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A Game Theoretic Approach in Green Supply Chain Management

Hong Shi
University of Windsor

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by

Hong Shi

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A Game Theoretic Approach in Green Supply Chain Management

by

Hong Shi

APPROVED BY:

Dr. Mike Wang, Department Reader

Dr. Esaignani Selvarajah, Outside Department Reader

Dr. Guoqing Zhang, Co-Advisor

Dr. Kevin Li, Co-Advisor

Dr. Zbigniew Pasek, Chair of Defense

January 19, 2011

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ABSTRACT

Common social issues are usually criticized considering the potential interrelationship between corporate social responsibility (CSR) and supply chain management. Companies and manufacturers in supply chain networks have been pressured by a growing concern for CSR from governments, organizations, and consumer, and have to bear at least some CSR under policies and regulations. However, naturally, members in a decentralized supply chain network make decisions to maximize their individual net profits. This thesis aims to allocate CSR to members in a non-integrated supply chain over time. Specifically, we formulate a model that crosses through multi-periods by a dynamic discreet Stackelberg game. We then apply control theory and calculus variations to obtain an equilibrium point at where both the profits of members and the level of CSR taken by Supply Chains are maximized. The findings of this thesis serve three subjects: supply chain management, social science, and game theory application.

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CHAPTER ONE

CHAPTER ONE

INTRODUCTION

Corporate Social Responsibility (CSR), which shows consideration for the environment, consumers, charities, minority groups, employee welfare, and community development, has received a great deal of attention in recent years. A rapidly growing number of large, medium, and even small-sized companies are increasingly focused on CSR. This is mainly because, along with rising consumer awareness of the conditions or circumstances under which products are manufactured, distributed, and sold, consumers often criticize supply chains for several social issues, such as environmental protection, safety, ethical implications, and human rights. Not only consumers, but also governments and organizations believe that it is high time to interfere in the CSR of supply chains for the long-term benefits of society. A variety of regulations and policies related to CSR have been made to negotiate and guide contemporary company members of supply chains, making it unavoidable for them to assume at least some CSR.

However, in a decentralized supply chain, members, including raw material suppliers, manufacturers, distributors, wholesalers, and retailers, try to gain advantages in the competitive relationship. They make their decisions based on maximization of their own profits, while bearing the burden of CSR may lead to decreased profits. These behaviors lead to an equilibrium status at which both the profits of members and the level of CSR taken by the supply chain maximizes. Finding the equilibrium of a decentralized supply chain on CSR in a time horizon has been a challenge, and modeling a decentralized supply chain with CSR has become a topic of great interest from both practical and research perspectives. The main objective of this thesis is to properly formulate this problem and find the equilibrium point in the sharing of CSR among the members of an supply chain.

1.1 Introduction

In this thesis, the supply chain network is modeled as a two-tier, nonintegrated, vertical control system involving a supplier and a manufacturer. As a monopolist, the manufacturer determines its wholesale price, controls the retail price, and negotiates its raw material prices with suppliers. Furthermore, in the thesis, we only consider the social obligation dimension of CSR rather than its social voluntary dimension. This means that firms are forced by regulations or policies to accept CSR.

This thesis discusses how members in the supply chain system interact with each other in such a situation. Specifically, each firm in the supply chain network makes decisions in order to maximize its individual net profits; meanwhile the entire SC has to bear certain CSR. Consequently, members take as little CSR as possible toward their own benefit. In order to deal with the conflict, we applied a long term Stackelberg game and explored the equilibrium results of the decentralized supply chain network in which all members take CSR into consideration. Optimal amount of CSR is allocated to each member in the supply chain. For a better understanding of the allocation of CSR to members in a decentralized supply chain network and the decisions the members make in the dynamic Stackelberg game to maximize their own profits, a practical case study of Ball

Corporation and Coca-Cola is provided, and a numerical example is proposed along with highly efficient algorithms. Managerial insights are demonstrated in terms of several sensitivity analyses.

1.2 Thesis Organization

In this thesis, we propose a model that perfectly allocates CSR to members in a decentralized supply chain through a dynamic Stackelberg game. The remainder of this thesis is organized as follows:

In Chapter Two, a general literature review of both CSR and SC management is presented. Moreover, this chapter surveys the game theoretic concept applications in supply chain analysis, and outlines the game theory-related areas of supply chain management.

In Chapter Three, a model to allocate CSR to members in a three-tier, multi-period, and decentralized supply chain network model is presented and each manufacturer's degree of investment into CSR is clarified to ensure maximum profits. Specifically, Chapter Three shows how CSR is evaluated as capital, and why the application of dynamic Stackelberg game theory is necessary to apply to this model. The fundamental knowledge of the model and criteria for choosing different game theories are explained. The assumptions and notation of the model are defined. Two formulations are provided the leader of the game being either the supplier or the manufacturer.

In Chapter Four, practical case study of Ball Corporation and Coca-Cola is provided, and a numerical example is proposed along with highly efficient algorithms. We analyze the results of the two cases in terms of three criteria, profits, the amount of investment, and the level of social responsibility taken by the supply chain. According to the analysis of the results, we conclude that choosing Ball Corporation as the leader of the game provides several advantages in many respects.

In Chapter Five, we conduct a sensitivity analysis by changing the values of several parameters. The sensitivities of time horizon, tax return rates, and social benefit parameters of the firms are discussed. Finally, based on the sensitivity analyses, managerial insights are highlighted.

In Chapter Six, we provide a summary of this work. Some future research directions are also discussed in this chapter.

CHAPTER TWO

CHAPTER TWO

LITERATURE REVIEW

In this thesis, the literature review is divided into those articles regarding corporate social responsibility, and those on game theoretic applications in supply chain management.

2.1 Literature Review of CSR

In recent years, a growing number of large, medium, and even small- sized companies have increasingly focused on CSR. They have realized the need to develop strategies that extend their traditional corporate governance processes beyond firm boundaries to their supply chain partners (Kytle & Ruggie, 2005). Firms have embraced the importance of working collaboratively with their supply chain partners to enhance their CSR performance (Nalebuff & Brandenburger, 1996).

Not only companies, but also governments, organizations, and consumers have been considering CSR. A variety of regulations and policies related to social responsibility have been made to negotiate and guide the members of the entire supply chain. For instance, after the financial misrepresentation at leading companies, such as Enron (Prentice, 2003) and WorldCom (Hitzig, 2004), led to extensive loss of investor savings, the Sarbanes-Oxley Act was established to make companies accurately account for their corporate financial reporting (Bernardi & LaCross, 2005), Between 2000 and 2007, approximately 50 international framework agreements were negotiated in the field of CSR between multinational companies and international trade union federations to define labor standards for the workers of the company workers, their subsidiaries and, in many cases, their subcontractors (Sobczak, 2007).

Moreover, along with rising consumer awareness of the conditions or circumstances under which products are manufactured, distributed, and sold, consumers have criticized several social issues, such as environmental protection, safety, ethical implications, and human rights, considering the potential interrelationship between social responsibility and supply chain management. For instance, consumers and non-government organizations criticized Nike regarding sweatshop labor issues at its overseas suppliers. Nike initially declined social responsibility for its supply chain partners but later shifted its stance under increased public pressure (Zadek, 2004). The entire apparel industry now takes a more diligent approach to supply chain CSR, employing extensive supplier labor codes (Emmelhainz & Adams, 1999). Since consumers have started to be concerned about the behavior of food companies and their level of social responsibility in ensuring quality standards, the food industry has been used as a reference example to elucidate the role of CSR in achieving competitive advantage (Maloni & Brown, 2006).

2.1.1 Definition of CSR

Although CSR is a well-established concept, there is not a general consensus on the meaning of CSR in practice (Carroll & Buchholtz, 2000; Joyner & Payne, 2002; Roberts, 2003). There is an apparent lack of a consistent definition of CSR, mainly because the nature of the relationship between business and society fluctuates with the relevant issues of the day, and partly because of the problem of operationally determining the managerial implications of such a definition (Canoll & Buchholtz, 2000). In another words, the definitions of concepts used to identify the nature of CSR, such as sustainable development, corporate citizenship, sustainable entrepreneurship, the triple bottom line, and business ethics, are never really clear (Marrewijk & Werre, 2003). Since there is no certainty as to how CSR is defined in either the corporate or academic world, some scholars claim that there is not a basic definition for CSR (Jackson & Hawker, 2001); however in fact, there are productive definitions rather than not just one, because people talk about CSR as it applies to specific interests, which makes the interpretations of CSR different and biased (Van Marrewijk, 2003). There is no methodology to verify whether those definitions are biased or not; hence, an unbiased definition has not been developed.

2.1.2 Methodology of Definition of CSR

Based on the existing productive definitions, attempts have been made to develop a robust and clear definition of CSR. In so doing, three common methodologies have been applied to derive an expectant definition.

Since Bowen established the first formal definition of CSR (Carroll, 1999), many researchers have attempted to derive and update portable definitions of CSR based on literature reviews. For instance, Moir (2001) combined Bowen’s definition with some concepts of business management, while Joyner and Payne (2002) and Garter and Jennings (2004) compiled a comprehensive summary of all available definitions.

Without these literature reviews, the history of CSR definitions could not be tracked and overviewed.

Other scholars have conducted interviews to address the social construction of CSR, mainly because the points of view of respondents concerning CSR are easily recorded and analyzed through interviews. For example, O'Dwyer (2002) investigated the interpretations of CSR from 29 managers. Azer (2001) explored three popular definitions of CSR in terms of the results of interviews of 11 business representatives. Although interviews indicate in-depth knowledge regarding the social nature of CSR, this methodological approach has its own drawback. Interviews usually focus on specific questions and limited details; therefore, it is relatively difficult to demonstrate a general definition.

In this decade, CSR has been interpreted by many other theories. For instance, Van Marrewijk (2003) philosophically analyzed the definitions of CSR. Matten and Crane (2005) defined CSR by introducing the term of citizenship in political science. Gobbels (2002) corrected that CSR is actually corporate societal accountability according to linguistics. These diverse approaches indicate that CSR is a multi-disciplined concept.

2.1.3 Analysis of definitions of CSR

A comprehensive analysis of 37 definitions of CSR was conducted by Alexander Dahlsrud (2006). These 37 definitions were gathered through an extensive review of the literature, involving both journal articles and web pages. The definitions originated from 27 authors and covered the time span from 1980 to 2003, although most definitions were published from 1998 onwards. The definitions were primarily of European and American origin, but definitions from India and Canada were also included (Dahlsrud, 2006).

In Dahlsrud's paper, the 37 definitions are divided into five dimensions, which are named to reflect the content of the phrases of coding schemes. The dimensions to which each definition is categorized are shown in Table 3.2.

The frequency counts are derived from Google, the largest and most commonly used search engine. The frequency counts of these 37 definitions referring to a specific dimension were summed to give the dimension scores. By dividing the dimension score by the sum of frequency counts for all the definitions, a dimension ratio was calculated to evaluate the relative use of each dimension. The dimension score and dimension ratio for each of the five dimensions in CSR definitions are discussed. Moreover, to analyze how many dimensions consist of a definition, frequency counts are defined in this article. Dahlsrud summarized the number of dimensions included in each definition and their percentage of the total frequency count, in frequency order.

2.1.4 Features of CSR

There is no argument about certain features of CSR are obvious. CSR consists of economic, legal, and ethical responsibilities, along with voluntary or philanthropic responsibility (Carroll, 1979; 1991). Social responsibility is part of a firm’s social activities as well as its social obligations (Sethi, 1975).

Based on the two main characteristics of CSR, the link between business and the larger society and the activities for environmental and social issues (Carroll & Buchholtz, 2000; Marrewijk & Werre, 2003), the content of CSR can be extended to many aspects, including the environment (Shrivastava, 1995), diversity (Clair et al., 1997), human rights (Jennings & Entine, 1999), philanthropy (Clarkson, 1995), and safety (Wokutch, 1992). The key achieved consensus on the concept of CSR is that this new subject should be viewed as interdisciplinary.

2.1.5 Significance of CSR

There are numerous underlying incentives to explain the popularity of CSR. According to early research, there is a relationship between a company’s corporate reputation and performance indicators, such as profitability and customer satisfaction (Porter & Kramer, 2006; Chad & Fraser, 2006; Schiebel & Pochtrager, 2003; Murphy & Verschoor, 2002; Simpson & Kohers, 2002).

Also, a great number of researchers claim that CSR has a significant impact on the purchasing decisions of firms (Roberts, 2003; Bowersox, 1998; Stock, 1990). In other words, it is prudent for companies to anticipate future CSR issues in their supply chains, and to integrate supply chain CSR standards into daily operations. For example, for firms in the clothing industry, the external pressure from social organizations and consumers can be relatively eased by CSR; manufacturers in food chains can more easily manage and control their suppliers and retailers to maintain the quality standard of their products.

CSR is an opportunity for some firms, such as the Fair Trade organization, to show their consideration for ethics and society. Therefore, a great number of companies operate intending to promote CSR through cooperation with supply chain partners.

All case studies about CSR demonstrate that developing an effective strategy can reward companies with reputation enhancement, license to operate, avoidance of litigation, recruitment and retention of employees, and the development of processes, products, and strategic innovations. It is, therefore, obvious that companies have begun to see the strategic advantages of being socially responsible and to work on their social, environmental, and economic issues.

2.1.6 Previous studies on CSR

In the early research, many CSR studies were in the form of case studies. Researchers tended to use large companies as examples to demonstrate how CSR activities are beneficial for long-term development by effecting their strategies and performance in the long run. Moreover, many researchers were interested in understanding entrepreneurs' motivations to participate in CSR. Basically, some firms consider CSR a way to enhance their reputation due to public concerns over social issues, such as the environment, human rights, and ethics. Other companies adopt CSR because they believe it promotes long-term profits in many respects, including stable suppliers, low cost delivery, and extended market demand. These benefits are proved by some well-known case studies of large international companies, such as Nike, Gap, H&M, Wal-Mart, and Mattel (Frost & Burnett, 2007). For example, to integrate CSR into its business model, Gap Inc., developed an effective labor standards assurance program, which has innovated its business strategy over time.

Based on these case studies, some scholars have a more macroscopic point of view of the significance of CSR in the supply chain. Corporate social responsibility is viewed as an organizational philosophy that directs firms to consider and minimize the social impact of their profit making activities, which may detract from the core function of a business – profits. Indeed, scholars studying CSR have long debated the significance of CSR in supply chain management. Some researchers advocate that CSR incurs additional operational costs and limits a firm’s strategic choices (Ullmann, 1985; Vance, 1975); while others argue that there is no link between CSR and financial performance (Abbot & Monsen, 1979). Recently, a reached consensus on the impact of CSR on SCM is that a positive relationship between CSR and SCM definitely improves a firm’s own benefits (Cornell & Shapiro, 1987; Moskowitz, 1972; Spicer, 1978).

According to these previous studies, involvement of CSR is actually beneficial for the long-term strategy of members in a supply chain system from many aspects. Firstly, a comprehensive consideration of the economic, ecological, and social aspects of business practice contributes to the sustainability of a supply chain (Svensson, 2007). In addition, CSR is critical for effective supply chain management to facilitate coordination across purchasing, manufacturing, distribution, and marketing functions (Hervani & Helms, 2005). Excluding sustainability of supply networks, corporate reputation and even company image, which are characterized by consumer activism and profile brands, are attributed to CSR (Roberts, 2003).

2.1.7 Modeling of CSR

A supply chain usually includes raw material suppliers, manufacturers, distributors, wholesalers, and retailers. Each member in the supply chain tries to gain advantages, whether in a competitive or in a cooperative relationship. These behaviors will eventually lead to an equilibrium status in a decentralized supply chain network. Researchers point out that a member in a supply chain may change its behavior to increase its own profit; this voluntary shift may induce decreased total profit. Therefore, modeling a decentralized supply chain has become a topic of great interest from both practical and research perspectives in order to generalize the network structure and simplify the study of supply chains (Lee & Billington, 1993). Lee and Billington (1993) point out the importance of developing decentralized supply chain models that allow for a generalized network structure and simple computation. Lederer and Li (1997) analyze competition among firms having customers who are sensitive to delay time. Nagurney et al. (2002a) present a supply chain network equilibrium model consisting of three-tier decision makers in a network with governing equilibrium conditions. Nagurney et al.

(2002b) extend their approach to include electronic commerce in the form of business-to-business and business-to-consumer transactions. Dong et al. (2002) consider multi-criteria decision making within a supply chain but with only two tiers of decision makers. Nagurney and Toyasaki (2003) extend previous work to consider three tiers of supply chain. Dong et al. (2003, 2004) introduce random demands into a two-tier supply chain network model. Nagurney et al. (2005) develop a multi-criteria supply chain network model in which both physical and electronic transactions are allowed, and supply-side as well as demand-side risks are included in the formulation.

Indeed, equilibrium modeling is not new in many fields, such as transportation (Florian & Hearn, 1995), economics (Arrow & Intrilligator, 1982), and finance (Nagurney & Siokos, 1997). However, game theory and equilibrium models were not applied to CSR study until two decades ago. Sethi (1975) introduced a taxonomy in which a firm’s social activities include social obligations as well as more voluntary social responsibility. Carroll (1979, 1991) developed a framework for CSR that consists of economic, legal, and ethical responsibilities. Carter et al. (2000) explored the effect of environmental purchasing on firm performance and show that environmental purchasing is significantly related to both net income and cost of goods sold. Carter and Jennings (2002) also suggest that CSR has a direct and positive impact on supplier performance. Other CSR activities identified in the literature involve the environment (Shrivastava, 1995), human rights (Jennings & Entine, 1999), philanthropy (Clarkson, 1995), and safety (Wokutch, 1992).

Although these CSR activities show consideration for the environment, consumers, charities, minority groups, employee welfare, community development, and so on, it is difficult to evaluate the value or benefit of these efforts, because they are rarely considered in the context of supply chain management.

2.2 Supply Chain Management and Game Theory

Before the literature reviews of game theoretic concepts applications in supply chain management and game theory-related areas of supply chain management, a general literature review of supply chain management and game theory is presented.

2.2.1 Supply Chain Management

A supply chain is "a system of suppliers, manufacturers, distributors, retailers, and customers where materials flow downstream from suppliers to customers and information flows in both directions" (Tayur, Ganeshan and Magazine, 1999). Supply chain management also can be defined as a set of management processes. For example, SCM is defined by LaLonde as "the process of managing relationships, information, and materials flow across enterprise borders to deliver enhanced customer service and economic value through synchronized management of the flow of physical goods and associated information from sourcing to consumption" (Mentzer, 2001).

Following LaLonde, many SCM-related researchers have devoted themselves to operations management and marketing problems, such as inventory control, production and pricing competition, capacity investments, service and product quality competition, advertising and new product introduction. For example, Tayur, Ganeshan and Magazine (1999) edited a book emphasizing quantitative models for SCM, and proposed a taxonomic review and a framework to help both practitioners and academic researchers better understand the current state of SCM research. Wilcox, Howell, Kuzdrall and Britney (1987) presented a brief survey of the papers on the price-quantity discount. McAlister (1988) reviewed a model of distribution channels incorporating behavior dimensions.

Most significant and interesting topics arising in SCM emphasize the coordination and competition among members in a supply chain channel. In a centralized supply chain the "central" decision maker may coordinate the members' activities in order to increase the competitive capability of the entire supply chain. game theory is not used in these types of centralized problems. On the contrary, in a decentralized supply chain, each supply chain member is an independent decision maker. Consequently, various game-related issues arise in the analysis of decentralized supply chains with competition; besides, supply chain members may agree to a contract to coordinate their strategies in order to improve the global performance of the system as well as their individual profits. For this type of decentralized supply chain with coordination, channel members may not only achieve supply chain-wide optimization but they also would have no incentives to deviate from the global optimal solution. Naturally, a prime methodological tool for dealing with these problems is non-cooperative game theory, which focuses on the simultaneous or sequential decision-making of multiple players under complete or incomplete information (Leng & Parlar, 2005).

2.2.2 Game Theory

Since game theory was established to solve problems involving conflict and cooperation in the early 1940s, it has been often applied in diverse areas, such as anthropology, auctions, biology, business, economics, management labor arbitration, philosophy, politics and warfare. Game theory is a powerful tool for analyzing situations in which the decisions of multiple agents affect each agent's payoff; therefore, game theory is usually used to deal with interactive optimization problems. Many economists in the past few centuries have worked on what can be considered game-theoretic models. John von Neumann and Oskar Morgenstern are formally credited as the fathers of modern game theory. Their classic book, "Theory of Games and Economic Behavior" published in 1944, summarizes the basic concepts existing at that time.

In the last five decades, there has been a radical increase in the number of publications about applications of game theory in operational research and industrial management. As Citing Shubik (1955) said, "In the 50s ... game theory was looked upon as a curio- sum not to be taken seriously by any behavioral scientist. By the late 1980s, game theory in the new industrial organization has taken over ... game theory has proved its success in many disciplines”. Coincident with the increase, several reviews focusing on the application of game theory in economics or management science appeared. Shubik (1995) first gave an early survey of game theoretic applications in management science. Feichtinger and Jorgensen (1983) published a review that was restricted to differential game applications in management science and operations research. More recently, Wang and Parlar (1989) presented a survey of static game theory applications in management science problems. Jorgensen (1982) gave a review of applications of differential games in advertising.

However, not until the last two decades has there been a renewed interest by academics and practices in the management of supply chains; new emphasis has been placed on the interactions among the decision makers constituting a supply chain. This has resulted in a proliferation of publications in scattered journals dealing with the use of game theory in the analysis of supply chain-related problems (Leng & Parlar, 2005).

2.3 Game Theoretic Concepts Applications in Supply Chain Management

In the last few years, the two most important reviews among those focusing on game theoretical applications in supply chain management were published. The first review outlines game theoretic concepts and surveys the applications of game theory in supply chain management (Cachon & Netessine, 2004). Cachon and Netessine classified games developed for SCM into four categories based on game theoretical techniques. In each category, the authors presented the major techniques that are commonly used in the existing papers and those that could be applied in future research. Another famous reviewer overviewed approximately 130 papers based on a classification of SCM topics (Leng & Parlar, 2005). Unlike Cachon and Netessine, who highlighted game-theoretical techniques, Leng and Parlar focused on the operation areas of SCM to which the game theory is applied.

In this section, we introduce the Game theoretic concepts applications in supply chain management. According to the literature review of Cachon and Netessine, games that were developed for supply chain management can be classified into four categories. They are Non-cooperative static games, dynamic games, cooperative games, and signaling, screening and Bayesian games. We first introduce non-cooperative games, the type of game that has received the most attention in the recent SCM literature. Other game theoretic concepts, such as cooperative games and dynamic games, are discussed next.

2.3.1 Non-cooperative Static Games

Although some instances of using similar concepts date back several centuries, the solution of non-cooperative game theory was formally introduced by John Nash in 1950. In the usual form of non-cooperative static games, the players choose strategies simultaneously and commit to their chosen strategies. Non-cooperative game theory seeks a rational prediction of how the game will be played in practice. A player’s strategy can be thought of as the complete instruction for which actions are to take in the game. For example, a player can give his or her strategy to a person that has absolutely no knowledge of the player's payoff or preferences, and that person should be able to use the instructions contained in the strategy to choose the actions the player desires. As a result, each player's set of feasible strategies must be independent of the strategies chosen by the other players; in other words, the strategy choice by one player is not allowed to limit the feasible strategies of another player..

2.3.2 Cooperative Games

The subject of cooperative games first appeared in the seminal work of von Neumann and Morgenstern (1944). However, for many years, cooperative game theory did not gain as much attention in the economics literature as non-cooperative game theory. Cooperative game theory involves a major shift in paradigms as compared to non-cooperative game theory; the former focuses on the outcome of the game in terms of the value created through cooperation of a subset of players but does not specify the actions that each player will take, while the latter is more concerned with the specific actions of the players. Also, unlike non-cooperative games, in which the players are unable to make binding commitments before choosing their strategies, in a cooperative game, players are able to make binding commitments; in a cooperative game, players can make side-payments and form coalitions. Hence, cooperative game theory allows the modeling of outcomes of complex business processes that otherwise might be too difficult to describe, such as negotiations, answering more general questions, and determining how well the firm is positioned against competition (Brandenburger &Stuart, 2000). However, papers employing cooperative game theory to study supply chain management were scarce. The first paper employing cooperative games in SCM was one by Wang and Parlar (1994), who analyzed the newsvendor game with three players, first in a non-cooperative setting and then under cooperation with and without Transferable Utility. However, application of cooperative game theory is becoming more popular due to the prevalence of bargaining and negotiations in supply chains.

2.3.3 Dynamic Games

While most SCM models are static, including all newsvendor-based models, a significant portion of SCM literature is devoted to dynamic models, in which decisions are made over time. The three dynamic games that are often applied to SCM are the Stackelberg game, stochastic game, and differential game.

