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Competition and cooperation between supply chains in multi-objective petroleum green supply chain: A game theoretic approach

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ABSTRACT

Petroleum Supply Chain is one of the most important and sophisticated managing missions in both developing and developed countries. Nowadays, environmental pollution is another critical factor in designing the petroleum supply chain. This importance encourages the governments to minimize the amount of environmental pollution and maximize their obtained profit simultaneously, by enacting required legislations on the transportation modes and the refineries. Considering maximizing the job creation and each stakeholder's profit, and minimizing the emission of CO_2 and other greenhouse gases at the same time is called Sustainable Petroleum Supply Chain which has been paid little attention despite its significance. Therefore, the modelling of petroleum supply chain considering sustainability and pricing issues is investigated for the first time in this work and a sustainable competitive petroleum supply chain (SCPSC) model is developed to minimize pollution while maximizing the profits and job creation. This problem is a two level model. The first level in SCPSC is the competition between the supply chains of the government and the private sectors, which is modelled by the game theory approach including Nash and Stackelberg equilibria. The optimal price and demand for each supply chain determined in the first level are considered as the second level parameters. In the second level, the optimal values of the decisions in designing the petroleum supply chain will be obtained by solving Mixed Integer Linear Programming (MILP) under the mentioned three objective functions. Finally, the proposed model is applied to a real world case in the national Iranian oil company (NIOC). Based on the results of the Stackelberg equilibrium, the government profits increase by 11.12% while that of the private sector decreases by 25.4 and 28.11%. Increasing in the government profit is due to increased demand provided by government. The results show that the whole profit of the petroleum supply chain in Nash equilibrium is 9.8% more than that in the Stackelberg equilibrium.

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1. Introduction

Although, sustainable supply chain is currently of interest to many researchers, the sustainability has not been paid much attention in Petroleum Supply Chain (PSC). According to the Carter and Rogers' sustainability definition "the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals is the systematic coordination of key inter-organizational business processes for improving the long term economic performance of the individual company and its supply chain" (Carter and Rogers, 2008). Considering the following aims at the same time, sustainability is an inalienable part of the petroleum supply chain:

- Many environmental regulations have been enacted by the governments to reduce the environmental and pollution effects.
- Maximizing the profit of whole chain such as the other supply chains.
- Most of the governments enforce the stakeholders by enacting appropriate regulations to increase the created job in the chain.

Beside of the sustainability, the competition is another important factor in the PSC. Because, different parts of a petroleum supply chain are controlled by different stakeholders and stakeholders'

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attempt to maximize their profits emerges competition. This can be defined as a complete competition which is not enough to analyze the developing countries PSC, and we need to take into account the other ongoing factors.

In the developing countries, PSC is controlled by governments, which spend millions of dollars on refined petroleum products such as gasoline, diesel, etc. In these countries, large volume of subsidies causes artificial low prices and the economic and financial problems, this in turn causes fading out of optimization of economic consumption and market competitions (Cheon et al., 2013). Considering the economic and financial problems, countries take corrective measures such as gradual reduction of subsidies to ultimately complete elimination and inclusion of private sector in the petroleum supply chain. Therefore, like in the developed countries, there are various stakeholders in the petroleum supply chain and the main challenge is between the supply chains of the government and private sector to determine their price and demand balance. Hence, three other factors that play important role in optimizing of the PSC are: i) rate of the reduction in subsidies in different periods. ii) Government's subsidized price. iii) Government's unsubsidized price.

As mentioned before, the subsidies will be gradually diminished in each year with respect to government planning. Thus, the prices (subsidized and unsubsidized) are adjusted by the government and the private sectors for each of the products as well as their demand based on the amounts of subsidies i.e. determined and paid by the government every year. In other words, the government and private supply chains compete to determine the adjusted prices and demands which is referred as a competitive chain. This competition can be non-cooperative. Despite the significance of pricing in PSC, the pricing of petroleum products by considering competition between private sectors and government chains has hardly been dealt with in the literature. Just Moradi Nasab et al. (2016) proposes an integrated economic model (IEM) of fossil fuel energy planning for government and private sectors. In their study, there is competition between refineries within the refinery level, between distribution centers (DCs) within the distribution center level, and between refineries and DCs. Under these conditions, part of the refineries and DCs are under the control of government and the remainder are controlled by the private sectors. whereas, the non-cooperative competition between the private sectors and government chains have been considered in this study.

