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Equilibrium analysis in multi-echelon supply chain with multi-dimensional utilities of inertial players

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Abstract

In a supply chain, the importance of information elicitation from the supply chain players is vital to design supply chain network. The rationality and self-centredness of these players causes the information asymmetry in the supply chain and thus situation of conflict and non-participation of the players in the network design process. The supply chain players' non-participation or reluctance to participate in supply chain contract is due to the dynamics of the system evolving with many competitive players in supply chain. In this paper, a game theoretical dynamic pricing model has been proposed to elicit the information from the players. With the objective of maximizing the social utility, efforts have been made to value behavioural issues of supply chain. On the other hand, the reluctance of player due to the information asymmetry is measured in the form of *inertia* experienced by the players due to anxiety and dynamics in the market. Distinguishing cases based on level of risk and variety of product are considered to show the effect of inertia on social utility and corresponding output for each echelon of supply chain. The paper provides supply chain managers an efficient decision making ability to achieve conflict-free outcome with the maximum utility.

Keywords: Multi-echelon supply chain model, dynamic pricing, supply chain formation, revenue management, inertia.

1. Introduction

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A supply chain is a system of organizations or enterprises performing operations on raw materials until reaching the customer in the form of finished product. A standard serial supply chain consists of multiple echelons where every echelon consists of one or more players. Players in each of these echelons are considered as rational and egotistical in nature. This implies that every player has the objective to maximize his/her own profit and choose an appropriate strategy accordingly. Sometimes, the optimal strategy chosen by one player may conflict with others' choice of optimal strategy whilst designing supply chain network. This results in conflicts between echelons of supply chain. In game theory literature, this situation refers to non-equilibrium. One way to achieve the equilibrium is by designing the supply chain efficiently for the outcome, which is acceptable to all the players in supply chain, namely the *social outcome*. The design for efficient outcome is possible through a strategy with the help of incentives for the supply chain players (e.g. Laffont and Martimort (2009); Mas-Colell et al. (1995)). This activity of designing supply chain is called Supply chain formation. Many authors have defined the supply chain formation in the perspective of designing supply chain, such as in Walsh and Wellman (2000) it is referred as the process of bottom-up assembly of complex production systems and determining the structure and terms of exchange relationship, and in Narahari and Srivastava (2007), it is defined as identifying a set of activities in supply chain operations and its allocation to the partners/suppliers/members of supply chain.

The supply chain formation is then viewed as the systematic design of efficient supply chain to avoid the conflicting situation(s) among players between consecutive echelons. In cooperative supply chain, it is referred as the system in which the supply chain players make mutual agreement about setting the strategy in supply chain. Systematic and synchronized operations between the players can avoid this conflict. However, in the non-cooperative supply chain system, the mutual agreement becomes difficult resulting in conflict in the supply chain. In this paper, we are dealing with non-cooperative environment of supply chain with the motive of maximum throughput. The supply chain throughput measured as total utility gain defines the quantification of satisfaction level of supply chain players. In analyzing these utilities, it

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may appear that the players in supply chain are reluctant to participate in the supply chain formation process that is based on the social outcome. In this paper, this reluctance is refereed as *inertia of the player*. The objective of this paper is to model this inertia for different settings in supply chain and analyze the impact of this inertia on the supply chain outcome and total utility of the supply chain earned during the supply chain formation process. To cover the wide spectrum of supply chain players and for variety of products, this paper considers cases with three types of players and analyses the utility with high-price and low-price products or services. After this study, a decision maker will be able to control the behavioural issues of the supply chain players and accommodate the inertial adjustment in the total throughput.

The remaining part of the paper is organized as follows. Section 2 covers the theoretical background required of this study. Section 3 reviews past work on this topic and covers wide prospective of supply chain formation. Section 4 presents model for demand, inertia and also the constraints for optimization problem to be solved for the supply chain formation. In section 5, the experiments designed and results are discussed to that demonstrates the inertia and its effects on utility for entire supply chain. Section 6 gives some of the managerial implications from this paper. Section 7 concludes the paper with future research directions.

2. Theoretical background

2.1 Utility and social utility function

In economics, as defined earlier, utility measures the level of satisfaction of a player over the possible strategies to choose in the contract. When it comes to individual satisfaction, then utility becomes subjective measure and thus difficult to quantify. There exists another concept derived from utility analysis called social utility that leads to social outcome. In the supply chain formation problem, the social utility measures the satisfaction of the enterprises for the social optimal outcome of supply chain formation process. The role of the supply chain manager is to design the supply chain in order to

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maximize the total utility of supply chain combining each echelon's utility as an objective function for social outcome. This social utility analysis for supplier-buyer tier of supply chain can be referred to as combined form of individual utilities (e.g. Kogan and Tapiero (2007)). Panchal and Jain (2011a), with the help of real life case example, have shown that the social utility outperforms in comparison with individual utilities of supply chain players.

Most of the times, the utility or in some cases social utility is a function of single parameter (e.g. Wurman and Wellman (1999); Walsh and Wellman (2000); Narahari and Srivastava (2007)). In other words, the social utility function is single dimensional measure of satisfaction over all possible singleton strategies. In case when a decision has to be taken over strategy set consisting more than one dimension or parameter, one has to consider all the important dimensions while modelling utility function. In the particular case of serial supply chains, the two important operational decisions are quantity and price per unit. On introducing the rationality, these operational decisions become the strategic parameters in utility analysis. Hence, along with individual utility, the social utility also expressed as a function of quantity and price per unit: $u^{so}(q, p)$. Thereby, the desirable outcome is (q^*, p^*), which will satisfy the argument of social utility giving the maximum throughput in comparison with any other strategic mix of (q, p). Equation 1 represents this definition of social outcome with social utility.

$$(q^*, p^*) = \underset{(q,p)}{\operatorname{argmax}}\, u(q, p) := \left\{ (q, p) \middle| u^{so}(q^*, p^*) \geq u(q, p) \right\} \qquad (1)$$

2.2 Inertia in supply chain

The notion of inertia exists in supply chain formation or any trading process. Su (2009), has defined inertia as the inherent tendency to refrain from making purchase or trade. Inertia in social utility is defined here as the reluctance level to change in the way of trading for social outcome. A person, who does not have motivation to change trading policies, has a high inertia while dealing with supply chain formation. Conversely, a person who changes quickly or motivated to change has a minimal inertia. As a supply chain manager, it becomes easy to handle the supply chain network related issues with less inertial player.

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The level of inertia depends on the level of risk the players are willing to take. Higher the risk, higher is the inertia of the players and vice versa.

