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ANALYSIS OF THE REVENUE-SHARING CONTRACT UNDER DIFFERENT POWER STRUCTURES

With Application in the Biodiesel Niche Market

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SUMMARY

Empirical studies show that many supply chain integration and collaboration efforts are challenged with issues over channel power imbalance and control rather than mutual, win-win intentions [1]. Channel power here refers to an agent's relative ability to control the decision making process in the supply chain. Channel firms have differing amounts of relative power due to size, brand identity or other parameters, and such differences have significant effects on operational decisions and overall efficiency. Channel efficiency is a measure of the performance of the system compared to the centralized system which is subject to improvement by first identifying the intra-chain dynamics which cause inefficiency and then modifying the structure of these relationships by applying suitable contract. Supply chain contracts help to more closely align individual incentives with global optimization targets. They divide profits, and distribute costs and risks arising from various sources of uncertainty, e.g. market demand, selling price, product quality, and delivery time between the entities in the supply chain. However, utilizing contract when there are competing producers in the supply chain, has received less attention in the literature. The current work seeks to study this situation by modeling a two-supplier-single-retailer supply chain while assuming the two suppliers could be imbalanced in power. This model is then applied for analyzing the biodiesel niche market in Singapore by considering the competition between new biodiesel producers and current fossil fuel producers. The agents' profits and total channel efficiency are examined under different market conditions to determine how the suppliers' optimal decisions differ with respect to the substitution degree of products.

Initially, to gain better insight into the biodiesel market, the feasibility of producing biodiesel in Singapore is reviewed. Presently, advanced technologies to utilize biomass as a large scale

source of energy have been developed by engineers in National University of Singapore (NUS). However, in simple economic terms, biomass-derived fuels are at a disadvantage. Compared to petroleum-based diesel, the high cost of biodiesel is a major barrier to its commercialization as traditional economic analyses rarely take into account the environmental and health benefits associated with the utilization of an environmentally friendly resource. This dissertation explores the potential for new feedstocks to be converted to biodiesel in order to reduce production costs. The results show that collecting waste oil from commercial and industrial grease separators and households for a waste-to-energy program is a reasonable strategy to lower costs. Furthermore, based upon the numerical example developed in the study, it is shown that utilizing revenue sharing contract could help both producers increase their profits while it is also in favor of end customers and leads to higher demand. Conducting more extensive numerical examples is left for the future studies.

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c_i	Supplier i's cost per unit
w_i	Supplier i's wholesale price
r_i	Retail price of product i at the market
m_i	Retail margin of product i
h_i^R	Retailer's holding cost of product i per unit per period
h_i^S	Supplier i's holding cost per unit per period
p	Retailer's lost sale penalty for each lost demand
t	Supplier i's outsourcing cost per unit
x_i^R	Retailer's units of inventory on-hand of product i
x_i^S	Supplier i's units of inventory on-hand
Q_i^R	Retailer's base-stock level of product i
Q_i^S	Supplier i's base-stock level
φ_i	Retailer's share of revenue generated from each unit of product i
α_i	Supplier i's customer brand loyalty
β_i	Supplier i's demand sensitivity
γ	Degree of product substitution
z_i	Supplier i's on-hand service level
ε	Random variable assumed to follow the normal distribution
μ	Mean of random variable ε
σ	Standard deviation of random variable ε
F(.)	Normal cumulative distribution function
f(.)	Normal probability density function
Φ(.)	Standard normal *cdf*
ϕ(.)	Standard normal *pdf*

Chapter 1: Introduction

1.1 Supply Chain Coordination

A decentralized supply chain is referred to as being coordinated if it can achieve the same profit as in a centralized scenario. Choosing proper coordinating contracts can lead to agents' individual decisions being optimal for the supply chain as a whole and to reach the same performance as an integrated system. However, aligning individual incentives for channel efficiency is a challenging task. In fact, the powerful companies, given their dominant positions, have little incentive to regulate their power, while the small firms have relatively little flexibility in opting out of these games of power [1]. Analyzing the situations when imbalanced power firms agree to contract has received less attention in the literature. The focus of this dissertation is on the use of contracts under different power structures by modeling a two-supplier-single-retailer supply chain while assuming that one supplier could hold greater power than another. As there exists a strategic interaction among the agents' decisions, game theory is applied to model the interactions and the optimal decisions of the channel members are obtained.

The model is then utilized to analyze the biodiesel niche market in Singapore where there are a new biodiesel producer and an existing diesel producer and it is assumed the diesel producer has greater power than the biodiesel producer. We explore the Nash equilibrium of the pricing game in two different competition levels through numerical examples and show how adopting contracts could affect the profits and the efficiency.

1.2 Biodiesel as an Alternative Fuel

To gain better insight into biodiesel production competition, the fuel market in Singapore is briefly reviewed. Singapore as a modern country is highly dependent on oil. One of the major fuel consumers is the transportation section which contributes to about 19% of the total CO_2 emissions of the country, with the fossil fuel-based (primary consumption) transport sub-sector accounting for 17% which shows the significant contribution of the transport sector in greenhouse gas (GHG) emissions. While oil currently supplies much of the Singapore's energy and transportation demand, the increasing difficulty of constant supply and the associated problems of pollution and global warming are acting as major impetuses for research into alternative renewable energy technologies. The future growth of the country highly depends on overcoming energy resource limitations and the government is currently promoting many programs such as deployment of compressed natural gas (CNG) vehicles and the provision of green vehicle incentives (e.g. additional registration fee rebates) but the need for investigating new marketable, alternative sources of energy is obvious.

Biodiesel is a promising option among available environmentally friendly energy sources. It is a renewable and biodegradable diesel fuel with less harmful emissions than petroleum-based diesel fuel. The recycling of CO_2 with biodiesel contributes to a 78% reduction of CO_2 emissions. Also, the presence of fuel oxygen allows biodiesel to burn more completely resulting in fewer unburned materials [2].

This dissertation initially seeks to study the potential of producing and utilizing biodiesel as an alternative fuel in Singapore and determine the estimated volume and quality of available feedstocks that can be used to produce biodiesel. The organization of the thesis is as follows. In

Chapter 2 the feasibility of biodiesel production and the availability of feedstocks in Singapore are investigated. Chapter 3 focuses on developing models of the supply chain and obtaining the optimal decisions and tries to investigate the coordination mechanisms. In Chapter 4 numerical examples are conducted to clarify the proposed model. Finally in Chapter 5 we summarize our results and propose some further research directions.

Chapter 2: Biodiesel Production

2.1 Introduction

Biodiesel refers to a vegetable oil or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, propyl or ethyl) esters. It is typically made by chemically reacting lipids (e.g., vegetable oil, animal fat) with an alcohol. The most common way to produce biodiesel is by transesterification, which refers to a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid alkyl esters (i.e., biodiesel) and glycerol (Figure 2.1).

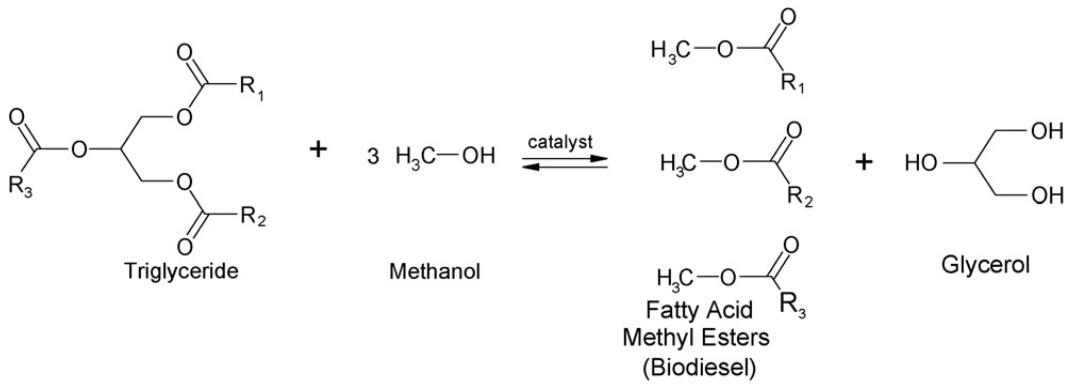

Figure 2.1 Transesterification reaction

The most popular source for producing biodiesel is vegetable oil such as rapeseed oil which is generally favored in Europe, palm oil which is most commonly used in Asia and soybean oil, which is favored in US. In addition to these oils there are several other vegetable oils, such as corn, flax, sunflower, and peanut which are available but with a higher price. Many research efforts have been done to find other crops which can be used as biomass. Kadam et al. [3] study the use of rice straw as biomass in California. They review different harvesting techniques and determine a total delivered cost of 20$/ton using post harvesting baling and high density bales.

Mani et al. [4] describe and characterize the grinding properties of several crops in terms of energy required for grinding. Lewandowski et al. [5] study four varieties of perennial grasses and show that the high yields, low input requirements and multiple ecological benefits make perennial grasses a good source of biomass for US and Europe. Switchgrass and miscanthus are the two species with the best potential. The overall potential for biomass production has been estimated through number of researches [6-10].