2.3.3.1 Sequential Moves: Stackelberg Game

In 1934, Stackelberg introduced the simplest dynamic game, which was named after him. In a Stackelberg duopoly model, the leader chooses a strategy first, and then the follower observes this decision and makes his own strategy choice. Intuitively, the first player chooses the best possible point on the second player’s best response function. Clearly, the first player can choose a Nash Equilibrium, so the leader is always at least as well off as he would be in NE. Hence, if a player were allowed to choose between making moves simultaneously or being a leader in a game with complete information, he would always prefer to be the leader. However, if new information is revealed after the leader makes a play, then it is not always advantageous to be the leader. Whether the follower is better off in the Stackelberg or simultaneous move game depends on the specific problem setting. To find the equilibrium of a Stackelberg game, which is often called the Stackelberg equilibrium, we need to solve a dynamic multi-period problem via backwards induction. Actually, the existence of Stackelberg equilibrium is easy to demonstrate, given the continuous payoff functions. However, uniqueness may be considerably more difficult to demonstrate. Even though there are some difficulties in application of Stackelberg game, it has still been considered a popular and appropriable method to solve dynamic problems in SCM.

2.3.3.2 Simultaneous Moves: Repeated and Stochastic Games

A different type of dynamic game arises when both players take actions in multiple periods. The two major types of multiple-period games are non-time-dependent dynamic games and time-dependent dynamic games in the multi-period game without time dependence, the exact same game is played over and over again; hence, the term repeated games. The strategy for each player is now a sequence of actions taken in all periods. In this case, there are no links between successive periods other than the players' memory about actions taken in all the previous periods. Although repeated games have been extensively analyzed in economics literature, it is awkward in an SCM setting to assume that nothing links successive games; typically, in SCM, there is some transfer of inventory and/or backorders between periods. Consequently, repeated games, thus far, have not found many applications in SCM literature. In time-dependent multi-period games, players' payoffs in each period depend on actions taken in the previous, as well as current, periods. Typically, the payoff structure does not change from period to period (so-called stationary payoffs). Clearly, such a setup closely resembles multi-period inventory models, in which time periods are connected through the transfer of inventories and backlogs. Due to this similarity, time-dependent games have found applications in SCM literature. The most often used time-dependent multi-period game in SCM is stochastic games or Markov games.

2.3.3.3 Differential Games

Discrete dynamic games in discrete time involve a sequence of decisions that are separated in time; while differential games provide a natural extension for decisions that have to be made continuously. The standard tools needed to analyze differential games are the calculus of variations or optimal control theory (Kamien & Schwartz, 1981). In a standard optimal control problem, a single decision-maker sets the control variable that affects the state of the system. In contrast, in differential games, several players select control variables that may affect a common state variable and/or the payoffs of all players. Hence, differential games can be regarded as a natural extension of the optimal control theory. There are two distinct types of player strategies in a differential game: open-loop and closed-loop, which is also sometimes called feedback. In the open-loop strategy, the players select their decisions or control variables once at the beginning of the game and do not change them so that the control variables are only functions of time and do not depend on the other players' strategies. Open-loop strategies are simpler in that they can be found through the straightforward application of optimal controls, which makes them quite popular. In contrast, in a closed-loop strategy, the player bases his strategy on current time and the states of both players' systems. Hence, feedback strategies are subgame-perfect. There are numerous applications for differential games in economics and marketing, especially in the area of dynamic pricing. Since many SC models rely on continuous-time processes, it is natural to assume that differential games should be intensively applied in SCM literature. However, the applications of differential games in SCM are quite limited, even though they may be popular in some disciplines (Basar & Olsder, 1999).

2.4 Game Theory– Related Areas of Supply Chain Managment

Supply chain-related game theoretical applications are found in five categories. There are inventory games with fixed unit purchase cost, inventory games with quantity discounts, production and pricing competitions, games with other attributes and games with joint decisions on inventory, and those with production/pricing and other attributes (Leng & Parlar, 2005).

2.4.1 Inventory Games with Fixed Unit Purchase Cost

Inventory management problems involving competition may arise in either horizontal or vertical channels; however a great number of articles about competition of inventory management are in horizontal channels. Parlar (1988) developed a single period context game theoretic model of competition between two players. He proved the existence and uniqueness of the Nash equilibrium and showed that cooperation between two players can increase their profits. Wang and Parlar (1994) extended the model to describe a three-person game in the same context, a single-period inventory competition with substitutable products. More recently, Avar and Baykal-Gursoy (2002) extended Parlar's model to the infinite horizon and lost-sales case and examined a two-person non-zero-sum stochastic game under the discounted payoff criterion. In another early work on single-period models, Nti (1987) examined an inventory procurement model with n competitive organizations. In a random demand setting, Nti proved that a unique Nash equilibrium exists. Lippman and McCardle (1997) analyzed a competitive newsboy mode in both oligopoly and duopoly contexts. In Mahajan and van Ryzin (2001), a more general model with inventory competition was analyzed with dynamic choice behaviour of heterogeneous consumers and its effect on firms' inventories and profits. Anupindi, Bassok, and Zemel (2001) developed a general framework to analyze two-stage decentralized distribution systems where retailers face stochastic demands. Granot and Sosic (2003) extended the results to a three-stage model.

Meanwhile, the vertical competition issues related to inventory control were also studied. Cachon (1999) considered a two-echelon competitive supply chain inventory problem with a single supplier and a single retailer that faces stochastic demand. Cachon showed that there is a pair of unique Nash equilibria, and that equilibrium is not an optimal solution for global supply chain performance. Cachon then extended the above models to analyze the competitive and cooperative inventory issue in a two-echelon supply chain with one supplier and a few retailers. Wang, Guo, and Efstathiou (2004) extended the model to a one-supplier and retailer situation where the supply from the supplier might not satisfy the demand of multiple retailers. In their model, the authors separated sufficient supply from the supplier and insufficient supplies from the supplier.

Moreover, several Nash equilibrium contracts were designed for system-wide optimal cooperation. Raghunathan (2003) considered a one-manufacturer and one-retailer supply chain with correlated demand at the retailer and applied the Shapley value concept to analyze the expected manufacturer and retailer shares of the surplus incurred due to information sharing. The author examined the impact of demand correlation on the value of information sharing and the relative incentives of manufacturers and retailers to form information sharing partnerships. Another paper in this area is by Corbett (2001) who studied the well-known model in a supplier-buyer supply chain with conflicting objectives and asymmetric information.

2.4.2 Inventory Games with Quantity Discounts

Quantity discount policy is a common marketing scheme adopted in many industries. With this policy, the buyer has an incentive to increase his/her purchase quantity to obtain a lower unit price. The quantity discount scheme plays an important role in the analysis of two-stage vertical supply chains.

Recently, several reviews focusing on quantity discounts have been published. Monahan (1984) developed and analyzed a quantity discount model to determine the optimal quantity discount schedule for a vendor. However, Joglekar (1988) pointed out some shortcomings as well as the contribution of this previous model. The shortcomings are due to several implicit assumptions that make Monahan's results impractical. In response to these comments, Monahan (1988) argued that the principal purpose is to provide an introductory model in this area. Lee and Rosenblatt (1986) also extended Monahan's model by addressing two important issues, which are to impose some constraints on the amount of price discount so as to make it less than the selling price of the product, and to revise the order-to-order assumption to the situation for the supplier to order a larger quantity than the buyer's order amount.

Lai and Staelin (1984) investigated the same problem with Monahan's model, under cooperative and competitive environments. Extending Lai and Staelin's work, Kohli and Park (1989) examined a cooperative game theory model of quantity discounts to analyze a transaction-efficiency rationale for quantity discounts offered in a bargaining context. Kim and Hwang(1989) studied the effects of quantity discount on supplier's profit and buyer's cost in the competitive and cooperative contexts. They explored how the supplier decides the discount schedule, given the assumption that the buyer always behaves optimally by using the classic EOQ inventory decision. Chiang et al. (1994) investigated the game theoretic discount problem in both two-stage competition and cooperative contexts. Similar to the papers by Chiang, Jeuiand and Shugan (1983), Parlar and Wang (1994) investigated the discounting scheme of the seller and a linear ordering decision of a group of homogeneous customers in a game framework. The effect of a discount scheme on joint maximum gain for the seller and the buyer was also examined. An extension of this model was also studied by Parlar and Wang (1995) with incomplete information. Another similar work was published by Corbett and Groote (2000).

In a paper on cooperation, Weng (1995) presented a model for analyzing the impact of joint decision policies on channel coordination in a supply chain including a supplier and a group of homogeneous buyers. Weng showed that quantity discounts alone are not sufficient to guarantee joint profit maximization, and that all unit and incremental discount policies have the same effect on coordination under complete information. Li and Huang (1995) also addressed the problem of cooperation between seller and buyer. By utilizing the uniform quantity discount policy in a Stackelberg game system, Wang (2001) also investigated the coordination issue between a vendor (supplier) and a group of independent buyers. Chen, Federgruen, and Zheng (2001) adopted a power-of-two policy to coordinate the replenishments within a decentralized supply chain with one supplier and multiple retailers. Wang (2004) considered a similar decentralized supply chain and developed a coordination strategy that combines integer-ratio time coordination and uniform quantity discounts. Wang showed that integer-ratio time coordination provides a better coordination mechanism than power-of-two time coordination. Further, Wang and Wu (2000) proposed an optimal quantity discount schedule for a supplier with different buyers.

2.4.3 Production and Pricing Competition

The earliest publications dealing with production/pricing competition are from Cournot (1838) and Bertrand (1883). Coumot derived the production equilibrium in a market where two producers supply similar products to the same market, while Bertrand focused on pricing equilibrium. A large number of papers extending Coumot and Bertrand's results have appeared in economics and management science literature. Shapley and Shubik (1838) applied game theory to study a monopolistic price competition among sellers with differentiated products. Levitan and Shubik (1971) studied price variation and duopoly. Hutchinson and Meyer (2002) investigated the impact of a firm’s reputation on its pricing equilibrium strategies. Joint production and pricing strategies were also considered. Klemperer and Meyer (1986) analyzed the Nash equilibrium prices and quantities as strategic variables in a one-stage duopolistic game with differentiated products. Using a differential game approach, Jorgensen (1986) considered a continuous-time game problem to compute optimal production, and purchasing and pricing policies in a two-stage vertical channel involving one manufacturer and one retailer. Corbett and Karmarkar (2001) developed an explicit game model of Nash-characterized and Coumot competition in serial multi-tier supply chains with price-sensitive linear deterministic demand.

Other papers focus on price constraints. The first publication emphasizing channel cooperation in this category was by Zusman and Etgar (1981) with a combined application of economic contract theory and Nash bargaining theory. McGuire and Staelin (1983) studied four industry structures induced by two types of channel systems, consisting of two manufacturers. They (1983) also studied the effect of product substitutability on Nash equilibrium distribution structures in a duopoly competitive system. For the decentralized competitive problem mentioned, Moonhy (1988) studied the effect of strategic interaction on the Nash equilibrium strategy. Dong and Rudi (2004) proposed a game model for supply chain interaction between a manufacturer and a number of retailers with a transshipment scheme.

Several recent papers have investigated pricing policy used as a means for coordinating supply chains. Zhao and Wang (2002) developed a Stackelberg game for a two-level supply chain where a manufacturer acts as leader and a distributor/retailer acts as follower. Chiang, Chhajed, and Hess (2003) developed a price-setting game for a two-level supply chain where a manufacturer directly sells a single product to online customers rather than via his independent retailers. Choi (1991) studied the effect of the existence of a channel intermediary on the intensity of horizontal competition between two manufacturers. He considered two Stackelberg games and one Nash game between the two manufacturers and one common retailer.

The Stackelberg equilibrium was also found explicitly in terms of the model parameters. With the linear demand function, Choi (1991) reached the conclusion that it benefits a manufacturer to maintain exclusive retailers, while a retailer should prefer to have several manufacturers. Trivedi (1998) extended and analyzed three channel structures dealing with competition at both the two-manufacturer and two-retailer levels. Kadiyali, Chintagunta, and Vilcassim (2000) also extended Choi's work by allowing a continuum of possible channel integration between manufacturers and a retailer instead of three-channel interaction games.

2.4.4 Games with Other Attributes

Various other papers are concerned with diverse topics, such as capacity decisions, service quality, product quality, advertising, and new product introduction.

2.4.4.1 Capacity Decisions

Cachon and Lariviere (1999) conducted an equilibrium analysis on a capacity-constrained system where a supplier utilizes linear, proportional, and uniform allocation schedules. They (1999) also applied manipulated and truth-inducing capacity allocation schemes to study a retailer’s order behavior and a supplier's capacity choice problem. Furthermore, Cachon and Lariviere (2001) investigated a forecast sharing model of a manufacturer and a supplier. Mallik and Harker developed a game model involving multiple product managers and multiple manufacturing managers who forecast the means of their respective demand and capacity distributions. Hall and Porteus (2000) considered a game where firms compete on capacity investment for market share; they assumed that the market share of either firm depends on the prior realized level of customer service.

2.4.4.2 Service Quality

A firm's response time to customer demand is an important factor implicitly affecting its profitability. Kalai, Kamien, and Rubinovitch (1992) proposed a two-server game theoretic model with exponential service time and Poisson arrival of customers. Gans (2002) developed a model of many suppliers competing on service quality for customers whose choices respond to random variation of quality. The following papers examined other models associated with service quality. Cohen and Wang (1997) developed a Stackelberg game model of product life cycle. Chu and Desai (1995) proposed a game model to describe a manufacturer motivating a retailer with two incentive schedules, such as Consumer Satisfaction assistance and a Consumer Satisfaction Index bonus.

2.4.4.3 Product Quality

The literature related to product quality competition in supply chain management is limited. Reyniers and Tapiero (1995) determined the effect of contract parameters on the quality of the end product in a vertical channel including a supplier and a producer. Extending Reyniers and Tapiero's model, Lim (2001) designed producer-supplier contracts with incomplete information. The paper, emphasizing the product quality signaling mechanism, was published by Chu and Chu (1994), who analyzed a game theoretical model of a manufacturer selling a product through a reputable retailer to signal its product quality. It was shown that, in equilibrium, manufacturers of high quality distribute their product through highly reputable retailers, while, in turn, manufacturers of low quality distribute products through retailers without prominent reputations.

2.4.4.4 Advertising and New Product Introduction

One of the earliest game theory models for an oligopolistic market with advertising competition was developed by Balch (1971). In this paper, each market decides on the advertising outlay to maximize its individual profit and market share in the next production/marketing period. Another early paper by Deal (1979) determines the optimal time of advertising expenditure over a finite planning horizon in a dynamic duopoly competitive situation. Amaldoss et al. (2000) examined three types of strategic alliances that may help participants to compete, such as same-function alliances, parallel development of new products, and cross-functional alliances. Desai (2000) studied how a high-demand manufacturer uses advertising, slotting allowances, and wholesale prices to signal high new product demand to retailers. The author also investigated the impact of a retailer's uncertainty on the effectiveness of a manufacturer's advertising

2.4.4.5 Games with Joint Decisions on Inventory, Production/Pricing, and Other Attributes

In many realistic problems, supply chain members encounter problems involving two or more decisions that must be made simultaneously. For example, Joint Inventory and Production or Pricing Decisions, Joint Inventory and Capacity Decisions, Joint

Production or Pricing and Capacity Decisions, Joint Production or Pricing and Service or Product Quality Decisions, Joint Production or Pricing, and Advertising or New Product Introduction Decisions.

In conclusion, operations management has been slow to adopt game theory. Recently, an explosion of game theory papers in SCM has been witnessed, because SCM is an ideal candidate for the application of game theory. Even though the application of game theory to supply chain management is still in its infancy, much more progress will soon follow. For example, most of these papers utilize only a few game theoretic concepts; in particular, the concepts related to non-cooperative static games. The relative lack of game theory applications in SCM can be partially attributed to the absence of game theory courses in the curricula of most doctoral programs in operations research management.

CHAPTER THREE

CHAPTER THREE

FORMULATION AND METHODOLOGY

In this chapter, we consider a vertical two-tier supply chain involving a manufacturer and a supplier. We create a model regarding the allocation of CSR to each member of a supply chain by dynamic Stackelberg game theory. We formulate the problem by choosing, in turn, both the supplier and the manufacturer as the leader of the game. To provide a clear explanation of our model, some crucial fundamental knowledge about this model is introduced in the next section.

3.1 Foundation of the Model

Game theory is not new in supply chain management. Table 3.1 shows the types of game theory that are often applied on supply chain management (The New Palgrave Dictionary of Economics, 2008).

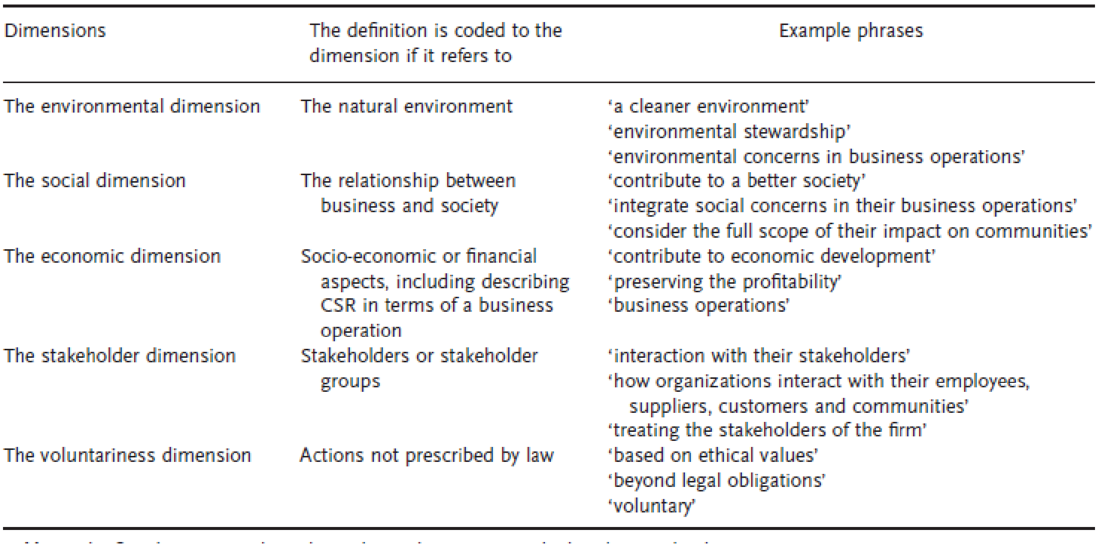
A1:	**Cooperative**	**A2:**	**Non-cooperative**
B1:	**Symmetric**	**B2:**	**Asymmetric**
C1:	**Zero-sum**	**C2:**	**Non-zero-sum**
D1:	**Simultaneous**	**D2:**	**Sequential**
E1:	**Perfect information**	**E2:**	**Imperfect information**
F1:	**Finitely**	**F2:**	**Infinitely**
G1:	**Discrete**	**G2:**	**Continuous**
H1:	**One-player**	**H2:**	**Many-player**

Table 3.1 Types of Game Theory

Selecting the proper game model to formulate our problem is a key in determining whether the formulation is practical and whether a feasible solution is available. The following sections explain the criteria for choosing suitable game theory.

3.1.1 Definition of Corporate Social Responsibility

The definition of CSR has been discussed and argued for several decades. Researchers have tried many ways to get a clear and robust definition of CSR. Three methodologies are often used. The first method is to derive an updated definition from literature review; the second is to interview businessmen and managers; the third is to interpret CSR through other theories, such as philosophy and economics. However, so far, no consensual definition is available. According to Carroll's (1999) review of CSR definitions in academic literature, gathered through an extensive review of journal articles and web pages, 37 definitions of CSR had been found and analyzed. The definitions originated from 27 authors and covered a time span from 1980 to 2003. As Carroll points out, these definitions are divided into five dimensions, as listed in Table 3.2.



Dimensions	The definition is coded to the dimension if it refers to	Example phrases
The environmental dimension	The natural environment	'a cleaner environment' 'environmental stewardship' 'environmental concerns in business operations'
The social dimension	The relationship between business and society	'contribute to a better society' 'integrate social concerns in their business operations' 'consider the full scope of their impact on communities'
The economic dimension	Socio-economic or financial aspects, including describing CSR in terms of a business operation	'contribute to economic development' 'preserving the profitability' 'business operations'
The stakeholder dimension	Stakeholders or stakeholder groups	'interaction with their stakeholders' 'how organizations interact with their employees, suppliers, customers and communities' 'treating the stakeholders of the firm'
The voluntariness dimension	Actions not prescribed by law	'based on ethical values' 'beyond legal obligations' 'voluntary'

Table 3.2 Five Dimensions of Corporate Social Responsibility

Table 3.2 shows, in general, that CSR is defined as corporate activity and its impact on different social groups, which may be related to many issues including diversity, the environment, human rights, natural resources, and even stakeholder benefits. The dimensions 1-4 describe the features of the definition. The fifth dimension is voluntariness activities based on ethical values. The voluntariness dimension is the only CSR that is not prescribed by law; in other words, voluntary CSR is an arbitrary decision that companies make through their own will. Therefore, our model and formulation do not include the fifth dimension CSR.

Furthermore, it is obvious that CSR is an abstract and fussy term. In order to ensure that CSR can be evaluated and allocated to each tier and that the optimal solution can be approached through the model, in our model, the firm’s capital is assumed to be the key essential element for taking social responsibility. Indeed, in reality, all forms of social responsibility, such as environmental protection, labor, ethnic issues, and technology updates, are involved in investment strategies. Since all kinds of CSR are simply expressed as investments, a long-term allocation of social responsibility among members of a supply chain vertical system can be derived from the firms’ investment shares over time. In this way, an abstract CSR can be estimated and computed in our formulation, and our model can be viewed as a long-term co-investment game model in supply chain social responsibility.

3.1.2 Repeated Game with Complete Information

The CSR issues included in dimensions 1-4 pertain to diversity, the environment, human rights, nature resources, and stakeholder benefits. Each of these issues is too complicated to be solved in the short-term; the resolution that a supply chain determines, thus, would be a long-term investment plan. Long-term investments are held for many years before investors realize reasonable returns. As a result, when the supply chain system has to assume certain CSR under regulations or policies, the game the firms in the supply chain play with one another crosses through multi-periods, which constitutes a repeated game.

Moreover, in many real-life situations, a supply chain system that is stable enough to bear social responsibility normally already cooperates well and runs smoothly. The beliefs of members in the supply chain about each other are derived from past experiences of interacting with each other. That is, there may be certain things that an individual firm in a supply chain is willing to reveal to other members that are involved in long-term relationships with it, and other things that it intends to conceal (Myerson, 1991). For example, we might expect that an individual company would generally let other players know about its contributions toward taking social responsibility, but would try to maintain uncertainty about its cost and benefits.

Taking those factors into account, we defined the model as a repeated game with complete information. Specifically, decisions are made numerous times, not just once, because after a stage game is played, the players again find themselves facing the same situation. The firms make decisions based on what they perceive about the future. Since players interact by playing a similar stage game, players have at least some information about the strategies chosen by others; thus, their play is contingent on past moves.

3.1.3 Discrete-time Dynamic Game

In a repeated game, players' moves depend continuously on time at all other points in time. It seems that a continuous dynamic game is a well-defined game for our model. As Myerson (1991) points out in his book "Game Theory Analysis of Conflict," in continuous time, the players can change from generosity to selfishness without there being any first point in time when someone was selfish. To avoid that, we must either somehow restrict the set of possible strategies for each player, or find a more sophisticated rule to define the realized outcome path for all pairs of possible strategies. Either way, this seems to be a difficult research problem (see Fudenberg & Tirole, 1991; Kalai & Smorodinsky, 1975).

A general approach in game theory is to work with discrete-time models. That is, we break up the continuous timeline into a countable sequence of intervals, each called a period (Myerson, 1991). We assume that each player can choose a new move only at the beginning of a period. We also define the length of a period as a year, which is long enough for players to respond to new information and change their decisions, so the discrete dynamic model can reasonably describe a real situation.

3.1.4 Open-loop Stackelberg Game

As mentioned in the literature review, there are many types of game theory that are often used to analyze problems of supply chain management. In a supply chain system, there are normally one or two members who are more powerful than the others, because they are the irreplaceable key parts in the chain (Bagchi, 1984). They might be a monopoly manufacturer, a supplier who has issued patents, or a successful retail chain. Indeed, it is not impossible for all firms in the supply chain to make decisions and take actions simultaneously when the more powerful player has the advantage to take action first. Thus, in this model, to consider this realistic sequential game, we chose the Stackelberg game.

In a typical two-player Stackelberg dynamic game, one player, the leader, chooses his actions before the other player, the follower. Each player's actions in the previous period of the repeated game are revealed to the other player before the next repetition. Importantly, the follower must have some information about the leader's choice; otherwise the difference in time would have no strategic effect (Basar & Olsder, 1999).