The inertial effect of players on supply chain formation is an important issue for the decision maker. In a full-fledged supply chain system, the decision maker has the tendency to retain the supplier/s from previous decision epoch under the assumption of "level of trust". Given the condition of trusting the past suppliers, the total utility earned in the supply chain might be less than expected. For example, the retained supplier may offer the same product with high price by raising the stakes of market demand to the decision maker or on buyer may ask the seller the same product with low price. These different interests of enterprises due to inertia in the supply chain creates the conflict in the decision making process. Modelling and analyzing the inertia will help to understand the major hurdle in designing supply chain (Su (2009)). The then defined utility function should be adjusted to inertial effects for efficient and pragmatic approach of supply chain formation. Inertia in utility represents the loss of utility due to the reluctance of the players. The objective of supply chain formation is to maximize the total utility taking into account the inertial effects on the total utility gain of supply chain players.

2.3 Risk and inertia in supply chain

Risk and inertia in the supply chains are closely related. The major categories of supply chain players are classified based on their level of risk or risk taking ability in the supply chain: Risk-seeking, Risk-neutral and Risk-averse. The risk-seeking players are willing to take the risk of changing the trading strategies even for expensive products. For example, in FMCG sector presence of many opportunity markets minimizes the risk of changing trading policies. On the contrary, the risk-averse players are highly reluctant to take the risk of changing strategy in trading expensive as well as non-expensive products. For example, the highly expensive products like ammunitions, fashion goods face the high risk from the players in changing the trades. The third category of the players is the Risk-neutral players who are neither too reluctant nor favouring the trading policies in supply chains. For example, manufacturing industries trading with raw material suppliers have invariable risk in the supply chain. The classification

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of players on risk level and classification of products on the price per unit level help forming the supply chain for efficient outcome.

2.4 Novelty of the proposed methodology

The proposed methodology for the supply chain formation is unique in identifying the supply chain players' behaviour in the supply chain and modelling it for the efficient decision making. The three cases considered here are identified based on the level of risk covering wide variety of the supply chain cases. The methodology for development of supply chain formation process has two paradigms: strategy making and supply chain optimization. Although these two paradigms are different from each other, the objective of both approaches is to improve the efficiency in supply chain decision making process. The strategy making paradigm uses game theory for developing the equilibrium strategy for the supply chain players. Whereas in optimization the inputs provided by the players are used to give back the output in the form of optimal value of parameters or dimensions. In game theoretic paradigm, each induced game has its corresponding optimization problem. The formulation of this optimization problem is crucial in achieving efficient outcome. Modelling the players' behaviour in the optimization problem is unique feature of proposed methodology where the formulated optimization problem is based on the novel approach of game theory. The objective function in the proposed methodology is to maximize the utility with inertial adjustments in each echelon of supply chain.

3. Literature review

3.1 Review on supply chain formation

The previous work on supply chain formation can be classified in four different categories based on the methodologies used. Figure 1 describes the major methodologies developed for the process of supply chain formation. The channel contract, in general, is the mutual agreement between the network players to form a contractual equilibrium. The usefulness of the contractual equilibrium has been revealed by some of the researchers working on computer networks (e.g. Niyato and Hossain (2007); Lee et al. (2006); Tsay

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and Agrawal (2004)). The structural and commercial point of view suggests that the supply chain networks and computer networks are similar. This approach combines a bargaining solution of supply chain and individual incentive constraints, which helps in identifying the relation in which players negotiate and outcomes of long-term contractual relationship (Watson (2007)). In the computer network design architecture, the multi-dimensional utility used by Lee et al. (2006) is function that formulates quality of distributed data with two parameters: amount of data transfer and reliability of data. In the coordinated supply chain system, Ryan et al. (2012) have analyzed the utility based on price and quantity as decision variables in the dual channel supply chain. On comparing the equilibrium solutions for individual and integrated system of supply chain, the contractual approach shows the potential improvement in the throughput. However, the behavioural aspect of supply chain players is not been considered.

Insert Figure 1 here

Another approach for the supply chain formation that leads to cooperative system is Negotiation. Negotiation is the predominant tool for solving conflicts of interest (Jain and Deshmukh (2009)). Weber et al. (1998), describe the use of two multi-criteria analysis tool, multi-objective programming and data envelopment to compare two or more suppliers to make decision of supplier selection with negotiation. Like in Qi et al. (2007), the negotiation models developed in the process of supply chain formation have limitations about strategies of players becoming predictable. To avoid this, it is required to design the dynamic knowledge inference system that is adaptable according to knowledge variation as human cognition and thinking (Jain et al. (2009)). Jain and Deshmukh (2009), have proposed a fuzzy-logic based negotiation procedure to select the supplier or form the supply chain.

The process of supply chain formation can be stimulated with promotional policies like quantity discount. This is an effort to come up with equilibrium price and quantity for the conflict-free outcome. Cho et al. (2009), have used optimal pricing approach to stimulate the demand or sales in two-level supply chain

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problems. The importance of the optimal pricing modelling is also realized when there is new product waiting for launch or at least in its transition phase (Li and Graves (2012)). Similarly in Ovchinnikov and Milner (2012), the end-of-period discounts modelling can be viewed as the dynamic pricing approach in the presence of buyer learning. Other important policies like feedback Stackelberg strategy (He et al. (2009)), group purchasing (Hu et al. (2012)) and holding the order for market anxiety (Zschocke et al. (2012)) uses the optimal pricing criteria for designing the network (for some supply chain network).

One more important methodology used in supply chain formation is the equilibrium analysis of game theoretic model of supply chain. The most important task before finding the equilibrium solution is to formulate the game. The efficient formulation of the game leads to the unique equilibrium solution. Wurman and Wellman (1999), have considered this problem as the allocation of total discrete demand from the buyer to supplier with the differential price: the competitive equilibrium bundle. The authors have established that competitive equilibrium bundle price always allocate the total demand efficiently among the suppliers. Wellman et al. (2001), have extended this idea to use price, derived from the bidding protocols, to form a market mechanism that can provide a competitive equilibrium. The problem of finding out the competitive equilibrium is the decentralized decision making problem where the supply chain players choose the optimal local response (Walsh and Wellman (2000)). This may lead to the mismatched local and global outcome in the supply chain. It is very difficult to form a mechanism that leads to the unique outcome of price and quantity in multi-dimensional utility analysis. However use of different auction mechanisms has shown the possibility of achieving efficient mechanism (e.g. Che (1993); Beil and Wein (2003); Parkes and Kalagnanam (2005); Levin et al. (2009); Perrone et al. (2010); Rao et al. (2012); Wang (2013)) .