In addition to sustainability and competition, network design decisions including capacity expansion of facilities and pipelines routes, transportation modes, inventory and assignment for each sector, including private sectors chains and government chains are considered in PSC to achieve the global optimum solution (Shah et al., 2010; Hasani et al., 2013).

According to the literature, limited number of studies have been conducted in PSC, which are classified in Table 1. Each of these papers has focused on solving a sub-problem of the PSC network. However, local improvement at any sub-level does not necessarily lead to overall improvement (Shah et al., 2010).

As observed in the Table 1, most researches have focused on the midstream and downstream supply chains and only a few have dealt with all three levels of downstream, midstream and upstream. In addition, in spite of the importance of different stakeholder and competitions in PSC, the presence of different stakeholders in PSC has only been investigated by Fernandes et al. (2013). Although the competition and the presence of deferent stakeholders in the midstream petroleum supply chain including refineries which is important, only the competition in the downstream petroleum supply chain has been considered in Fernandes et al. (2013). Moreover, none of the works have considered pricing in PSC design (Table 1).

Regarding the decision making levels (Strategical, Tactical, Operational), only the tactical level in the supply chain was carried out in most researches and only a few works have simultaneously dealt with strategic and tactical levels. In the case of petroleum supply chain decisions, most works have covered inventory, procurement of raw materials and production rates by considering only one objective function, which is usually profit or costs. As it mentioned before, sustainability is an important aspect in PSC, but none of the studies have regarded it along with PSC network design.

According to Table 1, the only paper which investigates the environmental concerns in its constraints is (Ribas, 2011). Their concern is the amount of pollutants produced that should not exceed a minimum limit. Only (Khosrojerdi et al., 2012) has considered the two objective functions of profit and the level of customer service, simultaneously.

Altogether, none of these researches have studied the sustainability, competition, and PSC network design. Therefore, the necessity of proposing a multi-objective, multi-level, multi-stakeholder and multi-stage sustainable competitive petroleum supply chain (SCPSC) by considering the decisions in strategic and tactical levels is completely clear.

In this SCPSC, the network supply chain design (in strategic and tactical levels), pricing and demand decisions should be made at the same time. This SCPSC includes the government and private sector supply chains competing with each other to determine their petroleum price and demand. This competition is non-cooperative and one of the approaches for modeling such competition is the application of game theory. This study investigates the chain competition and sustainability in the supply chain simultaneously for the first time. Despite the importance of chains competition, none of the researches have studied it in the design phase of PSC. According to the literature, in the supply chains other than petroleum, only a few researches have studied the chain to chain competition.

McGuire and Staelin (1983) studied the effect of product substitutability on Nash Equilibrium distribution structures between two suppliers each selling through an independent retailer. Their results show that product distribution through a company store is preferable for low degrees of substitutability and the decentralized distribution system is preferable for a more highly substitutable one. Higher profits can be caused by supply chain decentralization, as explained by Moorthy (1988). This is linked to the concept of strategic interaction. Wu and Chen (2003) studied the quantity of competition between two chains in which a single manufacturer and two retailers facing a newsvendor demand are included. Baron et al. (2008) extended the seminal work of McGuire and Staelin (1983) and investigated the Nash Equilibrium of an industry with two supply chains. In their study, each chain includes a single manufacturer and a single retailer modeled by a Nash Bargaining on the Wholesale (BW) price. Their model is extended by Wu et al. (2009), who have considered demand uncertainty. Their results show that decentralization on the wholesale price may be Nash Equilibrium over infinitely many periods and integration in both chains is the unique Nash Equilibrium over one period decision. Other studies, which have considered chain to chain competition include Ai et al. (2012), Wu and Chen (2003), Nagurney et al. (2002), Rezapour et al. (2011a,b), Rezapour and Farahani (2010), Anderson and Bao (2010), Zhang (2006), Xiao and Yang (2008), Boyaci and Gallego (2004).

Sustainable supply chain is another aspect of SCPSC, and some works that have studied it are discussed briefly in the following. In this group, some researches have investigated the environmental dimension and greenhouse gas emission including Ubeda et al. (2011), Pan (2010), Wang et al. (2011) and Venkat (2007). Also, a

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