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Optimizing Coordination in the Metformin Supply Chain Using Quantity Discounts and Government Subsidies: A Case Study of Iran's Healthcare System

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Abstract


Access to essential medications like metformin in Iran's healthcare system is significantly enhanced by preventing financial distress and ensuring robust cash flow through integrating quantity discounts and government subsidies. This study investigates their role in optimizing supply chain coordination, enhancing profitability, and reducing costs. By examining a two-tier pharmaceutical supply chain involving collaboration among government entities, pharmaceutical companies, and insurers under price controls, the research employs analytical models to assess their impact on stakeholder coordination and overall efficiency. The findings demonstrate that these strategies improve collaboration and optimize total supply chain profits. This study provides actionable insights into leveraging quantity discounts and government subsidies to strengthen coordination in Iran's pharmaceutical supply chain, ultimately ensuring equitable access to high-quality medications.

Keywords: Coordination, Pharmaceutical supply chain, Discount, Insurance policies, Government subsidies, Logistics.

1 | Introduction

Access to essential medications like metformin in Iran's healthcare system is enhanced through quantity discounts and government subsidies, ensuring robust cash flow and preventing financial distress. The pharmaceutical supply chain, encompassing production, distribution, and sales, is critical for community health [1]. Effective coordination among interdependent participants is vital to improve profitability and ensure reliable access to medications [2].

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In decentralized supply chains, participants often prioritize individual gains, reducing overall efficiency. Notable contracts include buy back [3], revenue sharing [4], sales rebate [5], quantity flexibility [6], trade credit [7], quantity discount [8]. These serve to stimulate demand and manage it effectively. Unlike demand management tools that focus on forecasting, coordination contracts incentivize alignment [9].

Governments are crucial in supply chain coordination, supporting R&D [10], market regulation [11], pricing [12], and welfare [13]. Interventions incentivize members via covering investment costs, subsidizing production, expanding markets through advertising, offering low-interest loans, providing tax exemptions, and paying tariffs as subsidies [13]. In Iran, where drug prices are regulated, multiple retailers produce metformin, requiring non-pricing strategies like quantity discounts to gain market share [14]. Government subsidies and policies support equitable access, reduce financial burdens, and strengthen the healthcare system [15]. This study examines how quantity discounts and subsidies optimize coordination in Iran's metformin supply chain, improving accessibility and public health.

Access to essential medications like metformin in Iran's healthcare system is significantly enhanced by preventing financial distress and ensuring robust cash flow through quantity discounts and government subsidies. This study explores a two-tier pharmaceutical supply chain in countries like Iran, involving distributors and retailers, to optimize coordination. Government-insurer collaboration sets medication coverage and reimbursement rates, with subsidies reducing patient costs and boosting equity [16]. Misaligned financial flows between suppliers and insurers can cause bankruptcies, disrupting drug access. Quantity discounts align stakeholders, enhancing profitability and stability. This paper's contributions include:

- I. Pioneering analysis of quantity discounts and subsidies for supply chain coordination in Iran's pharmaceutical sector.
- II. Incorporating incentive contracts' impact on demand, considering competing distributors' terms.
- III. Highlighting government-insurer policies ensuring affordable medication access. Analytical models show these strategies foster collaboration, reduce costs, and ensure equitable access to high-quality medications, offering insights for Iran's supply chain.

Section 2 defines the problem and presents mathematical models for supply chain coordination. Section 3 compares contracts used for coordination. Section 4 conducts numerical experiments and sensitivity analyses on contract parameters, providing managerial insights. Section 5 summarizes findings and concludes.

2 | Problem Description and Formulation

Access to essential medications like metformin in Iran's healthcare system is significantly enhanced by preventing financial distress and ensuring robust cash flow through quantity discounts and government subsidies. This study analyzes a two-stage pharmaceutical supply chain in countries like Iran, involving a distributor and retailers (pharmacies) for a specific medication. Multiple distributors supply drugs to pharmacies under varying contractual agreements. Government-insurer collaboration sets medication coverage and reimbursement rates, with insurers covering part of the costs and patients paying the rest within a specified timeframe (*Fig. 1*). Misaligned financial flows between suppliers and insurers can cause financial strain, disrupting drug access and patient health outcomes. This research explores quantity discount contracts to mitigate coordination challenges, enhancing accessibility and supply chain stability.