3.2 Review on inertial amendments in utility analysis

In this paper, one extension in the literature on supply chain formation is to model the supply chain players' behaviour; especially the reluctance in the supply chain formation. The importance of using the previously defined inertia and its adjustment have been realized by few of the researchers (e.g. Cachon and Swinney (2009); Levin et al. (2009); Su (2009); Zhao et al. (2012)). Cachon and Swinney (2009) have considered three types of consumers (buyer) on the basis of their behaviour in the supply chain; myopic, bargain-hunting and strategic consumers. The authors have analyzed different strategies like quick-response capabilities and no quick-response capabilities in designing the supply chain network based on investment. Levin et al. (2009) have modelled the strategic behaviour of the supply chain players using the stochastic dynamic game theory approach. The motive of achieving the equilibrium price (subgame-perfect equilibrium) in dynamic settings of supply chain shows that the strategic consumer has huge impact on the revenue gain if players' dynamics is ignored. Unlike above, Su (2009) has provided both positive and negative impact of inertial consumer on profits. The author has provided the recommendations in the form of dynamic pricing policies to cope up with the behavioural or inertial buyer. Similarly, in Zhao et al. (2012), the consumer behaviour to wait before purchasing is considered as inertial strategy from the consumer. The dynamic pricing problem is used to derive the optimal pricing policies in this environment. The problem is analyzed with respect to inertia depth (extent of inertia) and breadth (probability of consumer affected by inertia). The marginal effect of inertia depth on the total revenue earned is decreasing whereas a marginal effect of inertia breadth on the firms' optimal prices is increasing.

After scanning plethora of the literature on supply chain players' behaviour for supply chain formation process, we have found that consumer inertia have potential impact on the profit or revenue gained in the supply chain. The modelling inertia for different cases is vital in making the efficient supply chain operations. The classified cases in the literature are general rule base criterion. It is still required to link these classifications with the level of risk the players are willing to take. It is also learned from the literature that it is required to analyze the threshold on the underlying parameters for the auction mechanism used in the supply chain formation process. The motivation for this paper is to *use the dynamic pricing modelling approach to model the inertia in the supply chain and derive the threshold analysis of the underlying parameters*. This paper addresses the basic research questions in supply chain

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formation process. How inclusion of inertia affects the utility and corresponding outcome? Is it worth to consider the inertia while supply chain formation process modelling? How the parameters behave with the induced dynamics for different cases stated? To answer these questions, this work comes up with the formulation of the complete problem of multi-echelon supply chain formulation problem. The dynamic pricing problem has the objective to maximise the total utility gain subject to the constraints like discount allowed in the dynamic environment of supply chain.

4. Model formulation

Consider the single product which can be offered to the end user through supply chain echelons i ($i \in N$). The trading over price per unit and quantity parameter is conducted in the closed channel between any two echelons. The supply chain formation process aims at achieving the socially acceptable optimal decision, i.e. social outcome. This optimal decision based on utility analysis is difficult in presence of the inertia from the players towards the social outcome. As a result, this reluctance level is affecting value of the objective function; here the total utility gain. The inertia (Γ) is defined as the reluctance level of the player and is quantified as the loss in the total utility earned in each echelon of the supply chain. In this section, topological model of the supply chain formation problem is presented which includes demand modelling based on the players' valuation, inertia modelling and discount modelling.

It is important to consider major constraints in this problem, e.g. in our case the allowed discount (d_i) in each echelon is one of the major constraint of the problem. The modelled discount function is piece-wise linear for a range (j) of values of quantity and price per unit. And this discount function value should not exceed a certain limit (Maximum discount, b'). Panchal and Jain (2011b) have observed the practice of piecewise linear discount function in one of their case studies while modelling the social utility function. Moreover the discount function is concave with two parameters, quantity and price, which instead referred as piece-wise surface function; this also suggests that there is unique maximum discount allowed in specified range of quantity and price. Regarding the utility functions, their quasi-linearity is assumed. Let the utility in i^{th} echelon be the function of more than one parameter/dimension; quantity proposed q_i

and offered price p_i along with the inertia of the player Γ_i. In Equation 2, the quasi-linear form of utility function is represented.

$$u_i(q_i, p_i, \Gamma_i) = \pi_i(q_i, p_i) - \Gamma_i \quad \forall i \in N \qquad (2)$$

The physical interpretation of Equation 2 is that the i^{th} echelon's utility is linear with inertia but non-linear with the utility exclusive of inertia. The non-linear part of the utility function is of multi-dimensional form which is function of underlying parameters.

4.1 Demand model

Let there be a single supplier s and a single buyer b in two-tier supply chain. While deciding the respective strategies, buyer and supplier express the initial willingness for buying and selling, respectively. The willingness of buyer considers his/her own margin, whilst seller's willingness is over selling underlying product or service. Let (q_s, p_s) and (q_b, p_b) be two possible offers from the supplier and buyer, respectively. The supplier and the buyer decide these parameters on the basis of their own individual valuations. Figure 2 represents the distribution of individual utilities of supplier and buyer uniformly distributed within the population of 0 to 1. The conflict in the individual interest affects not only the valuation but also the respective demands. The willingness of supplier and buyer comes with any price greater than P_s and less than P_b, respectively. And this willingness becomes the respective demand from the supplier and buyer Q_s and Q_b, respectively.

Insert Figure 2 here

Both players want to maximize their profits. The demand for any possible outcome (q_s, p_s) and (q_b, p_b) is $Q_s = [1 - p_s]$ and $Q_b = [p_b]$ for $0 \le p_s \le 1$ and $0 \le p_b \le 1$, respectively (Chiang et al. (2003)). The monopolist supplier supplies the exclusive buyer at a wholesale price, w, and incurs a cost per unit, c_s, that

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includes the cost of manufacturing and in-bound and out-bound logistics. Their corresponding profits (per unit) are determined by Equation 3.

$$\pi_s = (w - c_s)(1 - p_s) \text{ or } \pi_s = (w - c_s)(1 - p_b) \qquad (3)$$

and the profit for the buyer is

$$\pi_b = (p_s - w)(1 - p_s) \text{ or } \pi_b = (p_b - w)(1 - p_b) \qquad (4)$$

When combining the two profit equations (3 and 4) for the social utility which gives us the optimal parameters (q^{so}, p^{so}). If both the firms have decided to work synchronized towards the social outcome (q^{so}, p^{so}), then the profit would be

$$\pi^{so} = (p^{so} - c_s)(1 - p^{so}) \qquad (5)$$

Putting Equation 5 in Equation 2, the social utility becomes

$$u^{so}(q^{so}, p^{so}, \Gamma^{so}) = q^{so}(p^{so} - c_s)(1 - p^{so}) - \Gamma^{so} \qquad (6)$$

The social utility in Equation 6 corresponds to the outcome which is socially accepted by the player in the supply chain. In some cases, it is assumed that there is demand with certainty for the social utility which is agreeable for the players involved in it (i.e. ($(1 - p^{so}) = 1$).