An advantage of the using vegetable oil crops for biodiesel is the employment and rent increase in agricultural areas, as well as the impact over related industries. In Europe it is important to stress that it is most economic for the farmer to produce energy crops on set-aside land in order to receive the subsidies defined within the European Union agricultural policy.

On the other hand, although plant feedstocks are highly used in the world, they may cause some problems. Much of the biofuel that Europeans use are imported from Brazil, where the Amazon is being burned to plant more sugar and soybeans, and Southeast Asia, where oil palm plantations are destroying the rainforest habitat of orangutans and many other species.

In addition, according to the report by the organization for economic development (OECD), biofuels will have a major impact on the farming sector. Even without demand for the green fuel, recent falls in output will keep the feedstock prices high. Although the national farmers' union said that UK agriculture already has enough capacity to meet the nation's demand for both food and fuel crops, it seems that it would affect the feedstock prices such as sugar, palm oil etc. and also food prices. The report also describes that the grain required to fill the petrol tank with ethanol is sufficient to feed one person per year. Assuming the petrol tank is refilled every two weeks, the amount of grain required would feed a hungry African village for a year.

Another main concern is that biodiesel produced from plant feedstocks is not economical yet. Compared to petroleum-based diesel, the high cost of biodiesel is a major barrier to its commercialization. It costs approximately one and a half times that of petroleum-based diesel depending on feedstock oils [11,12]. According to previous studies, approximately 70–95% of the total biodiesel production cost arises from the cost of raw material [13,14]. Therefore, finding a cheaper alternative to the conventional feedstock is the most logical means of reducing production cost. One of the promising ideas is to recycle the wastes. Using waste water, grease, oil, plastics etc. could greatly reduce the cost of biodiesel because they are available at a relatively low price. In addition, biodiesel production from wastes offers double environmental benefits as it's both renewable and recycled. Since biodiesel production from waste grease would not compete with food supplies and due to several other unique advantages such as having better energy balance and being more effective in reducing the greenhouse gasses, it has attracted the majority of attention to itself lately. In the following we review some of the waste-to-energy practices carried out for producing biodiesel.

2.2 Literature Review

The economic feasibility and further reduction in the cost of biodiesel production has been a major subject of research. Finding a cheaper alternative to the conventional feedstock is the most logical means of reducing production cost. Soap stock [15], waste grease [16,17], and rendering plant products [18] are potential alternative feedstocks that make biodiesel production economically viable. Soap stock, a byproduct of the refining of vegetable oils, is a potential biodiesel feedstock. By means of simple chemical methods, this low-quality underutilized feedstock can be used to produce biodiesel. This product is comparable in composition, similar

in engine performance and emissions, and predicted to be more economical to produce than biodiesel from refined soybean oil [15].

Another example is the meat industry wastewater. Meat processing plants use huge amount of water. Only a small amount of this quantity becomes a component of the final product; the remaining part is wastewater of high biological and chemical oxygen demand, high fat content and dry residues [19]. According to Jonhs [20], meat industry wastewater is rich in oils and greases, sanitizers and blood. They may cause some environmental problems and the operational costs related to the discharge, land disposal and re-use of wastes are high. Rennio et al. [21] suggest utilizing this biofuel (dried sludge) for steam generation which has shown to be a viable alternative. This type of fuel has a high heating value, and it is a renewable energy source. They show that the utilization of this sludge as a biomass fuel for steam generation, reduces disposal and processing costs, as well as avoids environmental and health problems for staff and community close to these industries, and establishes a cheaper and cleaner energy source for the meat industry segment.

Recycling technology for converting plastic wastes to oil has also drawn much attention in the world. The basis theories and the technology for industrialization of plastic liquefaction have been developed in Huang et al., and Li et al. [22,23].

Another important biofuel feedstock is waste cooking oil (WCO). According to Green Oasis Environmental Incorporation, one gallon of waste oil can contaminate one million gallon of water. In addition, waste grease in sewers can cause many problems for water reclamation plants. Currently WCO is a disposal problem. If this waste grease is used as a fuel, it would not only

provide another source of energy, but it also increases the value of waste grease making it a commodity instead of a disposal burden.

Waste cooking oil has been introduced in the biodiesel production line as early as 1994 when the first industrial WCO biodiesel plant was commissioned in Austria. This was followed by a market gain in its popularity in 1998 and 1999, when set-aside lands for industrial crop production had been abscised to 5%, crude vegetable oil costs were high, and petrodiesel prices were at record low [24]. Since then many efforts have been made to the development of waste cooking oil as a biodiesel feedstock [25-27]. The sources of the waste feedstock, particularly restaurants and catering establishments, have jumped into the bandwagon of WCO biodiesel production. McDonald's in Austria, for example, recovers WCO from their outlets and converts it into biodiesel. The biodiesel produced is used to run the Austrian truck fleet of McDonald's [28]. McDonald's Austria installed this process in 2003 and the practice is expanding, most recently in Malta. In Manila, police are looking to convert their patrol cars to run on a mixture of diesel and used cooking oil from McDonald's. And finally in the UK, McDonald's recently started using its own waste cooking oil to make biodiesel, which will be then used in its entire truck fleet of 155 vehicles [28]. The conversion of used cooking oil into biofuels for transportation vehicles, heating, and other purposes is being actively pursued in the recent McDonald's Worldwide Corporate Responsibility Report [28]. According to the McDonalds' Environmental Report 2004, in all European countries they decided to collect and recycle used oil from the fryers. At the end of 2003, more than 90 percent of all restaurants were integrated in a recycling scheme for waste oil. They have actively pursued recycling capacities for their used oil in the chemical industry and an increasing amount for the production of biofuels. The objective is to create a closed chain so that used oil from restaurants goes into the production of

biodiesel, which in turn can be used by the distribution trucks. Recycling this way reduces not only waste, but the demands on non-renewable resources and emissions that contribute to climate change. At these times of high all prices companies are also benefiting from the favorable costs of biofuel, together with an enhanced public relations image.

Another success story in the application of WCO biodiesel is the Malta initiative. A local company has ventured into recovering WCO from household and commercial establishments in Malta and converted this into biodiesel. The company offers a free waste oil collection service from catering outlets and hotels at no cost and provides 1 liter of free oil for every 25 liters of donated used cooking oil. The biodiesel produced from WCO yielded a competitive price of 28 cents per liter as compared to 29 cents for mineral diesel. The price differential is expected to widen as the mineral diesel price in Malta is expected to rise in the next few years [29].

A recent study by Montefrio [30] has been done to determine the technical and economic feasibility of the production and utilization of biodiesel derived from waste cooking oil in Marikina city. It explores the engineering, environmental, social science, economics and policy perspectives of a novel waste-to-energy program, by evaluating the environmental implications of such a program, as well as the legal and political capacities needed for project realization.

The interest in biodiesel production from WCO is rising as more and more government agencies and private companies realize the huge volume of waste grease produced in urban areas. In a recently commissioned study by the US National Renewable Energy Laboratory [31] on urban waste grease production in the metropolitan areas in the United States, an average of 9 pounds/year per person of yellow grease (waste cooking oil) and 13 pounds/year per person of trap grease were produced in 1998. According to this paper, the studied metropolitan areas had

an average of 1.4 restaurants per 1000 people which shows an enormous potential reservoir of alternative feedstock that is waiting to be tapped for biodiesel production.

In the next section, we investigate alternative feedstocks available in Singapore which can be converted to biodiesel. The required feedstock can be obtained from two main resources: grease interceptors and households. In the following, we examine these two resources in more details.

2.3 Feedstocks Available in Singapore

2.3.1 Waste Grease from Grease Interceptors

Currently restaurants and other food establishments are required to have devices known as grease traps. These grease traps can help to prevent the expulsion of waste vegetable oil and grease into the sewer system. Waste grease from grease interceptors is collected by contractors and sent to water reclamation plants for disposal. The products of the current disposal process of waste grease are sludge and biogas (methane). The biogas produced during the anaerobic digestion process is used for heating in plant power generation by the dual fuel engines and the sludge after anaerobic digestion is for disposal. To obtain more details about the process involved (i.e. frequency of collection, cost of service, eventual destination of extracted grease, etc.) in emptying the grease interceptors an interview was carried out with the senior manager of the water reclamation network department, public utilities board (PUB).

According to the interview, there are approximately 6,300 grease interceptors in Singapore. The size of grease interceptor varies from 1 cubic meter to 1.5 cubic meters. Currently 21 contractors are involved in extraction of greasy wastes from the grease interceptors and all are delivering to PUB. The cost of service is a commercial arrangement between the contractor and its clients.

The extracted greasy wastes are sent to PUB's water reclamation plant for disposal and PUB charges the contractors disposal fee of $7/m^3.