Next, we explain why we define the Stackelberg game used in our model as open-loop, as opposed to close-loop. In a close-loop information structure, the result of an event or phenomenon in the past will influence an occurrence or occurrences of the same defined event or phenomenon in the present or future. Unlike a close-loop structure, open-loop information structure assumes that the players must formulate their decisions at time T only with knowledge of the initial condition of the state at time zero (Medanic & Radojevic, 1987). Since the actions in past periods are revealed to players in our dynamic game model with complete information, whether players make their current decisions for rest periods based on their observations on the opponent’s past actions or not, is another issue that must be clarified. Actually, after a supply chain system makes its long-term investment plan and starts the project toward bearing CSR, it is more important for the players that the project is executed perfectly than how much CSR will be taken at the end of the game. This is mainly because they have already considered how much CSR will be taken due to the project and how many years the project will take when they make their long-term investment plan. Therefore, the players compute their input into a system using only the current state and its model of the system; also, they do not use feedback to determine if its output has achieved the desired goal of the input. This means that the system does not observe the output of the processes that it is controlling and the players can credibly pre-commit their firms' investment return plans at period zero for the entire game. This criterion quite matches the definition of an open-loop information structure. It is practicable to apply the open-loop Stackelberg game instead of the feedback Stackelberg game. Therefore, we define our Stackelberg dynamic game is an open-loop.

3.2 Structure of the Model

As we introduced previously, this model is a three-tier, multi-period, decentralized, and also non-integrated vertical control system supply chain network (Figure 3.1), in which each firm makes its decision in order to maximize its individual net profits. The network showed in Figure 3.1 is a typical regular supply chain system in the real world; this is also the supply chain system our model aims to solve.

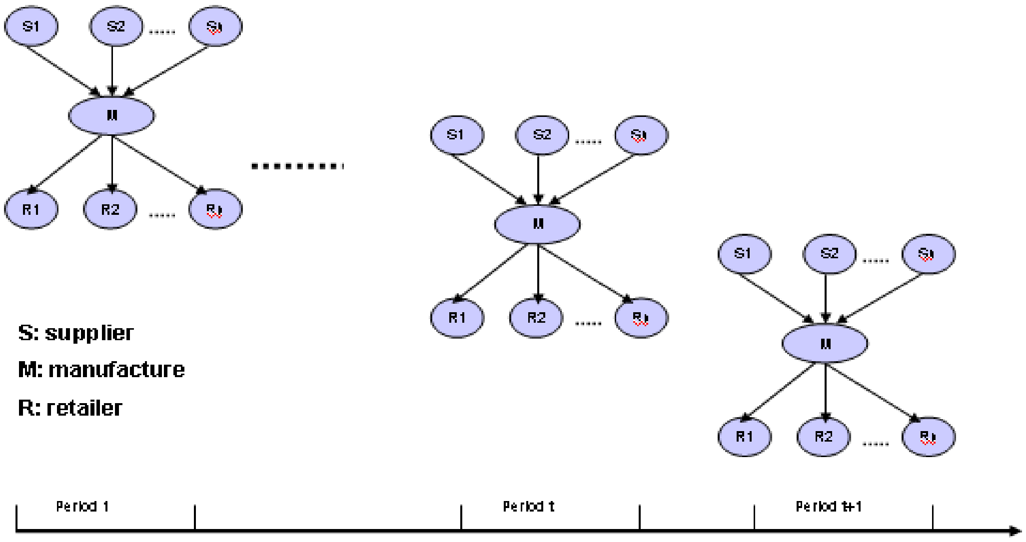


Figure 3.1 Structure of the Supply Chain that the Model Aims to Formulate

All retailers and suppliers at the same level are identical and symmetrical such that they make decisions simultaneously. In later sections of this thesis, we assume that only one supplier and one retailer are involved in playing the Stackelberg game as well as allocated social responsibility. The model is simplified as in Figure 3.2 below.

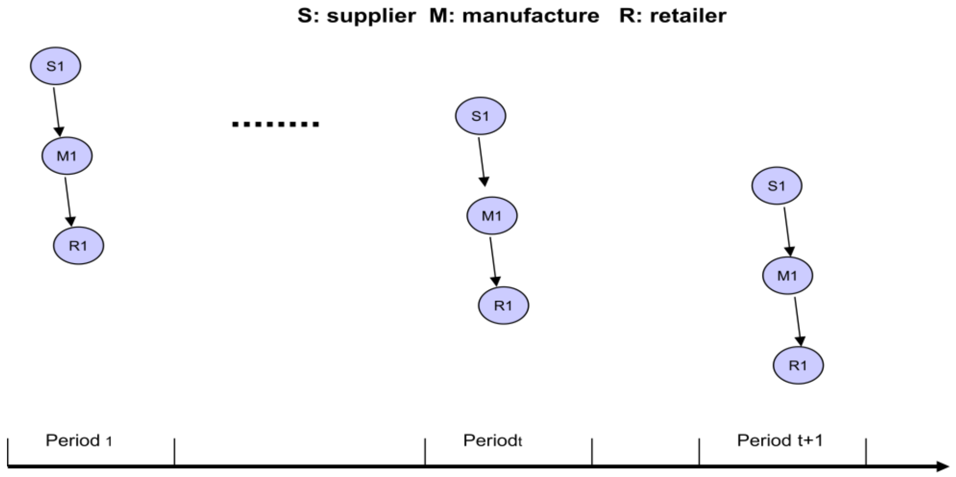


Figure 3.2 Simplified Version of Figure 3.1

The manufacturer produces and supplies a single product at the same lot sale price to multiple retailers who then sell the product to dispersed and independent markets at uniform retail prices. To determine the uniform retail price and capture more consumer surplus, the manufacturer applies a two-part tariff price discrimination technique to its partially or fully monopolistic market. This thesis assumes that the manufacturer's retail price is composed of two parts: a fixed retailers' profit of per-unit sale in addition to a per-unit lot sale charge. Thus, Figure 3.3 is a simplified version of Figure 3.2.

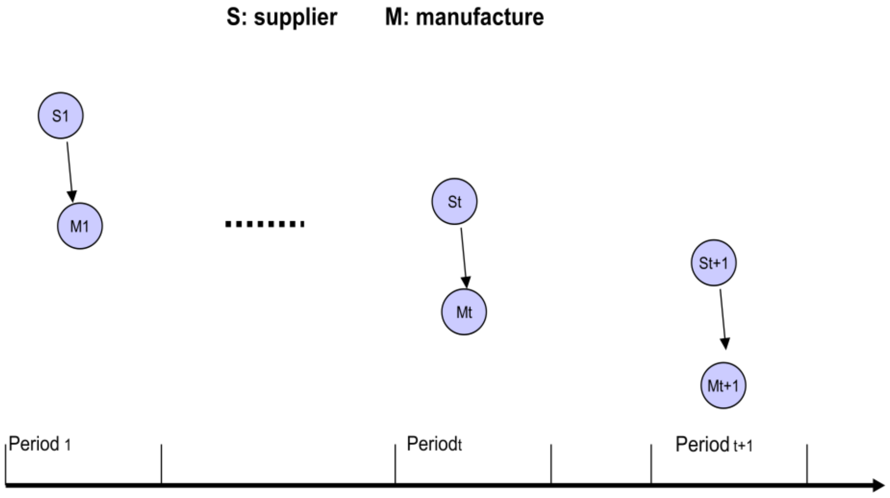


Figure 3.3 Final Formulated Version of Figure 3.1

The network shown by Figure 3.3 is the model we actually formulated, although in a real world situation, the formulation shown in Figure 3.1 would be the one used to solve the problem of a supply chain system.

3.3 A general Formulation of Stackelberg Theory

The Stackelberg game model has been extensively used to study dynamic optimization problems in supply chain management. A dynamic game has the following structure: (1) the state of the dynamic system at any time t is characterized by a set of variables called the state variables, (2) controls are to be decided by the game players, (3) the evolution of the state variables over time is described by a set of differential equations involving both state and control variables, and (4) each player has an objective function that he/she wants to maximize by his/her choice of decisions (Xiuli He, 2007).

We solve an open-loop Stackelberg game by backward induction, which is to substitute the follower’s response function derived from solving the optimization problem of the follower, given the leader's response to the leader's objection function. Secondly, in a vertical control system, it is impossible for all players to make decisions and take actions simultaneously, so the game should be played based on Stackelberg equilibrium rather than Nash equilibrium.

He, Gutierrez, and Sethi (2007) illustrate a general model for a Stackelberg differential game involving two players playing the game over a fixed finite horizon, as detailed below.

Objective function of the follower and its Hamiltonian function:

$$\underset{P(.)}{Max}\left\{ J_R\left(X_{0,}p(.);w(.)\right)=\int_0^t e^{-\rho t}\pi_R\left(X(t),w(t),r(t)\right)dt \right\}$$

$$X_{(t)}=F\left(x(t),w(t),r(t)\right),$$

$$X_{(0)}=X_0$$

Where the function F represents the rate of sales, ρ is the follower's discount rate, and X_0 is the initial condition. The follower's Hamiltonian

$$H_R(x,r,\lambda_R,w)=\pi_R(x,w,r)+\lambda_R F(x,w,r)$$

Where λ_R is the vector of the shadow prices associated with the state variable X; and it satisfies the adjoin equation

$$\lambda_R=\ell\lambda_R-\frac{\partial H_R(x,r,\lambda_R,w)}{\partial x} \qquad \lambda_R(T)=0$$

Here we have suppressed the argument t as is standard in the control theory literature, and we will do whenever convenient and when there arises no confusion in doing so. The necessary optimality condition for the follower's problem satisfy

$$\frac{\partial H_R}{\partial r} = 0 \;\Rightarrow\; \frac{\partial \pi_R(x,w,r)}{\partial r} + \lambda_R \frac{\partial F(x,w,r)}{\partial r} = 0$$

$$get \;\; r^*(x,r,\lambda_R)$$

We assume that the Hamiltonian H_R is jointly concave in the variables X and r for any given w: Then above condition is sufficient for the optimality of r. From the necessary this condition, we derive the follower's best response $r*(X,w,\lambda_R)$

Objective function of the follower and its Hamiltonian function:

$$\underset{w(.)}{Max}\left\{J_M\left(X_{0,}w(.)\right) = \int_0^t e^{-\mu t}\pi_M\left(x,w,r(x,w,\lambda_R)\right)dt\right\} by$$

$$X_{(t)} = F\left(x,w,r(x,w,\lambda_R)\right)$$

$$X_{(0)}(0) = X_0$$

$$\lambda_R = \ell\lambda_R - \frac{\partial H_R(x,r(x,w,\lambda_R),\lambda_R,w)}{\partial x}$$

$$\lambda_R(T) = 0$$

Where μ is the leader's discount rate and the above differential equations are obtained by substituting the follower's best response $r*(X,w,\lambda_R)$ in the state equation and the adjoin equation of the follower respectively. We formulate the leader's Hamiltonian

$$H_M = \pi_M(x,\lambda_R,w,r(x,w,\lambda_R),\lambda_M,\varphi) + \lambda F(x,w,r(x,w,\lambda_R)) - u\frac{\partial H_R(x,r(x,w,\lambda_R),\lambda_R,w)}{\partial x}$$

Where λ_M and μ are the shadow prices associated with X and λ_R respectively, and they satisfy the adjoint equations

$$\begin{aligned}
\dot{\lambda}_M &= u\lambda_M - \frac{\partial H_M(x, \lambda_R, w, r(x, w, \lambda_R), \lambda_M, w)}{\partial x} \\
&= u\lambda_M - \frac{\partial H_M(x, w, r(x, w, r(x, w, \lambda_R))}{\partial x} - \lambda_M \frac{\partial F(x, w, r(x, w, \lambda_R))}{\partial x} - u\frac{\partial^2 H_R(x, r(x, w, \lambda_R), \lambda_R, w)}{\partial x^2} \\
\dot{\varphi} &= u\varphi - \frac{\partial H_M(x, \lambda_R, w, r(x, w, \lambda_R), \lambda_M, \varphi)}{\partial \lambda_R} \\
&= u\varphi - \lambda_M \frac{\partial F(x, w, r(x, w, \lambda_R))}{\partial \lambda_R} - u\frac{\partial^2 H_R(x, r(x, w, \lambda_R), \lambda_R, w)}{\partial \lambda \partial x}
\end{aligned}$$

$\lambda_M(T) = 0$ and $\varphi(0) = 0$ are the boundary conditions.

Applying the concepts and algorithm of above general model built by He, Gutierrez and Sethi, we formulate our model in next section.

3.4 Formulation

When a supply chain system has to take some social responsibility due to regulations or policies, the firms in the supply chain system are conflicted between taking responsibility and maximizing their own benefit. The objective of our model is to maximize the profits of both players, along with maximizing the level of social responsibility taken by the supply chain system. The results of the model demonstrate whether the firms derive benefit from playing the games, and who should be the leader of the Stackelberg game.

3.4.1 Assumptions

To ensure that the equilibrium of this model can be reached, some assumptions of the framework are made, as described below.

- The market inverse demand function is $P^M(q_t) = a - bq_t$ (Mankiw, 2004); retail price is determined by quantity.
- In order to avoid losing market share in a monopolistic market, the manufacturer controls the downstream price to get out of double marginalization. Franchise fees or two-part tariffs are feasible ways to reach this goal (Tirole, 1988). We assume that the manufacturer extracts profit from retailers by franchise fees f; thus, we have the manufacturer's lot sale price $P^M(q_t) = a - bq_t - f$.
- The supply chain network is decentralized, but is also vertically integrated due to monopoly, which is a necessary and sufficient condition to apply to the Stackelberg game in this model.
- Although the decisions the players make cross through a whole year, firms often make their investment plan once in an account year; it is practical to formulate the problem using a discrete continuous time dynamic model instead of a differential one.
- All kinds of social responsibility are assumed to be expressed as investment I_t .
- All retailers and suppliers at the same level are identical and symmetrical such that they make decisions simultaneously, so that the model can be simplified to involve just one supplier and one retailer.
- As a monopolist, the manufacturer determines its wholesale price, and controls the retail price, but cannot negotiate its purchasing price. The supplier controls the quality of parts or raw materials, and determines the technique level of the products. We, therefore, choose either the supplier or manufacturer to be the leader.
- The state variable is the current social responsibility taken by the firms of the supply

chain system. It is a function of time and an accumulated amount of investment of the firms $x_{t+1} = \alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M$. Here, β_1 is the rate of converting the supplier's capital investment in CSR to the amount of CSR taken by the supply chain; while β_2 is the rate of converting the Manufacturer's capital investment in CSR to the amount of CSR taken by the supply chain.

- Taking certain social responsibility is beneficial to firms. Functions $B_S(x_t) = \delta x_t \text{ and } B_M(x_t) = \tilde{\delta} x_t$ (Thomas, 1998) represent social benefit to the supplier and the manufacturer when x_t social responsibility is taken by the supply chain system.

- The government forces firms to take certain social responsibility through policies or regulations, but also encourages and rewards them for doing so. Below functions $T_t^S = \tau I_t^S[1+\theta(I_t^S + I_t^M)]$ and $T_t^M = \tau I_t^M[1+\theta(I_t^S + I_t^M)]$ measure the values of the tax returns to the supplier and the manufacturer (Feibel, 2003). Both τ and θ are tax return policy parameters. Specifically, τ is the rate of individual post tax return on investment (ROI), and θ is rate of supply chain's post tax return on investment (ROI).

- A certain percentage of investment by the supplier is paid off by the manufacturer in various ways; for example, the manufacturer pays more to get environmentally friendly raw materials or parts from the supplier.

- The goal of both the supplier and the manufacturer is to maximize their cumulated profits over the T periods with respect to their choice of output.

- The game goes through finite periods, T. Generally, the payback period for long-term investment is ten years, so we set $T = 10$.

3.4.2 Notations and Definitions

To formulate the model, we have provided the notations and definitions below.

Variables

t	Period t
T	Planning horizon
q_t	Demand quantity at period t
a	Market potential
b	Price sensitivity
f	Franchise fee
x_t	State variable, degree of taking SR
H^S	Hamiltonian function of the followers
H^M	Hamiltonian function of the leader
J_t^S	Objective function of the supplier
J_t^M	Objective function of the manufacturer
$B^M(x_t)$	Social benefit of the supplier
$B^S(x_t)$	Social benefit of the manufacturer
$T^S(x_t)$	Tax return of the supplier
$B^M(x_t)$	Tax return of the manufacturer
I_t^M	The amount of investment of the manufacturer
I_t^S	The amount of investment of the supplier
d	The percentage of investment of the supplier payoff
w	Price of the supplier's raw material
δ	Parameter of the supplier's social benefit
$\tilde{\delta}$	Parameter of the manufacturer's social benefit
λ	Quantity discount parameter of the price of raw material
α	Deteriorating rate of the level of current social responsibility
τ	The rate of individual post tax return on investment (ROI)
θ	The rate of supply chain's post tax return on investment (ROI)
β_1	The rate of converting the supplier's capital investment in CSR to the amount of CSR taken by the supply chain
β_2	The rate of converting the manufacturer's capital investment in CSR to the amount of CSR taken by the supply chain

Table 3.3 Notations and Definitions

3.5 Mathematical Model: Case One

In this thesis, the Stackelberg dynamic game is applied by selecting, in turn, either the supplier or the manufacturer as the leader. In fact, the supplier controls the quality of the parts or raw materials, and determines the technique level of the products; therefore, it may be as powerful as the manufacturer in implementing the allocation of investment into social responsibility. We formulated the situation in which the supplier is the leader in the Stackelberg game as case one.

3.5.1 State Variable and Control Variables

As any problem formulated as a dynamic game, this model has a state variable and control variables. We define the state variable as the level of social responsibility taken by companies, and the control variables are the capital amounts invested in taking social responsibility. Specifically, all of the social responsibility taken by firm j at period t can be expressed as investment I_t^j. The level of current supply chain investment in supply responsibility is x_t; therefore the accumulation of level of social responsibility taken by the firms is given by

$$x_{t+1} = \alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M$$

Where α is the deteriorating rate of the level of current social responsibility; β_1 is the rate of converting the investment of the supplier to social responsibility; and β_2 is the rate of converting the investments of the supplier to social responsibility.

3.5.2 Objective Function and Constraints

The objective functions of both the supplier and manufacturer attempt to optimize their net benefits. To do this, they need to minimize the cost of raw materials and investment in taking social responsibility, and maximize sale revenues and benefits from taking social responsibility as well as tax returns. In the model, the objective functions of the dynamic game cost function are made to depend only on the control vectors and the static variable.

In our formulation, the profit function of the supplier at a single period is defined by the following equation:

$$F_t^S = P_t^S q - cq + B_t^S(x_t) + T_t^S(I_t^S, I_t) - I_t^S + dI_t^M$$

Where P_t^S is the price of the product the supplier sells to the manufacturer; $B_t^S(x_t)$ is the social benefit of the supplier; and $T_t^S(I_t^S, I_t)$ is the tax return of the supplier.

$w, \delta\, and\, \tau$ are parameters. Let $P_t^S = w$, $B_t^S(x_t) = \delta x_t^2$, and

$T_t^S(I_t^S, I_t) = \tau I_t^S \left[1 + \theta(I_t^S + I_t^M)\right]$.

Thus, the objective function of the supplier is

$$J_t^S = \arg\max \sum_{i=1}^{T} P_t^S q_t - cq_t + B_t^S(x_t) + T_t^S(I_t^S, I_t) - I_t^S + dI_t^M$$
$$= \arg\max \sum_{i=1}^{T} w q_t - cq_t + \delta x_t^2 + \tau I_t^S \left[1 + \theta(I_t^S + I_t^M)\right] - I_t^S + dI_t^M$$

Similarly, the profit function of the manufacturer at a single period is defined as:

$$F_t^M = P_t^M(q_t)q_t - P_t^S q_t + B^M(x_t) + T^M(I_t^M) - I_t^M$$

In the function, $P_t^M(q_t)$ is the retail price of the product of the manufacturer; $B_t^M(x_t)$ is the social benefit of the manufacturer; and $T_t^M(I_t^M, I_t)$ is the tax return of the manufacturer. Let $P_t^M(q_t) = a - bq_t - f$. $B^M(x_t) = \tilde{\tilde{\delta}} x_t^2$, and $T^M(I_t^M) = \tau I_t^M \left[1 + \theta(I_t^S + I_t^M)\right]$. $a, b, f, \tilde{\tilde{\delta}}$ *and* τ are parameters.

Therefore, the objective function of the manufacturer is

$$J_t^M = \arg\max \sum_{i=1}^{T} P_t^M(q_t)q_t - P_t^S q_t + B^M(x_t) + T^M(I_t^M) - I_t^M$$
$$= \sum_{i=1}^{T} (a - bq_t - f)q_t - Wq_t + \tilde{\tilde{\delta}} x_t^2 + \tau I_t^M \left[1 + \theta(I_t^S + I_t^M)\right] - I_t^M$$

3.5.3 Hamiltonian Function and Necessary Conditions

Since we consider this dynamic game an optimal control problem, the Hamiltonian function is a practical way for us to find the equilibrium of the game (Sethi & Thompson, 2000).

For fixed I_t^S , the Hamiltonian function of the manufacturer is defined by

$$H_t^M = J_t^M + P_{t+1}^M\left(\alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M\right)$$
$$= (a - bq_t - f)q_t - wq_t + \bar{\delta}x_t^2 + \tau I_t^M\left[1+\theta(I_t^S + I_t^M)\right] - I_t^M + P_{t+1}^M\left(\alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M\right.$$

This means, to any announced strategy I_t^S of the leader, there is a unique optimal response of the follower I_t^M , satisfying the following necessary conditions:

$$\frac{\partial H_t^M}{\partial I_t^M} = \tau\left[1+\theta(I_t^S + I_t^M)\right] + \tau\theta I_t^M - 1 + P_{t+1}^M\beta_2 = 0$$

$\Rightarrow$

$$I_t^M = \frac{1-\tau-\tau\theta I_t^S - P_{t+1}^M\beta_2}{2\tau\theta} \tag{1}$$

$$x_{t+1} = \frac{\partial H_t^M}{\partial P_{t+1}^M} = \alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M$$

$$x_{t+1} = \alpha x_t + \beta_1 I_t^S + \beta_2\left(\frac{1-\tau-\tau\theta I_t^S - P_{t+1}^M\beta_2}{2\tau\theta}\right)$$
$$= \alpha x_t + \beta_2\frac{(1-\tau-P_{t+1}^M\beta_2)}{2\tau\theta} + \left(\beta_1 - \frac{\beta_2}{2}\right)I_t^S \tag{2}$$

$$P_t^M = \frac{\partial H_t^M}{\partial x_t} = 2\bar{\delta}x_t + \alpha P_{t+1}^M \tag{3}$$

Now, making the best unique decision, the supplier is faced with the optimal control problem. To obtain the Stackelberg strategy of the supplier, we maximize the objective function of the supplier by its Hamiltonian function.