4.2 Inertia model

Consideration of inertia in the utility analysis is possible through; in certain percentage loss in the utility or formulating the inertia as a function of underlying parameters. Former way of inertial adjustments is more convenient option however not the best possible way because of the subjectivity. Aforementioned concept of inertia can be identified in three different classes of supply chain players based on the level of risk; Risk-seeking, Risk-neutral and Risk-averse. The assumed loss in Risk-seeking, Risk-neutral and Risk-averse classes is 10%, 50% and 90%, respectively. Another way for considering inertia in analysis is formulating the inertia function with the help of historical data of quantity and price (multi-dimensional

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inertia). This historical data represents how the quantity and price have been traded in the past which signifies conservative nature of the trading process. The historical distribution of quantity and price is assumed to follow the normal distribution with mean quantity and price representing mostly traded data. In case of normal distribution, variance represents the level of risk the players are willing to take. More the variance less is the risk for the player and vice versa. Sometimes, the skewed distribution is also preferable for the players who choose specific range of quantity and price. For example price per unit and quantity can be assumed to follow positively and negatively skewed distribution interchangeably to captured biasness of players for particular range of price per unit and quantity.

The behavioural analysis of the two parameters is captured with the help of simple regression analysis. The regression function is observed as the extent of reluctance from the players in the past. Using this as a base, one can accommodate the conservative natures of the players in the supply chain. For the simple case, the inertia is considered as a loss of revenue earned from the trading. So the loss in the revenue or can be modelled with conventional model of inertia used in general analysis ($\Gamma_i = q_i * p_i$). On plugging the regression function of quantity and price, the final inertia function is multiple order function of underlying parameters. The resultant optimization problem is the non-linear constrained optimization problem with two variables; price and quantity.

4.3 Discount modelling

The discount d_i, in general, is the pricing policy worked out to seek the participation of the inertial player. To facilitate the unique maximum discount for the trading, it is important to model the discount function as a concave function. However it is very difficult to accommodate the smooth concave function for the discount as there exists caps/bounds on both price and quantity (Hobbs and Pang (2007)). The more practical and convenient way to model the discount is by assuming piece-wise linearity. Like in this paper, in the case of two parameters discount function is the piece-wise surface function, each piece in the range of quantity and price represents the maximum discounts allowed in that range. This discount function is the constraint in the formulated optimization problem. The maximum discount availed in the

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ranges of prices and quantities have the cap on it in order to construct the approximate concave shape of discount function. The ranges of the *p* and *q* are the break points for the discount function. The discount in *j*th range is a linear function of *p* and *q*. The piece-wise surface function approximates the required concave function of discount. In the following formulation, Equation 7 is the piecewise surface function (approximate concave) for the allowed discount in different ranges of *p* and *q*. Equation 8 and 9 define the range for the price and quantity within which the corresponding discount function is implemented. Equation 10 and 11 captures the phenomenon of negotiation process in which increasing price decreases the quantity (demand) is represented.

$$p_i^j \Big/ q_i^j = a * q_i^j * x^j + b * p_i^j * y^j \le b^j \forall i \in N \qquad (7)$$

$$l_j^q * x^j \le q_i^j \le u_j^q * x^j \qquad (8)$$

$$l_j^p * y^j \le p_i^j \le u_j^p * y^j \qquad (9)$$

$$l_{j+1}^q < l_j^q \text{ and } u_{j+1}^q < u_j^q \qquad (10)$$

$$l_{j+1}^p > l_j^p \text{ and } u_{j+1}^p > u_j^p \qquad (11)$$

Where, $j \in J$ is the range or the intermediate brake point in the approximate concave function of discount. l_j^q, u_j^q and l_j^p, u_j^p are the lower and upper range of *j*th range of quantity and price, respectively. Also $a, b, c \in \Re$, b^j is the maximum discount offered in the range *j* and $x^j, y^j \in \{0,1\}$. Equations 12 to 15 are required to make the piecewise surface function to give unique value of discount while using it for the optimization problem of utility maximization. Here p_i^j and q_i^j are the dummy variable created for the piecewise surface function. On solving this optimization problem one of these variables become the global variable p_i and q_i, respectively.

$$\sum_{j=1}^{J} p_i^j = p_i \forall i \in N \qquad (12)$$

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$$\sum_{j=1}^{J} q_i^j = q_i \forall i \in N \quad (13)$$

$$x_0 + \sum_{j=1}^{J} x^j = 1 \quad (14)$$

$$y_0 + \sum_{j=1}^{J} y^j = 1 \quad (15)$$

The shape of this discount function in the ranges of price and quantity will look like as shown in the Figure 3. The shaded part of the curved surface shows the feasible areas for the discount function because of the nature of the traded quantity and price in defined supply chain formation process (increasing quantity decreased the price and vice versa).

Insert Figure 3 here

Equation 16 gives the objective function for the entire problem. This objective function is weighted average value of total utility gained from the trade considering the minimal expected value of utility from the trade (a_{i0}). The weights are each parameter (a_i's) of Equation 16 represents the preference value of those parameters (quantity, price, social utility). In Equation 16, it is considered that the players in each echelon will have preference over different parameters. The first term on right-hand side in this equation is the non-traded utility that represent the situation where q_i=0 and p_i=0. In other words, it is the lower bound of utility exercised when there are no trades. The second and third term refers to the preference given to the quantity and price, respectively. This preference varies with the type of product considered for the trading. For the high-price products these coefficients are, $a_{i2} \geq a_{i1}$ and vice versa for low-price products its $a_{i1} \geq a_{i2}$. The coefficient for the fourth term in Equation 16 measures the preference for social utility for i^{th} echelon. This newly formulated objective function for the complete supply chain is to maximize the utility of each echelon with the inertial effects on social utility including the preferences choice of the each player over the underlying parameters in the supply chain formation process.

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$$\sum_{i=1}^{N} u_i(q_i, p_i) := \sum_{i=1}^{N} \left[a_{i0} + a_{i1} q_i + a_{i2} p_i + a_{i3} u_i^{so}(q_i, p_i, \Gamma_i) \right] \tag{16}$$

where, $u_i^{so}(q_i, p_i, \Gamma_i)$ is the social utility defined in Equation 6. Here,

- i is the echelon of supply chain
- q_i is the quantity of the echelon i
- p_i is the price of the echelon i
- c_m^i is the cost to manufacture the product
- Γ_i is the i^{th} echelon's inertial effect
- a_{i0} represents the lower bound for the utility to i^{th} player in supply chain
- a_{i1} i^{th} player's weight for the quantity while modelling utility
- a_{i2} i^{th} player's weight for price per unit while modelling utility
- a_{i3} i^{th} player's weight for the social utility while modelling utility

To see the effect of inertia on the utility and also to analyze the three cases of the player, it is required to design distinguished experiments. The two major tests or experiments designed in this paper are; High-price products/services and Low-price products/services. The Section 5 covers design of these experiments and results of designed experiments with assumed inputs for the optimization problem.