The maintenance frequency varies with the intensity of usage. It is the responsibility of the premises owner to determine the optimal maintenance period. However, the maintenance interval could vary from once a week to once every 2 months. Assuming 6,300 grease interceptors with size of 1.25 m^3, with a removal once per month then this approximately equals to 7.8 million liters of feedstock per month. At 90% yield approximately 7 million liters of biodiesel can be produced per month from the waste grease collected by PUB.

We also collected some sample of the waste grease reached to PUB. According to the preliminary laboratory analysis this greasy waste has the necessary properties to be converted to biodiesel in a two-step catalyzed biodiesel reactor. However, there may be a need to retrofit a pre-treatment step into the external biodiesel producer's system to handle the high free fatty acids (FFA) content of the waste grease.

Depart from the waste grease which is sold to PUB for disposal, there are huge amount of waste cooking oil that are collected by several companies in Singapore. This waste cooking oil which can also be a great potential for producing biodiesel is currently sold to overseas facilities for processing into animal feed, soap and wax.

2.3.2 Waste Grease from Households

In order to determine the estimated volume and quality of waste grease generated by households, questionnaire surveys and informal interviews were conducted. The survey questionnaires (see Appendix A) were distributed to 20 students of National University of Singapore who were

randomly selected. They were asked to collect the waste cooking oil generated by their family for one month and record the following information in a sheet:

- Approximate volume of WCO generated by the households;
- The type and brand of the oil which they usually use;
- The number of times the oil is re-used.

The questionnaire survey was designed to answer the following questions:

- What is the quality of the used cooking oil upon recovery after it is recycled several times for cooking?
- What is the current practice in the disposal of used cooking oil at the household level?
- How much cooking oil is consumed per average household in Singapore?
- How much potential WCO can be recovered based on household perception and experience?
- How willing are the residents of Singapore to participate in this initiative?

A short background of the study was given at the start of the survey to acquaint the respondents with the study. Based on the results of the survey and the WCO samples, the waste grease collected by students has the required quality in order to be converted to biodiesel. Furthermore, the estimated waste cooking oil generated by each family member is around 200 ml per month. Results also show that about 70% of the respondents are willing to continue the collection of their waste oil if the government starts a comprehensive project on WCO collection. According to these results waste cooking oil from household provides a good potential as biodiesel feedstock in Singapore.

In summary, the future of biodiesel production from waste in Singapore appears promising due to numerous benefits beyond simply the financial returns. Energy independence, greenhouse gas mitigation, and waste reduction are among the benefits. Several other issues, such as unstable fossil fuel prices, advancement in gasification and gas turbine technology, and speedy market development of bio-based co-products (pulp wood or chemicals), could also provide a healthy market for bio-energy in the future. Potential future carbon policies that reduce greenhouse gas emissions will also make biomass feedstock more competitive with fossil fuels. And biomass energy can become a viable alternative in the Singapore energy future. The largest market for biodiesel probably will be as a fuel additive. Biodiesel may also be marketed for applications in which reducing emissions of particulates and unburned hydrocarbons are paramount, such as school and transit buses. Because additives that improve diesel fuel properties can sell for a price above that of the diesel fuel, the cost disadvantage for biodiesel would not be as great in the additive market.

Chapter 3: Producer's Revenue Sharing Contract

3.1 Introduction

Empirical studies show that many supply chain integration and collaboration efforts are challenged with issues over channel power imbalance and control rather than mutual, win-win intentions [1]. Differences in power between supply chain agents can have significant effects on operational decisions and overall supply chain efficiency. To capture the effect of imbalance in power between the two producers, in this chapter we consider different possible channel configurations in a two-supplier-single-retailer supply chain. Two possible relative power configurations are constructed, where S_1 and S_2 denote the supplier/producer 1 and 2, respectively, and R denotes the retailer (Figure 3.1). If S_1 holds more (bargaining) power than S_2 in the supply chain, it is represented by $S_1 \rightarrow S_2$, and $S_1 \leftrightarrow S_2$ indicates that S_1 and S_2 both have equal decision-making power. As shown in Figure 3.1, in the first structure, both suppliers have equal decision-making power over the retailer; and the second case captures the situation when S_1 is dominant in the market, holding more power than S_2.

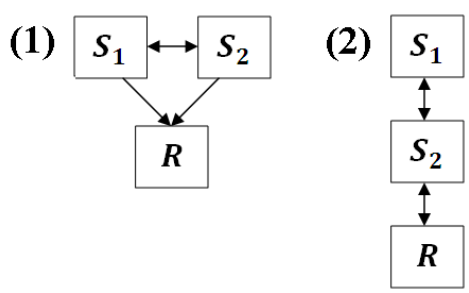

Figure 3.1 Supply chain power structures

In the following we analyze pricing games between the agents based on these two structures and we obtain the optimal strategies of each player. We continue our analysis by investigating the impact of adopting revenue sharing contract by suppliers on the supply chain members' profits and channel performance.

3.2 Literature Review

In this section we review some of the references related to our work. We highlight those that explore the effect of supply chain power through game theoretic formulations and focus on how different supply chain structures and decision hierarchy affect the choice of contracts in coordination. We also study models that analyze the (R, T) policy which is applied in our supply chain formulation.

There are several works related to supply chain power. Choi [32] examines how channel profits for two manufacturers and one retailer vary under different divisions of channel power by using different game-theoretic models to represent different divisions of channel power. Kadiyali et al. [33] extend the vertical Nash and Stackelberg leader-follower interactions between two manufacturers and a retailer studied by Choi to a continuum of possible channel interactions. Trivedi [34] also follows Choi's work by modeling a channel structure in which there are duopoly manufacturers and duopoly common retailers. Lee and Staelin [35] examine the impact of channel price leadership in a supply chain. Liu et al. [36,37] model a scenario where power refers to the ability of an agent to determine an ex-ante value for retail price markup. Etgar [38] and Stern and Reve [39] analyze the impact of power on performance; and Brown et al. [40] examine the impact of channel power on inter-firm relationships.

Granot and Yin [41] study system performance and supplier coalition under the assumption of suppliers having equal power for two cases: first, suppliers move to set wholesale prices and the retailer follows by setting the stock size; second, the retailer moves first in setting wholesale prices and suppliers follow with stocking decisions who also retain the overstock risk. Wang [42] also studies system performance, but assumes the retailer serve as the Stackelberg leader over the suppliers, and suppliers can move either simultaneously or sequentially in pricing and production decisions; also see Jiang and Wang [43]. Bernstein and DeCroix [44] investigate multi-tier assembly systems in which the downstream firm(s) holds higher decision-making power over the upstream agents, and all firms at the same tier move simultaneously. Carr and Karmarkar [45] and Corbett and Karmarkar [46] study competition within a multi-echelon assembly supply chain with a deterministic demand assumption. Most of the previous supply chain interaction models are typically either two-stage Stackelberg games or one-stage non-cooperative games with all suppliers sharing an equal or balanced power. Shi [47] in his study examines situations when suppliers have an unequal decision making power over each other so that one or more suppliers can exercise Stackelberg leadership over the other suppliers and explores the influence of each agent's decision making power on the strategic interactions and performance within a multi-supplier-one-retailer supply chain.

Previous studies show different power structures lead to different channel performance. Generally a centralized system, where a single decision maker has the ability to make all decisions regarding inventory allocation, manufacturing policies, shipping frequency, etc. provides a first-best solution for overall supply chain profit (see [48,49]). However, a decentralized supply chain, in which each agent seeks to optimize his own expected profit, leads to sub-optimal solution [50]. That is, the profit of a decentralized supply chain is less than that of

an integrated supply chain due to a lower stock quantity or a higher retail price. Due to this effect, it is desirable to design proper contract forms to improve the overall efficiency. Supply chain coordination models aim to identify agreements that increase the overall performance and, if possible, induce the channel to achieve the same profit (or cost) as in the centralized scenario. A well designed contract can lead to an agent's individual decision being even optimal as a whole for the supply chain. In this case, there will be no double marginalization, that is, the supply chain is coordinated. Contracts that provide coordination have been vastly studied in the literature. For instance, see return policies [51-53], revenue sharing [54], quantity discount [55,56], quantity flexibility [57], sales rebate [58], options contract [59], price discount or "bill back" contracts [60]. Also see Tayur et. al [61], Cachon [62], Lariviere [63], and Sahin and Robinson [64] for excellent reviews.

We conclude our review with a discussion of those centralized and decentralized models that analyze the (R, T) policies. In a (R, T) policy, the inventory position is reviewed every T periods and an order is placed, if necessary, to raise the inventory position back to R. The majority of the papers that analyze (R, T) systems assume customer demand is deterministic [65,66]. The authors develop heuristics for fixed interval ordering policies (e.g. power-oftwo) that are very effective in most settings. Analysis of (R, T) policies when demand is stochastic has received much less interest. Promising results have been achieved through the use of heuristics, e.g. Naddor [67,68], who analyzes so-called tZ policies, which are identical to (R, T) policies, in both deterministic and stochastic environments. The author proposes heuristic solutions for cases when the distribution of demand is known. Atkins and Iyogun [69] propose a heuristic that finds a lower bound on the cost of the optimal (R, T) policy. Eynan and Kropp [70] propose a simplified (approximate) cost function to study the single product, periodic review problem.