We fix the value of I_t^M in constraint (1), and then get the Hamiltonian function of the manufacturer:

$$H_t^S = J_t^S(x_{t+1}) + P_{t+1}^S(x_{t+1}) + u_t(P_t^M$$

J_t^S is the objective function of the supplier

$$J_t^S = wq_t - cq_t + \delta x_t^2 + \tau I_t^S\left[1+\theta(I_t^S + I_t^M)\right] - I_t^S + dI_t^M$$

Substitute the value of I_t^M into the equation above.

$$\begin{aligned} J_t^S &= wq_t - cq_t + \delta x_t^2 + \tau I_t^S\left[1+\theta(I_t^S + I_t^M)\right] - I_t^S + dI_t^M \\ &= wq_t - cq_t + \delta x_t^2 + (\tau-1)I_t^S + \tau\theta(I_t^S)^2 + I_t^S\left(\frac{1-\tau-P_{t+1}^M\beta_2}{2\tau\theta}\right) - \frac{\tau\theta(I_t^S)^2}{2} + d\left(\frac{1-\tau-P_{t+1}^M\beta_2}{2\tau\theta}\right) - \frac{d\tau\theta I_t^S}{2\tau\theta} \\ &= \frac{\tau\theta(I_t^S)^2}{2} + \left[(\tau-1) + \left(\frac{1-\tau-P_{t+1}^M\beta_2}{2\tau\theta}\right) - \frac{d}{2}\right]I_t^S + wq_t + \delta x_t^2 + d\left(\frac{1-\tau-P_{t+1}^M\beta_2}{2\tau\theta}\right) - cq_t \end{aligned}$$

Substitute the value of x_{t+1} into $P_{t+1}^S(x_{t+1})$.

$$P_{t+1}^S\left(\alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M\right) = P_{t+1}^S\left[\alpha x_t + \beta_2\frac{(1-\tau-P_{t+1}^M\beta_2)}{2\tau\theta} + \left(\beta_1 - \frac{\beta_2}{2}\right)I_t^S\right.$$

Substitute the value of P_t^M in constraint (3) into $u_t(P_t^M)$.

$$u_t(P_t^M) = u_t(2\tilde{\delta} x_t + \alpha P_{t+1}^M)$$

Consequently, the unique optimal response of the follower is determined from the equations below in conjunction with constraints (1) and (3).

$$\frac{\partial H_t^S}{\partial I_t^S} = \tau\theta I_t^S - \frac{(1-\tau+P_{t+1}^M\beta_2+d)}{2} + P_{t+1}^S(\beta_1 - \frac{\beta_2}{2}) = 0$$

$$\Rightarrow$$

$$I_t^S = \frac{(1-\tau-P_{t+1}^M\beta_2+d)}{2\tau\theta} - \frac{P_{t+1}^S(\beta_1 - \frac{\beta_2}{2})}{\tau\theta} \qquad (4)$$

Other constraints are,

$$x_{t+1} = \frac{\partial H_t^S}{\partial P_{t+1}^S} = \beta_2 \frac{(1-\tau-P_{t+1}^M\beta_2)}{2\tau\theta} + (\beta_1 - \frac{\beta_2}{2}) I_t^S + \alpha x_t \qquad (5)$$

$$P^S = \frac{\partial H_t^S}{\partial x_t} = 2\delta x_t + \alpha P_{t+1}^S + 2\tilde{\delta} u_t \qquad (6)$$

$$u_{t+1} = \frac{\partial H_t^S}{\partial P_{t+1}^M} = -\frac{\beta_2}{2} I_t^S - \frac{(\beta_2)^2}{2\tau\theta} P_{t+1}^M + \alpha u_t \qquad (7)$$

$$P_t^M = 2\tilde{\delta}x_t + \alpha P_{t+1}^M \tag{3}$$

$$I_t^M = \frac{1-\tau-\tau\theta I_t^S - P_{t+1}^M \beta_2}{2\tau\theta} \tag{1}$$

The equilibrium point of the Stackelberg game is the solution of the objective function of the supplier corresponding to constraints (1) to (7).

3.5.4 Augmented Discrete Hamiltonian Matrix

There are many methods to solve the optimal control problem formulated in 3.4.4. We chose one of the most popular algorithms given by Medanic, which is an augmented discrete Hamiltonian matrix.

First, we assume

$$\begin{bmatrix} \tilde{x}_{t+1} \\ \tilde{P}_t \end{bmatrix} = \begin{pmatrix} A & B \\ C & A \end{pmatrix} \begin{bmatrix} \tilde{x}_t \\ \tilde{P}_{t+1} \end{bmatrix} + \begin{pmatrix} D \\ E \end{pmatrix} = \begin{pmatrix} A\tilde{x}_t + B\tilde{P}_{t+1} + D \\ C\tilde{x}_t + A\tilde{P}_{t+1} + E \end{pmatrix}$$

$$\tilde{x}_{t+1} = \begin{pmatrix} x_{t+1} \\ u_{t+1} \end{pmatrix} \quad \tilde{P}_{t+1} = \begin{pmatrix} P^S_{t+1} \\ P^M_{t+1} \end{pmatrix}$$

$$\Rightarrow$$

$$\tilde{x}_{t+1} = \begin{pmatrix} x_{t+1} \\ u_{t+1} \end{pmatrix} = \left(A\tilde{x}_t + B\tilde{P}_{t+1} + D\right) = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} x_t \\ u_t \end{pmatrix} + \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \begin{pmatrix} P^S_{t+1} \\ P^M_{t+1} \end{pmatrix} + \begin{pmatrix} d_1 \\ d_2 \end{pmatrix}$$

$$= \begin{pmatrix} a_{11}x_t + a_{12}u_t + b_{11}P^S_{t+1} + b_{12}P^M_{t+1} + d_1 \\ a_{21}x_t + a_{22}u_t + b_{21}P^S_{t+1} + b_{22}P^M_{t+1} + d_2 \end{pmatrix}$$

Where A, B, and C are 2 × 2 matrices, and D is a 2 ×1 matrix.

Based on the augmented Hamiltonian matrix and constraints (1) to (7), we can calculate the value of vector of matrices A, B, and D.

$$a_{11} = \alpha, a_{12} = 0, a_{21} = 0, a_{22} = \alpha \;\Rightarrow\; A = \begin{pmatrix} a & 0 \\ 0 & a \end{pmatrix}$$

And

$$b_{11} = -\frac{(\frac{\beta_2}{2} - \beta_1)^2}{\tau\theta}$$

$$b_{12} = -\frac{(\beta_2)^2}{2\tau\theta} - (\frac{\beta_2}{2} - \beta_1) \times \frac{\beta_2}{2\tau\theta} = -\frac{\beta_2(\beta_1 - \frac{3\beta_2}{2})}{2\tau\theta}$$

$$b_{21} = -\frac{(\beta_2)^2}{2\tau\theta} - \frac{\beta_2}{2}(\frac{\beta_2}{2} - \beta_1) \times \frac{1}{\tau\theta} = \frac{\beta_2(\beta_1 - \frac{3\beta_2}{2})}{2\tau\theta}$$

$$b_{22} = -\frac{\beta_2}{2} \times \frac{\beta_2}{2\tau\theta} = -\frac{\beta_2{}^2}{4\tau\theta}$$

$\Rightarrow$

$$B=\begin{pmatrix} -\dfrac{(\frac{\beta_2}{2}-\beta_1)^2}{\tau\theta} & -\dfrac{\beta_2(\beta_1-\frac{3\beta_2}{2})}{2\tau\theta} \\ \dfrac{\beta_2(\beta_1-\frac{3\beta_2}{2})}{2\tau\theta} & -\dfrac{\beta_2{}^2}{4\tau\theta} \end{pmatrix}$$

And

$$d_1=\frac{\beta_2(1-\tau)}{2\tau\theta}+(\beta_1-\frac{\beta_2}{2})\times\frac{(1-\tau+d)}{2\tau\theta}=\frac{(1-\tau)(\beta_1+\frac{\beta_2}{2})-d(\frac{\beta_2}{2}-\beta_1)}{2\tau\theta}$$

$$d_2=-\frac{\beta_2}{2}\times\frac{(1-\tau+d)}{2\tau\theta}+\frac{\beta_2 d}{2\tau}=\frac{\beta_2\left[(\theta-1)d-(1-\tau)\right]}{2\tau\theta}$$

$\Rightarrow$

$$D=\begin{pmatrix} \dfrac{(1-\tau)(\beta_1+\frac{\beta_2}{2})-d(\frac{\beta_2}{2}-\beta_1)}{2\tau\theta} \\ \dfrac{\beta_2\left[(\theta-1)d-(1-\tau)\right]}{2\tau\theta} \end{pmatrix}$$

Similarly, we can get the value of matrices C and E:

$$\tilde{p}_t=\begin{pmatrix} p_t{}^S \\ p_t{}^M \end{pmatrix}=\left(C\tilde{x}_t+A\tilde{P}_{t+1}+E\right)=\begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix}\begin{pmatrix} x_t \\ u_t \end{pmatrix}+\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}\begin{pmatrix} P^S_{t+1} \\ P^M_{t+1} \end{pmatrix}+\begin{pmatrix} e_1 \\ e_2 \end{pmatrix}$$

$$\begin{pmatrix} p_t{}^M \\ p_t{}^S \end{pmatrix}=\begin{pmatrix} c_{11}x_t+c_{12}u_t+a_{11}P^S_{t+1}+a_{12}P^M_{t+1}+e_1 \\ c_{21}x_t+c_{22}u_t+a_{21}P^S_{t+1}+a_{22}P^M_{t+1}+e_2 \end{pmatrix}$$

Thus,

$$c_{11}=2\delta,\ c_{12}=2\tilde{\delta},\ c_{21}=2\tilde{\delta},\ c_{22}=0 \qquad \Rightarrow \qquad C=\begin{pmatrix} 2\delta & 2\tilde{\delta} \\ 2\delta & 0 \end{pmatrix}$$

And

$$e_1 = 0,\ e_2 = 0 \quad \Rightarrow \quad E = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

3.5.5 Resolution

We solve the tracking problem defined above by sweep method (see Bryson & Ho, 1975). First we assume a linear relation between $\tilde{p}_t$ and $\tilde{x}_t$; thus, the optimal controls can then be determined at each time step based on the current estimated state.

$$\tilde{p}_t = S_t \tilde{x}_t + g_t$$

$$\tilde{x}_{t+1} = Ax_t + B\tilde{p}_{t+1} + D$$

$$\Rightarrow$$

$$x_{t+1} = (I_{2\times2} - BS_{t+1})^{-1}(A\tilde{x}_t + Bg_{t+1} + D)$$

And

$$\tilde{p}_{t+1} = Cx_t + A\tilde{p}_{t+1} + E$$

$$\Rightarrow$$

$$S_t = C + AS_{t+1}(I_{2\times2} - BS_{t+1})^{-1}A$$

$$g_t = AS_{t+1}(I_{2\times2} - BS_{t+1})^{-1}(Bg_{t+1} + D) + Ag_{t+1} + E$$

S_t and g_t are determined by the backward equations. The boundary condition suggests the following solution:

$$\tilde{x}_1 = \begin{bmatrix} x_1 \\ 0 \end{bmatrix} \ \tilde{p}_{t+1} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$\Rightarrow$

$$S_{t+1} = 0_{2\times 2}, \ and \ \ g_{t+1} = 0_{2\times 1}$$

$$S_t = C, \ and \ \ g_t = E$$

We solve this problem by Matlab 7.0. Specifically, we get the different values of $S_t \ and \ g_t$ at all points in time by backward loop; then get the corresponding values of $\tilde{x}_t$ and $\tilde{p}_t$ by forward loop. Following the value of $\tilde{x}_t$ and $\tilde{p}_t$, we obtain the values of $x_t, \ I_t^S, I_t^M, \ p_t^S, \ p_t^M$ for all points in time.

3.6 Mathematical Model: Case Two

In general, a monopolistic manufacturer determines its wholesale price, controls the retail price, and negotiates its purchasing price with the suppliers. Thus, the manufacturer has an advantage over the supplier to manage both downstream and upstream activities. This situation is considered to be case two. That is, the manufacturer is the leader of the game, while the supplier is the follower.

The computation of case two is quite similar to case one. We omit the details and explanation here, and only list the results, as follows.

3.6.1 Hamiltonian Function and Constraints of the Supplier

$$J_t^S = \arg\max \sum_{i=1}^{T} P_t^S q_t - cq_t + \delta x_t^2 + \tau I_t^S \left[1+\theta(I_t^S + I_t^M)\right] - I_t^S + dI_t^M$$

For fixed I_t^M

$$\begin{aligned} H_t^S &= J_t^S + P_{t+1}^S\left(\alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M\right) \\ &= Wq_t - cq_t + \delta x_t^2 + \tau I_t^S\left[1+\theta(I_t^S + I_t^M)\right] - I_t^S + dI_t^M + P_{t+1}^S\left(\alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M\right) \end{aligned}$$

$$\frac{\partial H_t^S}{\partial I_t^S} = \tau I_t^S\left[1+\theta(I_t^S + I_t^M)\right] + \tau\theta I_t^S - 1 + P_{t+1}^S\beta_1 = 0$$

$$\Rightarrow$$

$$I_t^S = \frac{1-\tau-\tau\theta I_t^S - P_{t+1}^S\beta_1}{2\tau\theta}$$

$$\begin{aligned} x_{t+1} &= \frac{\partial H_t^S}{\partial P_{t+1}^S} = \alpha x_t + \beta_1 I_t^S + \beta_2 I_t^M \\ &= \alpha x_t + \beta_1 \frac{(1-\tau-\tau\theta I_t^S - P_{t+1}^S\beta_1)}{2\tau\theta} + \beta_2 I_t^M \\ &= \alpha x_t + \beta_1 \frac{(1-\tau-P_{t+1}^S\beta_1)}{2\tau\theta} + (\beta_2 - \frac{\beta_1}{2}) I_t^M \end{aligned}$$

$$P_t^S = \frac{\partial H_t^S}{\partial x_t} = 2\delta x_t + \alpha P_{t+1}^S$$

3.6.2 Hamiltonian Function and Constraints of the Manufacturer

For fixed I_t^S

$$H_t^M = J_t^M(x_{t+1}) + P_{t+1}^M(x_{t+1}) + u_t(P_t^S)$$

$$
\begin{aligned}
J_t^M &= \arg\max \sum_{i=1}^{T} P_t^M(q_t)q_t - P_t^S q_t + B^M(x_t) + T^M(I_t^M) - I_t^M \\
&= (a - bq_t - f)q_t - Wq_t + \tilde{\delta}x_t^2 + \tau I_t^M \left[1 + \theta(I_t^S + I_t^M)\right] - I_t^M \\
&= (a - bq_t - f)q_t - Wq_t + \tilde{\delta}x_t^2 + (\tau - 1)I_t^M + \theta\tau(I_t^M)^2 + \frac{(1 - \tau - P_{t+1}^S\beta_1)}{2\tau\theta} I_t^M - \frac{\theta\tau}{2}(I_t^M)^2 \\
&= (a - bq_t - f)q_t - Wq_t + \tilde{\delta}x_t^2 + (\tau - 1)I_t^M + \frac{\theta\tau}{2}(I_t^M)^2 + \frac{(\tau - 1 - P_{t+1}^S\beta_1)}{2} I_t^M
\end{aligned}
$$

$$P_{t+1}^M(x_{t+1}) = P_{t+1}^M \left[\beta_1 \frac{(1 - \tau - P_{t+1}^S\beta_1)}{2\tau\theta} + (\beta_2 - \frac{\beta_1}{2})I_t^M + \alpha x_t \right]$$

$$u_t(P_t^S) = u_t(2\delta x_t + \alpha P_{t+1}^S)$$

$$\Rightarrow$$

$$\frac{\partial H_t^M}{\partial I_t^M} = \tau\theta I_t^M + \frac{(1 - \tau - P_{t+1}^S\beta_1)}{2} + P_{t+1}^M(\beta_2 - \frac{\beta_1}{2}) = 0$$

$$I_t^M = \frac{(1 - \tau - P_{t+1}^S\beta_1)}{2\tau\theta} + \frac{(\frac{\beta_1}{2} - \beta_2)P_{t+1}^M}{\tau\theta}$$

$$\frac{\partial H_t^M}{\partial I_t^M} = \tau\theta I_t^M + \frac{(1 - \tau - P_{t+1}^S\beta_1)}{2} + P_{t+1}^M(\beta_2 - \frac{\beta_1}{2}) = 0$$

$$x_{t+1} = \frac{\partial H_t^M}{\partial P_{t+1}^M} = \beta_1 \frac{(1 - \tau - P_{t+1}^S\beta_1)}{2} + (\beta_2 - \frac{\beta_1}{2})I_t^M + \alpha x_t$$

$$P_t^M = \frac{\partial H_t^M}{\partial x_t} = 2\tilde{\delta}x_t + \alpha P_{t+1}^M + 2\delta u_t$$

$$u_{t+1} = \frac{\partial H_t^M}{\partial P_{t+1}^S} = -\frac{\beta_1}{2} I_t^M - -\frac{(\beta_1)^2}{2\tau\theta} P_{t+1}^M + \alpha u_t$$

$$P_t^S = 2\delta x_t + \alpha P_{t+1}^S$$

$$I_t^S = \frac{1 - \tau - \tau\theta I_t^S - P_{t+1}^S\beta_1}{2\tau\theta}$$

3.6.3 Augmented Discrete Hamiltonian Matrix

Assume,

$$\begin{bmatrix} \tilde{x}_{t+1} \\ \tilde{P}_t \end{bmatrix} = \begin{pmatrix} A & B \\ C & A \end{pmatrix} \begin{bmatrix} \tilde{x}_t \\ \tilde{P}_{t+1} \end{bmatrix} + \begin{pmatrix} D \\ E \end{pmatrix} = \begin{pmatrix} A\tilde{x}_t + B\tilde{P}_{t+1} + D \\ C\tilde{x}_t + A\tilde{P}_{t+1} + E \end{pmatrix}$$

$$\tilde{x}_{t+1} = \begin{pmatrix} x_{t+1} \\ u_{t+1} \end{pmatrix} \quad \tilde{P}_{t+1} = \begin{pmatrix} P^M_{t+1} \\ P^S_{t+1} \end{pmatrix}$$

$\Rightarrow$

$$\tilde{x}_{t+1} = \begin{pmatrix} x_{t+1} \\ u_{t+1} \end{pmatrix} = \left(A\tilde{x}_t + B\tilde{P}_{t+1} + D \right) = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} x_t \\ u_t \end{pmatrix} + \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \begin{pmatrix} P^M_{t+1} \\ P^S_{t+1} \end{pmatrix} + \begin{pmatrix} d_1 \\ d_2 \end{pmatrix}$$

$$= \begin{pmatrix} a_{11}x_t + a_{12}u_t + b_{11}P^M_{t+1} + b_{12}P^S_{t+1} + d_1 \\ a_{21}x_t + a_{22}u_t + b_{21}P^M_{t+1} + b_{22}P^S_{t+1} + d_2 \end{pmatrix}$$

$\Rightarrow$

$$a_{11} = \alpha, a_{12} = 0, a_{21} = 0, a_{22} = \alpha$$

$$b_{11} = -\frac{(\beta_2 - \frac{\beta_1}{2})^2}{\tau\theta}$$

$$b_{12} = -\frac{(\beta_1)^2}{2\tau\theta} + (\beta_2 - \frac{\beta_1}{2}) \times \frac{\beta_1}{2\tau\theta} = -\frac{\beta_1(\beta_2 - \frac{3\beta_1}{2})}{2\tau\theta}$$

$$b_{21} = -\frac{(\beta_1)^2}{2\tau\theta} - \frac{\beta_1}{2}(\frac{\beta_1}{2} - \beta_2) \times \frac{1}{\tau\theta} = \frac{\beta_1(\beta_2 - \frac{3\beta_1}{2})}{2\tau\theta}$$

$$b_{22} = -\frac{\beta_1}{2} \times \frac{\beta_1}{2\tau\theta} = -\frac{\beta_1^2}{4\tau\theta}$$

$$d_1 = \frac{\beta_1(1-\tau)}{2\tau\theta} + (\beta_2 - \frac{\beta_1}{2}) \times \frac{(1-\tau)}{2\tau\theta} = \frac{(1-\tau)(\beta_2 + \frac{\beta_1}{2})}{2\tau\theta}$$

$$d_2 = -\frac{\beta_1}{2} \times \frac{(1-\tau)}{2\tau\theta} = -\frac{\beta_1(1-\tau)}{4\tau\theta}$$

$$\tilde{p}_t = \begin{pmatrix} p_t^{\ M} \\ p_t^{\ S} \end{pmatrix} = \left(C\tilde{x}_t + A\tilde{P}_{t+1} + E \right) = \begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix} \begin{pmatrix} x_t \\ u_t \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} P_{t+1}^M \\ P_{t+1}^S \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \end{pmatrix}$$

$$\begin{pmatrix} p_t^{\ M} \\ p_t^{\ S} \end{pmatrix} = \begin{pmatrix} c_{11}x_t + c_{12}u_t + a_{11}P_{t+1}^M + a_{12}P_{t+1}^S + e_1 \\ c_{21}x_t + c_{22}u_t + a_{21}P_{t+1}^M + a_{22}P_{t+1}^S + e_2 \end{pmatrix}$$

$$\Rightarrow$$

$$c_{11} = 2\tilde{\delta},\ c_{12} = 2\delta,\ c_{21} = 2\delta,\ c_{22} = 0$$

$$e_1 = 0,\ e_2 = 0$$

The next chapter provides a numerical example of the results of these two cases.

3.7 Summary

In this chapter, a model for the allocation of CSR to members of a supply chain is described. It shows how CSR is evaluated as capital, and why game theory is necessarily applied to this model. The foundations of the model and the criteria for choosing the different game theories were previously explained in this thesis. The assumptions and notations of the model were explained and defined. An introduction to the Stackelberg game was also provided. Two formulations were provided, using either the supplier or the manufacturer as the leader of the game.

CHAPTER FOUR

CHAPTER FOUR

A CASE STUDY AND NUMERICL EXAMPLES

In this chapter, we construct a numerical example in which both the manufacturer and supplier are forced by the government to take social responsibility for environmental protection. The regulation requires the members of the supply chain to use greater amounts of recycled materials in their packaging.

4.1 the Background of the Companies and Organizations

This numerical example focuses specifically on Ball Corporation, one of the largest producers of metal beverage cans in the world, its representative customer, Coca-Cola, and their requirements to meet the standards of the Aluminum Can Council (ACC).

Ball Corporation operates more than 40 facilities in 10 countries. It manufactures rigid packaging products, primarily for foods and beverages, and supplies aerospace and other technology products and services to governmental and commercial customers. Ball manufactures approximately 45 billion recyclable aluminum and steel beverage cans annually; it also produces approximately 6.5 billion two and three-piece steel food cans each year in the U.S. and Canada and more than 5 billion PET bottles in the U.S. Through its joint ventures, Ball is one of the largest suppliers of aluminum cans in China.

Coca-Cola Enterprises Inc. (CCE) is the world’s largest marketer, distributor, and producer of products manufactured by Coca-Cola Inc. In 2006, CCE achieved total revenue of $19.8 billion, distributing 42 billion bottles and cans, 19 % of the Coca-Cola

Company’s volume worldwide. Operating in 46 states, Canada, and portions of Europe, CCE employs 74,000 people who operate 444 facilities, 55,000 vehicles and 2.4 million vending machines, beverage dispensers, and coolers.

At the Coca-Cola Company, providing top-quality products and ensuring responsibility are the highest business objectives. Taking social responsibility is one of the promises that extend to all of its products. Coca-Cola emphasizes the importance of responsible policies and complies with local laws and regulations; to this end, it takes responsibility for holding its direct suppliers and bottling partners to standards no less than those required by applicable law.

As in other global companies, Coca-Cola often takes social responsibility regarding environmental issues. To protect the environment, Coca-Cola has been working to advance technologies that allow them to use greater amounts of recycled materials in their packaging. Since introducing the first-ever beverage container with recycled PET in 1991, it has continued to make significant investments in the development of environmentally and economically viable recycling technologies. The Coca-Cola Company is using recycled content PET in more than 17 markets around the world. Recycling plastic for reuse yields financial benefits, requires less energy than producing bottles with virgin materials, and reduces waste and greenhouse gases. The most notable accomplishment is that more than half of the metal in Coca-Cola’s aluminum cans is recycled.

The ACC is a joint effort between the Can Manufacturers Institute and the Aluminum Association. The vision of the ACC is to be the voice of the aluminum can industry, to promote and foster recycling solutions, to educate consumers and customers about the positive attributes of aluminum beverage cans, and to explore new markets for them.

The aluminum can is the most recycled beverage package in the world and events like the America Recycles Day (ARD) Challenge are aimed at increasing the recycling rate and highlighting the sustainable benefits of aluminum beverage cans. The America Recycles Day Challenge continues to raise recycling awareness and reinforce the industry's commitment to sustainability and the environment, and support local businesses and charities in the community.

4.2 Description of the Problem

In this section, we describe the problem facing Ball Corporation and Coca-Cola in the year 2000. As commonly known, Ball Corporation distributes a wide range of branded can products. These products are sold to Coca-Cola worldwide. Thirty years ago, the beverage can market was dominated by three-piece tinplate steel cans. Throughout the 1970s, steel battled aluminum for this market. Although steel is cheaper than aluminum, the aluminum can defeated the steel can for some of its obvious attributes. The aluminum can is the fastest chilling beverage container and is very effective at maintaining the fizz of the beverage until it is opened. Other advantages include allowing more efficient use of shelf space, cost, filling speed, and the ability to advertise right on the can.

However, the main reason steel cans were replaced with aluminum is, except for being recycled indefinitely without losing any of their properties, aluminum cans contain more than 51% recycled content, which is much more than any other beverage container material. With the advent of environmentalism and the energy crisis, aluminum had new allies in deposit legislation and in recycling. Because of the inherent value of recycled aluminum cans to aluminum companies, distributors and canners pressed makers for more aluminum cans to help cover collection and accounting costs in deposit states. Aluminum companies, led by Reynolds Metals (Richmond, VA) and Alcoa, created recycling programs that educated consumers that recycling aluminum cans back into new cans saves energy. Under pressure from the government and organizations, beverage supply chain firms considered the use of recycled aluminum cans as a necessary way to take social responsibility for the environment and a sustainable society.

Currently, most metal beverage cans made in the United States are manufactured from aluminum, whereas in some parts of Europe and Asia approximately 55% are made of steel and 45% from aluminum alloy. It was inevitable that Ball Corporation and Coca-Cola would switch from steel to aluminum alloy cans.