5. Experimental design

5.1 Experiment for modelling inertia

Three cases based on risk level of the players are considered to represent the Inertia: Risk averse, Risk neutral and Risk seeking. Figure 4 shows the histograms of the normally distributed generated data for quantity in all three cases considered for analysis (similar histogram can be shown for price data). Mean of quantity and price for these cases is same $\mu_i^q = 50$ and $\mu_i^p = 50$ and standard deviation is $\sigma_i^q = 2, 5, 10$ and $\sigma_i^p = 2, 5, 10$ for risk-averse, risk-neutral and risk-seeking players, respectively. The

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concept of inertia is implicit in these histograms for the different classes of players. For risk-averse player the configuration he/she chooses is around the mean of the parameters, which depicts the higher inertia of that player. Similarly, the risk-seeking player with more options of trading has less inertia.

Insert Figure 4 here

Figure 5 shows the results of the regression between price and quantity. It is found that there exists the linear regression with quantity and price per unit.

Insert Figure 5 here

Equation 17 gives the regression between these two parameters. It gives the inertia for these cases, where the regression of two parameters is accommodated.

$$q_i \cong -p_i + (\mu^q + \mu^p) \quad (17)$$

and the inertia function is given by Equation 8,

$$\Gamma \cong p_i * q_i = -p_i^{\ 2} + (\mu^q + \mu^p) * p_i \quad (18)$$

The regression functions of the three cases are different from each other in coefficient of the regression function. Although it is simple linear regression between the two parameters, for the case of modelling behaviour using the dynamic pricing is justified. These cases are related to Price-response function, demand function etc. Referred in Phillips (2005), for some cases, the assumed skewed distribution for the *q* and *p* has the similar regression analysis outcome.

5.2 Design of experiments for optimization

Two distinguished cases to analyze the utility with the inertial effects of the players are considered here. For these two cases on product price (high price and low price), the values of the coefficients are assumed as inputs for the optimization problem. The assumed values of the inputs are based on the specific

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observations made in the procurement process of considered Indian Railways Catering and Tourism Corporation (IRCTC) Limited industry. The differentiation between the two cases is clear from the trend in the values of these coefficients. Table 1 shows the input values of the coefficients in high-price products cases for the supply chain of five echelons. The value for the basic utility expected from the trading (a_{i0}) is increasing as the product value is added towards downstream of supply chain. For this case, initially there is more weight (a_{i1}) for price based trading to avoid the accumulation of total price at the end customer. On the other hand, less weight (a_{i2}) for the quantity based trading, as there are some expected losses (scrap) of quantity during the process of building the products. The weight for the social utility (a_{i3}) can be assumed uniform throughout each echelon of the supply chain. This is because the social outcome is equally important for all the echelons of supply chain. Also in the low-price product case all the inputs are assumed in solving the optimization problem. The rest of input values are self-explanatory for the high-price products and also for increasing price decreases quantity phenomenon.

Insert Table 1 here

Similarly, Table 2 shows the inputs for the low-price products considered in the optimization problem. These values are different from the Table 1 for the reason of lower price of the products. The values in the Table 2 depicts the importance or seriousness of the players in each echelon for each of the parameters.

Insert Table 2 here

Similarly, coefficients for the discount function are assumed based on the above two cases. Table 3 and Table 4 provide the input for the discount function in Low-price and High-price products cases. The input values in Table 3 and 4 are based on the case studied by Panchal and Jain (2011b).

Insert Table 3 here

Insert Table 4 here

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To see the effect of inertia on utility an experiment (Test I) is designed. Test I has two parts: inertia as a function of the underlying parameters modelled for the cases (Equation 18) and inertia as a percentage loss in the utility. The implication of the Test I is on the decision for the inertia consideration in utility analysis. The impact of inertia along with the level of risk needs to be analyzed in the supply chain formation process. However the inertia model given in Equation 18 does not differ for risk-based cases. To see the impact of level of risk in the supply chain Test II is designed where the losses due to inertia are assumed for the defined cases.

5.3 Results of optimization

Using the inputs for Test I and Test II, the formulated optimization problem in Section 4 is solved for optimal parameters and corresponding utility of the entire supply chain.

Test-I: *Utility analysis with fixed percentage loss and the modelled form of inertia, which is function of two parameters (q, p)*. For this test, Table 5 gives the comparative analysis of utilities with modelled form of inertia and the utility with assumed percentage loss (The percentage loss in the utility increases with downstream echelons of forward supply chain) for high-price product. The level of risk towards the downstream of supply chain increases due to the anxiety of the market at consumer end, especially for the new product.

Insert Table 5 here

From Test I results, it is observed that the modelled inertia in this paper always result in higher utility as compare to assumed percentage loss in utility for each echelon *i*. However there is no significant difference in the optimal parameters in both the cases. Even so the impact on utility is important to consider in the supply chain formation. Similarly, Table 6 represents result for low-price product. In this case as well, the modelled inertia gives the maximum inertia as compare to the assumed losses one.

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Insert Table 6 here

From these results in Test I, it is observed that the modelled inertia will always end up in giving maximum inertia. The tested model of inertia for high-price and low-price product shows the similar observation.

Test II: The significant difference in the utility analysis of Test I improvise the supply chain formation process by considering modelled inertia. However, the effect of inertia with risk-based player is only observable for assumed percentage loss in the utility. Here there are three types of players with assumed percentage of loss in the utility; Risk-seeking-10%, Risk-neutral-50% and Risk-averse-80 or 90%. Table 7 shows the results for low-price products in quantity, price and utility tuple format for each of the echelons *i*.

Insert Table 7 here

Similarly, results for the high-price products are shown in Table 8. In both the cases in Test II, it appears that there is significant difference in optimal utility as well as the optimal parameters for three different cases. The difference in the optimal parameters is predominant from the risk-averse case. To see this difference the graphs are plotted against these cases (see Figure 6).

Insert Table 8 here

Figure 6 gives the comparative analysis of low-price and high-price products for risk-based cases of the player. On the basis of these plots, it is very clear that the inertia has the noticeable influence on the utility, which is sensitive to underlying parameters. This information can be used to decide the threshold values in the auction mechanism for supply chain formation process.

Insert Figure 6 here

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5.4 Research findings and implications

From these results, following are some important findings related to the decision making process of supply chain formation can be derived:

- In Test I, the inertia effect has been tested on the total utility earned in the supply chain. In this test, it is found that the modelling inertia as a function of the underlying parameter ($\Gamma_i(q_i, p_i)$) results in more utility as compare to the assumed losses in the utility gain G_i. The significant difference between the two utilities suggests the use of modelling inertia in the utility analysis.
- The second remark on inertia analysis in Test I is related to the optimal parameters of supply chain formation process. The optimal parameters in two variations do not show major change. However it does not mean the two variations in inertia are insignificant. In fact, this gives motivation for player in supply chain for not changing the preferences over the strategy base (quantity and price).
- In Test II, the result for the three cases based on risk shows that the inertial effect on the utility is substantial in Risk-neutral and Risk-averse players. It is also observed that the optimal outcome pair of supply chain formation process only differs for risk-averse players.
- In Test II, it is also observed that the influence of parameters on the utility along with their sensitivity for inertia. From Figure 6, it is observed that the inertia is price sensitive, especially for high-price products.

