on physicians' prescribing behavior and drug price increases [26]. The consequences of the reports and discussions from the Keefauver hearings permanently affected the pharmaceutical industry [25].

As a result, changes were made in the laws regarding pharmaceutical patent registration and drug effectiveness. These changes led to the emergence of specialized generic pharmaceutical drug manufacturers. Also, Studies in pharmaceutical markets started to focus on demand and supply dynamics. By aligning the characteristics of the pharmaceutical market with administrative price monopoly markets, new topics such as barriers to entry into the pharmaceutical industry, high investment costs, and competition among manufacturers for survival became research subjects. The significant impact of generic product entry after patent expiration on competition and drug prices led researchers to investigate generic products. As a result, the generic product market emerged as an independent market. Additionally, the effects of advertising on competition and sales increase for leading market companies became a topic of interest for researchers. Furthermore, after a decade of the Keefauver hearings, studies on the social impact of legislative actions also became a part of the pharmaceutical literature [26].

2.2. Inter-chain competitive structure

All Research conducted separately by McGuire and Staelin [27], Jeuland and Shugan [28] are the first studies that have examined competition between supply chains with price-dependent deterministic demand. Wu and Chen [29] also analyzed the effect of the structure of each chain on the decisions of each chain and the strategic behavior of each member. They can be considered one of the first studies in which two competing chains, each including a manufacturer and two independent retailers, were evaluated in a competitive environment with uncertain demand, and by examining various structures, the optimal supply chain structure was determined. A year later, Boyaci and Gallego [30] investigated competition between two chains consisting of a manufacturer and a retailer producing similar products. They assumed that the market environment forces the chains into similar pricing and competition levels in customer service. In the following study, Liu and Wang [31] analyzed competition between two chains using a game theory approach. They demonstrated that the performance of an organization and the entire chain is affected by its own and its competitor's chain structure. In 2008, Xiao and Yang [32] developed a supply chain model with two-echelon chains and a leader-follower structure, considering demand as a random function dependent on price and service level. Subsequently, Anderson and Bao [33] examined the competition between n two-echelon supply chains, each consisting of a manufacturer and a retailer, with deterministic and linear demand. They reported the investigation results of the effects of different supply chain structures at a certain level of market competition. Li et al. [34] examined various supply chain structures involving competition between two supply chains with an independent producer and retailer. They also compared, investigated, and selected various manufacturer coordination contracts. Mahmoodi and Eshghi [35] proposed a model that considered price competition between two independent supply chains and integrated pricing decisions with a coordination contract for wholesaling. In the subsequent research, Saghaeeian and Riemannian [36] considered an integrated two-chain model competing in price and lead time and examined wholesaling contracts and quantity discounts. In general, competition between supply chains (as seen in Table 1) has received less attention from researchers, and fewer articles have been published in this area in the last two decades [29-37-38]. The difference between this study and existed literature has been demonstrated in the Table1.

2.3. Pharmaceutical supply chains through the past decade

The quantitative models of the pharmaceutical drug supply chain available in the research literature since 1984 can be divided into three categories, shown in Figure 1.

Pharmaceutical supply chain and logistics network design models: The subject of supply chain network design involves strategic decision-making that affects the chain's efficiency. This encompasses decisions at both strategic and operational levels, such as facility numbers and capacities, product quantities/qualities, and distribution optimization to minimize costs and lead time. Research also includes models for optimizing logistics in new product supply chains, covering various aspects like production stages, suppliers, manufacturers, storage, distribution, and transportation optimization [39-40-41].

Optimization models of pharmaceutical drug supply chain: These models have been chiefly proposed and developed concerning the analysis and impact of policies and optimal inventory control strategies in downstream components of the supply chain such as pharmacies and hospitals.

With covid outbreak in 2019, Optimization models developed that considered impact of the pandemic as large-scale disruption on resilience of supply chain [39-42].

Inventory models: Briefly, Literature on research in the field of optimization models for supply chain management has yet to be developed due to the complexity, high number of pharmaceutical products, and unique interactions between supply chain levels that affect optimization. The proposed models have considered simplifying assumptions, leading to a disconnection from the actual space and environment of the supply chain. To develop more realistic models, greater emphasis is required on coordination and the development of powerful algorithms. To address these challenges, various optimization methods, techniques, and approaches have been proposed [39-43].

2.4. Game theory in supply chain management

Game theory holds a significant position in supply chain management, evident through numerous studies exploring its application in supply chain networks and coordination. It serves as a vital tool for analyzing conflict and cooperation situations, finding applications in diverse domains like economics, business, auctions, and politics since its inception in the 1940s. Historically, operational managers and research experts neglected game theory tools, but recent years have witnessed a growing interest in utilizing game theory to address supply chain management challenges. Supply chains of manufacturers, suppliers, distributors, retailers, and customers face conflicting interests that can impact their long-term strength and competitiveness. Game theory provides a key approach to address these issues, enabling coordination and competition among supply chain components. Decentralized supply chains can lead to two outcomes: competitive behavior among chain members, each seeking maximum profit, or agreements for overall supply chain profitability. Game theory offers initial modeling for such scenarios, focusing on simultaneous or sequential decision-making with complete or incomplete information [44].