They propose simple heuristics to address the joint replenishment problem for multiple items. Rao [71] finds the optimal single-item (R, T) policy for a compound Poisson and a Brownian motion demand processes. The author also studies how the deterministic (R, T) policy and the (Q, r) optimal policy compare to the optimal (R, T) policy and proposes a power-of-two (R, T)-based heuristic to analyze the multiproduct joint replenishment problem. Another related reference to the (R, T) model is Cachon [72], who analyzes the influence of order size and delivery frequency on supply chain demand variability.

Applying periodic inventory review policy (R, T), we extend previous studies by proposing a model for analyzing the effect of asymmetric power within the supplier group where suppliers could choose to offer revenue sharing or conventional wholesale price contracts. Reviewing different channel coordination contracts, it is clear that the outcomes and structure of these contracts highly depend on the agents' relative channel power, which may be a function of the agents' relative size, market presence, etc. However, the effect of channel power on model performance in presence of contracts has not been extensively studied. An important contribution of our study is that it explores the impact of applying revenue sharing contract on the supply chain performance where two competing suppliers are imbalanced in power.

In the following, by utilizing a generic model of the two-supplier-single-retailer supply chain, we extend the analysis of channel power to include the situation that suppliers can adopt revenue sharing contract. We study and derive the unique Nash equilibrium solutions for two non-cooperative games with random price dependent demand in which suppliers offer substitutable products to a common retailer under periodic inventory review policy ((R, T) policy). Stochastic price sensitive demand functions are built for two substitutable products, and given these demand

functions, optimal pricing rules for the producers and the retailer are obtained. Since the pricing strategy of one firm affects the demand streams of other firms, there exists a strategic interaction among the agents' decisions; therefore game theory is applied to analyze this problem.

3.3 Modeling Framework

Consider a supply chain consisting of three risk neutral firms, two producers/suppliers and one retailer where all players possess full information. The products are shipped from the suppliers to the retailer at a wholesale price and then the retailer sells substitutable products of both producers to a price-sensitive market. The producers could apply revenue sharing or conventional wholesale price contract. Under the revenue sharing contract, the supplier is paid a wholesale unit price, plus an agreed percentage from the profit the retailer generates.

At the beginning of the time horizon, the supplier i and the retailer agree to a contract with one parameter φ_i, which is the retailer's share of revenue from each unit sold. Based on this formulation, a conventional wholesale price contract is a special case of revenue sharing with $\varphi_i = 1$. Given the share of the revenue, the producer i chooses his wholesale price w_i and the retailer determines the retail price r_i. All decisions are made once at the beginning of the time horizon and they remain unchanged throughout its duration.

The product i is produced at a unit cost of c_i, and incurs a holding cost of $h_i^S(h_i^R)$ per unit per period at the producer i (retailer). The producer i utilizes outsourcing at a cost of t per unit, if a retailer order cannot be satisfied. A lost sale penalty of p incurs at the retailer for each lost demand. To avoid the trivial case when it is optimal for the retailer to buy nothing, we enforce the constraint $r_i > w_i$ and to avoid unrealistic outsourcing costs we require $r_i + p \geq t$.

Figure 3.2 shows the sequence of events over the time horizon in a periodic review policy. The sequence is initiated with a production run at the supplier, which will be used to replenish the retail inventory at the beginning of the next cycle. At the beginning of each replenishment cycle, the retailer has x_i^R units of inventory on-hand and places an order with the supplier that replenishes the retailer's inventory to the base-stock level, Q_i^R.

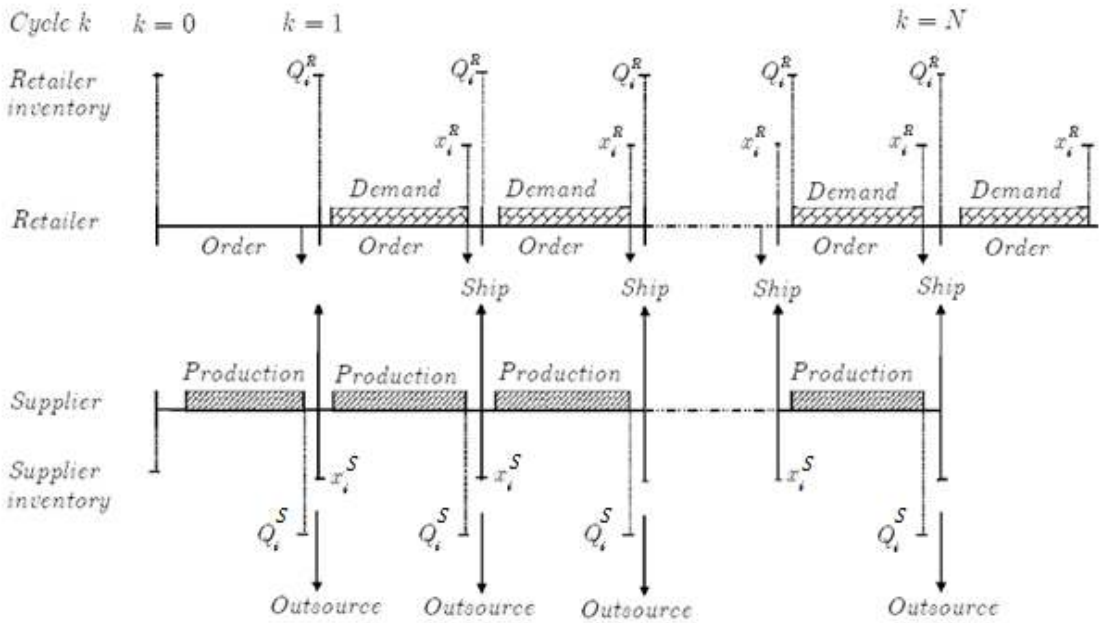

Figure 3.2 Sequence of events

The producer i begins cycle k with x_i^S units in inventory (immediately after shipping to the retailer) and produces up to Q_i^S. The inventory level of product i for the producers and the retailer are defined as $Q_i^S = X_i + q_i^S$ and $Q_i^R = X_i + q_i^R$ respectively. Because the lost sales penalty cost is high, both producers seek to avoid it when possible by setting $q_i^S = \mu + z_i\sigma$ where z_i characterizes the on-hand service level and is determined by producers considering their penalty costs in order to best responding to the uncertainty in demand. Furthermore, the

length of time between successive shipments (replenishment cycle), is considered unit and lead time between the supplier and the retailer is negligible. The retailer faces a random price dependent demand function D_i for the product i: $D_i = X_i + \varepsilon$ where

$$X_i = \alpha_i - \beta_i r_i + \gamma\left(r_j - r_i\right) \;\; for \;\; i, j = 1,2 \quad (i \neq j) \tag{3.1}$$

is a decreasing function that captures product substitution and the price dependency of the products, and ε is a random variable assumed to follow the normal distribution; while $F(.)$ represents the normal cumulative distribution function of ε, $f(.)$ the normal probability density function and μ and σ are the mean and standard deviation of ε, respectively.

The coefficient α_i represents the customer brand loyalty that is price independent, β_i represents product i's demand sensitivity on its own retail price, and γ denotes the degree of product substitution, which accounts for the effect of retail price differences of the two substitutable products $(\alpha_i, \beta_i, \gamma \geq 0)$ [73]. Thus $\gamma = 0$ represents the case when the two products are completely independent, and as γ increases, the degree of product substitution and consequently the competition between the two products, increases.

3.4 Benchmark System

In this section, we formulate the problem of the centralized scenario as our benchmark where a single decision maker chooses the retail prices of both products that maximize the expected supply chain profit. The base model used in this essay, is similar to as in [74] however we extended their model by considering the application of revenue sharing contracts and examined a

more general case in which there are two competing suppliers offering substitutable products to a common retailer.