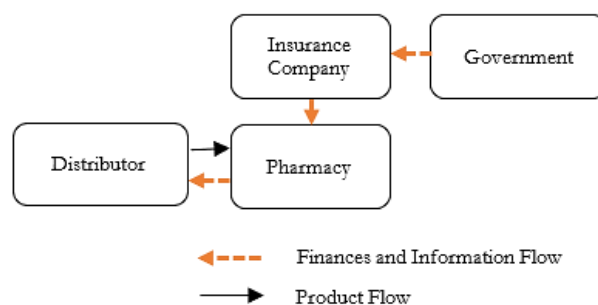


Fig. 1. A view of the members of the pharmaceutical supply chain under investigation along with their relationship with the government.

The paper details the assumptions and notations used, and provides additional assumptions and notations as needed.

2.1 | Notation and Indices

The following notations are used throughout the paper:

N_u	The set of pharmacies indexed i .
J	The set of substitute products indexed j .

Parameters:

$I(t)$	Inventory level at time t .
$I_i(t)$	Inventory level of the i^{th} pharmacy at time t .
D_i	Demand function of i^{th} pharmacy.
α_i	The maximum estimated demand of i^{th} pharmacy.
p	Selling price per unit.
β_1	The credit period' length sensitivity of the medication.
N	The duration of paying the share of costs covered by insurance.
λ	The quantity discount parameter offered to distributor (a decision variable).
η_j	The quantity discount parameter's sensitivity of the substitute product j .
λ_{s_j}	The quantity discount parameter offered of the substitute product to retailer j .
o_d	The ordering cost per order for the distributor.
w	The wholesale price from the supplier to the pharmacy.
c	The cost of supplying each unit by the supplier.
h_r	The holding cost of pharmacy excluding any interest per year.
h_d	The holding cost of distributor excluding any interest per year.
θ	The portion of the medicine cost paid by the patient.
I_v	The opportunity interest loss per year.
T	The replenishment cycle time in years (a decision variable).
Q	The order quantity (a decision variable).
π_d	The distributor's profit.
$\pi_{r,i}$	The profit function of the i^{th} retailer (pharmacy).
π_{sc}	The supply chain's average profit.

2.2 | Assumptions

Access to essential medications like metformin in Iran's healthcare system is significantly enhanced by preventing financial distress and ensuring robust cash flow through quantity discounts and government subsidies. The proposed mathematical models for a two-stage pharmaceutical supply chain are based on the following assumptions:

Time and inventory:

- I. Infinite time horizon
- II. Instantaneous replenishments
- III. No inventory shortages

Product characteristics:

- I. Focus on one generic medication (post-patent) with consistent quality.
- II. Multiple retailers produce the same product category.
- III. Metformin, with a 5-year expiration and short sales cycles, is non-perishable.
- IV. Favorable storage conditions at distributors and pharmacies ensure quality.

Demand and contracts:

- I. Demand depends linearly on contract terms and substitute products.
- II. Distributors offer quantity discounts; no ordering fees due to competition. Therefore, the proposed demand function is developed as follows.

$$D_i = \alpha_i(1 + \beta_1 \lambda - \sum_j \eta_j \lambda s_j). \quad (1)$$

Financial and insurance:

- I. Insurance settlement periods exceed reimbursement dates.
- II. Distributors earn interest on revenue after retailer payments.

These assumptions align the model with real-world pharmaceutical supply chain dynamics, enhancing coordination and accessibility.