4.3 Application of the Model

The soft drink manufacturing industries have had a relatively stable market share in recent years. According to statistics, the market share of Coca-Cola is 42.7%, while 30.8% of the market share belongs to Pepsi; the other 16.5% of the market belongs to the Dr. Pepper Snapple Group (Dr. Pepper, 7UP, Snapple, Schweppe's).

Between Coca-Cola and Pepsi, the market share is so large and stable that they are often considered a classic duopoly study and analysis case. Since there is almost no difference between the production costs of Coca-Cola and Pepsi, this principal duopoly model is a

Cournot duopoly—a duopoly based on quantity competition. It is reasonable that the companies of a Cournot duopoly are viewed as a monopoly in their own market share range when their respective market shares remain unchanged for long period of time. Therefore, Coca-Cola can be considered the monopoly manufacturer of the model in this numerical example.

Ball Corporation is one of the world's leading suppliers of rigid metal packaging products and services, primarily to the beverage and food industries. In its mission to accelerate aluminum can replacement, Ball Corporation is involved in more matters than Coca-Cola. Ball Corporation negotiates with aluminum mills and suppliers, innovates their production lines, communicates with the ACC and other organizations, and updates its technology to increase aluminum can recycling rates. It is obvious that Ball Corporation can be the leader in the Stackelberg game.

Both Ball Corporation and Coca-Cola are powerful in the metal packaging and soft drink industries. The supply chain network in which they exist is decentralized.

4.4 The Numerical Examples

It is difficult to parameterize this model because of a lack of precise data and because of its high-level of abstraction. This section provides rationales that we hope yield parameter values that are the right order of magnitude (detailed in Table 4.1). Certain parameters are varied to explore the sensitivity of the conclusions with respect to those values.

Parameter	Interpretation of the parameter	Value
a	**Market potential**	**6**
b	**Price sensitivity**	**0.00001**
q_t	**Annual demand quantity**	**100000**
f	**Franchise fee**	**0.5**
T	**Planning horizon**	**10**
D	**The percentage of investment of the supplier payoff**	**0.5**
c	**The price of aluminum**	**2.4**
w	**The price of an aluminum can**	**3.6**
δ	**Parameter of social benefit to the supplier**	**0.1**
$\tilde{\delta}$	**Parameter of social benefit to the manufacturer**	**0.2**
λ	**Quantity discount parameter of the price of the raw material**	**0**
α	**Deteriorating rate of the level of current social responsibility**	**0.9**
τ	**Rate of individual post tax return on investment (ROI)**	**0.2**
θ	**Rate of supply chain's post tax return on investment (ROI)**	**0.001**
β_1	**Rate of converting the supplier's capital to CSR**	**0.9**
β_2	**Rate of converting the manufacturer's capital to CSR**	**0.9**

Table 4.1 Rationales

The parameter that is the easiest to interpret is the tax return rate τ. It is common in policy to assume that firms are able to apply an annual tax return of 5 to 20% of their revenue. We take the high end of this range $\tau = 0.2$ to show that the government is eager to encourage Ball Corporation and Coca-Cola to replace steel cans with aluminum cans.

Parameters a and b are also easy to define. We assume the annual sale of a can product is 100,000 cases, that is $q_t = 100000$. The inverse demand function $p(q_t) = a - bq_t$ is a function that maps the quantity of output demanded to the market price for that output. The price function is different in terms of types of retailer. Here, we just consider supermarkets whose sales account for over 80% of Coca-Cola's annual sales. The average wholesale price (without promotions) of Coca-Cola to supermarkets is $5 per case; if the lot sale price is increased to $6, customers will switch to buying other brands or drinks. Thus, we can easily derive the value for parameters $a = 6 \ and \ b = 0.00001$. Coca-Cola controls the retail price to get out of double marginalization, match its sale strategies, and compete with Pepsi. It lets supermarkets make $0.5 for the sale of one case of can product. We set $f = 0.5$.

The parameters $B^S(x_t) = \delta x_t$ and $B^M(x_t) = \tilde{\delta} x_t$ are the potential benefits Ball Corporation and Coca-Cola obtain from using aluminum cans, such as increased demand, better reputation, rewards from some organizations, and so on. $\delta \ and \ \tilde{\delta}$ are percentages of the current sum of the firms' investment to take social responsibility. We set $\delta = 0.1 \ and \ \tilde{\delta} = 0.2$.

Any investment deteriorates by 5 to1 5% each year due to inflation. We set $\alpha = 0.1$ here. A long-term investment plan normally lasts ten years. We assume that the time horizon is $T = 10$.

We chose the average price of raw aluminum material ($0.1/can) and an aluminum can ($0.15/can) in the metal packing industry according to Ball Corporation's purchase price for aluminum and the price of the aluminum can that Ball Corporation sells to Coca-Cola. This turns out to be $c = 2.4 \ and \ w = 3.6$. Coca-Cola's investment to switch to aluminum cans can be used to train workers, update production lines, or pay increased costs incurred in the production of the aluminum cans. The percentage of investment that Coca-Cola pays to Ball Corporation for the difference between aluminum cans and steel cans is represented by d. We set $d = 0.5$ here.

4.5 A static Numerical Example of the Model (T=1)

In this section, a static numerical example is given to allocate the amount of investment in aluminum can replacement to Coca-Cola and Ball Corporation in the first round.

In this example, we first assume that the supplier, Ball Corporation, is the leader; the manufacturer, Coca-Cola, is the follower. This corresponds to case one in Chapter Three. In case one, the Ball Corporation, as a Stackelberg leader, decides the amount of its investment in the project based on maximizing its net profit at period one, taking into account Coca-Cola's expected sales at the first stage. At the second stage, Coca-Cola, acting as a Stackelberg follower, decides its investment amount after the manufacturing department's decision is given. Then, we assume that Coca-Cola is the leader and Ball Corporation is the follower. This corresponds to case two in Chapter Three. All conditions and settings in case two are the same as those in case one.

We apply a backward reduction to show the result of the Stackelberg game at first round, T=1. That is, we first anticipate the follower's best response to any announced investment plan from the leader. The anticipation is derived from solving the optimization problem of the follower, given the leader's investment plan. We then substitute the follower's response function into the leader's problem and solve for the leader's optimal investment plan. This investment plan of the leader, together with the retailer's best response to that plan, constitutes Stackelberg equilibrium for the aluminum can replacement.

4.5.1 Problem Formulation and Computation (Case One)

In case one, Ball Corporation is the Stackelberg leader, while Coca-Cola is the Stackelberg follower. Their profit functions are similar to those described in Chapter Three.

$$F_t^S = P_t^S q_t - cq_t + B_t^S(x_t) + T_t^S(I_t^S, I_t) - I_t^S + dI_t^M \tag{1}$$

The above function maximizes the profit of Ball Corporation, the supplier. P_t^S is the price of the supplier; $B_t^S(x_t)$ is the social benefit to the supplier, and $T_t^S(I_t^S, I_t)$ is the tax return of the supplier. Let $P_t^S = w$, $B_t^S(x_t) = \delta x_t^2$, and w, δ *and* τ are parameters, $T_t^S(I_t^S, I_t) = \tau I_t^S\left[1+\theta(I_t^S + I_t^M)\right]$.

$$F_t^M = P_t^M(q_t)q_t - P_t^S q_t + B^M(x_t) + T^M(I_t^M) - I_t^M \tag{2}$$

This function maximizes the profit of Coca-Cola, the manufacturer. $P_t^M(q_t)$ is the retail price of the manufacturer's product; $B_t^M(x_t)$ is the manufacturer's social benefit; $T_t^M(I_t^M, I_t)$ is the manufacturer's tax return; and w, δ *and* τ are parameters; let $P_t^M(q_t) = a - bq_t - f$, $B^M(x_t) = \tilde{\delta}x_t^2$, $T^M(I_t^M) = \tau I_t^M\left[1+\theta(I_t^S + I_t^M)\right]$.

We substitute T=1 into functions (1) and (2) to get the objective functions of Ball Corporation and Coca-Cola, below:

$$Max\ \ F_1^S = (P_1^S - c)q_1 + \delta x_1^2 + \tau I_1^S\left[1+\theta(I_1^S + I_1^M)\right] - I_1^S + dI_1^M \tag{3}$$

$$Max\ \ F_1^M = (a - bq\ - f)q\ + \tilde{\delta} x_1^2 + \tau I_1^M\left[1+\theta(I_1^S + I_1^M)\right] - I_1^M \tag{4}$$

Coca-Cola, acting as a Stackelberg follower, decides its investment amount by optimizing its profits at period one, given the Ball Corporation's investment plan.

For given fixed I_1^S, the first derivative of $F_t^M(I_1^M)$ is

$$\tau I_1^M\left[1+\theta(I_1^S + I_1^M)\right] + \tau\theta I_1^M - 1 = 0$$
$$\Rightarrow$$
$$(I_1^M)^* = \frac{1-\tau-\tau\theta I_1^S}{2\tau\theta}$$

Substituting this optimal $(I_1^M)^* = \dfrac{1-\tau-\tau\theta I_1^S}{2\tau\theta}$ into the function of $F_t^S(I_1^S)$,

$$F_1^S = (P_1^S - c)q_1 + \delta x_1^2 + \tau I_1^S\left[1+\theta(I_1^S + \frac{1-\tau-\tau\theta I_1^S}{2\tau\theta})\right] - I_1^S + d\,\frac{1-\tau-\tau\theta I_1^S}{2\tau\theta}$$

Then taking first order, we get

$$(I_1^S)^* = \frac{1+\dfrac{d}{2}-\dfrac{\tau+1}{2}}{\tau\theta}$$

We substitute the values of the other parameters in rationales into the above profit functions to get the values of $(I_1^M)^*$ and $(I_1^S)^*$

$$(I_1^S)^* = 6.5\times 10^3$$

$$(I_1^M)^* = 1.25\times 10^3$$

We then substitute the values of the other parameters in rationales and the values of $(I_1^M)^*$ and $(I_1^S)^*$ into the above profit functions to get the value of the objective functions of Ball Corporation and Coca-Cola as represented below:

$$F_1^S = (3.6-2.4)\times 1^5 + 0.1\times I_1^S \times \left[1+0.001(I_1^S + I_1^M)\right] - I_t^S + 0.4\times I_t^M$$
$$\Rightarrow$$
$$(F_1^S)^* = 1.196875\times 10^5$$

$$Max\ F_1^M = (6-1-0.5-3.6)\times 1^5 + 0.1\times I_1^M \times \left[1+0.001(I_1^S + I_1^M)\right] - I_t^M$$
$$\Rightarrow$$
$$(F_1^M)^* = 8.98\times 10^4$$

4.5.2 Problem Formulation and Computation (Case Two)

In case two, Coca-Cola is the Stackelberg leader, while Ball Corporation is the Stackelberg follower. We repeat the computation as in case one, to obtain the solution of the optimization problem for case two, as shown below:

$$(I_1^S)^* = 2.25\times 10^3$$

$(I_1^M)^* = 4.5 \times 10^3$

$(F_1^S)^* = 1.2129375 \times 10^5$

$(F_1^M)^* = 8.94375 \times 10^4$

4.5.3 Solution Analysis of the Static Example

We compare the above results with the output of the Matlab 7 code. This comparison is shown in Table 4.2.

T=1	IM	IS	FM	FS	resource
case one	**1250**	**6500**	**89800**	**119687.5**	**calculated by hand**
case one	**1250**	**6500**	**89843.75**	**119687.5**	**output of Matlab 7**
case two	**4500**	**2250**	**88987**	**121293.75**	**calculated by hand**
case two	**4500**	**2250**	**88987.5**	**121293.75**	**output of Matlab 7**

Table 4.2 Comparison of manually calculated results and the Matlab output

From Table 4.2, it is evident that there is little difference between the optimal solutions for the profits of Ball Corporation and Coca-Cola calculated manually and the output of Matlab. There is no difference between their optimal CSR investment plans.

4.6 A dynamic Numerical Example of the Model (T=10)

In this section, we draw the results of the equilibrium from our modeling, two-stage Stackelberg dynamic games. In the model, the strategies available at each period are the amount of investment made in using aluminum cans and recycling. The equilibrium is valid when each player's predicted strategy is its best response to the predicted strategies of the other players.

In a Stackelberg game, the first move gives the leader a crucial advantage. There is also the important assumption of perfect information in the Stackelberg game; the follower must observe the quantity chosen by the leader. If the follower cannot observe the leader's move, it is no longer rational for the follower to choose. However, it must be that there is imperfect information and the follower is unable to observe the leader's move because it is irrational for the follower not to observe if possible, once the leader has moved. If the leader can observe, it will, so that it can make the optimal decision.

We first assume that the supplier, Ball Corporation, is the leader of the game. Ball Corporation is forced by policies or regulations to only supply aluminum cans to Coca-Cola. Coca-Cola has to pay more to purchase aluminum cans rather than steel cans, modify its production lines and machines for the much lighter weight aluminum cans, update its recycling management, and replace wooden pallets with plastic pallets. Specifically, Ball Corporation announces the amount of investment I_t^S to Coca-Cola with the purpose of optimizing its own expected profit, given Coca-Cola’s best response. Coca-Cola decides its amount of investment I_t^M in order to maximize its own expected profit.

We can also assume the manufacturer, Coca-Cola, is the leader of the game. Similarly, Coca-Cola is forced by policies or regulations to only purchase aluminum cans from Ball Corporation. Ball Corporation has to negotiate with new raw material suppliers, aluminum mills, modify its new production lines, and train employees. Similar to the first case, Coca-Cola announces the amount of its investment I_t^M to Ball Corporation with the purpose of optimizing its own expected profit, given Ball Corporation’s best response. Ball Corporation decides the amount of its investment I_t^S in order to maximize its own expected profit.

Equilibrium can be established when the leader moves first and the follower moves second. In this structure, equilibrium can be deducted by using backwards induction, in which we solve the second stage in advance, given the outcome from the first stage.

4.7 Solutions Analysis (T=10)

In this section, we discuss the results of the Stackelberg game played by Ball Corporation and Coca-Cola. The three key criteria to be considered are the profits of both companies, the amount of investment, and the level of social responsibility taken by the supply chain.

4.7.1 Profits Analysis

The fundamental purpose of this thesis is to analyze the total net profits and the objective functions of Ball Corporation and Coca-Cola gained in the game over time. How do Ball Corporation and Coca-Cola make decisions and take actions to follow the policies and/or regulations? Since we assume that all players seek to gain maximum profits, profit analysis would be carried out in order to answer the original questions.

The profits of Coca-Cola and Ball Corporation, when Ball Corporation is the leader of the game, are illustrated by Figure 4.1.

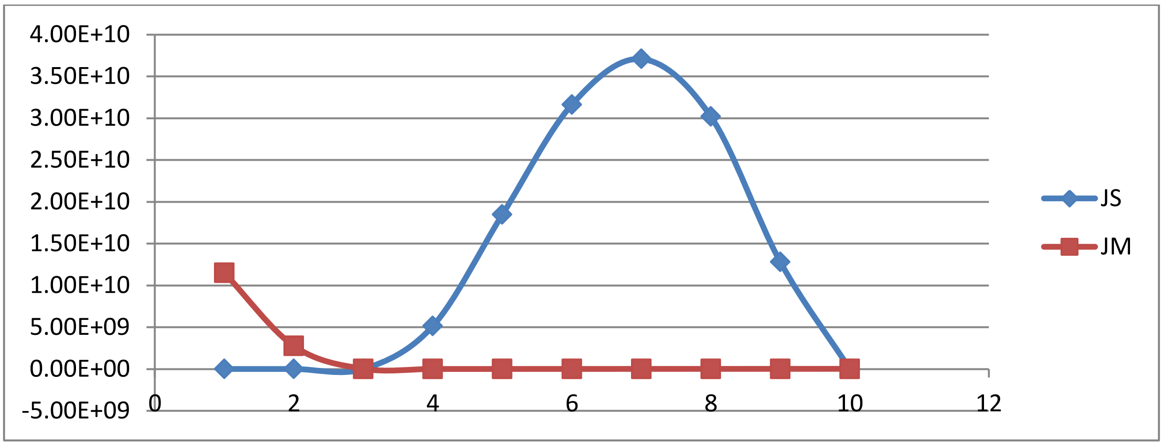


Figure 4.1 Profits of Ball Corporation and Coco-Cola in Case One

The graph shows the trend of Coca-Cola and Ball Corporation's profits from periods one to ten in a Stackelberg game in which Ball Corporation is the leader. The profits of Ball Corporation noticeably decrease by 50% in the first three years and appear quadri-curve during period four to ten. The profits of Coca-Cola decrease sharply by more than ten times in the first four periods, and then remain almost unchanged at about one million dollars.

The profits of Coca-Cola and Ball Corporation, when Coca-Cola is the leader of the game, are illustrated by Figure 4.2.

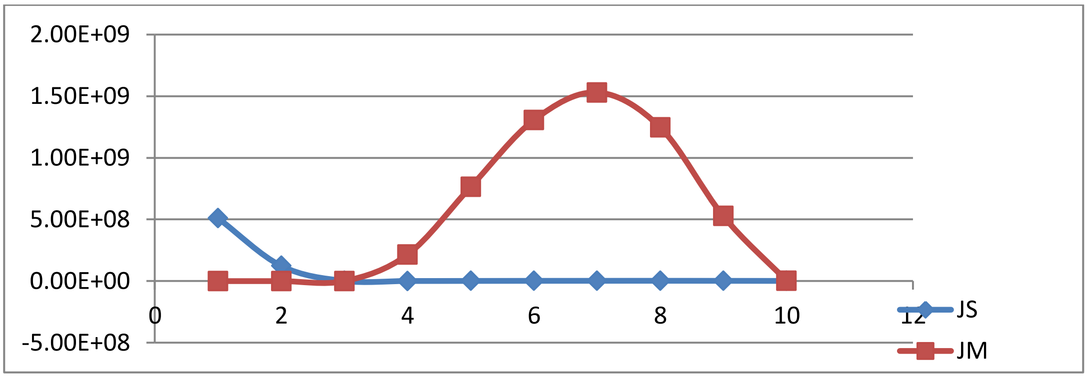


Figure 4.2 Profits of Ball Corporation and Coco-Cola in Case Two

The leader, Coca-Cola, does not make a profit in the first year, and shows a slight increase in profits in both the second and third years. From period four to ten, Coca-Cola's profits dramatically increase and then decrease and appear quadri-curve. The profits of Ball Corporation smoothly decrease in the first three years, and then remain stable until period ten.

4.7.2 Investments Analysis

The investments of Coca-Cola and Ball Corporation, when Ball Corporation is the leader of the game, are shown, over time, by Figure 4.3, below.

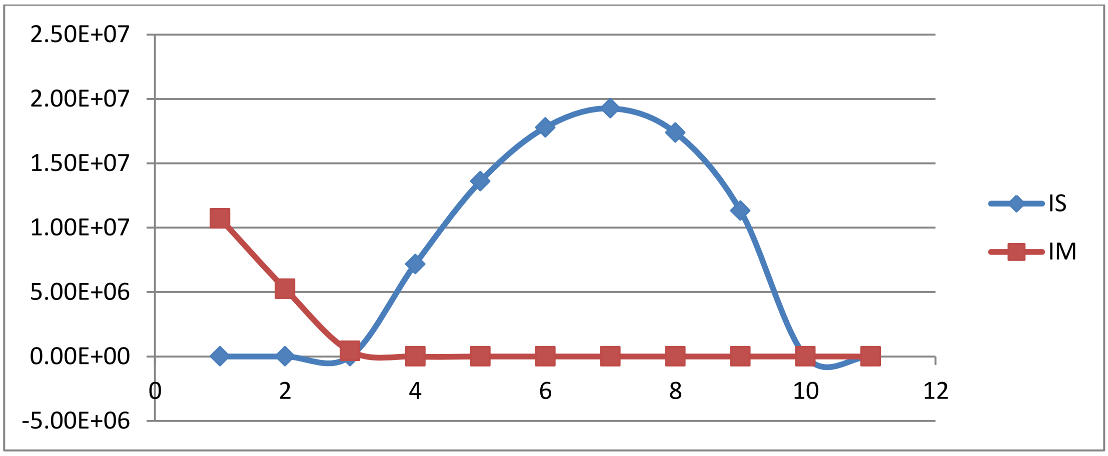


Figure 4.3 Investments of Ball Corporation and Coco-Cola in Case One

As the leader of the game, Ball Corporation derives benefits from Coca-Cola, and does not actually take any money from its own funds to invest in the aluminum project during the first three years. To keep the game going, Ball Corporation invests in the project by millions each year for the remaining seven years. Meanwhile, as the follower in the game, Coca-Cola makes large investments in the project in the first three years. Subsequently, its investment in and benefit from the project tend to balance out.

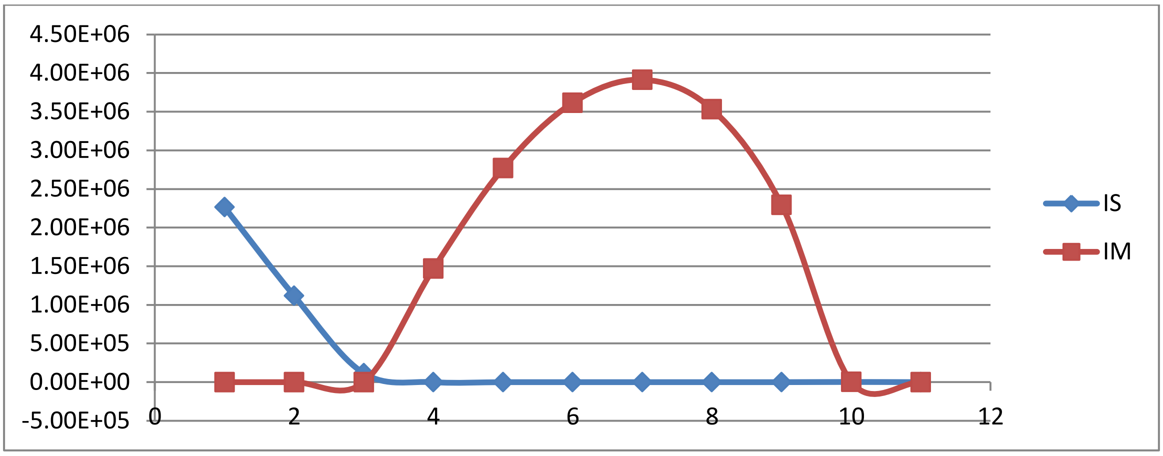


Figure 4.4 Investments of Ball Corporation and Coco-Cola in Case Two

Similarly, as shown by Figure 4.4, when Coca-Cola is the leader of the game, the replacement of steel cans does not impact its net profit for the first three years. From the fourth year, Coca-Cola spends hundreds of thousands of dollars on the project each period. In contrast, the follower pays for the project in the first two years, but its net profit decreases in the long run due to the use of aluminum cans over the next eight years.

4.7.3 Social Responsibility Analysis

Another key criterion we analyze is the social responsibility of the project. In fact, in the game, what governments, organizations, and even society is concerned about is how much social responsibility is taken by the supply chain system.

Since we estimate the social responsibility taken by Ball Corporation and Coca-Cola by investment, the level of social responsibility taken via replacing steel cans with aluminum ones could be discussed and demonstrated by examining Figures 4.5 and 4.6.

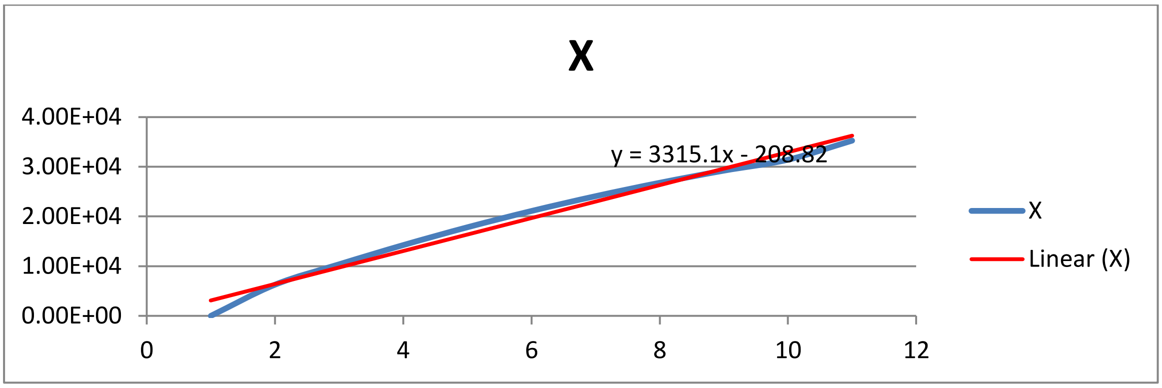


Figure 4.5 Level of Corporate Social Responsibility in Case One

The above figure shows the changes in social responsibility taken by Ball Corporation and Coca-Cola during the game in which Ball Corporation is the leader. The level of social responsibility taken by both Ball Corporation and Coca-Cola keep steadily increasing with time. To show the property of the curve, we add a trend line and its equation to the curve.