Let Π_i^C denote the expected centralized channel profit from product i in cycle k, and $\Pi^C = \sum_{i=1}^{2} \Pi_i^C$ the total expected centralized channel profit from both products.

$$\Pi_i^C = Revenue - Retailer's\ holding\ cost - Retailer's\ penalty\ cost$$
$$- Supplier\ i's\ holding\ cost - Outsourcing\ cost - Production\ cost$$

$$\begin{aligned}\Pi_i^C &= r_i \min\left\{Q_i^R, D_i\right\} - h_i^R\left(Q_i^R - D_i\right)^+ - p\left(D_i - Q_i^R\right)^+ - {h_i^S}/{2}\left(Q_i^S + x_i^S\right) \\ &- t\left(Q_i^R - x_i^R - Q_i^S\right)^+ - c_i\left(Q_i^S - x_i^S\right)\end{aligned} \tag{3.2}$$

Where $x_i^R = (Q_i^R - D_i)^+$ and $x_i^S = (Q_i^S - Q_i^R + x_i^R)^+$ denote the retailer's and the supplier i's on-hand inventory of the product i respectively in cycle k. Then we have:

$$\begin{aligned}\Pi_i^C &= Q_i^R\left(r_i - t\right) - \left(r_i - t + h_i^R\right)E\left[\left(Q_i^R - D_i\right)^+\right] - pE\left[\left(D_i - Q_i^R\right)^+\right] - h_i^S Q_i^S \\ &+ \left(t - c_i + {h_i^S}/{2}\right)\min\left\{Q_i^S, Q_i^R - E\left[\left(Q_i^R - D_i\right)^+\right]\right\}\end{aligned} \tag{3.3}$$

In order to meet the retailer's demand and to avoid outsourcing costs, the supplier i chooses his inventory level (Q_i^S) to be greater than $Q_i^R - E[(Q_i^R - D)^+]$, therefore $min\{Q_i^S, Q_i^R - E[(Q_i^R - D_i)^+]\} = Q_i^R - E[(Q_i^R - D)^+]$. And (3.3) can be simplified as:

$$\begin{aligned}\Pi_i^C &= Q_i^R\left(r_i - t + {h_i^S}/{2}\right) - \left(r_i + h_i^R + {h_i^S}/{2} - c_i\right)E\left[\left(Q_i^R - D_i\right)^+\right] \\ &- pE\left[\left(D_i - Q_i^R\right)^+\right] - h_i^S Q_i^S\end{aligned} \tag{3.4}$$

Proposition 3.1: In the centralized system, the total supply chain profit function is jointly concave in r_1 and r_2 and the optimal product i's retail price is uniquely determined by

$$r_i^* = \frac{\left\{\begin{array}{l}(\beta_j+\gamma)\left(\alpha_i+q_i^R-E\left[\left(Q_i^R-D_i\right)^+\right]+\beta_i\left(c_i+\frac{h_i^S}{2}\right)\right)\\ +\gamma\left(\alpha_j+q_j^R-E\left[\left(Q_j^R-D_j\right)^+\right]+\beta_j\left(c_i+\frac{h_i^S}{2}\right)\right)\end{array}\right\}}{2\left(\beta_i\beta_j+\gamma\left(\beta_i+\beta_j\right)\right)} \tag{3.5}$$

Proof: Two decisions are made simultaneously. The Hessian matrix of the centralized profit function is negative-definite and the determinant is given by:

$$\begin{vmatrix}\frac{\partial^2\Pi^C}{\partial r_1^2} & \frac{\partial^2\Pi^C}{\partial r_1 r_2}\\ \frac{\partial^2\Pi^C}{\partial r_2 r_1} & \frac{\partial^2\Pi^C}{\partial r_2^2}\end{vmatrix} = \begin{vmatrix}-2\left(\beta_i+\gamma\right) & 2\gamma\\ 2\gamma & -2\left(\beta_j+\gamma\right)\end{vmatrix} \tag{3.6}$$

and there exists a unique Nash equilibrium. The optimal retail prices can be obtained by solving first order condition of Π^C for $i, j = 1,2$ simultanously:

$$\frac{\partial\Pi^C}{\partial r_i} = \left(\beta_i+\gamma\right)\left(-2r_i+c_i+\frac{h_i^S}{2}\right)+\alpha_i+q_i^R-E\left[\left(Q_i^R-D_i\right)^+\right]-\gamma\left(-2r_j+c_j+\frac{h_j^S}{2}\right)=0 \tag{3.7}$$

3.5 Decentralized System

In the decentralized supply chain the supplier i is paid a wholesale unit price w_i by the retailer who in turn charges a retail price r_i from the end customers where $r_i = w_i + m_i$ and m_i is the retail margin. The retailer also shares a portion of the revenue to the producer in return for a

lower wholesale price, where φ_i represents the portion of the revenue from product i to be kept by the retailer ($0 < \varphi_i \leq 1$).

The expected profit functions of channel members are given by:

$$\Pi_i^R = Q_i^R(\varphi_i r_i - w_i) - (\varphi_i r_i + h_i^R - w_i)E\left[\left(Q_i^R - D_i\right)^+\right] - pE\left[\left(D_i - Q_i^R\right)^+\right] \tag{3.8}$$

$$\begin{aligned}\Pi_i^S = {} & (w_i - t + (1-\varphi_i)r_i)\left\{Q_i^R - E\left[\left(Q_i^R - D_i\right)^+\right]\right\} - h_i^S Q_i^S \\ & + \left(t - c_i + {h_i^S}/{2}\right) \min\left\{Q_i^S, Q_i^R - E\left[\left(Q_i^R - D_i\right)^+\right]\right\}\end{aligned} \tag{3.9}$$

Similar to the centralized scenario, considering $min\{Q_i^S, Q_i^R - E[(Q_i^R - D_i)^+]\} = Q_i^R - E[(Q_i^R - D)^+]$ the suppliers profit can be simplified as:

$$\Pi_i^S = (w_i - c_i + (1-\varphi_i)r_i + {h_i^S}/{2})\left\{Q_i^R - E\left[\left(Q_i^R - D_i\right)^+\right]\right\} - h_i^S Q_i^S \tag{3.10}$$

We apply our model for the two power structures shown in Figure 3.1 for the scenario that $\varphi_i = 1$, i.e., conventional wholesale price contract, and obtain the optimal decisions.

3.5.1 Balanced Power Structure

In balanced power structure, both suppliers are assumed to have equal power over the retailer. The suppliers declare their decisions first and then the retailer follows with responding by respective retail prices. Under this Stackelberg formulation where the suppliers hold greater channel power, each supplier chooses his wholesale price using the response function of the retailer, given the wholesale price of the competitor's product. Because we assume that all

players possess full information, thus the supplier i can deduce the retailer's optimal response and plan accordingly.

Proposition 3.2: In balanced power structure, the retailer's reaction function given wholesale prices is jointly concave in m_1 and m_2 and the optimal policy for the retailer is:

$$m_i^* = \frac{\left(\beta_j + \gamma\right)\left(\alpha_i + q_i^R - E\left[\left(Q_i^R - D_i\right)^+\right] - \beta_i w_i\right) + \gamma\left(\alpha_j + q_j^R - E\left[\left(Q_j^R - D_j\right)^+\right] - \beta_j w_j\right)}{2\left(\beta_i\beta_j + \gamma\left(\beta_i + \beta_j\right)\right)} \tag{3.11}$$

Proof: The Hessian matrix is the same as in the centralized scenario and the condition for maximization is satisfied.

Proposition 3.3: Taking the retailer's reaction function into consideration the supplier i' respective profit function is concave in w_i and the Nash equilibrium wholesale price for product i is:

$$w_i = \frac{\left\{\begin{array}{l}\left(\beta_j\gamma + \gamma^2\right)\left(c_j + \frac{h_j^S}{2} + h_i^S + 2c_i\right) + \gamma\left(\alpha_j + q_j^R - E\left[\left(Q_j^R - D_j\right)^+\right]\right) \\ + \left(\beta_j + \gamma\right)\left(2\alpha_i + \beta_i\left(h_i^S + 2c_i\right) + 2q_i^R - 2E\left[\left(Q_i^R - D_i\right)^+\right]\right)\end{array}\right\}}{3\gamma^2 + 4\left(\beta_i\beta_j + \gamma\left(\beta_i + \beta_j\right)\right)} \tag{3.12}$$

Proof: The second derivative of Π_i^S with respect to w_i is negative $d^2\Pi_i^S / dw_i^2 = -b - \gamma < 0$ and the optimal policy for producers are derived from the first-order conditions of respective profit maximization problem by solving (3.13) for $i = 1,2$ simultaneously. Substituting the reaction function (3.12) in (3.11), the corresponding retail margin can be obtained.

$$\frac{d\Pi_i^S}{dw_i} = \frac{1}{2}\left[\left(\beta_i + \gamma\right)\left(-2w_i + c_i + \frac{h_i^S}{2}\right) + \alpha_i + q_i^R - E\left[\left(Q_i^R - D_i\right)^+\right] - \gamma w_j\right] = 0 \tag{3.13}$$

3.5.2 Imbalanced Power Structure

In this structure, the leader supplier takes the retailer's and the follower supplier's reaction functions into account for his own wholesale price decisions, while the follower supplier determines his wholesale price taking into account the retailer's reaction function, given the leader producer's decisions. The retailer's optimal policy is the same as (3.11).