These results are important for a decision maker to analyze the supply chain in perspective of inertial players and design the supply chain for the social outcome. Figure 7 shows the framework for the supply chain formation process in which modelled inertia is considered to model supply chain players' behaviour. This framework is designed for the IRCTC case presented in Panchal and Jain (2011b).

Insert Figure 7 here

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The implications of discussed results on the decision making process are can be summarized in following two major points.

- The higher utility with the modelled form of inertia as compared to the individual utility implies the importance of the modelled form of inertia to the decision makers of supply chain, who seeks to achieve the maximum utility in supply chain. The result of which, the decision makers can rely on the supply chain formation process with modelled form of inertia.
- The second major implication from the results is the price-sensitivity of inertia. Among the two parameters considered, price per unit should be given higher preference while negotiating with players. This threshold analysis of the two parameters helps in designing the reverse auction mechanism for the supply chain formation process. From the results, the imminent auction mechanism should have higher threshold for price per unit as compared with quantity.

6. Managerial insights

Managerial implications of the obtained results are used to answer these questions. In this paper, three cases based on the level of risk and for two types of product covers wide spectrum in supply chain of Indian Railways Catering and Tourism Corporation (IRCTC) Limited. The same analysis should work for the organization with heterogeneous products, dynamic environment where the decisions are based on the price per unit and quantity. This analysis may also apply to organizations with variety of risky players in supply chain. For instance, in IRCTC supply chain, presence of the dominant buyer induces the risk in the non-dominating suppliers. Following questions may rise in the management responsible for the decision making to which the proposed methodology is answerable.

What is the most important concern of the players in supply chain? This is important to know reason behind the lack of participation from the players in supply chain. The elicitation of this information needs much more experience and maturity. In dynamics of supply chain, it is very difficult to achieve this

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maturity. The modelled inertia in this paper not only identifies the cause of this non-participation but also helps in finding out the efficient optimal solution. The different cases studied in this paper find out that the inertia of the players is price sensitive. In other words to answer the question to supply chain manager, the players have concern over the price than the quantity of interest. In developing the supply chain formation, the supply chain manager need to create policies, which are price oriented that the quantity enabled.

Risky players or just an obstruction in efficiency? The risk-based cases considered in this paper are considerate of all the possible horizons of player's behaviour. The inertia model presented in this paper is unique for all the cases of risk. Also the utility of the combined echelons of supply chain with inertia is the maximum with respect to utility with constant losses in utility as inertia. This is demonstrated with all the possible cases of risk and type of products to make the job of supply chain manager easier.

Is the supply chain formation with modelled inertia increases efficiency? Efficiency in the supply chain comes with the more utility with as minimum conflicts as possible. The utility analysis in this paper designed for objective function of maximum utility and the outcome with this maximum utility is the conflict free outcome. From the results in both the experimental designs, it is found that the utility is the maximum in all the cases of risk as well as the price based cases for the modelled inertia in the supply chain. In supply chain of organizations like IRCTC, it is required to design supply chain for all the players without giving undue advantage to particular organization or a dominant organization for that matter.

7. Conclusion and future scope

This paper analyzes and models the inertia of the players which represents the conservativeness of the player in the supply chain trading. The results obtained for the comparison of the utilities in different settings through these tests shows that the inertia of the players' to be price sensitive. In other words, while making any decision in supply chain network design or supply chain formation, it is required to give more attention for the price per unit in high risky environment of supply chain players. The efficiency of proposed supply chain formation process in this paper is improved in the form of total utility gain of supply chain. This is considered to be contributing significantly in the supply chain formation literature. Another major contribution of the study in this paper is in terms of threshold analysis of parameters in supply chain formation process. The imminent auction mechanism can use this result in deciding the threshold on the two parameters. For example, the high-price product should have more concern for the price per unit parameter than the quantity in the dynamic and risky environment of supply chain. The novelty of the work in this research paper is based on the above facts portrayed from the results produced from the tests conducted.

In this paper, the regression function is similar for all the cases of risks and also the modelled inertia gives much more utility gain as compare to the assumed percentage losses in utility. For this reason, different model of inertia may lead to some of the interesting and more general cases. This extension will add more value for the application point of view of supply chain formation. There is also possibility to extend the work by adding more constraints other than discount provided in the supply chain formation process. The possible constraints are related to the capacity allocation, demand at each echelon of supply chain and the material balance between the different supply chain echelons. The application point of view for this work can cover global supply chain where the behavioural issue of the wider spectrum of players is more concerned.

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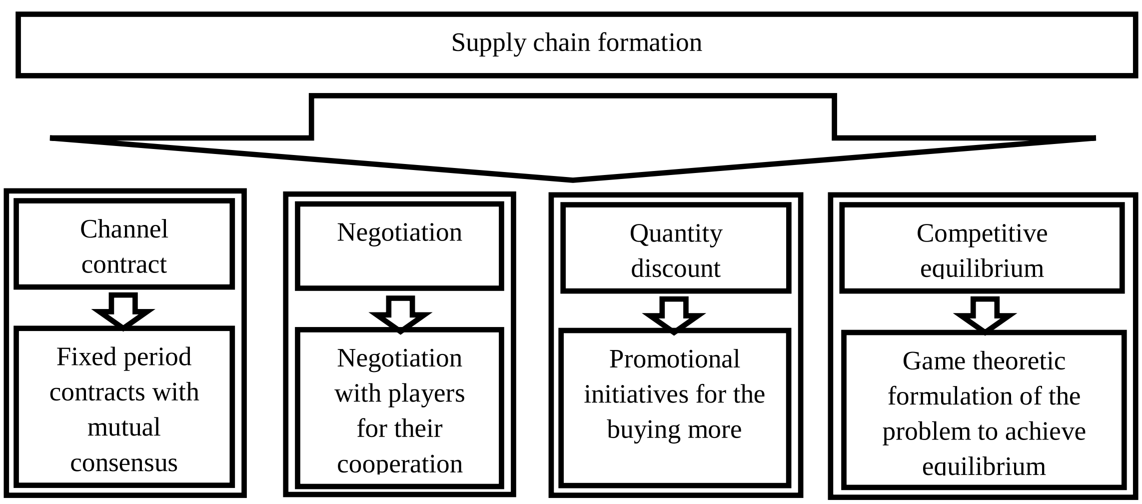