Researchers often concentrate on non-cooperative equilibria in supply chain coordination through contractual agreements or use Nash and Stackelberg games to model situations with complete information and specific demand functions. Cooperative game approaches have been proposed for market allocation. Specific closed-loop equilibrium solutions are employed based on the conditions of the supply chains being studied. In cases with symmetric information, the Eliasberg equilibrium model aids in addressing coordination and cooperation issues, while non-cooperative Bayesian games are used for situations with incomplete information [43-44-45-46]. Other optimization tools like queuing theory, recursive methods, and genetic algorithms can also tackle coordination and cooperation challenges, especially in situations with incomplete information. There are generally two game theory models widely used in supply chain management: the Nash and Stackelberg models. The Nash model focuses on situations where information exchange among supply chain echelons and levels is impossible. Players representing different entities in the supply chain choose strategies to maximize their outcomes based on rival decisions. The combination of these selected strategies, known as equilibrium, results in a Nash equilibrium if each player's chosen strategy leads to the best outcome for them. Also, players make independent decisions with complete information and equal power. It is widely applicable and has been used in various two-player models in supply chain management, such as Bertrand duopoly and common-pool resource problems [47].

On the other hand, the Stackelberg model describes scenarios where players independently optimize their objectives. Players are categorized as leaders and followers based on the order of decision-making and response. Leaders first choose their strategies and act to achieve their highest utility, while followers react based on the leaders' decisions. Both models offer valuable insights into supply chain dynamics and decision-making interactions at different levels. They help understand how players' strategies impact the overall performance and profitability of the supply chain. The following section describes fully the pricing model for brand-generic medicines [48].

3. Methods

In this section, after delineating the issue at hand, the fundamental framework grounded in the existing industry conditions for determining the pricing of domestically manufactured brand-generic medicines is expounded. Brand-generic medicines are bioequivalent to generic medicines produced by another manufacturer after the patent expiration of the leading brand drug and marketed under a proprietary name. They may have differences from the generic medication available in the market, but these differences are limited to inactive ingredients or excipients like packaging material, color, or stabilizers [49].

The core objective of this paper is to tackle a pivotal challenge faced by pharmaceutical manufacturers, namely, the attainment of equilibrium between the price and quality facets of pharmaceutical products. This equilibrium is achieved by establishing the optimal price for brand-generic pharmaceutical products, associated with managing quality costs and brand image. By scrutinizing the prevailing conditions within I.R.Iran's pharmaceutical sector and aligning the competitive framework of two supply chains with the industry's competitive landscape, the preliminary model for the interaction between two-echelon supply chains is considered. This model is constructed by incorporating the linear demand function of distributors, which is contingent on price and brand quality. To initiate, the research introduces the demand functions for brand-generic and generic products, customer surplus, and social welfare functions pertinent to the study. Subsequently, the objective functions governing the different components of the supply chain are delineated across various scenarios, encompassing decentralized supply chain operations, cost-sharing contracts, and incentive subsidy policies. The methodologies for deriving these objective functions are expounded.

3.1. The Problem Description

The foundational conceptual framework of the supply chain network includes both a brand-generic medicines supply chain (as depicted in Figure 2) and a generic medicines supply chain. Precisely conveyed, customers' pharmaceutical product demands are relayed to the distributors, who then commence the procurement process through orders placed with the manufacturers. Seeking to expand their market share and profitability, manufacturers respond to increasing demand, partake in competition based on pricing, and elevate the quality standard of pharmaceutical products. In this study, the enhancement of brand quality and brand equity involves examining the varying levels of investment between brand-generic manufacturers and their counterparts in various quality improvement strategies and branding initiatives.These strategies encompass bolstering quality management at different stages, including pre-production, production, and post-production phases. Moreover, efforts are made to differentiate the generic manufacturer's product to foster a positive perception among consumers. These quality-focused strategies and decisions typically bear minimal influence on production expenses, indicating that manufacturers can elevate product quality without escalating unit production costs, such as through process refinement initiatives [50]. Distributors strategically analyze and make determinations concerning the retail pricing of products with the aim of enhancing their profitability.

3.2. Model Assumptions.

In this study, deliberate efforts have been made to meticulously align the foundational assumptions of the model with the actual prevailing conditions and extant literature on modeling practices. The model in focus comprises two distinct pharmaceutical supply chains, each composed of independent manufacturers and distributors operating autonomously. At its core, this model is centered around a specific pharmaceutical product, manufactured to satisfy market demand and subsequently routed through a distribution entity for dissemination. Notably, the distribution of pharmaceuticals in this context adheres to an indirect pathway through distributor networks, a necessity imposed by regulatory constraints within the local restriction. In order to model the problem, the paper considers the following assumptions:

1. All players are rational.
2. Manufacturers are restricted from engaging in direct distribution of medications to retailers or final consumers.
3. The demand function is specified as a deterministic and linear equation, denoted as, $D = a - bp$, where the demand is influenced by variables like product pricing, brand quality, and the prices of competing products. Quality spillover effects on generic pharmaceutical product demand are theorized such that enhancements in brand-generic product quality are anticipated to correspond with a reduction in generic pharmaceutical product demand.
4. The bioequivalence of products between two manufacturers allows for homogeneity.
5. The production approach is make-to-order (MTO), and any shortage in the supply chain components is not permitted. Manufacturers and distributors possess the capacity to fulfill all incoming orders and requests.
6. The entirety of drug-related data and information pertains to individual pharmaceutical drug units. The terminology of medicine price and pricing pertains to the valuation of a single drug unit. For simplification in this model, a medicine product is equated to 100 units.
7. In third scenario, the government's provided subsidy is a proportion of the raw material costs associated with the brand-generic product.