For the other case in which Coca-Cola is the leader of the game, the curve expressing the level of social responsibility taken, the trend line, and its equation are shown in Figure 4.6.

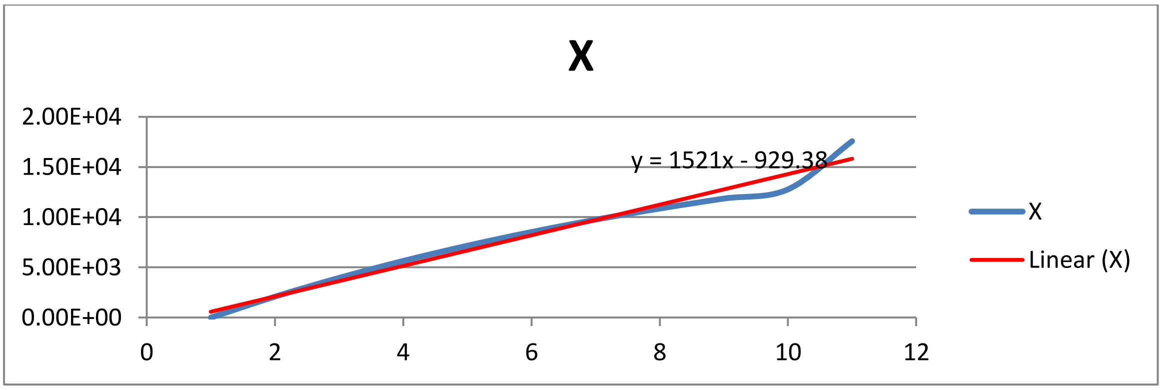


Figure 4.6 Level of Corporate Social Responsibility in Case Two

4.8 Comparison of the Two Cases (T=10)

We analyzed the results of the two cases in terms of three criteria: profits, the amount of investment, and the level of social responsibility taken by the supply chain. A comparison of the two cases will reveal which case has more advantage over the other.

4.8.1 Motivation Analysis

Although Ball Corporation and Coca-Cola have to replace steel cans with more expensive and softer aluminum cans, they still pursue maximum net profit under the circumstance. Profit is the key reason they play a long-term game in implementation of the policy. We compare the profits of Ball Corporation and Coca-Cola over a time horizon, first playing the game and then, without playing the game.

Figures 4.7 and 4.8, below, show a comparison for the first case in which Ball Corporation is the leader of the game.

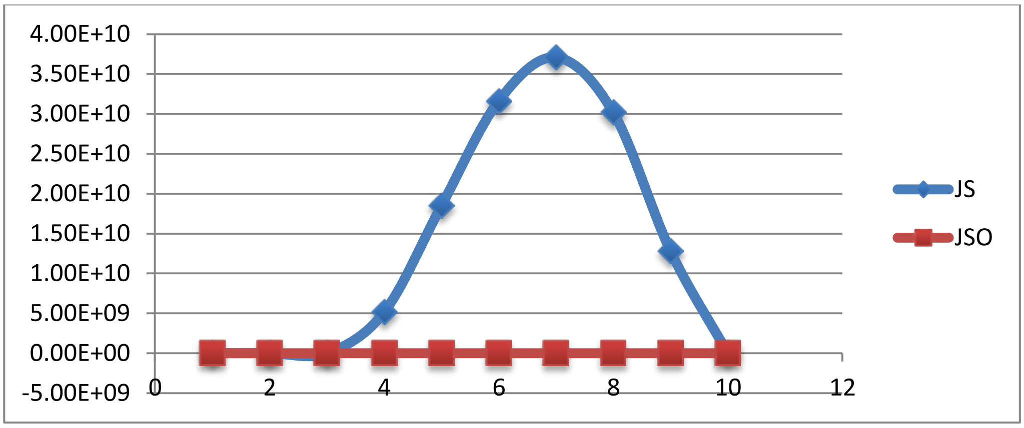


Figure 4.7 Comparison of the Supplier's Profit, Playing Game One and Without Playing Game

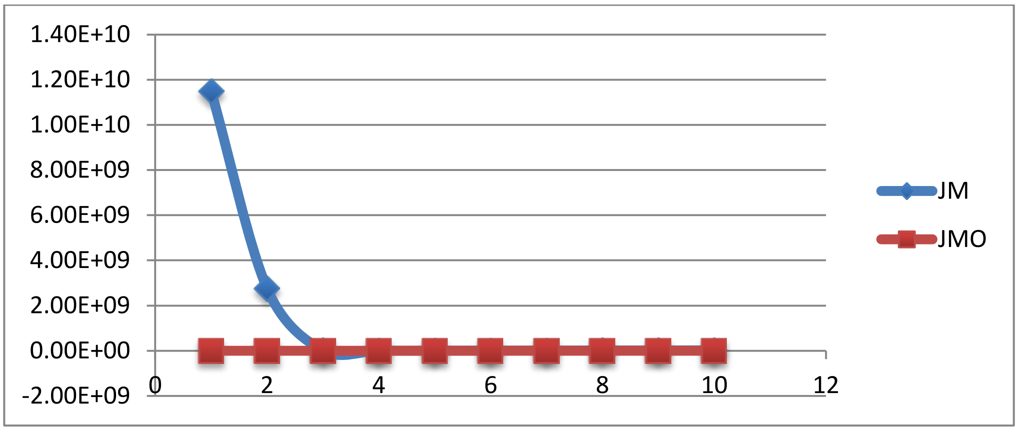


Figure 4.8 Comparison of the Manufacturer's Profit, Playing Game One and Without Playing Game

Figures 4.7 and 4.8 show the difference in Ball Corporation's profits when playing the game and without playing. JS_O is Ball Corporation's profit without playing the game; JS is their profit when playing the game with Coca-Cola. As in the first graph, the second one shows the difference in Coca-Cola's profits. Obviously, both companies gain extra profit from playing the games.

The next two figures show the comparison for the second case, in which Coca-Cola is the leader of the game.

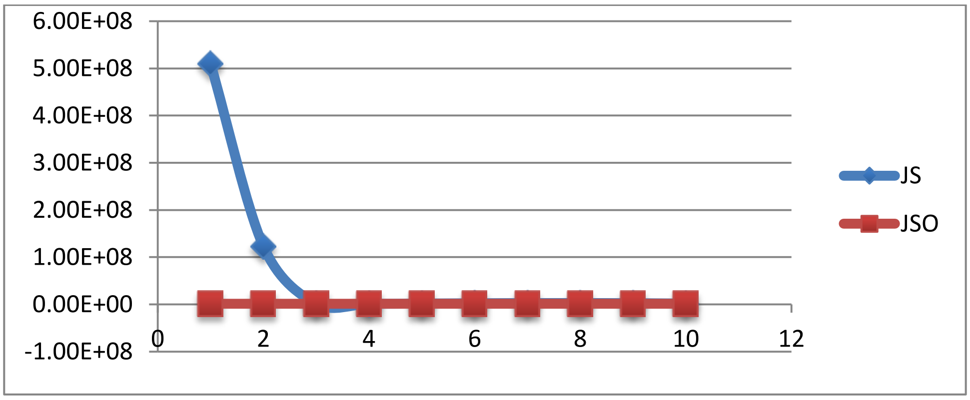


Figure 4.9 Comparison of the Supplier's Profit, Playing Game Two and Without Playing Game

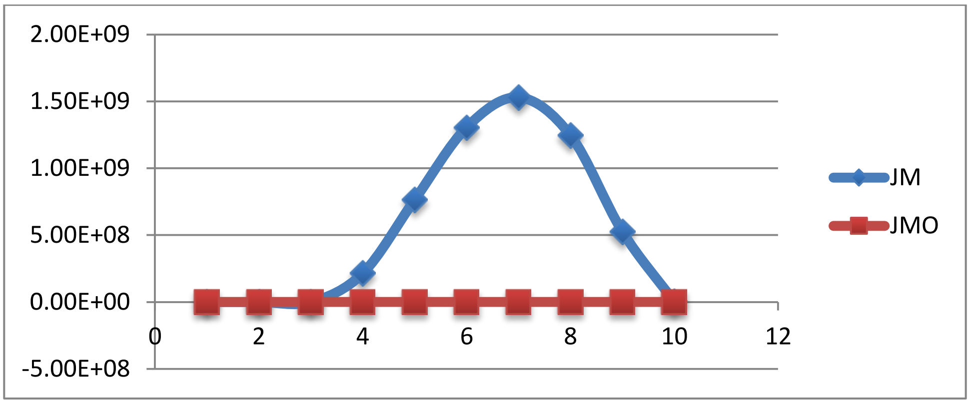


Figure 4.10 Comparison of the Manufacturer's Profit, Playing Game Two and Without Playing Game

In Figure 4.9, it is apparent that playing the game is beneficial to Ball Corporation in the first year, but that Ball Corporation's profits with playing the game is less than without the game. The difference between JS and JSo remains relatively stable in the last five years. Unlike Ball Corporation, in Figure 4.10, Coca-Cola, the leader, increases its profits from the second year by playing the game with its supplier.

In sum, for the first case, in which the supplier is the leader of the game, both the supplier and manufacturer are motivated to play the game because their benefits are increased; however, for the second case, in which the manufacturer is the leader, the supplier might have less motivation as it loses money by playing the game.

4.8.2 Profits Analysis

Now, we compare the profits gained by Ball Corporation and Coca-Cola in case one and case two, respectively. In Figures 4.11 and 4.12, JS1 and JS2 are the benefits of the supplier made in case one and in case two; similarly, JM1 and JM2 are the benefits of the manufacturer made in case one and in case two.

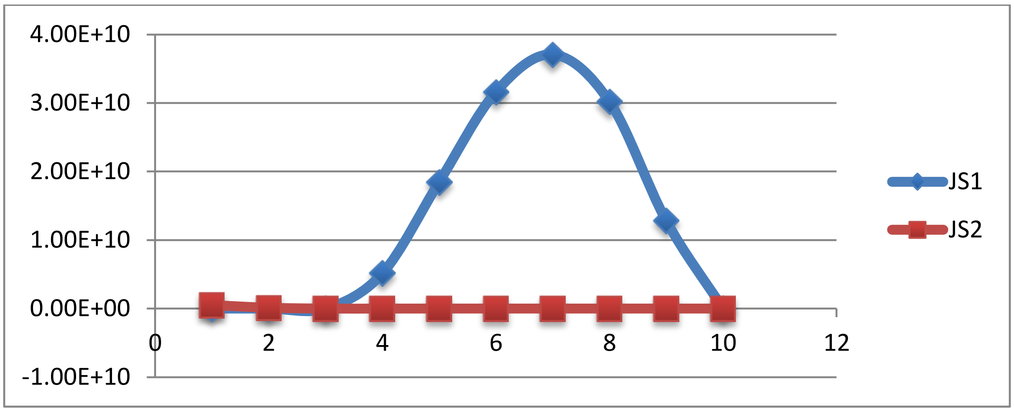


Figure 4.11 Comparison of the Supplier's Profit in Case One and Case Two

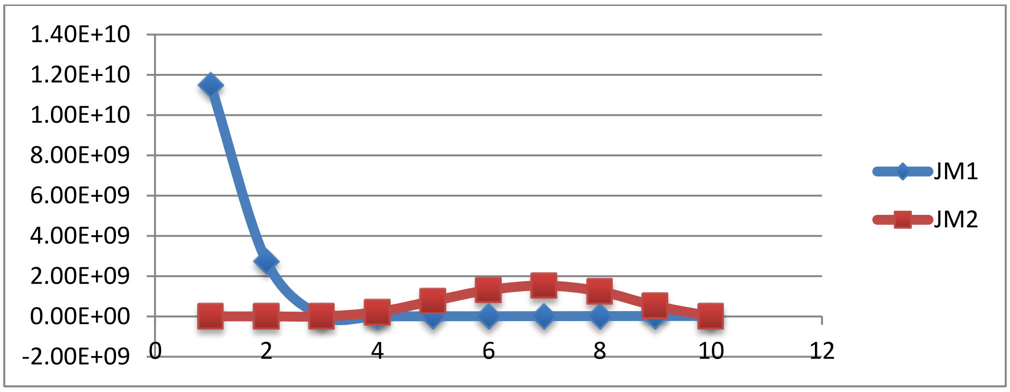


Figure 4.12 Comparison of the Manufacturer's Profit in Case One and Case Two

Clearly, the profits of both Ball Corporation and Coca-Cola in case one are much greater than in case two. It is obvious to conclude that the benefits to the supplier, the manufacturer, and the entire supply chain are increased when the supplier is the leader in a Stackelberg game.

4.8.3 Social Responsibility Analysis

We also discuss the difference between case one and case two in the amount of social responsibility taken by the supply chain.

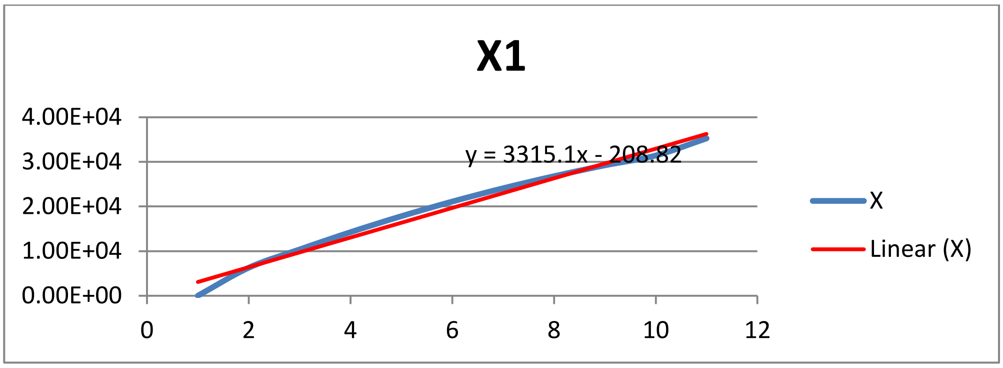


Figure 4.13 Trend Line of the Level of CSR in Case One

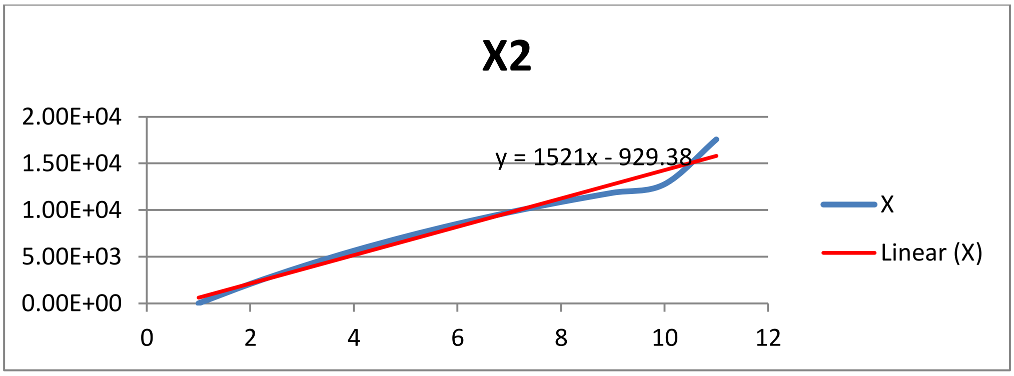


Figure 4.14 Trend Line of the Level of CSR in Case Two

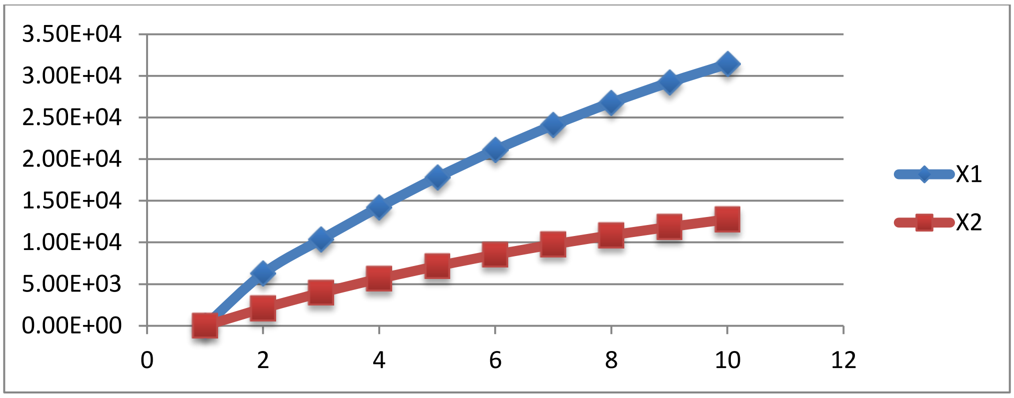


Figure 4.15 Comparison of the Level of CSR in Case One and Case Two

In Figures 4.13 and 4.14, curve one stands for the level of social responsibility in case one, and curve two represents the level of social responsibility in case two. By analyzing the slopes and intercepts of the two trend lines of the curve, we can see that not only was more social responsibility taken by the companies in case one, but also that the growth rate of the level of social responsibility as time goes on is larger in case one than in case two. In other words, the goal of making the supply chain take more social responsibility is better achieved when the supplier is the leader of the game. Based on this dynamic numerical example, we easily draw the conclusion that Aluminum Can Council should let Ball Corporation be the leader to implement the project if the level of CSR taken by companies is only concerned about, because more CSR is borne by the beverage supply chain. This conclusion might be helpful for regulator to make their policies, because the amount of CSR taken by supply chains is the one of the key criteria about which governments and consumers concern. Moreover, this conclusion leads to an important managerial insight. That is, when governments release policies to regulate some social issues by forcing supply chains to involve in, it would be better if they make the content of policies in terms of the needs of Ball Corporation for a better performance.

4.8.4 Investment Analysis

The amount of investment Ball Corporation and Coca-Cola make in the ten years in each case is considered, illustrated by the figures below.

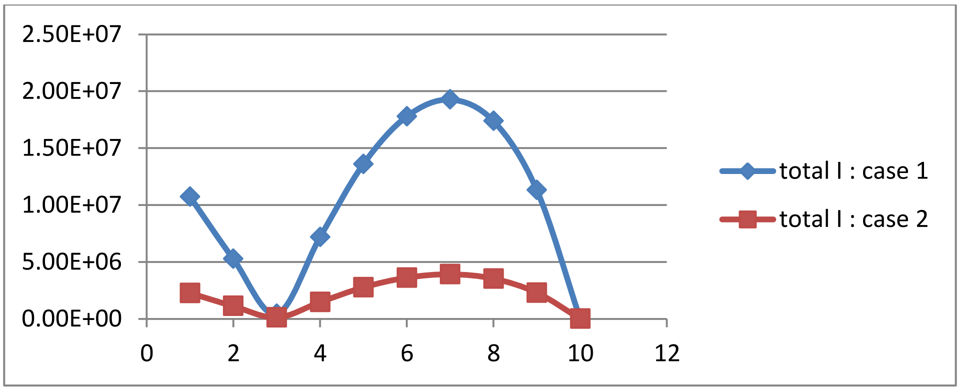


Figure 4.16 Comparison of Total Investment in Case One and Case Two

In graph 4.15, curve one I1 stands for the total investment made by Ball Corporation and Coca-Cola in case one. It can be seen that the companies spent much more money on social responsibility in case one than in case two.

4.9 Summary

This chapter presented a numerical example. That is, Ball Corporation and Coca-Cola had to replace their steel cans with aluminum under a new regulation released by the ACC. We studied two different cases: In case one the supplier was chosen as the leader of the game; while in case two, the manufacturer was the leader. We analyzed the results of the two cases in terms of three criteria: profits, the amount of investment, and the level of social responsibility taken by the supply chain. According to the above analysis, Aluminum Can Council should let Ball Corporation be the leader to push other companies in the beverage supply chain to replace steel cans in channels by aluminum cans. The reasons are listed as below. Firstly, unlike case two, both the supplier and manufacturer had motivation to play the games because their benefits definitely increased in the first case; secondly, the profits of both Ball Corporation and Coca-Cola were much greater in case one than in case two; thirdly, the goal to make the supply chain take more CSR was better achieved by the game played in case one. This conclusion can be applied to other cases as long as the assumptions we make for the numerical are satisfied. For examples, the manufacturer is or can be viewed as a monopoly, and the supplier is as powerful as the manufacturer so that both of them can be the leader of the game.

CHAPTER FIVE

CHAPTER FIVE

SENSITIVITY ANALYSIS AND MANAGERIAL INSIGHTS

In this section, we examine the experimental parameters used in the numerical solutions for the model, and then analyze these results to obtain insights into the contract properties for industrial practice. Based on the meanings and properties of the parameters, sensitivity analysis is conducted for parameters in three groups: time horizon parameters T ; tax return parameters of $T^M(x_t)$ and $T^S(x_t)$, which are τ *and* θ; and the social benefit parameters of $\beta^M(x_t)$ and $\beta^S(x_t)$, which are δ *and* $\tilde{\delta}$.

5.1 Sensitivity Analysis of the Conclusion to Parameter T

We first consider the parameter of T (the time horizon). In the numerical example, we let $T = 10$ to illustrate how social responsibility is allocated over time by a dynamic Stackelberg game. As noted in Chapter Three, ten years is the maximum horizon for most company projects. Therefore, parameter T is selected from 1 to 10. To correspond with the other fixed parameters, the results of the sensitivity analysis of parameter T are shown in Figures 5.1 through 5.5.

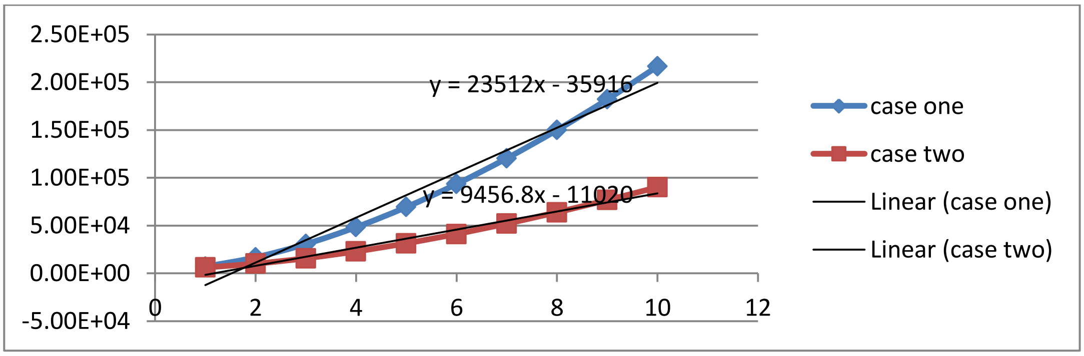


Figure 5.1 Sensitivity of X to T

Figure 5.1 shows the trends of the state variable X for both cases. It is easy to understand that the level of social responsibility taken by the supply chain accumulates as time goes by. We also find that, in case one, both the value of X and the growing rate of X over time are higher than those in case two. As a result, we easily interpret that the supply chain system bears more social responsibility when the supplier is the leader rather than the manufacturer. The result also demonstrates that the time horizon doesn't impact the above conclusion. We then compare the profits of the manufacturer and supplier with the time only contract. Those results are illustrated by Figures 5.2 and 5.3.

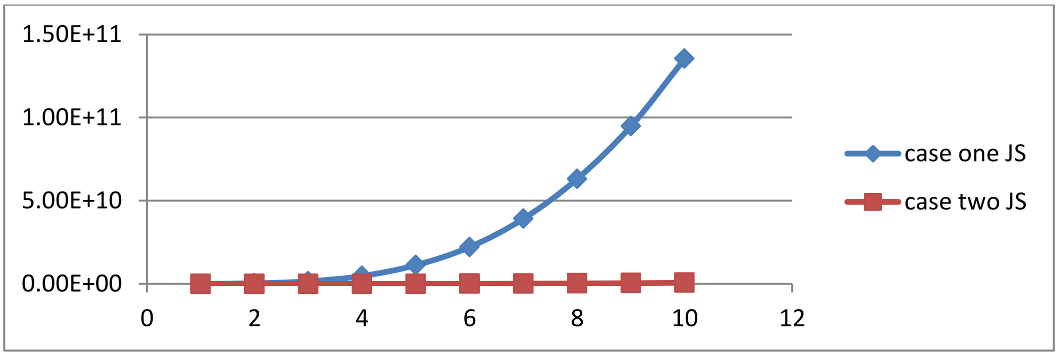


Figure 5.2 Sensitivity of JS to T

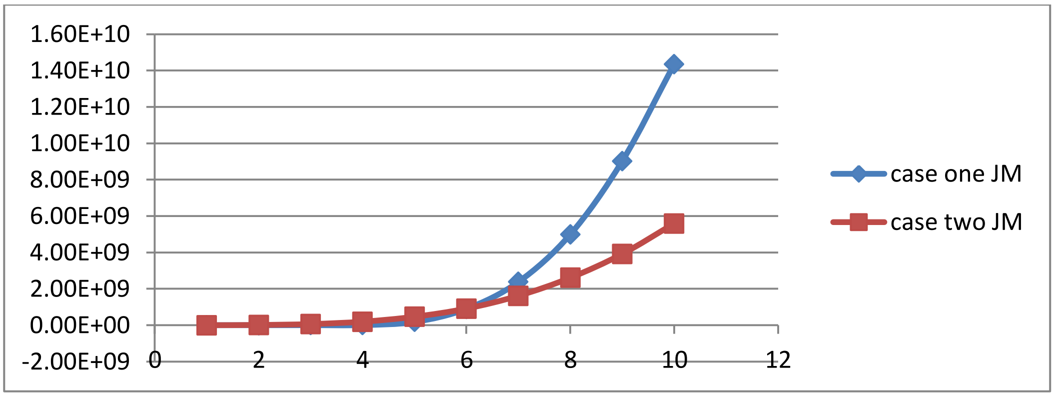


Figure 5.3 Sensitivity of JM to T

Observing the profits of both the supplier and the manufacturer at each period, we find the JS in case one generally larger than the corresponding JS in case two, which means no matter how many periods the game lasts, the manufacturer makes more profit from being the leader of the game. On the other hand, Figure 5.3 shows that being the leader of the game does not guarantee that the manufacturer's profits will increase. Specifically, from the seventh year, the profits of the manufacturer, when it is leader, are lower than when it is not. Therefore, the time sensitivity factor has a significant impact on the manufacturer's decision as to whether it wants to be the leader of the game.