Figure 1 Classification of methodology for supply chain formation problem

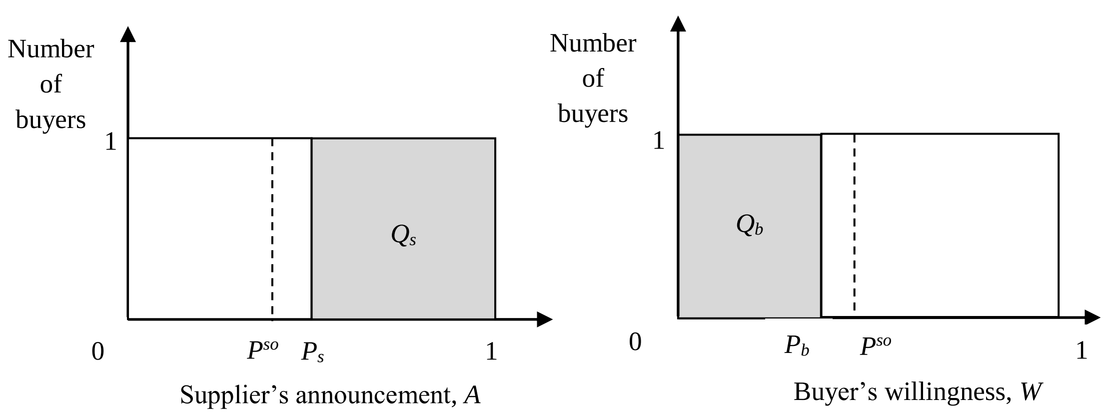

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Figure 2 Distribution of consumption value of Supplier and Buyer

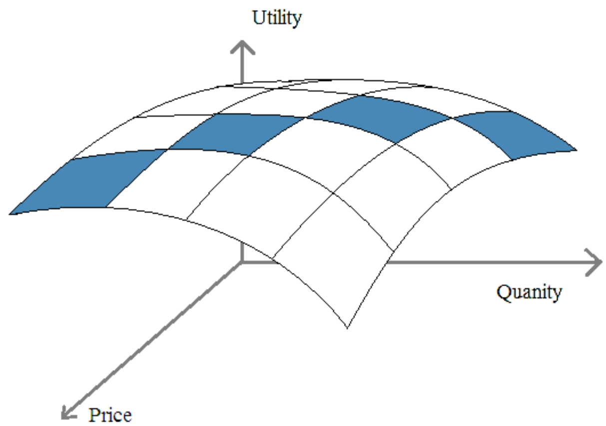

Figure 3 Feasible area of the discount function in the supply chain formation

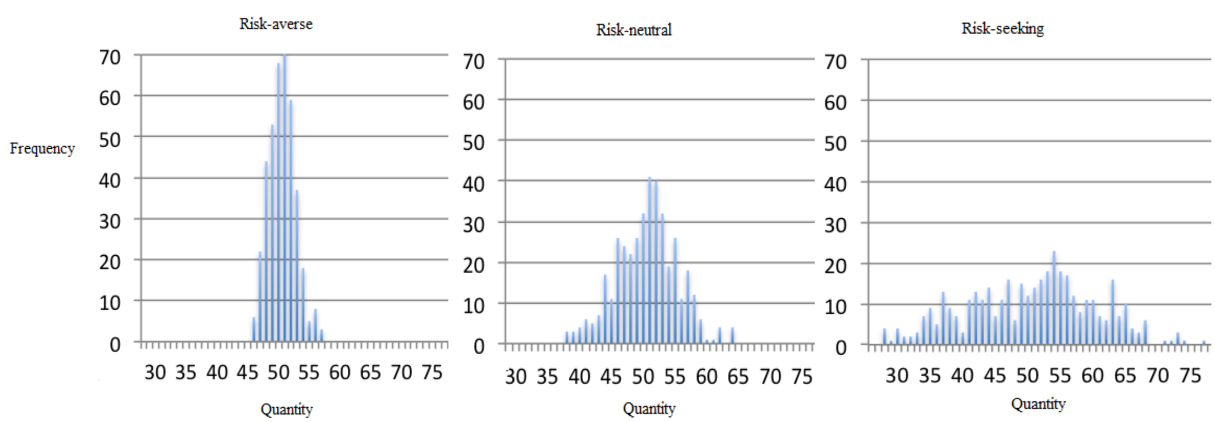

Figure 4 Histogram of quantity for three cases of players based on the risk

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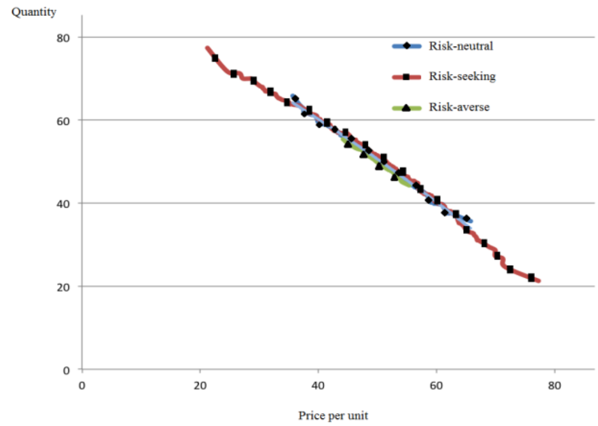

Figure 5 Regression of quantity (q) against price per unit (p)

Table 1 Inputs for the high-price product

Echelon *i*	a_{i0}	a_{i1}	a_{i2}	a_{i3}	c_m^i	μ_i^q	μ_i^p
1	500	0.10	0.90	0.10	10	30	3000
2	1000	0.30	0.70	0.10	20	25	4000
3	1500	0.50	0.50	0.10	30	25	6000
4	2000	0.70	0.30	0.10	40	20	9000
5	2500	0.90	0.10	0.10	50	16	13000

Table 2 Inputs for the low-price product

Echelon *i*	a_{i0}	a_{i1}	a_{i2}	a_{i3}	c_m^i	μ_i^q	μ_i^p
1	50	0.10	0.50	0.05	1	30	30
2	100	0.20	0.40	0.05	2	25	40
3	150	0.30	0.30	0.05	3	20	60
4	200	0.40	0.20	0.05	4	15	90
5	250	0.50	0.10	0.05	5	10	130

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Table 3 Inputs for the discount function in the case of low-price products

i	a_j (j =4)				b_j (j =4)				B_j (j =4)			
1	-1	-0.50	0.50	1	1	0.50	-0.50	-1	0	10	10	0
2	-0.50	-0.25	0.25	0.50	0.50	0.25	-0.25	-0.50	10	15	15	10
3	-1.50	-1	1	1.50	1.50	1	-1	-1.50	15	20	20	15
4	-2	-2.50	2.50	2	2	2.50	-2.50	2	20	25	25	20
5	-2.50	-2.75	2.75	2.50	2.50	2.75	-2.75	-2.50	25	40	40	25

Table 4 Inputs for the discount function in the case of high-price products

i	a_j (j =4)				b_j (j =4)				B_j (j =4) (10^3)			
1	-1	-0.50	0.50	1	1	0.50	-0.50	-1	0.10	0.12	0.12	0.10
2	-0.50	-0.25	0.25	0.50	0.50	0.25	-0.25	-0.50	0.12	0.14	0.14	0.12
3	-1.50	-1	1	1.50	1.50	1	-1	-1.50	7	8	8	7
4	-2	-2.50	2.50	2	2	2.50	-2.50	2	15	20	20	15
5	-2.50	-2.75	2.75	2.50	2.50	2.75	-2.75	-2.50	40	60	60	40