3.3. Symbols used in the model, parameters, and decision variables

For clarity, subscripts (*BG*) and (*G*) have been applied to differentiate the brand-generic chain from the generic supply chain. Additionally, subscripts (*m*) and (*d*) distinguish the elements of manufacturer and distributor chains, respectively. The variables in the second and third scenarios are denoted by superscripts (*c)* and (*s*).

The signs in Table 2 have been used to show the decision parameters and variables. Each of the parameters and decision variables of the model are briefly defined. The demand function in this research for the brand-generic pharmaceutical product is considered deterministic and a linear function dependent on the price and quality/image of the brand and the competing price of the generic product, similar to the functions in the research literature [51-52]

Brand-generic product demand function followed as:

$$D_{BG} = A - B_{BG} Pd_{BG} + B_G Pd_G + \lambda_1 Qb \tag{1}$$

The Generic product demand function followed as:

$$D_G = A + B_{BG} Pd_{BG} - B_G Pd_G - \lambda_2 Qb \tag{2}$$

In many industries characterized by the interplay of social and economic dimensions, a considerable number of organizations incorporate the customer surplus function into their overall objective. In the pharmaceutical sector, where clientele comprises patients, this particular function can be denoted as the patient benefits function. Within the ambit of this study, the process is delineated followed as [51]:

$$CS(Pd, Qb) = \int_{Pd_{BG}}^{Pd_{BG\max}} (A - B_{BG} Pd_{BG} + B_G Pd_G + \lambda_1 Qb)dx + \int_{Pd_G}^{Pd_{G\max}} (A - B_G Pd_G + B_{BG} Pd_{BG} + \lambda_2 Qb)dx \tag{3}$$

In this paper, the social welfare function is defined as the sum of the profit function of two supply chains and customer surplus, presented followed as:

$$SW = \Pi_{SC_{BG}}{}^{*} + \Pi_{SC_G}{}^{*} + CS(Pd^{*}, Qb^{*}) \tag{4}$$

3.4. First scenario: Decentralized supply chain model with Stackelberg producer leadership structure

In the first scenario, the integration of upstream and downstream organizations occurred horizontally, considering the Stackelberg producer leadership framework. This configuration can be construed as analogous to a unitary two-echelon supply chain. Within the context of the Stackelberg producer leadership structure within supply chains, primary decision-makers, acting as leaders, undertake initial determinations encompassing (wholesale) pricing and optimizing quality programs. Subsequently, subsequent decision-makers, serving as followers, pursue profit maximization objectives. Their decisions are contingent upon the purchase price established by the producers, impacting the determination of the (retail) price and optimal choices. The parity in influence characterizes both supply chains, establishing a Nash equilibrium. In essence, the outlined model conforms to a two-stage Stackelberg game. In this scenario, the wholesale prices of manufacturers W_{BG} and W_G and the amount of investment in improving brand quality/equity of the brand *Qb* are the first stage's decision variables. Manufacturers' profit functions are as follows:

$$\Pi_{m_{BG}} = (W_{BG} - c_{BG})(A - B_{BG}Pd_{BG} + B_G Pd_G + \lambda_1 Qb) - \frac{\alpha Qb^2}{2} \tag{5}$$

$$\Pi_{m_G} = (W_G - c_G)(A + B_{BG}Pd_{BG} - B_G Pd_G + \lambda_2 Qb) \tag{6}$$

And distributors' profit functions that are used as second-stage functions are represented below:

$$\Pi_{d_{BG}} = (Pd_{BG} - W_{BG} - cd_{BG})(A - B_{BG}Pd_{BG} + B_G Pd_G + \lambda_1 Qb) \tag{7}$$

$$\Pi_{d_G} = (Pd_G - W_G - cd_G)(A + B_{BG}Pd_{BG} - B_G Pd_G + \lambda_2 Qb) \tag{8}$$

After examining the first and second order of optimization conditions and proving the concavity of the objective functions, taking into account the range for some parameters and variables, the optimal values of the manufacturers' decision variables of the problem under this scenario are:

$$\begin{aligned} W_{BG} = {} & \frac{1}{(9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}(3\alpha(9A + c_G B_G - cd_G(5B_{BG} + 4B_G) + cd_{BG}(4B_{BG} + 5B_G)) + c_{BG}(6\alpha B_{BG} - \\ & 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)) \end{aligned} \tag{9}$$

$$\begin{aligned} W_G = {} & \frac{1}{B_G(9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}(3\alpha(c_{BG} + 5cd_{BG} - 4cd_G)B^2_{BG} - (2\lambda_1 - \lambda_2)((3A + 2c_G B_G - 3cd_G B_G)\lambda_1 + \\ & (-c_G B_G + 3(A + cd_{BG}B_G)\lambda_2) + 3B_{BG}(9A\alpha + 2\alpha c_G B_G - 5\alpha cd_G B_G - 2c_{BG}\lambda_1^2 + 3c_{BG}\lambda_1\lambda_2 + 2cd_G\lambda_1\lambda_2 - c_{BG}\lambda_2^2 - cd_G\lambda_2^2 \\ & + cd_{BG}(4\alpha B_G + \lambda_1(-2\lambda_1 + \lambda_2)))) \end{aligned} \tag{10}$$

$$Qb = \frac{1}{(9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}((9A - c_{BG}B_{BG} - 5cd_G B_{BG} + c_G B_G - 4cd_G B_G + cd_{BG}(4B_{BG} + 5B_G))(2\lambda_1 - \lambda_2)) \tag{11}$$