2.3 | Mathematical Model

Government insurance policies, paired with quantity discount strategies, enhance coordination in the pharmaceutical supply chain by reducing patient costs and incentivizing efficient distribution. This study examines how subsidies and discounts ensure equitable access to medications like metformin, maintain stable stock levels, and improve overall supply chain resilience. The profit of centralized, coordination, and decentralized are respectively represented by the π_c , π_{Trg} and π_{nc} . The mathematical model is presented:

$$\begin{aligned} \text{Max } \pi_{Trg-d} &= \frac{T(w(1 - \lambda) - c) \sum_i \alpha_i(1 + \beta_1 \lambda - \sum_j \eta_j \lambda s_j)}{T} \\ &- \frac{O_d}{T} - \frac{h_d}{T} \sum_i \alpha_i(1 + \beta_1 \lambda - \sum_j \eta_j \lambda s_j) \left[\frac{T^2}{2} \right] \end{aligned} \quad (2)$$

$$\text{Max } \pi_{Trg-r,i} = pD_i$$

$$\begin{aligned}
 & -\frac{1}{T} \left[w(1-\lambda) T \sum_i \alpha_i (1 + \beta_1 \lambda - \sum_j \eta_j \lambda s_j) + \right. \\
 & \quad \left. h_r \sum_i \alpha_i (1 + \beta_1 \lambda - \sum_j \eta_j \lambda s_j) \left[\frac{T^2}{2} \right] \right] \\
 & -\frac{p}{T} (I_v(1-\vartheta)N) T \sum_i \alpha_i (1 + \beta_1 \lambda - \sum_j \eta_j \lambda s_j).
 \end{aligned}$$

$$\pi_{\text{Trg-r.i}} - \pi_{\text{nc-r.i}} \geq 0. \quad T \leq m.$$

$$T \leq N. \quad \forall i \in \text{Nu}. \quad \forall j \in J.$$

$$p, \lambda, \lambda s_j, T. \text{ c. w. o. h. } I_v, I_e \geq 0.$$

The distributor's profit consists of four main components: revenue, purchase cost, ordering and holding cost. The retailer's profit consists of four main components: revenue, purchase cost and holding cost and opportunity cost of delayed insurance-government payments. The replenishment period must not exceed the medication's expiration date to avoid capital loss and reputational damage, and the distributor's profit under quantity discount coordination must meet or exceed its decentralized profit to ensure participation

3 | Solution Methodology

Access to essential medications like metformin in Iran's healthcare system is enhanced by preventing financial distress through quantity discounts and subsidies. This section outlines optimizing quantity discount rates in a two-stage pharmaceutical supply chain using the Stackelberg model. It proves solution uniqueness, models retailers-distributor interactions, and validates for accuracy (*Fig. 2*). The approach, integrating subsidies, maximizes chain profit and ensures equitable drug access in regulated markets.

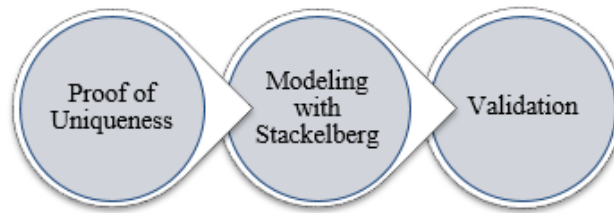


Fig. 2. Steps of the solution methodology.

3.1 | Proof of Existence and Uniqueness

A single optimal discount parameter and corresponding lot-sizes exist under all conditions to maximize the supply chain's profitability (available upon request)

3.2 | Modeling Interaction with the Stackelberg Method

This section examines coordination in the two-stage pharmaceutical supply chain (retailers and distributor) using quantity discounts within the Stackelberg approach:

- I. To determine the optimal discount rate λ^* based on the derivative of the distribution function with respect to the parameter is set to zero.
- II. To determine the optimal discount rate Q^* based on Equation $I(0) = Q$ (available upon request).

- III. Maximize total chain profit and ensures sustainable access to controlled drugs. In this process – Eq. (2), the retailers, as the leader, adjusts the discount rate, while the distributor, as the follower, optimizes order quantities, ensuring the Distributor Incentive Constraint.

Table 1. Sensitivity analysis of parameters on the example (centralized and decentralized functions are available upon request).