Table 5 Result of test I for the inertia analysis with high-price products

i	q_i	p_i	Utility with modelled inertia $\Gamma_i(q_i, p_i)$	Γ (%)	Utility with assumed inertia
1	30	4000	16062.31	10	14862.50
2	25	5000	16957.50	20	14862.50
3	25	7000	22429.55	30	20683.75
4	30	7530	26749.92	40	24503.00
5	25	12000	33597.44	50	30610.00

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Table 6 Result of test I for the inertia analysis with low price product.

i	q_i	p_i	Utility with modelled inertia $\Gamma_i(q_i, p_i)$	Γ (%)	Utility with assumed inertia
1	30	40	131.45	10	125.65
2	30	50	197.96	20	183.60
3	25	70	262.22	30	237.12
4	35.25	59.75	324.26	40	285.00
5	33.31	66.68	376.02	50	324.70

Table 7 Result of Low-price product case with tuple of outcome (q_i,p_i,u_i)

Echelon i	Risk-seeking	Risk-neutral	Risk-averse
1	(30,40,125.65)	(30,40,102.25)	(20,50,81.90)
2	(30,50,190.89)	(30,50,162.00)	(25,55,133.62)
3	(25,70,253.87)	(25,70,220.37)	(20,80,187.70)
4	(35.25,59.75,314.48)	(35.25,59.75,275.18)	(35.25,59.74,235.87)
5	(33.31,66.68,365.80)	(33.31,66.68,324.70)	(33.31,66.68,283.60)

Table 8 Result of High-price product case with tuple of outcome (q_i,p_i,u_i)

Echelon i	Risk-seeking	Risk-neutral	Risk-averse
1	(30,4000,14862.50)	(30,4000,10080.50)	(20,5000,6996)
2	(25,5000,15712.50)	(25,5000,10732.50)	(20,5500,7048)
3	(25,7000,20683.75)	(25,7000,13718.75)	(20,8000,8696)
4	(30,7530,24503)	(30,7530,15515)	(20,10000,8998)
5	(25,12000,30610)	(25,12000,18660)	(25,12000,9697.50)

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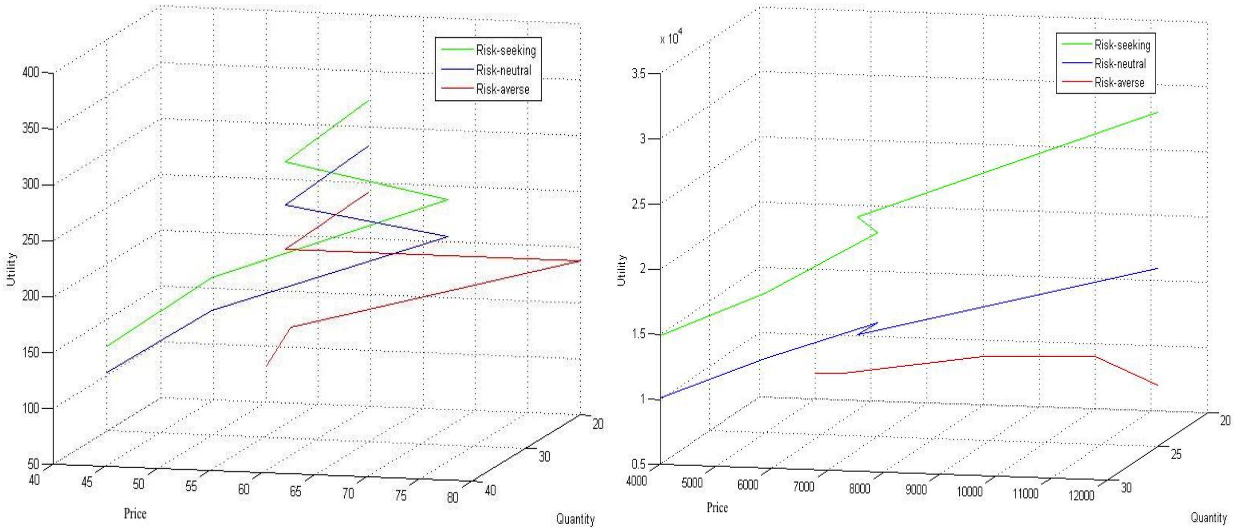

Figure 6 Comparative analyses of low-price and high-price products for risk-based cases of supply chain players

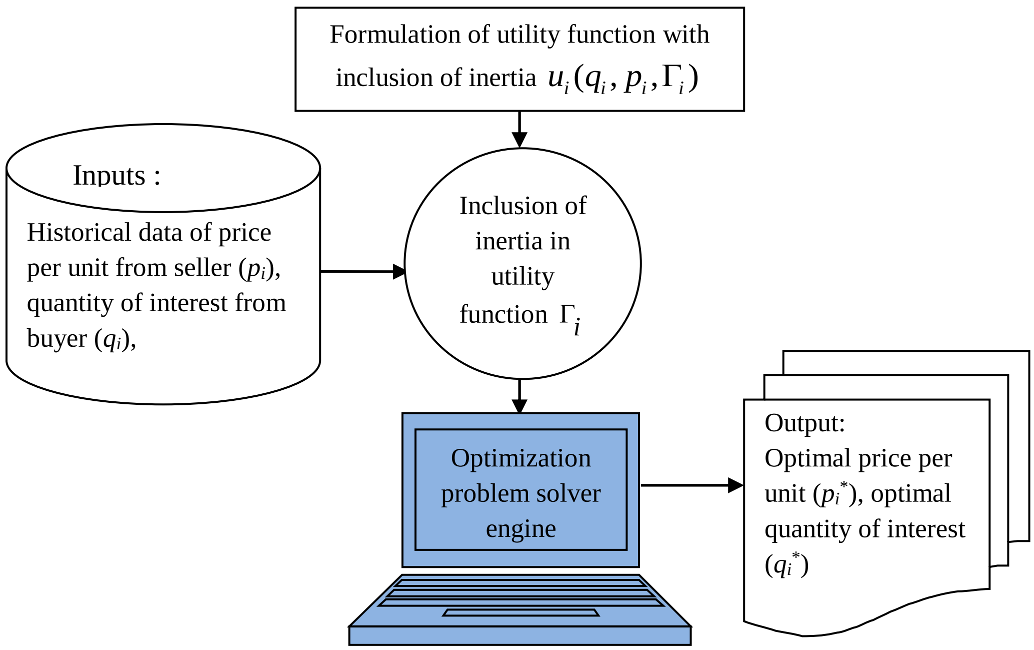

Figure 7 Framework for the supply chain formation process with inclusion of inertia of supply chain players