The retail prices of brand-generic and generic medicines are obtained followed as:

$$Pd^*_{BG} = \frac{1}{3}(3c_{BG} + cd_{BG} + \frac{2(-cd_{BG} + cd_G)B_G}{B_{BG}}) + \frac{4\alpha(9A - (cb_{BG} + 4cd_{BG} + 5cd_G)B_{BG} + c_G B_G + (5cd_{BG} - 4cd_G)B_G)}{9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2} \tag{12}$$

$$\begin{aligned} Pd^*_G = {} & \frac{1}{3B_G(9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}(3\alpha(4c_{BG} + 17cd_{BG} - 13cd_G)B^2_{BG} - (2\lambda_1 - \lambda_2)((12A + (3c_G - 5cd_{BG} + 8 \\ & cd_G)B_G)\lambda_1) + 4(3A + 4(cd_{BG} - c_G)B_G)\lambda_2)B_{BG}(108A\alpha + 15\alpha c_G B_G + 39\alpha cd_{BG} + B_G - 24\alpha cd_G B_G - 14\alpha cd_{BG}\lambda_1^2 - 10 \\ & cd_G\lambda_1^2 + (36c_{BG} - cd_{BG} + 37cd_G)\lambda_1\lambda_2 - 4(-3c_{BG} + cd_{BG} - 4cd_G)\lambda_2^2)) \end{aligned} \tag{13}$$

3.5. Second scenario: Decentralized supply chain model with Stackelberg producer leadership structure with cost-sharing contract

In this scenario, the brand-generic distributor is committed to paying *ω* a percentage of quality brand/equity investment costs of the brand-generic manufacturer under cost-sharing contracts, changes applied to profit brand-generic supply chain functions and function of brand-generic manufacture and distributer represented in order followed as:

$$\Pi^{c}{}_{m_{BG}} = (W^{c}{}_{BG} - c_{BG})(A - B_{BG} Pd^{c}{}_{BG} + B_{G} Pd^{c}{}_{G} + \lambda_1 Qb^{c}) - (1-\omega)\frac{\alpha Qb^{c^{2}}}{2} \quad (14)$$

$$\Pi^{c}{}_{d_{BG}} = (Pd^{c}{}_{BG} - W^{c}{}_{BG} - cd_{BG})(A - B_{BG} Pd^{c}{}_{BG} + B_{G} Pd^{c}{}_{G} + \lambda_1 Qb^{c}) - \omega\frac{\alpha Qb^{c^{2}}}{2} \quad (15)$$

In the second scenario, as in the first scenario, the solution of the two-stage Stackelberg game model is done recursively using backward induction. Therefore, based on the condition of first-order optimization, to obtain optimal retail prices at the level of distributors, it is necessary to solve the system of equations obtained from the first-order derivative of the distributors' profit functions concerning their variables simultaneously. Based on the optimization condition of the second order derivative, the resulting solution will be the absolute optimal solution if the concavity of the distributors' profit functions concerning the decision variables is separately proven, and first-stage decision variables are represented below:

$$W^{c}{}_{BG} = \frac{1}{-9\alpha(1-\omega)B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}(-3\alpha(1-\omega)(9A - cd_{BG}B_{BG} + c_G B_G + cd_G B_G) + c_{BG}(-6\alpha(1-\omega)B_{BG} + 10\lambda_1^2 - 13\lambda_1\lambda_2 + 4\lambda_2^2)) \quad (16)$$

$$W^{c}{}_{G} = \frac{1}{B_G(9\alpha(1-\omega)B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}(3\alpha(1-\omega)(c_{BG} + cd_{BG})B^2{}_{BG} + (2\lambda_1 - \lambda_2)((3A + 2c_G B_G - 3cd_G B_G)\lambda_1 + (-c_G B_G + 3(A + cd_G B_G)\lambda_2) + 3B_{BG}(-9A\alpha + 9A\alpha\omega - 2\alpha(1-\omega)c_G B_G + \alpha(1-\omega)cd_G B_G + 2c_{BG}\lambda_1^2 + 2cd_{BG}\lambda_1^2 - 3cd_{BG}\lambda_1\lambda_2 + c_{BG}\lambda_2^2 - cd_{BG}\lambda_2^2)) \quad (17)$$

$$Qb^{c} = -\frac{(9A - c_{BG}B_{BG} - cd_{BG}B_{BG} + c_G B_G + cd_G B_G)(2\lambda_1 - \lambda_2)}{-9\alpha(1-\omega)B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2} \quad (18)$$