Next, we analyze the sensitivity of the time horizon to the investments of the manufacturer and the supplier.

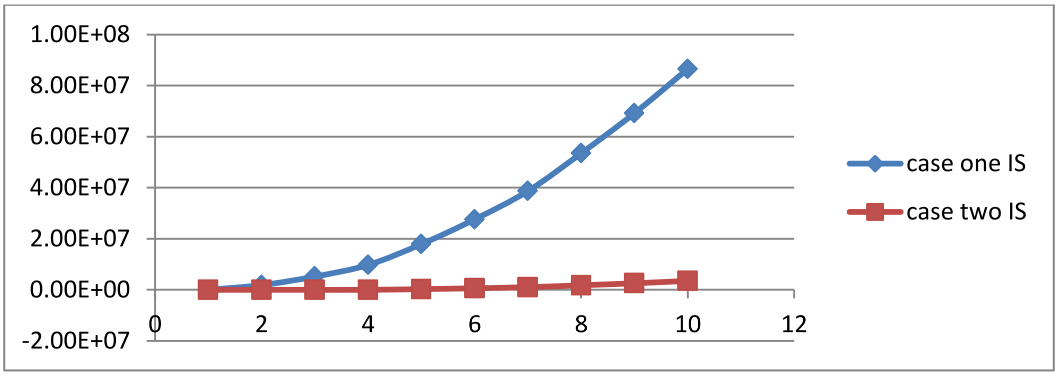


Figure 5.4 Sensitivity of IS to T

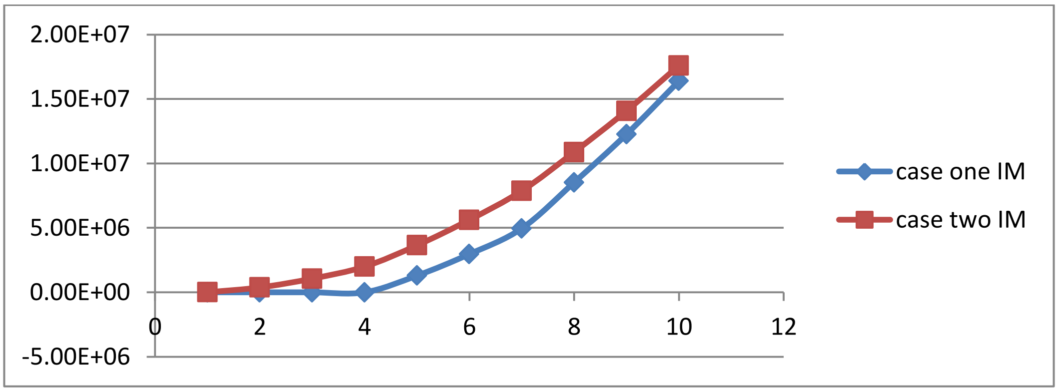


Figure 5.5 Sensitivity of IM to T

In Figure 5.4, the amount of the supplier's investment increases steeply as time goes by when it is the leader, while the supplier makes its investments steadily over time when it is the follower. Figure 5.5 indicates that the manufacturer significantly raises the amount of its investment in both cases. In sum, the raised rate of investment can be attributed primarily to parameters.

5.2 Sensitivity Analysis of the Conclusion to Parameters τ *and* θ

This section examines how the tax return sensitivity factors τ *and* θ, the parameters of the tax return, affect the results of the game. We examine the sensitivities of τ *and* θ to the state variable X, profits JM and JS, and investment IM and IS, respectively.

First, we consider the state variable X. In Figure 5.6 and 5.7, below, we compare the profits with that of the τ only contract. For both cases, the level of the state variable in the higher tax returns policy is generally larger than in the lower one. Specifically, X increases gradually as τ *and* θ increase; we also observe that when τ is greater than 0.15, the X starts to rise rapidly, while when τ is between 0.01 and 0.15, the value of X increases only slightly. Similarly, plotting the numerical results in Figure 5.7, we see that the rate of growth of X suddenly increases after θ reaches the point of 0.005.

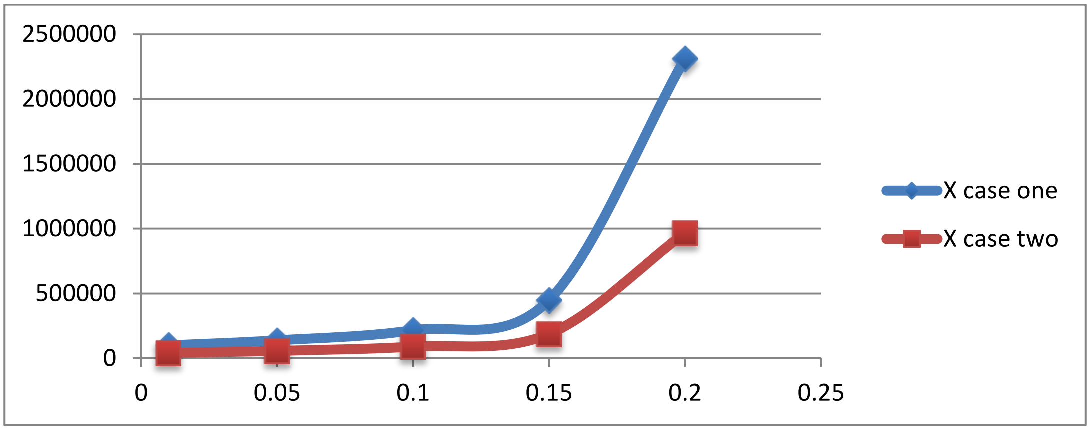


Figure 5.6 Sensitivity of X to τ

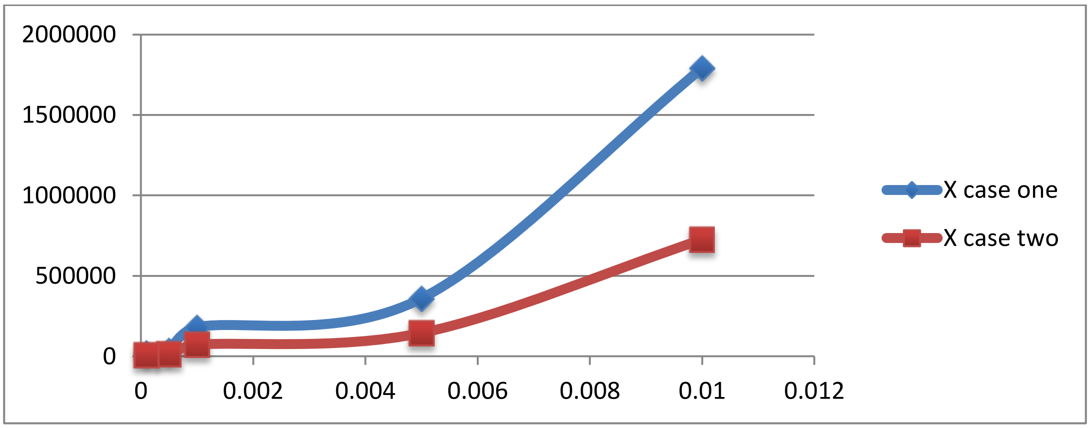


Figure 5.7 Sensitivity of X to θ

Furthermore, we examine the profits of the manufacturer and the supplier, JM and JS. Figures 5.8 through 5.11 show the sensitivity of τ *and* θ to the profits of the manufacturer and the supplier. The changes of profits of the two players along with the increasing tax return policy are quiet similar to the state variable X, as previously discussed; the rate of growth of JM and JS suddenly increases when τ is greater than 0.15 and θ is larger than 0.005. However, there is an exception–the impact of τ *and* θ to the profit of the supplier is not as strong as that of the manufacturer when the supplier is the follower in the game. In that situation, the profit of the supplier steadily changes.

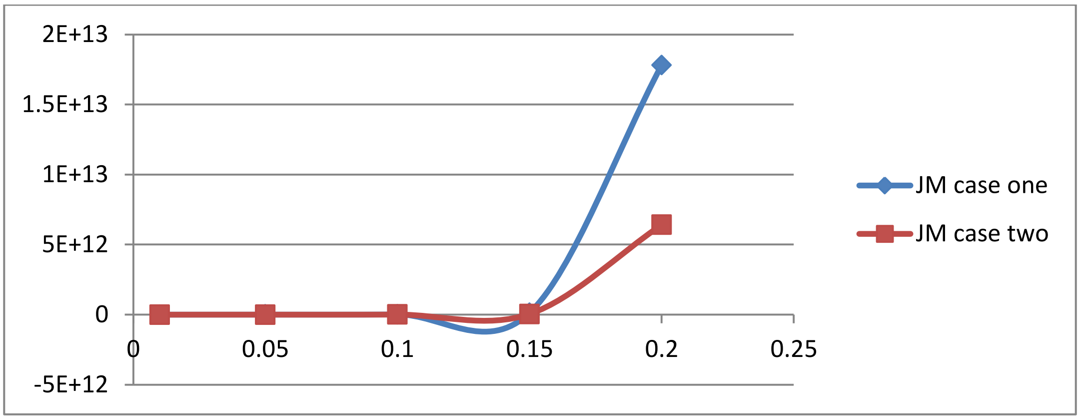


Figure 5.8 Sensitivity of JM to τ

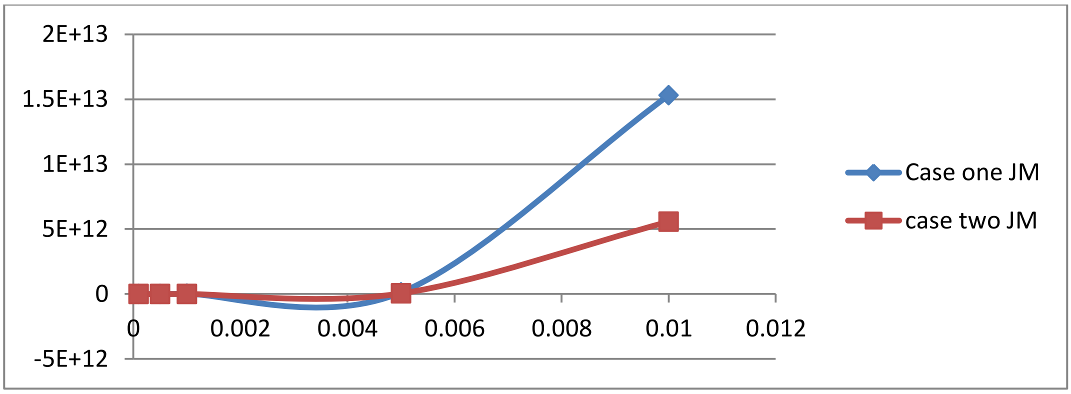


Figure 5.9 Sensitivity of JM to θ

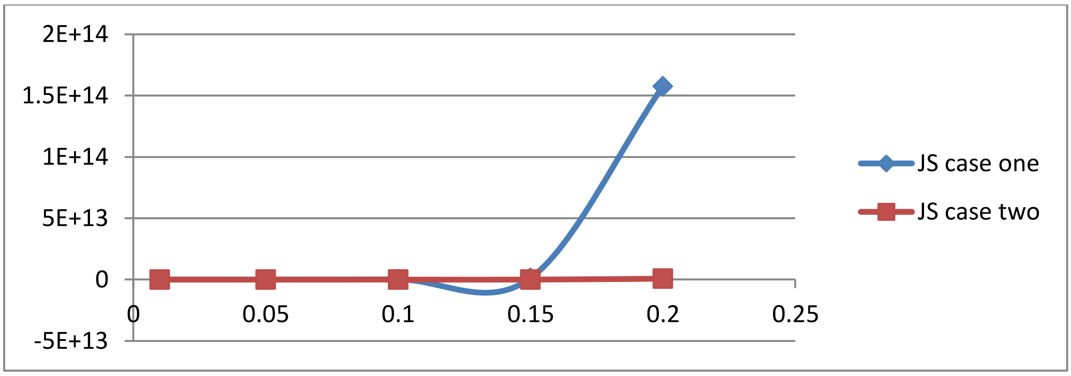


Figure 5.10 Sensitivity of JS to τ

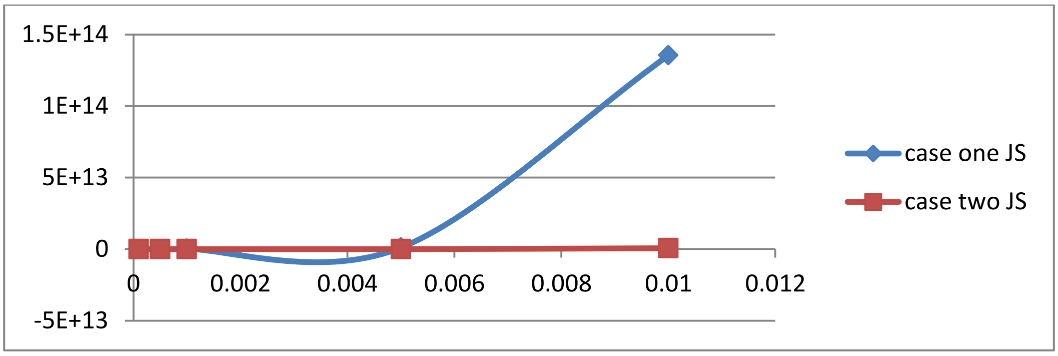


Figure 5.11 Sensitivity of JS to θ

The splitting of the investment in social responsibility between the manufacturer and the supplier with parameter τ and θ is also illustrated in Figures 5.12 through 5.15. Similar to the JS and JM, both IM and IS increase as the tax return policy improves. In particular, the amount of the manufacturer's investment in both cases and the amount of the supplier's investment in case one start increasing drastically as the value of τ becomes larger than 0.15 and the value of θ becomes greater than 0.005; the amount of the supplier's investment in case two continues to increase steadily.

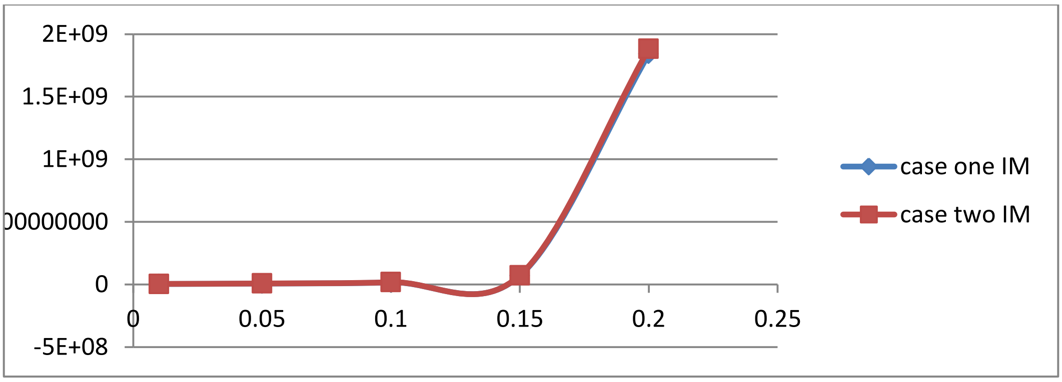


Figure 5.12 Sensitivity of IM to τ

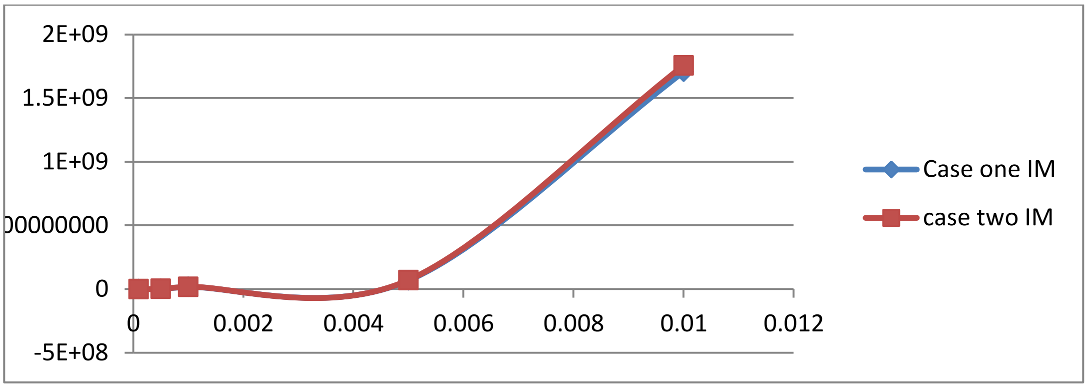


Figure 5.13 Sensitivity of IM to θ

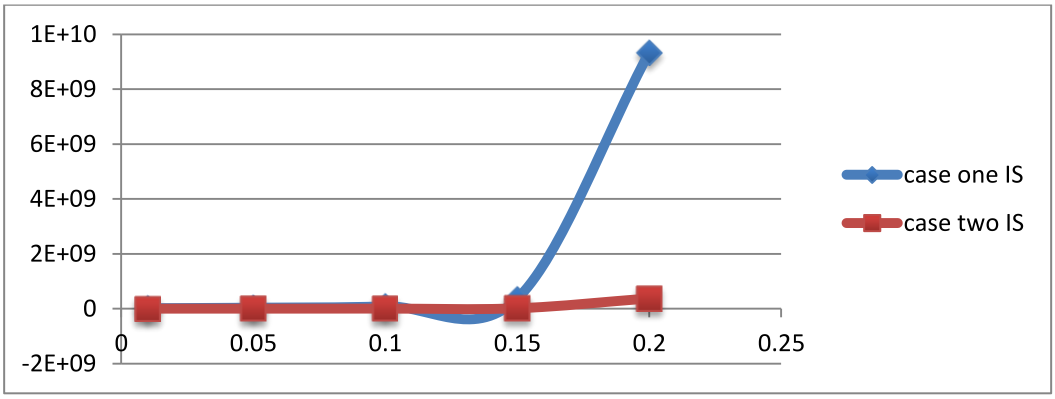


Figure 5.14 Sensitivity of IS to τ

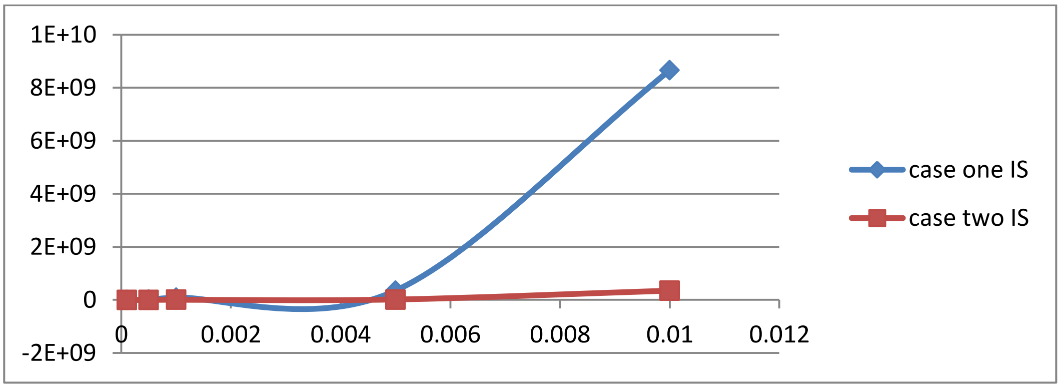


Figure 5.15 Sensitivity of IS to θ

In summary, both of the tax return parameters τ *and* θ strongly affect the investment decisions and profits of the two players. The degree to which they impact the solution may vary, but they impact the key factors in a positive way. This phenomenon can be easily explained as the higher the tax return, resulting in increased profits, the more investments the manufacturer and supplier would make. When the tax return parameters reach certain critical points, the two players would make more aggressive investments in social responsibility due to their significant profit gain.

With respect to industrial management, governments can set the tax return policies at minimum values of $\tau \in [0.01, 0.15]$ *and* $\theta \in [0.0001, 0.005]$ to collect more tax from the manufacturer and the supplier, because in the range of the state variable X, profits JM and JS and investments IM and IS are not really sensitive to the rates of τ *and* θ. Moreover, it is a good strategy for governments to adjust high tax return policies such as $\tau > 0.15$ *and* $\theta > 0.005$ in order to accelerate the motivation of the two players to take CSR.

5.3 Sensitivity Analysis of the Conclusion to Parameters δ *and* $\tilde{\delta}$

In this section, we analyze the effect of δ *and* $\tilde{\delta}$, and the social benefits of the supplier and the manufacturer, on X, JM/JS, and IM/IS.

First, we examine the state variable X. According to Figures 5.16 and 5.17, for case one in which the supplier is the leader of the game, the value of X is in direct ratio to δ, the parameter of social benefits of the supplier, and in inverse ratio to $\tilde{\delta}$, the parameter of social benefits of the manufacturer. In contrast, when the manufacturer is the leader, X is in direct ratio to $\tilde{\delta}$, the parameter of social benefits of the supplier, and in inverse ratio to δ. This implies that increasing the social benefit parameter of the follower or decreasing the social benefit parameter of the leader leads to a higher level of social responsibility. This phenomenon can be explained as the follower bears more risk with its increasing investment in social responsibility.

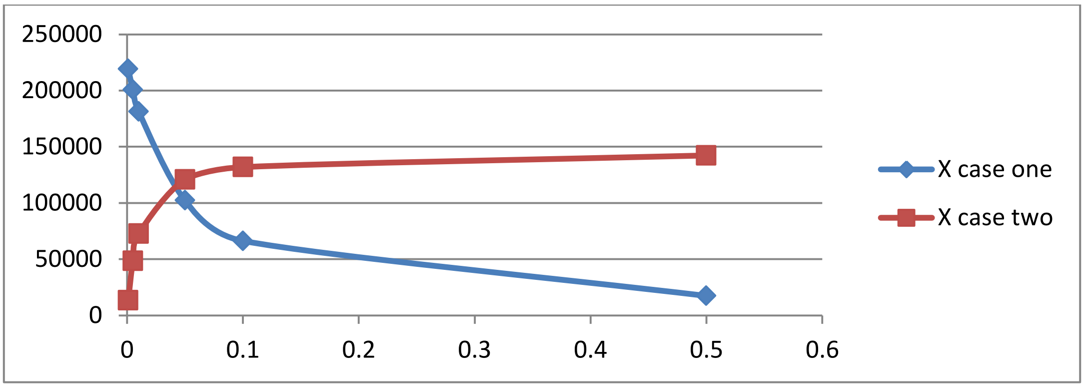


Figure 5.16 *Sensitivity of X to* δ

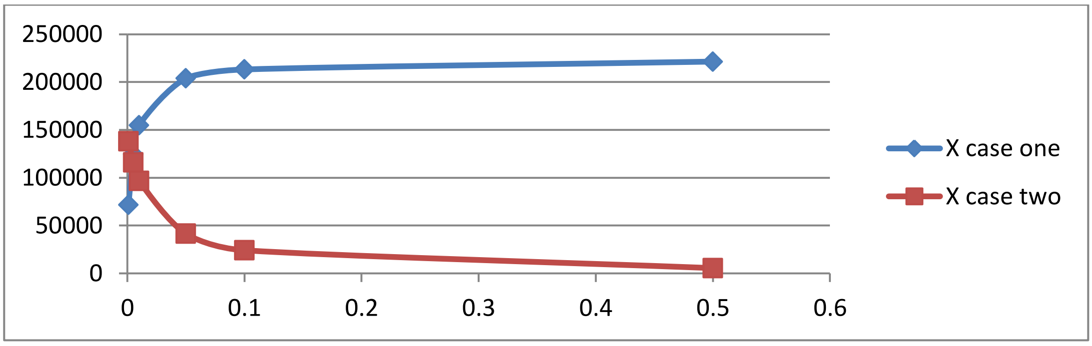


Figure 5.17 *Sensitivity of X to* $\tilde{\delta}$

As for the profits of the manufacturer and the supplier, JM and JS, Figures 5.18 through 5.21 show the sensitivity of δ *and* $\tilde{\delta}$ to the profits of the manufacturer and the supplier. Observing the trends in Figures 5.18 through 5.21, we found that, for both the manufacturer and the supplier, when they are the leaders in the game, their profits moderately decrease with the increase of their own social benefit parameter. When they are the follower in the game, their profits dramatically increase with the increase of their own social benefit parameter. This observation fits the fact that the leader appropriates the follower's share of channel profit when the social benefit the leader gains from the project has a tendency toward growth.