Proposition 3.4: In the imbalanced supply chain model, the leader and the follower supplier's profit functions are concave in w_i and the optimal wholesale prices are shown in (3.14) and (3.15).

$$w_2^* = \frac{\left(\beta_2 + \gamma\right)\left(c_2 + \frac{h_2^S}{2}\right) + \alpha_2 + q_2^R - E\left[\left(Q_2^R - D_2\right)^+\right] + \gamma w_1}{2\left(\beta_2 + \gamma\right)} \tag{3.14}$$

$$w_1^* = \frac{\left\{\begin{array}{l}\left(\beta_2 + \gamma\right)\left[\gamma\left(c_2 + \frac{h_2^S}{2}\right) + 2\alpha_1 + \beta_1\left(h_1^S + 2c_1\right) + 2q_1^R - 2E\left[\left(Q_1^R - D_1\right)^+\right]\right] \\ +\gamma\left(\alpha_2 + q_2^R - E\left[\left(Q_2^R - D_2\right)^+\right]\right) + \gamma\left(2\beta_2 + \gamma\right)\left(c_1 + \frac{h_1^S}{2}\right)\end{array}\right\}}{2\left(2\gamma\left(\beta_1 + \beta_2\right) + 2\left(\beta_1\beta_2\right) + \gamma^2\right)} \tag{3.15}$$

Proof: The second derivative of Π_2^S with respect to w_2 given w_1 and considering retailer's optimal policy, is negative ($d^2\Pi_2^S / dw_2^2 = -\left(\gamma + b\right) < 0$). Again by taking both retailer's and producer 2's reaction function into consideration, the second derivative of Π_1^S with respect to w_1

is negative (3.16) thus the maximization conditions are satisfied and therefore there exists a unique Nash equilibrium.

$$d^2\Pi_1^S / dw_1^2 = -\frac{2b^2 + \gamma^2 + 4b\gamma}{2(\gamma + b)} < 0 \tag{3.16}$$

Now we are interested to analyze the optimal decisions obtained in this section in order to understand the effect of products substitution degree on retail and wholesale prices. Note that to ensure positive retail margins, it is necessary to assume $\alpha_i + q_i^R - E\left[\left(Q_i^R - D_i\right)^+\right] \geq 0$. For $i = 1,2$ we have $\frac{dr_i^*}{d\gamma} < 0$ which shows that r_i^* monotonically decreases in γ and it reaches the integrated system's retail price as $\gamma \to \infty$. It follows that for $0 \leq \gamma < \infty$, both product's retail prices are higher compared to those of an integrated channel. In the same way, both wholesale prices monotonically decrease in γ and they reach the respective unit cost at the producer level as $\gamma \to \infty$. Furthermore, we examine the firms' optimal profit functions and the whole supply chain performance. It can be shown that $\frac{d\Pi^{SC}}{d\gamma} > 0$, $\frac{d\Pi_i^S}{d\gamma} < 0$, $\frac{d\Pi_i^R}{d\gamma} > 0$ which imply that the total supply chain profit improves with increase in competition among the suppliers and when the substitution degree is sufficiently high, the whole supply chain performs as an integrated system. Specifically, the retailer's profit monotonically increases and gains the total supply chain profit when two products are completely substitutable, while the supplier i's profits consistently decreases in γ and it vanishes as $\gamma \to \infty$.

Similar to wholesale price scenario, optimal decisions for revenue sharing contract can be obtained. However, the solutions are more complicated and cannot be analyzed in a

straightforward manner. Therefore, in the next chapter, numerical examples are conducted and the channel members' profits and performances are compared under different scenarios.

Chapter 4: Projected Costs and Numerical Examples

In this chapter we first review the projected prices of two popular biodiesel feedstocks: soybean oil and waste grease (yellow grease) and compare the production cost of biodiesel fuels by these two feedstocks based on the energy information administration's (EIA) data. Then a more detailed analysis of biodiesel production processes and costs is provided and numerical examples are conducted by applying the proposed model described in chapter 3, while assuming that there are a current diesel producer and a new biodiesel producer.

4.1 Biodiesel Production Costs

The feedstock cost of the oil or grease is the largest single component of biodiesel production costs. The energy information administration uses a process-costing approach to model the impacts of net feedstock production costs plus capital and operating costs. Soybean oil and yellow grease price projections are depicted in Tables 4.1 and 4.2 (Source: EIA).

Table 4.1 Projected prices for soybean oil (2002 Dollars per gallon)

Marketing Year	50 Million Gallons of Soybean Oil Used for Biodiesel Production	200 Million Gallons of Soybean Oil Used for Biodiesel Production
2004/05	1.95	2.22
2005/06	1.91	2.17
2006/07	1.87	2.15
2007/08	1.84	2.12
2008/09	1.86	2.20
2009/10	1.89	2.25
2010/11	1.94	2.35
2011/12	1.99	2.41
2012/13	2.06	2.47

Table 4.2 Projected prices for yellow grease (2002 Dollars per gallon)

Marketing Year	Price
2004/05	1.09
2005/06	1.07
2006/07	1.05
2007/08	1.04
2008/09	1.08
2009/10	1.10
2010/11	1.15
2011/12	1.18
2012/13	1.21

The comparison of projected production costs for diesel fuels (Table 4.3) shows that biodiesel from yellow grease is closer to being cost-competitive with petroleum diesel than is biodiesel from soybean oil, but the available supply of yellow grease will probably limit its use for biodiesel production.

Table 4.3 Projected production costs for diesel fuels by feedstock (2002 Dollars per gallon)

Marketing Year	Soybean Oil	Yellow Grease	Petroleum
2004/05	2.54	1.41	0.67
2005/06	2.49	1.39	0.78
2006/07	2.47	1.38	0.77
2007/08	2.44	1.37	0.78
2008/09	2.52	1.40	0.78
2009/10	2.57	1.42	0.75
2010/11	2.67	1.47	0.76
2011/12	2.73	1.51	0.76
2012/13	2.80	1.55	0.75

In Singapore, the waste grease can be bought from the waste collectors that currently dispose it to the Public Utilities Board (PUB). This waste collection infrastructure is also established in many other developed countries, and a new biodiesel producer could take advantage of this to lower grease collection and biodiesel production costs.

From the collected waste grease, high-grade biodiesel is produced via an advanced conversion processes that takes approximately 24 hours to complete. Production of biodiesel involves a two-step conversion process that has already been optimized and developed by engineers at NUS. The production process involves: separation of water and contaminants; acid pre-treatment to lower free fatty acids; chemical transesterification to biodiesel; and washing and dewatering of the biodiesel product. Conversion yield from waste grease to biodiesel is over 90% efficient. With the proposed process, high grade biodiesel is produced from low-grade waste oil as a cheaper and more environmental friendly alternative. The high margin of profit relative to other biodiesel producers who use conventional feedstocks, allows for the rapid development and expansion of waste to energy practices into local, regional and global markets.

4.2 Numerical Examples

This section focuses on analyzing the interactions between a new biodiesel producer and an existing diesel producer. It is assumed that the diesel producer is dominant in the market, holding more power than the new producer. This power structure is modeled as a three stage Stackelberg game where the leader producer (S_1) and the follower (S_2) represent diesel and biodiesel producers respectively. Based on the generic model constructed in chapter 3 we would like to examine if the less powerful producer (S_2) could increase his profits by adopting revenue sharing contract.

Four different scenarios are considered ($n = 1 - 4$): the first scenario investigates the case that both producers offer the wholesale price contract to the common retailer, the cases that either producer one or two offers revenue sharing are modeled in scenarios two and three respectively, and the forth scenario studies the situation that revenue sharing is offered for both products. So optimal retail price $\mathrm{r}_{\mathrm{ni}}^{*}$ and wholesale price $\mathrm{w}_{\mathrm{ni}}^{*}$ refer to supplier i's ($\mathrm{i} = 1,2$) products under scenario n, and similarly for $\Pi_{ni}^{S}, \Pi_{ni}^{R}$ and X_{ni}. Following Lariviere and Porteus [75], the efficiency of the decentralized system in scenario n, is represented by $E_n = \Pi_n^{SC}/\Pi^{C}$ where $\Pi_n^{SC} = \sum_{i=1}^{2}\left(\Pi_{ni}^{S} + \Pi_{ni}^{R}\right)$ and Π^{C} represent supply chain profit in scenario n and the centralized system profit respectively.