The optimal retail price of medicines under a cost-sharing contract is as:

$$Pd^{c^*}{}_{BG} = \frac{1}{9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2}(-4\alpha(1-\omega)(9A + c_G B_G + cd_G B_G) - c_{BG}(5\alpha(1-\omega)B_{BG} + 10\lambda_1^2 - 13\lambda_1\lambda_2 + 4\lambda_2^2) + cd_{BG}(-5\alpha(1-\omega)B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)) \quad (19)$$

$$Pd^{c^*}{}_{G} = \frac{1}{B_G(9\alpha(1-\omega)B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}(4\alpha(1-\omega)(c_{BG} + cd_{BG})B^2{}_{BG} - (2\lambda_1 - \lambda_2)((4A + (c_G B_G + cd_G B_G + 4A\lambda_2) + B_{BG}(-5\alpha(1-\omega)c_G B_G - 5\alpha(1-\omega)cd_G B_G - 4(9A(1-\omega) + c_{BG}(2\lambda_1^2 - 3\lambda_1\lambda_2 + \lambda_2^2) + cd_{BG}(2\lambda_1^2 - 3\lambda_1\lambda_2 + \lambda_2^2)))) \quad (20)$$

The overall profit function of the brand-generic supply chain is concave, and after checking the first order condition of optimization, we have the optimal cost-sharing ratio followed as:

$$\omega = \frac{22\lambda_1 - 23\lambda_2}{40\lambda_1 - 32\lambda_2} \quad (21)$$

3.6. Third scenario: Decentralized supply chain model with Stackelberg producer leadership structure considering government subsidy

In this scenario, a subsidy is given by the government (Food and Drug Organization) to the brand-generic producer. The paid subsidy covers part of the cost of raw materials and has a positive effect on the functions of the components of the brand-generic supply chain.

$$\Pi^{s}{}_{m_{BG}} = (W^{s}{}_{BG} - c_{BG} + s_{BG})(A - B_{BG} Pd^{s}{}_{BG} + B_G Pd^{s}{}_{G} + \lambda_1 Qb^{s}) - \frac{\alpha Qb^{s^2}}{2} \tag{22}$$

With the same approach as previous scenarios, optimal decision variables of the two-stage games are calculated followed as:

$$W^{s^*}{}_{BG} = c_{BG} - s_{BG} + \frac{3\alpha(9A - (c_{BG} + cd_{BG} - s_{BG})B_{BG} + (c_G + cd_G)B_G)}{9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)} \tag{23}$$

$$W^{s^*}{}_{G} = \frac{1}{B_G(9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}(3\alpha(c_{BG} + cd_{BG} - s_{BG})B^2{}_{BG} - (2\lambda_1 - \lambda_2)((3A + 2cd_G)B_G)\lambda_1 + (3A - (c_G$$
$$-3cd_G)B_G)\lambda_2) + B_{BG}(9A\alpha + \alpha(2c_G - cd_G)B_G - (c_{BG} + cd_{BG} - s_{BG})(2\lambda_1^2 - 3\lambda_1\lambda_2 + \lambda_2^2))) \tag{24}$$

$$Qb^{s^*} = \frac{(9A - (c_{BG} + cd_{BG} - s_{BG})B_{BG} + (c_G + cd_G)B_G)(2\lambda_1 - \lambda_2)}{9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2} \tag{25}$$

The optimal retail price of medicines and also, the optimal lower limit (S_{LBG})of the subsidy granted by the government from the point of view of the brand-generic producer had also been calculated, to obtain this optimal limit, the profit of the generic-brand producer should be higher than the state in which the government's incentive policy is not implemented in the form of subsidies. It is shown below:

$$Pd^{s^*}{}_{BG} = c_{BG} + cd_{BG} - s_{BG} + \frac{4\alpha(9A - (c_{BG} + cd_{BG} - s_{BG})B_{BG} + (c_G + cd_G)B_G)}{9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2} \tag{26}$$

$$Pd^{s^*}{}_{G} = \frac{1}{B_G(9\alpha B_{BG} - 10\lambda_1^2 + 13\lambda_1\lambda_2 - 4\lambda_2^2)}((4\alpha(c_{BG} + cd_{BG} - s_{BG})B^2{}_{BG} - (2\lambda_1 - \lambda_2)((4A + (c_G + cd_G)B_G) + \lambda_1$$
$$4A\lambda_2) + B_{BG}(36A\alpha + 5\alpha(c_G + cd_G)B_G - 4(c_{BG} + cd_{BG} - s_{BG})(2\lambda_1{}^2 - 3\lambda_1\lambda_2 + \lambda_2{}^2)) \tag{27}$$

$$s_{LBG} = \frac{1}{B^2{}_{BG}}(B_{BG}(-9A + (c_{BG} + cd_{BG})B_{BG} - (c_G + cd_G)B_G) + \frac{1}{6\alpha B_{BG} - (-2\lambda_1 + \lambda_2)^2}(((B_{BG}{}^2(-9A(c_{BG} - 4cd_{BG}$$
$$+5cd_G)B_{BG} - c_G B_G + (-5cd_{BG} + 4cd_G)B_G)^{1/2})(6\alpha B_{BG} - (-2\lambda_1 + \lambda_2)^2)(6\alpha(c_{BG} + 2cd_{BG} - cd_G)B_{BG}{}^2 + (2\lambda_1 - \lambda_2)$$
$$(2(9A + (c_G - 5cd_{BG} + 6cd_G)B_G)\lambda_1 - (9A + (c_G - 11cd_{BG} + 12cd_G)B_G)\lambda_2) + B_{BG}(-54A\alpha - 6\alpha(c_G - cd_{BG} + 2cd_G)$$
$$B_G - 4(c_{BG} + 6cd_{BG} - 5cd_G)\lambda_1{}^2 + 4(c_{BG} + 9cd_{BG} - 8cd_G)\lambda_1\lambda_2 - (c_{BG} + 12cd_{BG} - 11cd_G)\lambda_2{}^2))))) \tag{28}$$