Parameters	Centralized		Quantity Discount		Non-Coordinated		
	Q^*	$\pi_{sc\ or\ m+d}$	Q^*	$\pi_{sc\ or\ m+d}$	Q^*	$\pi_{sc\ or\ m+d}$	
C	15	20,845	12,795	52,673	11,500	20,845	10,895
	22.5	20,845	12,252	52,673	11,250	20,845	10,352
	30	20,845	11,710	52,673	11,000	20,845	9,810
	37.5	20,845	11,167	52,673	10,750	20,845	9,267
	45	20,845	10,625	52,673	10,500	20,845	8,725
T	90	10,422	5,855	26,336	5,500	10,422	4,905
	135	15,634	8,782	39,505	8,250	15,634	7,357
	180	20,845	11,710	52,673	11,000	20,845	9,810
	225	26,056	14,638	65,842	13,750	26,056	12,262
	270	31,268	17,565	79,010	16,500	31,268	14,715
w	25	20,845	11,710	52,205	10,750	20,845	9,810
	37.5	20,845	11,710	52,439	10,875	20,845	9,810
	50	20,845	11,710	52,673	11,000	20,845	9,810
	62.5	20,845	11,710	52,907	11,125	20,845	9,810
	90	20,845	11,710	53,141	11,250	20,845	9,810
p	50	20,845	5,855	52,673	5,500	20,845	4,905
	75	20,845	8,782	52,673	8,250	20,845	7,357
	100	20,845	11,710	52,673	11,000	20,845	9,810
	125	20,845	14,638	52,673	13,750	20,845	12,262
	150	20,845	17,565	52,673	16,500	20,845	14,715
ϑ	35%	20,845	10,625	52,673	10,500	20,845	8,725
	52.5%	20,845	11,167	52,673	10,750	20,845	9,267
	70%	20,845	11,710	52,673	11,000	20,845	9,810
	87.5%	20,845	12,252	52,673	11,250	20,845	10,352
	100%	20,845	12,795	52,673	11,500	20,845	10,895
O_d	30	20,845	11,760	52,673	11,050	20,845	9,860
	45	20,845	11,735	52,673	11,025	20,845	9,835
	60	20,845	11,710	52,673	11,000	20,845	9,810
	75	20,845	11,685	52,673	10,975	20,845	9,785
	90	20,845	11,660	52,673	10,950	20,845	9,760
h_r	1.5	20,845	11,760	52,673	11,050	20,845	9,860
	2.25	20,845	11,735	52,673	11,025	20,845	9,835
	3	20,845	11,710	52,673	11,000	20,845	9,810
	3.75	20,845	11,685	52,673	10,975	20,845	9,785
	4.5	20,845	11,660	52,673	10,950	20,845	9,760

Table 1. Continued.

Parameters	Centralized		Quantity Discount		Non-Coordinated		
	Q*	$\pi_{sc \text{ or } m+d}$	Q*	$\pi_{sc \text{ or } m+d}$	Q*	$\pi_{sc \text{ or } m+d}$	
λ_{sj}	5	20,853	11,760	52,907	11,125	20,853	9,860
	7.5	20,849	11,735	52,790	11,062	20,849	9,835
	10	20,845	11,710	52,673	11,000	20,845	9,810
	12.5	20,841	11,685	52,556	10,937	20,841	9,785
	15	20,837	11,660	52,439	10,875	20,837	9,760
β_1	0.5 β_1	20,845	11,710	52,439	10,875	20,845	9,810
	0.75 β_1	20,845	11,710	52,556	10,937	20,845	9,810
	β_1	20,845	11,710	52,673	11,000	20,845	9,810
	1.25 β_1	20,845	11,710	52,790	11,062	20,845	9,810
	1.5 β_1	20,845	11,710	52,907	11,125	20,845	9,810
η_j	0.5 η_j	20,853	11,760	52,907	11,125	20,853	9,860
	0.75 η_j	20,849	11,735	52,790	11,062	20,849	9,835
	η_j	20,845	11,710	52,673	11,000	20,845	9,810
	1.25 η_j	20,841	11,685	52,556	10,937	20,841	9,785
	1.5 η_j	20,837	11,660	52,439	10,875	20,837	9,760
h_d	1.5	20,845	11,760	52,673	11,050	20,845	9,860
	2.25	20,845	11,735	52,673	11,025	20,845	9,835
	3	20,845	11,710	52,673	11,000	20,845	9,810
	3.75	20,845	11,685	52,673	10,975	20,845	9,785
	4.5	20,845	11,660	52,673	10,950	20,845	9,760
α_i	0.5 α_i	10,422	5,855	26,336	5,500	10,422	4,905
	0.75 α_i	15,634	8,782	39,505	8,250	15,634	7,357
	α_i	20,845	11,710	52,673	11,000	20,845	9,810
	1.25 α_i	26,056	14,638	65,842	13,750	26,056	12,262
	1.5 α_i	31,268	17,565	79,010	16,500	31,268	14,715