The problem parameters are as following: for $i = 1,2$ and under the linear and additive model, the random variable ε is assumed to follow the normal distribution with mean $\mu_i = 0$ and standard deviation $\sigma_i = 5$. The total supply chain cost is $c_1 = 4$ and $c_2 = 7$ and $q_i^R = 3$. The product market base and demand sensitivity are considered $\alpha_i = 10^3$ and $\beta_i = 15$ respectively. The on-hand service level is $z_i = 0.9$. The inventory costs of the firms are $h_i^S = h_i^R = 0.001$ and the penalty costs are assumed to be zero. Whenever wholesale price contract, or revenue sharing is offered by producer i, the retailer's share of profit is assumed $\varphi_i = 1$ or $\varphi_i = 0.5$ respectively. With reference to Bichescu [74] for calculating the optimal decisions we use:

$$E\left[\left(Q_i^R - D_i\right)^+\right] = \int_{-\infty}^{q_i^R}\left(q_i^R - \lambda\right)dF(\lambda) = q_i^R F\left(q_i^R\right) - \int_{-\infty}^{q_i^R}\lambda dF(\lambda) = \left(q_i^R - \mu_i\right)\Phi\left(\frac{q_i^R - \mu_i}{\sigma_i}\right) + \sigma_i\phi\left(\frac{q_i^R - \mu_i}{\sigma_i}\right) \tag{4.1}$$

$$E\left[\left(D_i - Q_i^R\right)^+\right] = \left(\mu_i - q_i^R\right)\left[1 - \Phi\left(\frac{q_i^R - \mu_i}{\sigma_i}\right)\right] + \sigma_i\phi\left(\frac{q_i^R - \mu_i}{\sigma_i}\right) \tag{4.2}$$

where $\Phi(.)$ and $\phi(.)$ represent the standard normal *cdf* and *pdf*, respectively. We analyze and compare the supply chain performance under two different competition levels ($\gamma = 0$ *and* $\gamma = 100$) assuming each producer has two strategies, offering revenue sharing contract or wholesale price contract. The optimal decisions and the agents' profit percentages are calculated in four scenarios and summarized in Table 4.4 (when the products are non-substitutable ($\gamma = 0$)) and Table 4.5 (when $\gamma = 100$). Note that the centralized system profit is Π^C =28,025.

Table 4.4: Optimal decisions of channel members ($\gamma = 0$)

n	**1**	2	3	4
$\mathbf{w_{n1}}$	35.3	12.4	35.3	12.4
$\mathbf{w_{n2}}$	36.8	36.8	13.4	13.4
$\mathbf{m_{n1}}$	15.7	33.3	15.7	33.3
$\mathbf{m_{n2}}$	14.9	14.9	33.3	33.3
$\mathbf{r_{n1}}$	51.0	45.7	51.0	45.7
$\mathbf{r_{n2}}$	51.7	51.7	46.7	46.7
$\mathbf{\Pi^R_{n1}}$	3,675	3,267	3,675	3,267
$\mathbf{\Pi^R_{n2}}$	3,331	3,331	2,961	2,961
$\mathbf{\Pi^R_{n}}$	7,006	6,598	6,636	6,228
$\mathbf{\Pi^S_{n1}}$	7,350	9,800	7,350	9,800
$\mathbf{\Pi^S_{n2}}$	6,663	6,663	8,883	8,883
$\mathbf{\Pi^{SC}_{n}}$	21,019	23,060	22,869	24,911
$\mathbf{E_n}$	0.75	0.82	0.82	0.89
$\mathbf{X_{n1}}$	238.6	316.9	238.6	316.9
$\mathbf{X_{n2}}$	227.4	227.4	301.9	301.9
$\mathbf{X_n}$	466.0	544.3	540.5	618.8

According to our numerical examples summarized in Tables 4.4 and 4.5, the following properties hold in both cases ($\gamma = 0$ and $\gamma = 100$):

$$w_{21} \leq w_{41} < w_{31} \leq w_{11} \text{ and } w_{32} \leq w_{42} < w_{22} \leq w_{12} \tag{4.3}$$

$$r_{41} \leq r_{21} < r_{31} \leq r_{11} \text{ and } r_{42} \leq r_{32} < r_{22} \leq r_{12} \tag{4.4}$$

$$X_{31} = X_{11} < X_{21} \leq X_{41} \text{ and } X_{12} \leq X_{22} < X_{32} = X_{42} \tag{4.5}$$

$$\Pi^S_{11} = \Pi^S_{31} < \Pi^S_{21} < \Pi^S_{41} \text{ and } \Pi^S_{22} < \Pi^S_{12} < \Pi^S_{32} = \Pi^S_{42} \tag{4.6}$$

Table 4.5: Optimal decisions of channel members ($\gamma = 100$)

n	1	2	3	4
$\mathbf{w_{n1}}$	14.5	-5.0	14.5	-1.5
$\mathbf{w_{n2}}$	14.1	11.9	-3.6	-1.7
$\mathbf{m_{n1}}$	26.1	40.4	21.8	33.3
$\mathbf{m_{n2}}$	26.2	23.7	39.1	33.3
$\mathbf{r_{n1}}$	40.5	35.4	36.3	31.8
$\mathbf{r_{n2}}$	40.4	35.5	35.5	31.6
$\mathbf{\Pi^R_{n1}}$	9,760	10,843	8,173	8,676
$\mathbf{\Pi^R_{n2}}$	10,764	10,787	11,685	9,568
$\mathbf{\Pi^R_{n}}$	20,524	21,630	19,857	18,244
$\mathbf{\Pi^S_{n1}}$	3,919	4,189	3,919	5,226
$\mathbf{\Pi^S_{n2}}$	2,927	2,212	3,903	3,903
$\mathbf{\Pi^{SC}_{n}}$	27,370	28,031	27,679	27,372
$\mathbf{E_n}$	0.97	0.99	0.98	0.97
$\mathbf{X_{n1}}$	378	482	378	503
$\mathbf{X_{n2}}$	414	460	551	551
$\mathbf{X_{n}}$	792	942	929	1054

Comparing four scenarios it can be seen that when a producer offers revenue sharing, he charges lower wholesale price. Also in that case, the retail price is lower compared to the case that wholesale price is applied; which shows offering revenue sharing is in favor of the end customers and leads to higher demand.

It can also be seen that applying revenue sharing is in favor of the producer. Both leader and follower producers can increase their profits by utilizing revenue sharing contract. As discussed in chapter 3, by increasing the competition between the products (higher γ) suppliers' profits decrease. So our numerical example's results show that revenue sharing contract could help both producers gain higher profit share of the whole supply chain even under high product's substitution level.

On the other hand, channel efficiency of the supply chain shows different behavior under different competition levels. When the products are not substitutable ($\gamma = 0$) offerenig revenue sharing by both products leads to the highest efficiency and offering wholesale price by producers results to the least efficiency. However, under higher substitution level, ($\gamma = 100$), the scenario that only producer 1 offers revenue sharing (scenario 2) leads to the highest channel efficiency followed by scenario 3. Scenarios 1 and 4 achieve the same efficiency.

The results show the impacts of substitution degree of products and suggests that adopting revenue sharing can be beneficial at the supply chain level and improves total efficiency since it allows the supplier to share the demand uncertainty risk with his retailer, but additional compensation mechanisms are needed to motivate the retailer to share more of risk in order to reach the higher channel efficiency.

Note that our analysis is limited to study the pricing game under two specific substitution levels with specific demand and cost parameters. However, finding the Nash equilibrium of this game under all different substitution levels is complicated and the solution could differ in different situations. Analyzing other conditions is left for future work.

Chapter 5: Conclusion and Future Work

Contractual arrangements are efficient tools for channel members coordination and improving system-wide efficiency. Analyzing the agents' optimal decisions in a two-supplier-single-retailer supply chain where the suppliers are balanced or imbalanced in power, this dissertation seeks to examine how adopting a revenue sharing contract divides the profits by sharing the risks. Based on the numerical examples, under certain conditions it is possible for the both producer to increase their profits by offering revenue sharing contract. However the results defer under different product substitution levels or demand conditions. The numerical examples explore some special cases while future work could examine other possible market conditions.

The model used in this dissertation has relaxed several assumptions. However, it also has certain limitations. Firstly, the demand function is assumed to be linear which essentially simplifies the closed-form answers. Choi [32] shows that derivation of closed-form results is analytically challenging when nonlinear demand models are used, and the unique Nash equilibrium is no longer guaranteed. Further model generalization to nonlinear demand functions is useful for future research.

Secondly, it is usually assumed that the revenue percentage of the suppliers and retailers is pre-determined prior to the sales period. In the current work, it is assumed that this share of profit has a fixed value. However, another extension of this work could be to identify the optimal profit share between the supplier and the retailer.

Another limitation is the existence of symmetric information. Studies show all relevant information is not publicly available in reality. Therefore, the obtained results based on symmetric information assumption cannot explain the decisions in real market.

In summary this dissertation presents an explicit investigation of channel power in the presence of contract. An important contribution of the study has been an exploration of the impact of offering revenue sharing on the optimal decisions taken under different supply chain structures when the producers are balanced or imbalanced in their respective power. This study serves as a stimulus for further research

Bibliography

[1] Maloni, M., and W. Benton. Power influences in the supply chain. Journal of Business Logistics, 21 (1):49–73, 2000.

[2] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Biodiesel Handling and Use Guidelines", October 2004.

[3] Kadam, K. L.; Forrest, L. H. and Jacobson, W. A. (2000), Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects. Biomass Bioenerg., 18, 369-389.

[4] Mani S, Tabil LG, Sokhansanj S (2004) Grinding performance and physical properties of wheat and barley straws, corn stover and switchgrass. Biomass and Bioenergy, 27: 339–352.

[5] Lewandowski, I., Jonathan, M.O., Scurlock J. & et al. 2003. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. Biomass and Bioenergy 25, 335–361.