4. Dataset

For the examination of the outcomes and analysis of the suggested model across varied scenarios, authentic data concerning a pharmaceutical product has been employed in the capacity of a numerical example. Within this investigative endeavor, specifics and particulars relevant to the medicinal entity identified as a generic name (LOSARTAN POTASSIUM TABLET ORAL 25 mg), encompassing an oral solid tablet configuration, have been duly utilized. Procurement of the requisite data and essential information has been facilitated through the proficient contributions of experts affiliated with the pharmaceutical division. Furthermore, insights gleaned from consultations with pharmaceutical executives, alongside antecedent scholarly investigations, have been judiciously incorporated to facilitate the estimation of certain parameters. The empirical evidence and information employed in this study encompass an amalgamation of data spanning a decade, specifically from 2009 to 2020. It is pertinent to note that all monetary values are denominated in the standard currency unit of IRI. Rials are shown in Table 3.

[*] The monetary unit is Rial, the official currency in Iran at that time of research.

5. Results

Based on the available data and information in Table 3 and setting the required parameters, the demand functions of brand-generic and generic medicines are, respectively, follows:

$$D_{BG} = 731801 - 1.41Pd_{BG} + 5.8Pd_{G} + 0.47Qb \tag{29}$$

$$D_{G} = 731801 - 5.8Pd_{G} + 1.4Pd_{BG} - 0.00000002Qb \tag{30}$$

In the second and third scenarios considering the data, ω in the second scenario is equal to 0.55, and the optimal minimum amount of subsidy in the third scenario is equal to 98784. The optimal decision variables of wholesale prices, retail prices, and the optimal amount of investment in brand quality/equity for the brand-generic product customer surplus and social welfare in each scenario have been calculated, and comprehensive results of all scenarios are presented in Table 4.

6. Discussion

In the first scenario, the optimal price of the brand-generic product is about 300% higher than the price of the generic product. In the second scenario, as expected, with the coordination and cooperation of the manufacturer and the distributor in the brand-generic chain in the form of a cost-sharing contract and the distributor's 55% participation in the brand quality improvement costs, the profit of the brand-generic chain will increase by 1.5%. The wholesale price, i.e., buying from distributors, will increase by 2.5% compared to the case of no contract. The sharing of quality costs increases the investment in more than 100% of the product. This is consistent with the results of previous studies that in addition to improving the independent performance of each component, the cost-sharing contract can affect the performance of the entire supply chain and the quality of products. In general, it can be said that in the case of an agreement, by paying part of the costs by the distributor, the investment in the quality of the brand increases, and the manufactured product is offered to the distributor at a higher price.

Also, the retail price increases by about 3% due to the increase in the distributor's cost. In the generic chain, the wholesale price of the generic product will increase by 1.8% and its retail price by 2%. Examining the coordination effect of brand-generic supply chain components indicates a 10% increase in the profit of the generic chain. The positive impact of brand-generic supply chain coordination on customer surplus and social welfare is 10% and 45%, respectively. In the third scenario, the government subsidy amount equals 40% of the cost of brand-generic raw materials. By granting a subsidy to the brand-generic manufacturer and covering a part of the raw material costs of the brand-generic manufacturer, the positive effect of this subsidy on the wholesale prices of the brand-generic and generic products is in the form of a 3-5% reduction, respectively. As predicted, the subsidy affects the amount of qualitative development and will result in a decrease of 0.07%. Granting subsidies in the long term can affect the process of maintaining and improving the brand quality of brand-generic products. The retail price of the brand-generic product and the retail price of the brand-generic and generic product show a decrease of 2.5 to 3 percent compared to the non-subsidized state. The current subsidy of the total profit of the brand-generic chain has increased by about 0.68%, and the total profit of the generic chain has decreased by about 2%. Examining the effect of the subsidy on customer surplus shows a 3% increase. In this situation, social welfare has a significant increase of 43%. These results are consistent with the results of some research conducted in the field of coordination contracts. The sensitivity analysis results also show that with the increase in the amount of subsidy granted, the retail price of brand-generic products will decrease, and the profit of the entire brand-generic chain will increase relatively.

7. Managerial implications

According to results, the current pricing approach aims to ensure the short-term survival of generic companies by maintaining pricing parity between brand-generic and generic products, enabling pharmaceutical manufacturers to earn a viable profit margin. In the context of competitive market dynamics where manufacturers possess pricing autonomy, the optimal price of the brand-generic product demonstrates a substantial escalation, Moreover, within this pricing framework, the profitability obtained by the brand-generic manufacturer undergoes a noteworthy escalation, characterized by a fourfold increase compared to current pricing approach in I.R.Iran. The increase in profits can serve as a driving force for generic pharmaceutical companies to enter the brand-generic market, leading to investments in quality improvements and brand promotion. This shift has the potential to impact the brand-generic market and influence overall development strategies within the country's pharmaceutical industry.