3.3 | Validation

In this stage, the accuracy of the optimal discount rate rate λ^* and Q^* are validated through multi-scenario analysis. The model is tested in centralized (maximizing total profit) and decentralized (financial imbalance) settings, ensuring rate λ^* and Q^* keeps the distributor’s profit under coordination at least as high as its decentralized profit.

$$\pi_{nc-d} + \pi_{nc-m} \leq \pi_{Qd-d} + \pi_{Qd-m} \leq \pi_{ce}$$

4 | Case Statement

In this section, a number of numerical examples are solved and the related results are analyzed. Let’s assume $T=180$ day (≈ 0.49 year), $c = \$30/\text{unit}$, $w = \$50/\text{unit}$, $p = \$100/\text{unit}$, $\theta = 70\%$, $O_m = \$60/\text{order}$, $O_d = \$60/\text{order}$, $h = \$3 \text{ unit}/\text{year}$, $\alpha = 565/\text{year}$ and $m=1$ year. Deterioration rate is $\theta(t) = 0.01 t^{0.01}$ and $\eta_{1,2}$ and β_1 have uniform distribution on the interval (0,1). It is assumed that there are two substitutions, and $\lambda_{s1,2} = 80\%$. Parameter values are hypothetical, based on typical ranges in Iran’s pharmaceutical market,

to illustrate the model's applicability in regulated settings (Centralized and decentralized functions are available upon request).

The sensitivity analysis in *Table 1* of the study illustrates the impact of key parameters on profit and order quantity across centralized, non-coordinated, and coordinated (quantity discount) scenarios in Iran's metformin supply chain. Variations in potential demand (α) significantly influence profit and order quantity (Q^*), with a $\pm 50\%$ change in α increasing coordinated scenario profits from \$10,875 to \$11,125 and Q^* from 10,422.67 to 31,268.01 units, highlighting the importance of demand stimulation through marketing. The replenishment period (T) directly affects Q^* , with longer periods increasing order quantities but potentially reducing profits due to higher costs (e.g., centralized scenario profit drops from \$5,855 to \$17,565). Parameters like wholesale price (w) and production cost (c) show limited impact on Q^* in centralized and non-coordinated scenarios due to profit balancing between retailers and distributors, while selling price (p), set by the government, linearly boosts profits across all scenarios. The coordinated scenario demonstrates superior flexibility in leveraging quantity discounts, particularly with higher discount sensitivity (β_1), though constrained by competitor actions and government regulations, underscoring the need for strategic optimization of manageable variables like α and β_1 to enhance profitability and drug accessibility.

5 | Conclusions and Future Research

Access to essential medications like metformin in Iran's healthcare system is significantly enhanced by preventing financial distress and ensuring robust cash flow quantity discounts and government subsidies. This study demonstrates that not all discounts are profitable; each must be carefully evaluated to avoid mismatched cash flows, which may lead to financial distress and potential bankruptcy. In a two-tier pharmaceutical supply chain involving government, insurers, and companies under price controls, quantity discounts align stakeholders, reducing inefficiencies and boosting profitability. Government subsidies stabilize prices and enhance market access, addressing financial challenges. Analytical models show these strategies optimize supply chain profits and collaboration, ensuring equitable access to high-quality medications. These insights guide policymakers to strengthen public health. Future research could explore dynamic pricing, multi-product supply chains, or digital technologies to further improve coordination and accessibility in Iran's pharmaceutical sector.

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