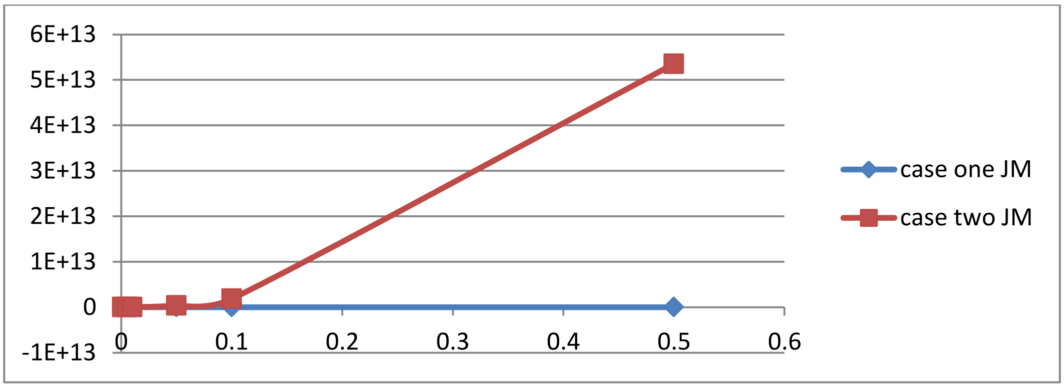


Figure 5.18 Sensitivity of JM to δ

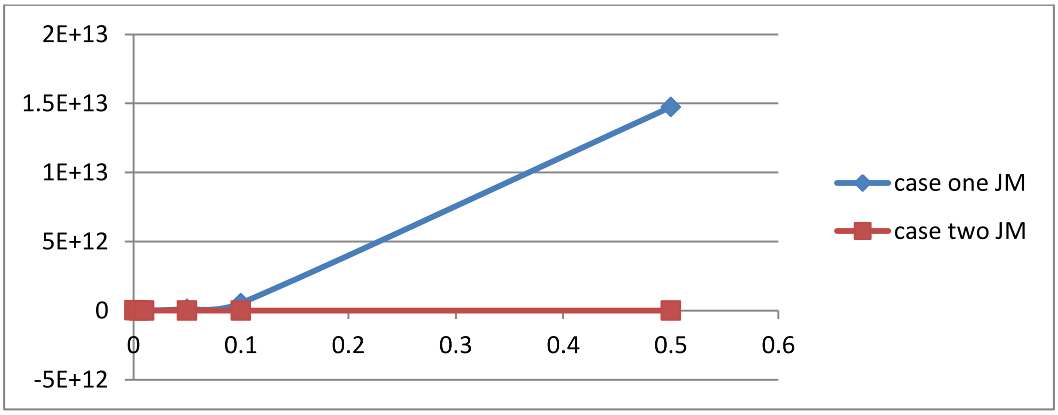


Figure 5.19 Sensitivity of JM to $\tilde{\delta}$

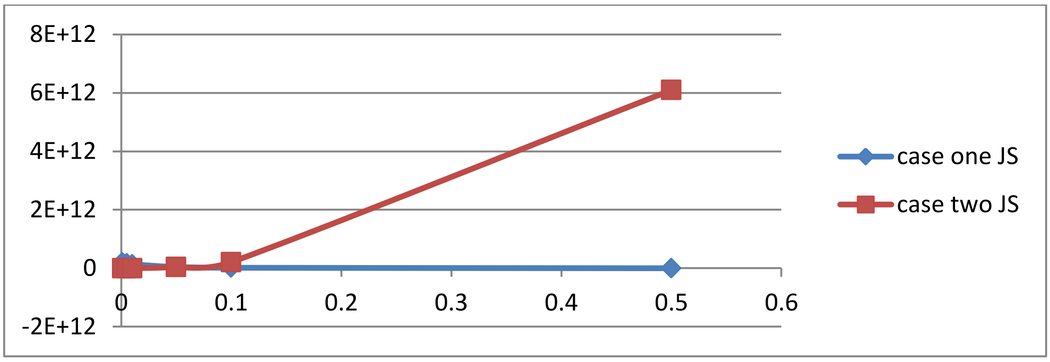


Figure 5.20 Sensitivity of JS to δ

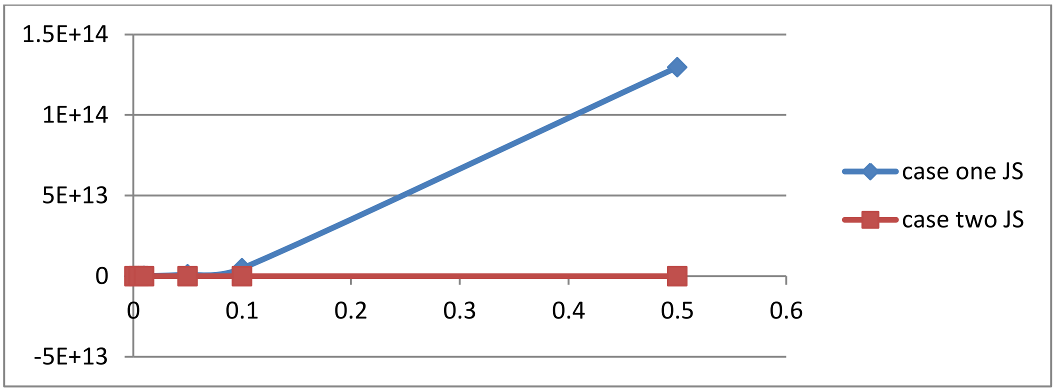


Figure 5.21 Sensitivity of JS to $\tilde{\delta}$

Finally, we examine how the social benefit sensitivity factors of the manufacturer and the supplier affect their investment decisions, IM and IS. According to Figures 5.22 through 5.25, the leaders of the game tend to invest less in social responsibility as their social benefit parameters increase over time; in contrast, the followers of the game increase their investment if their social benefit parameters continue to increase. This demonstrates that the leaders do have an advantage in making decisions to extract profits; meanwhile, the followers invest more if the increasing social benefits they gain from the project make up their loss.

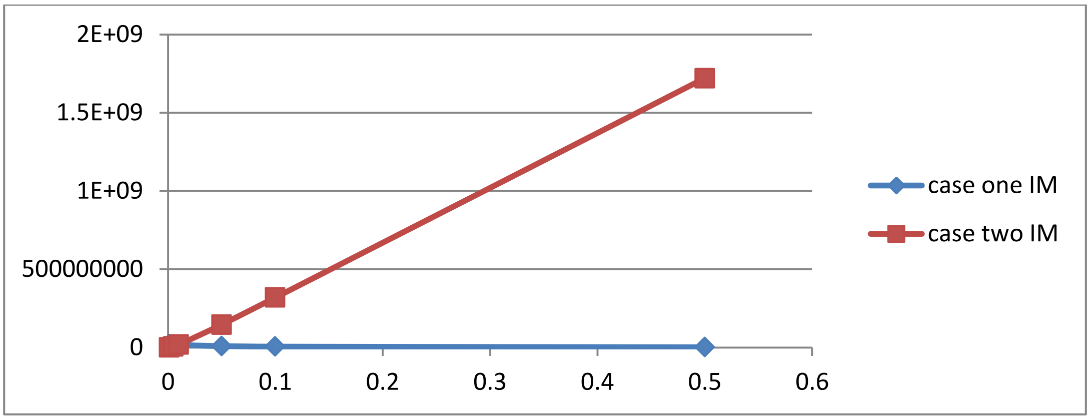


Figure 5.22 Sensitivity of IM to δ

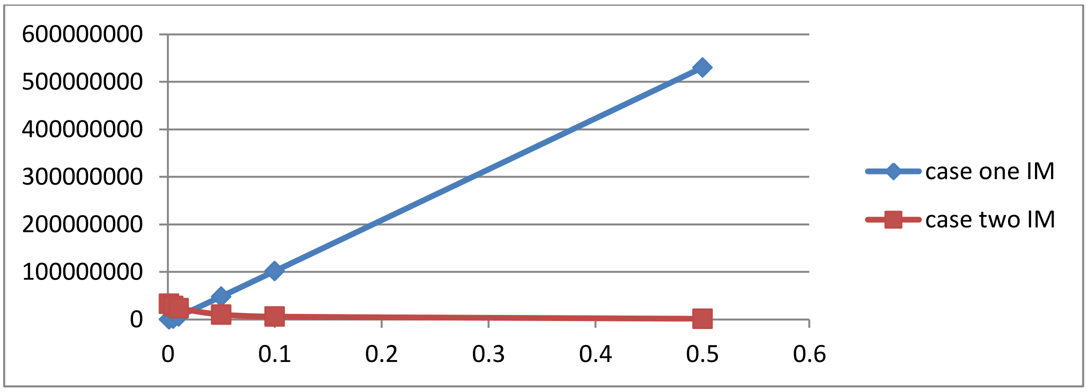


Figure 5.23 Sensitivity of IM to $\tilde{\delta}$

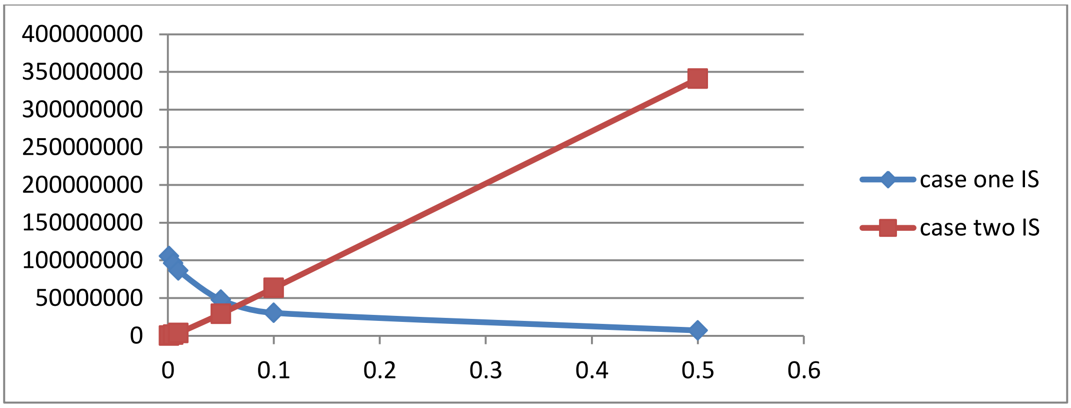


Figure 5.24 Sensitivity of IS to δ

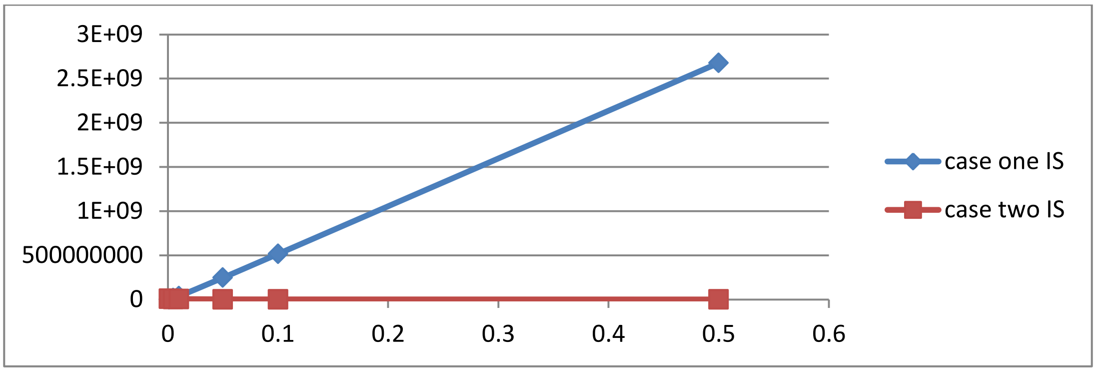


Figure 5.25 Sensitivity of IS to $\tilde{\delta}$

The above discussion shows that the government should let the manufacturer be the leader of the game if the supplier is the one that can obtain more social benefits from the project; likewise, the manufacturer should be the follower of the game if it is the one that can obtain more social benefit from the project.

5.4 Summary

In this chapter, to show how the model behavior responds to changes in parameter values, we conducted a sensitivity analysis by changing the values of T ; τ *and* θ ; and δ *and* $\tilde{\delta}$. Based on the sensitivity analyses, it was verified that horizon parameter T does not have a major impact on X, JM/JS, or IM/IS. Also, both of the tax return parameters τ *and* θ strongly affect the investment decisions and profits of the two players. However, the sensitivity of parameters δ *and* $\tilde{\delta}$ are more complicated; the effect of δ *and* $\tilde{\delta}$ on X, JM/JS, and IM/IS are different in case one and two, because the leader is different in each case. Meanwhile, we derive managerial insights according to the sensitivity of each parameter.

CHAPTER SIX

CHAPTER SIX
CONCLUDING REMARKS

This thesis addressed the problem of allocation of CSR to members in a decentralized supply chain network over time. The terminology of CSR was evaluated as investment, and the problem, thus, was successfully formulated by a dynamic Stackelberg game. Two cases, one when the supplier is the leader of the game and one when the manufacturer is the leader of the game, were analyzed and discussed. The equilibrium point at which members make their decisions to maximize profits in a time horizon was determined. A calculus variation algorithm was proposed and tested with both a case study and a numerical example.

6.1 Conclusion

In this thesis, we described the issue of implementing CSR among members of a supply chain. Governments have released a variety of regulations and policies to push supply chains to take various forms of CSR for the realization of long-term social benefits. It is unavoidable for supply chains not to bear at least some CSR under these regulations. However, members in a decentralized supply chain network tend to maximize their individual net profits. CSR is a risk for these organizations because it may lead to forced acquisition of additional raw materials and increased production and research costs. CSR can also provide several benefits, such as increased sales and tax returns and an enhanced corporate image. To deal with this conflict, we established a supply chain coordination scheme. The research objective of this thesis was to find the best way of allocating CSR to members of a non-integrated supply chain over time. To accomplish this, it was necessary to explore the equilibrium at which both the profits of the members and the level of CSR taken by the supply chain are maximized. We also needed to determine who should be the leader of a game to execute CSR regulations.

A comprehensive literature review was provided in Chapter Two. First, we pointed out that there is no general agreement on the appropriate definition of CSR, but that basically, CSR involves five dimensions including environmental issues, society, the economy, stakeholders, and voluntariness. Information on supply chain management and game theory was then presented. The application of game theoretic concepts in supply chain management, such as non-cooperative static games, dynamic games, and cooperative games, was introduced. Supply chain-related game theoretical applications were classified into five categories: inventory games with fixed unit purchase cost, inventory games with quantity discounts, production and pricing competitions, games with other attributes and games with joint decisions on inventory, and those with production/pricing and other attributes.

In Chapter Three, the model design and methodology for allocating CSR to members of a supply chain were described. First, fundamental knowledge was provided to indicate how CSR is evaluated as capital, and why game theory is necessary for application in this model. Specifically, we highlighted that only CSR dimensions one to four, which are obligatory and prescribed by regulation, were studied in this thesis. Since social issues are often related to capital, we considered a project with CSR as a long-term investment. The members of a supply chain play games with each other to maximize their own profits; thus, the model used was a long-term co-investment game model. We discussed the structure of information and the other properties of the game. Finally, the model was properly defined as an open-loop Stackelberg dynamic game. Furthermore, we explained why a general three-tier vertical supply chain network can be simplified in a model that only involves a monopoly and its one supplier. We assumed that all of the monopoly's suppliers and retailers were identical. In addition, the monopoly controlled the uniform price of its product with a two-part tariff, so that we could eliminate the retailer, who is not a decision maker, from the game. In Chapter Three, two formulations were provided by selecting, in turn, either the supplier or the manufacturer as the leader of the game. We then applied control theory and calculus variations to obtain an optimal solution for the dynamic game model.

A real case study was provided in Chapter Four. This case study focused on the supplier and manufacturer in a beverage supply chain. Ball Corporation and Coca-Cola were forced to replace steel cans with aluminum under a new regulation released by the Aluminum Can Council, because aluminum cans contain more recycled content than any other beverage containers. We studied two different cases: in case one, we chose the supplier as the leader of the game, while in case two, the manufacturer was the leader. Two numerical examples were then provided. The first one was a static numerical example. We allocated the cost of CSR to either Ball Corporation or Coca-Cola in the first round of the game. We calculated the results by hand. The other example was a dynamic numerical example, dividing time horizons into ten periods. The optimal solution was obtained from Matlab 7.0. Based on the Matlab ouput, we analyzed the results of the two cases in terms of three criteria: profits, the amount of investment, and the level of social responsibility taken by the supply chain. Based on the results of analysis, we concluded that the ACC should let Ball Corporation be the leader in implementing the project, because case one, in which Ball Corporation was the leader, provided several advantages over case two, in which Coca-Cola was the leader, in many respects. Firstly, in case one, both the supplier and the manufacturer were motivated to play the games because their benefits definitely increased. Secondly, in case one, the profits of both Ball Corporation and Coca-Cola were much higher than in case two. Thirdly, the goal of making the supply chain take more social responsibility was better achieved by the game in case one.

To determine if the conclusion that the supplier should be the leader of the game always holds, we conducted a sensitivity analysis based on the dynamic numerical example. We categorized the parameters into three groups: the time horizon parameter T; the tax return parameters of $T^M(x_t)$ and $T^S(x_t)$, which are τ and θ; and the social benefit parameters of $\beta^M(x_t)$ and $\beta^S(x_t)$, which are δ and $\tilde{\delta}$. According to the sensitivity analysis, the level of CSR taken by the supply chain was not sensitive to the time horizon, while the amount of profit realized by Ball Corporation and Coca-Cola was sensitive to the time horizon. We derived insight management from the sensitivity analysis of the conclusion to the time horizon. That is, if governments are only concerned about the level of CSR taken by supply chains, they should always let the supplier be the leader of the game. In contrast, if governments want to accelerate the motivation of the two players to take CSR by considering their benefit, they can choose the leader of the game from the supplier and the manufacturer in terms of the time horizon. Moreover, we know that both the tax return parameters τ and θ strongly affect the investment decisions and profits of the two players, but they do not impact the level of CSR. We realized another insight into management from the sensitivity analysis of the conclusion to the tax return policy. If governments want to collect more taxes from supply chains, they should set their tax return policy at the minimum point of the range of $\tau \in [0.01, 0.15]$ and $\theta \in [0.0001, 0.005]$. On the contrary, if they would like to encourage the supply chain to take CSR, they should establish a high tax return policy, at least letting $\tau > 0.15$ and $\theta > 0.005$. The sensitivity of the conclusion to social benefits parameters δ and $\tilde{\delta}$ was more complicated, because the choice of leader decides the impact of the parameters on the level of CSR, profits, and investments. The sensitivity analysis of δ and $\tilde{\delta}$ also showed some managerial insights. Governments should let the company that has the lower social benefit parameters be the leader, and the one that has the higher social benefit parameters be the follower of the game. This decision increases the level of CSR as determined by the supply, the profits, and the amount of investment of both companies.

The thesis concludes with contributions and future work in Chapter Six.

In conclusion, we properly evaluated the vague term “CSR” by considering it as a long-term investment. We selected a suitable game, an open-loop Stackelberg dynamic game, to address the problem. We modeled CSR in a decentralized supply chain from two different perspectives by assigning either the supplier or the manufacturer to be the leader of the game. We then applied feasible algorithms, control theory, and calculus variations to solve the problem. We also provided a case study and numerical examples, and programmed Matlab to obtain the solutions for the numerical examples. Based on the output of Matlab, we conducted a sensitivity analysis by examining three groups of parameters, and concluded the managerial insights.

This thesis successfully grounded game theoretical application to the allocation of CSR in supply chain management. The model can be applied to a large class of social issues, and the techniques of modeling, algorithms, and equilibrium analysis can be further applied to other CSR policies or contracts in a supply chain network.

6.2 Contributions

This thesis addresses the problem of allocation of CSR to members in a decentralized supply chain network over time. We found a way to evaluate the vague term “CSR” and successfully formulate the problem. A dynamic Stackelberg game with a calculus variation resolution is proposed and tested with both a case study and a numerical example. The main contributions of this paper and some suggestions are summarized as follows:

- The game theoretic strategy of coordination between firms in a supply chain on CSR is rarely discussed in current supply chain management literature.

- In the model, CSR, an otherwise nebulous concept, was represented by a concrete investment decision, so that the abstract CSR can be simply epitomized in the formula. In other words, the amount of investment in CSR of each member can be clearly defined so that optimal supply chain profit can be achieved in equilibrium by taking such CSR.

- This thesis provides a conceptual framework that could help both regulators and companies execute policies smoothly and efficiently. For example, how much CSR should each member in a supply chain network bear? Who should be the leader of the Stackelberg game?

- Based on the analysis of the equilibrium, the point at which both the profits of the players and the level of CSR taken by an SC are maximized? The managerial insights of the model not only discover a way to keep networks with CSR operating efficiently, but also provide tactics to command, improve, and control CSR projects. For instances, How long would the investment horizon be? How do governments design the tax return rates, either to collect the most tax or to accelerate the motivation of members to accept CSR?

- This model allocates overall social responsibility rather than just a certain social issue. This means that the proposed model can be applied to a large class of social issues. The technique of using equilibrium analysis, modeling, and the proposed algorithm can be further applied to other CSR policies or contracts in a supply chain network.

- The thesis proposes a dynamic model that crosses through ten periods. CSR has become a popular topic over the last several decades. However, most research has only focused on case studies. Researchers have discussed the significance of CSR, the properties of CSR, and the relationship between CSR and other disciplines. Game theory has been applied to CSR in the last decade to obtain Nash equilibrium and Stackelberg equilibrium. However, those equilibriums were derived from static models. In other words, a dynamic game has rarely been applied to CSR problems.

- This thesis took into account a number of factors, which make the model practical and realistic. For example, the Stackelberg game is suitable for an unequally powerful hierarchy in a supply chain; the two-part tariff considered in the model is a common strategy for global manufacturers.

In addition to the above advantages, at a glance, the model proposed by this thesis also provides the following improvements:

- The model formulates CSR coordination between members in a supply chain network by game theory.
- The optimal solution for the model is a Stackelberg equilibrium rather than a Nash equilibrium.
- The model studies a dynamic situation instead of a static case.

In conclusion, the main objective of this thesis was to allocate CSR to members in a supply chain by game theory. The framework that we developed for the CSR modeling and analysis of supply chain networks generalizes the recent works of researchers, but challenges their limitations. The findings of this thesis served three main subjects, all of which are very important to the fields of supply chain management, social science, and game theory application.

6.3 Future Works

The analyses and results of this paper could be extended in several directions.

First, when designing the state variable, we assumed that the initial level of CSR is zero, and the level of CSR at the period T+1, X_{t+1} is free. One reason to let it be free is that the regulator may not know what is or is not an acceptable final level of CSR. For some on-going projects, the value of the state variable at the initial and final period could be set according to terms of the situation.

Second, our model was a two-player Stackelberg game. The more powerful player was called the leader and the other player was called the follower. An extension is, of course, possible to “one leader-many followers” and even to “many leaders” and “many followers.”

Third, the application of the Stackelberg game concept to our model was within the framework of an open-loop information structure. Depending on the information structure, the open-loop information structure can be extended to feedback and global information structure.

Furthermore, an extension could be made to problems where there are more than two levels of hierarchy; again, the analysis of this paper could be carried over to such problems. By repeated application of the ideas used in the two-tier Stackelberg game, we could easily solve problems in a multi-level supply chain.

Finally, in our model, we assumed that both players made their investment plan at the beginning of each year, so it was reasonable to formulate the problem as a continuous discreet dynamic game. It would be a good extension to formulate the problem as a differential dynamic game.

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VITA AUCTORIS

Hong Shi, M.A.Sc. received B.A.Sc. from University of Science & Technology Beijing. Shi joined the Department of Industrial and Manufacturing Systems Engineering at University of Windsor, where she started her research in Sept. 2008. Her research interest is in supply chain management, game theory and operation research.