Government subsidies can be strategically utilized as an incentive mechanism, especially when manufacturers and distributors have the independence to determine prices according to market forces. These subsidies can function as a short-term control tool, steering market dynamics and influencing pricing strategies effectively.

Government subsidies can effectively control and lower the wholesale and retail prices of pharmaceutical products. However, this reduction in prices is usually facilitated by decreased raw material costs and a scaling back of investments aimed at enhancing product quality.in long term, these subsidies can impact entry dynamics to brand-generic market and product quality standards. They can also shape the direction of programs geared towards brand expansion and the innovation of new production techniques within the pharmaceutical sector. These long-term effects can be significant in influencing the competitive landscape and the strategies adopted by companies within the industry.

8. Conclusion

This paper contains innovations in the field of research problems and practical achievements. It is done to determine the optimal wholesale and retail prices in the competition between the two chains in terms of price and brand quality Also, in this paper, the problem of competition in the price and quality of the brand in two supply chains of brand-generic and generic in the supply chain network structure based on the Iran pharmaceutical industry was defined and modeled. The numerical analysis results demonstrate that the developed pricing model, when contrasted with the price acceptance approach typically utilized by manufacturers, can make the brand-generic manufacturer 4 times more profitable. Keeping the prices of brand-generic and generic pharmaceutical products close in the long term can challenge the development of the pharmaceutical industry. The effect of two scenarios of coordination and subsidization in the brand-generic supply chain on the profit of the chains, the benefit of patients, and social welfare as a factor of sustainable development of the chain was investigated. Also, the results showed that the overall profit of the brand-generic supply chain under the second scenario is associated with an increase of 2.5%. The cooperation in the second scenario caused a 100% increase in brand investment. it has shown the increase in competition and quality standard in case of changing the pricing approach. The model under the second scenario with a 10-40% increase in social welfare and benefit of patients showed that according to previous expectations, cooperation in the brand-generic supply chain can be effective in the development of the industry. In the third scenario where a government subsidy was provided, the results indicated a decrease of 0.07% in the investment in quality of brand. It establishes that using subsidies as an incentive does not guarantee a sustained improvement in quality over time.

For future research in this field, the basic model can be used for development.

- The model can be developed by increasing the number of supply chains, the number of levels within supply chains and changing the structure of the supply chain network. By adding a brand-generic supply chain of a new product, the effect of the introduction of a new brand product on the price and quality decisions of other chains can be investigated.

- By altering the competitive dynamics among chains and focusing on the leading chain, the impact on optimized prices and other relevant factors can be investigates and shedding light on the effects of reshaping competition within supply chain networks.
- Also, due to key role of suppliers and the cost of raw materials in the price decisions and profits of manufacturers and the effect of suppliers' performance on the credibility and quality of the manufacturer' brand, investigating supplier selection and disruptions within the supply chain and upstream organizations can yield valuable insights into enhancing supply chain performance and resilience. These analyses can inform strategies for managing supply chain risks, optimizing supplier relationships, and improving overall operational efficiency.
- Researchers and pharmaceutical supply chain managers may find the impact of controlled pricing policies, regulatory restrictions, and competitive dynamics on pricing and quality to be an appealing area of study. These factors present complex challenges and opportunities in the pharmaceutical supply chain. Studying how these variables interact can provide valuable insights into optimizing pricing strategies, navigating regulatory landscapes, enhancing quality standards, and gaining a competitive edge in the market.

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Figures

Fig. 1. Quantitative models of pharmaceutical drug supply chain methods.

Fig. 2. Basic model of supply chain network

Tables

Table 1. A selective chain competition research. Regarding all of the mentioned research, the Model approach is Game theory, and the Type of competition is Chain-Chain

Table 2. Description and detail of Symbols

Table 3. Aggregate information of a decade of investigated pharmaceutical products.

Table 4. Results of numerical analysis of scenarios.

9.Appendice

Fig. 1. Quantitative models of pharmaceutical drug supply chain methods.

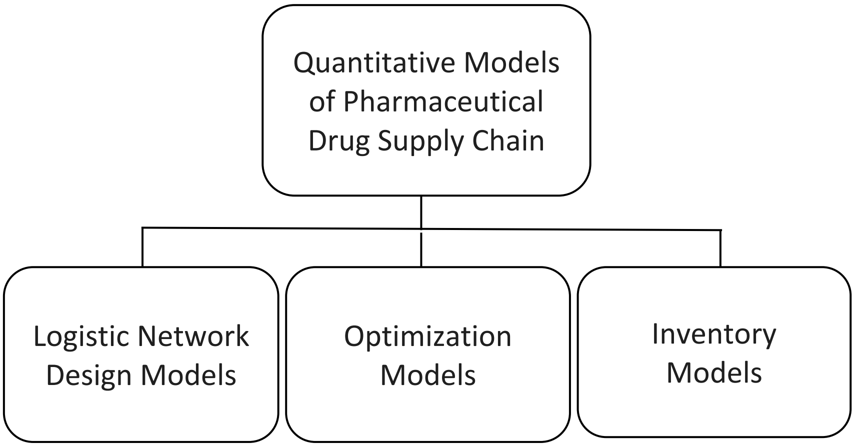

Fig. 2. Basic model of supply chain network.

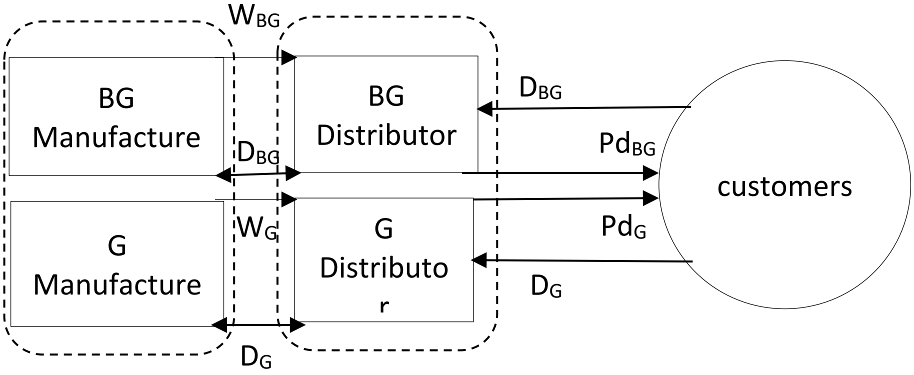

Table 1. A selective chain competition research. Regarding all of the mentioned research, the Model approach is Game theory, and the Type of competition is Chain-Chain

Chains no.	Competition level	Type of demand function	Ref.
2	Price	Linear and Deterministic	[18]
2	Quantity Produced	Linear and Stochastic	[20]
2	Service Level	Non-linear and Stochastic	[21]
2	Quantity Produced	Linear and Stochastic	[22]
2	Price and Service Level	Linear Stochastic	[23]
N	Price	Linear and deterministic	[24]
2	Price and Quantity Produced	Linear and Deterministic	[25]
2	Price	Linear and Stochastic	[26]
2	Price, Quantity Produced, and Lead Time	Linear and Deterministic	[27]
2	Price and Lead Time	Linear and Deterministic	[29]
2	Price and Quality of Brand	Linear and Deterministic	This study

Table 2. Description and detail of Symbols

Symbol	Type	Description
D_{BG}	Model parameter	Brand-generic product demand
D_G	Model parameter	Generic product demand
A	Model parameter	Market scale: The total market demand for pharmaceutical products that are available in the market in the form of domestically produced brand-generic and generics.
B_{BG}	Model parameter	Price elasticity coefficient of brand-generic product
B_G	Model parameter	Price elasticity coefficient of generic product
λ_1	Model parameter	Elasticity coefficient of brand quality (effect of brand-generic quality on its own demand)
λ_2	Model parameter	Cross elasticity coefficient of brand quality (the effect coefficient of brand-generic quality on the amount of generic drug demand)
α	Model parameter	Cost coefficient of brand quality of brand-generic product manufacturer
c_{BG}	Model parameter	Raw material costs of brand-generic product
c_G	Model parameter	Raw material costs of generic product
cd_{BG}	Model parameter	Brand-generic product's inventory and distribution fixed costs
cd_G	Model parameter	Generic product's inventory and distribution fixed costs
s_{BG}	Model parameter	Subsidy granted to brand-generic product manufacturer
ω	Model Decision variable	Quality cost-sharing ratio commitment percentage by brand-generic distributor
Pd_{BG}	Distributor Decision variable	Selling price of distributor of brand-generic product (Retail price of brand-generic product)
Pd_G	Distributor Decision variable	Selling price of the distributor of the generic product (Retail price of generic product)
Qb	Manufacturer Decision variable	Investment cost of the brand-generic product manufacturer to improve the quality of the brand for each product

Table 3. Aggregate information of a decade of investigated pharmaceutical products.

year	***Total demand***	***The price of losartan (Per unit)***	***The price of Lozar (Per unit)***	***Brand quality cost of Lozar (Per unit)***	***production cost of Lozar (Per unit)***
2009	1670867	1549520812	7100	52000	30000
2010	1791597	1983861998	31000	62000	42500
2011	1967492	3281516231	16000	93350	65000
2012	2333104	4413876078	23000	105800	99000
2013	2310508	6329269921	25500	153110.5	108390
2014	2772182	9170938400	27600	185000	155500
2015	2781113	9448943278	27000	190018.1	157500
2016	3036089	15196476892	28000	280000	201000
2017	3480163	20244803364	28000	325600	250000
2018	3735735	24033971786	32200	360000	280000
2019	3931615	27259349729	44000	387500	302920
2020	4140078	29787585116	50000	401951	324000

*The monetary unit is Rial, the official currency in Iran at that time of research.

Table 4. Results of numerical analysis of scenarios.

	Scenario 1: Decentralized supply chain	***Scenario 2: under cost-sharing contract***	***Scenario3: considering subsidy***
W^*_{BG}	2128643	2179315	2028462
$W_G{}^*$	521999	531788	507417
Qb^*	118646	270759	118559
Pd^*_{BG}	2802320	2883593	2715385
Pd^*_G	690024	704730	672236
$\Pi_{SC_{BG}}{}^*$	2125372680732	2158935563157	21825479950222
$\Pi_{SC_G}{}^*$	289610680231	318848846139	276032482741
CS	302190185100	332631312928	311713803269
SW	1935830830110	2810415722224	2770294281032

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