[6] Giampietro, M., S. Ulgiati, et al. (1997). "Feasibility of large-scale biofuel production – does an enlargement of scale change the picture?" Bioscience 47(9): 587-600

[7] Brendes, G., C. Azar, et al. (2001) "The feasibility of large-scale lignocellulose-based bioenergy production." Biomass & Bioenergy 20(5): 371-383

[8] Wolf, J., P. S. Bindraban, et al. (2003). "Exploratory study on the land area required for food supply and the potential global production of bioenergy." Agricultural Systems 76(3): 841-861

[9] Hoogwijk, M., A. Faaij, et al. (2005). "Potential of biomass energy out to 2100, for four IPCCSRES land-use scenarios." Biomass & Bioenergy 29(4): 225-257

[10] ORNL (2005). Biomass as Feedstock for a Bioenergy and Bioproducts Industry: Billion Ton Annula Supply. Oak Ridge, TN, Oak Ridge National Lab.

[11] Prokop, T., 2002. Personal Communication, Imperial Western Products, 14970 Chandler St., Coachella, CA 91720.

[12] Lott, M., 2002. Personal Communication, QSS Group Inc., 4500 Forbes Boulevard, Suite 200, Lanham, MD 20706.

[13] Krawczyk, T., 1996. Biodiesel. INFORM 7 (8), 801–822.

[14] Connemann, J., Fischer, J., 1998. Biodiesel in Europe 1998: biodiesel processing technologies. Paper presented at the International Liquid Biofuels Congress, Brazil, 15 pp.

[15] Haas, M. (2005). Improving the economics of biodiesel production through the use of low value lipids as feedstocks: Vegetable oil soapstock. Fuel Processing Technology, 86, 1087-1096.

[16] Mangesh, G., Dalai, K., & Dalai, A. (2006). Waste cooking oil – an economical source for biodiesel: A review. Industrial and Engineering Chemical Research, 45, 2901-2913.

[17] Dorado, M.P., Cruz, F., Palomar, J.M., & Lopez, F.J. (2006). An approach to the economics of two vegetable oil-based biofuels in Spain. Renewable Energy, 31, 1231-1237.

[18] Canakci, M. (2007). The potential of restaurant waste lipids as biodiesel feedstocks. Bioresource Technology, 98, 183-190.

[19] Sroka, E., Wladyslaw Kaminski, Jolanta Bohdziewicz, Biological treatment of meat industry wastewater, Desalination, Volume 162, 10 March 2004, Pages 85-91.

[20] Johns, M. R. (1995). Developments in wastewater treatment in the meat processing industry: a review. Bioresource Technology, 54, 203-216.

[21] Rennio F. de Sena, Andreia Claudino, Karine Moretti, Iris C.P. Bonfanti, Regina F.P.M. Moreira, Humberto J. Jose, Biofuel application of biomass obtained from a meat industry wastewater plant through the flotation process--A case study, Resources, Conservation and Recycling, Volume 52, Issue 3, January 2008, Pages 557-569.

[22] Huang Y, Yan H-X, Zhang Q-Y. Liquid fuel manufactured from waste plastics cracking. Plastics 2002;31(4):36–40 (in Chinese).

[23] Li X-X, Shi Y-F, Yu H-R. Preparation of fuel oil from plastic waste by catalytic cracking. Environ Protect Chem Ind 2002;22(2):90–4 (in Chinese).

[24] Pahl, G. (2005). Biodiesel: Growing a new energy economy. White River Jct., VT: Chelsea Green Publishing Company.

[25] Wu W. H.; Foglia T. A.; Marmer W. N.; Dunn R. O.; Goering C. E.; Briggs T. E. Low-temperature property and engine performance evaluation of ethyl and isopropyl esters of tallow and grease. J. Am. Oil Chem. Soc. 75: 1173–1177; 1998.

[26] Canakci M.; Van Gerpen J. Biodiesel production from oils and fats with high free fatty acids. Trans. ASAE 44: 1429–1436; 2001.

[27] Zhang, Y., Dube, M.A., McLean, D.D., Kates, M., 2003. Biodiesel production from waste cooking oil: 1. Process design and technology assessment. Bioresour. Technol. 89 (1), 1–16.

[28] McDonald's Europe. (2004). Environmental Report 2004.

[29] Jenkins, C., Gemma, M., Melville, C., & Townsend, A.K. (2004). Biodiesel: The clear choice for clean air in Malta. Unpublished manuscript.

[30] Montefrio, M. J. F. (2007). Production and utilization of biodiesel derived from waste cooking oil: a feasibility study of its application in Marikina city, Philippines, M.Sc. National University of Singapore

[31] Wiltsee, G. (1998). Urban waste grease resource assessment (NREL/SR-570-26141). Boulder, CO: National Renewable Energy Laboratory.

[32] Choi, C., Price competition in a channel structure with a common retailer. Marketing Science, 10 (4):271–296, 1991.

[33] Kadiyali, V., P. Chintagunta, and V. Vilcassim. Manufacturer-retailer channel interactions and implications for channel power: an empirical investigation of pricing in a local market. Marketing Science, 19(2):127–148, 2000.

[34] Trivedi, M. 1998. Distribution Channels: An Extension of Exclusive Retailership. Management Science 44(7) 896-909.

[35] Lee, E., and R. Staelin. Vertical strategic interaction: implications for channel pricing strategy. Marketing Science, 16(3):185–207, 1997.

[36] Liu, Y., M. J. Fry, and A. S. Raturi. Two-way price commitment in multi-period models. Working Paper. University of Cincinnati, College of Business, 2005.

[37] Liu, Y., M. J. Fry, and A. S. Raturi. Vertically restrictive pricing in supply chains with price dependent demand. Naval Research Logistics, 53(6):485–501, 2006.

[38] Etgar, M., Channel domination and countervailing power in distributive channels. Journal of Marketing Research, 13(3):254–262, 1976.

[39] Stern, L., and T. Reve. Distribution channels as political economies: A framework for comparative analysis. Journal of Marketing, 44(3):52–64, 1980.

[40] Brown, James R.; Robert F. Lusch and Carolyn Y. Nocholson (1995), "Power and Relationship Commitment: Their Impact on Marketing Channel Member Performance", Journal of Retailing, 7 (4), 363- 92.

[41] Granot, D., S. Yin. 2004. Competition and Cooperation in a Multi-Manufacturer Single-Retailer Supply Chain with Complementary Product. Working paper, University of British Columbia.

[42] Wang, Y. 2005. Joint Pricing-Production Decisions in Supply Chains of Complementary Products with Uncertain Demand. Operations Research, forthcoming.

[43] Jiang, Li., Y. Wang. 2005. Channel Structure and Performance for Complementary Products with Price-Sensitive and Uncertain Demand. Working paper.

[44] Bernstein, F., G. DeCroix. 2004. Decentralized Pricing and Capacity Decisions in a Multitier System with Modular Assembly. Management Science 50(9) 1293-1308.

[45] Carr, S., U. Karmarkar. 2005. Competition in Multiechelon Assembly Supply Chains. Management Science 51(1) 45-59.

[46] Corbett, C., U., Karmarkar. 2001. Competition and Structure in Serial Supply Chains with Deterministic Demand. Management Science 47(7) 966-978.

[47] Shi, X., (2006). Essays on Quantitative Analysis of Supply Chain Structures, Contracts and Coordination. Knoxville, PhD theses, The University of Tennessee, Knoxville.

[48] Clark, C., An informal survey of multi-echelon inventory theory. Naval Research Logistics Quarterly, (19):621–650, 1972.

[49] Federgruen, A., Centralized planning models for multi-echelon inventory systems under uncertainty. In S. C. Graves, A. H. G. Rinnooy Kan, and P. H. Zipkin, editors, Handbooks in Operations 123 Research and Management Science, vol.4 (Logistics of Production and Inventory), pages 133– 173. Elsevier Science Publishing Company B.V, Amsterdam, The Netherlands, 1993.

[50] Spengler, J. 1950. Vertical Integration and Antitrust Policy. Journal of Political Economy 58(4) 347-352.

[51] Pasternack, B. 1985. Optimal Pricing and Return Policies for Perishable Commodities. Marketing Science 4(2)166-176.

[52] Kandel, E. 1996. The Right to Return. Journal of Law and Economics 39(1) 329-356.

[53] Tsay, A. 2001. Managing Retail Channel Overstock: Markdown-Money and Return Policies. Journal of Retailing 77 457-492.

[54] Cachon, G. P., M. A. Lariviere. 2005. Supply Chain Coordination with Revenue-Sharing Contracts: Strengths and Limitations. Management Science 51(1) 30-44.

[55] Jeuland, A. P., S. M. Shugan. 1983. Managing Channel Profits. Marketing Science 2(3) 239-273.

[56] Weng, Z. 1995. Channel Coordination and Quantity Discounts. Management Science 41(9) 1509-1522.

[57] Tsay, A. A., and W. S. Lovejoy. Quantity-flexibility contracts and supply chain performance. Manufacturing and Service Operations Management, 1(2), 1999.

[58] Taylor, T. A., "Supply Chain Coordination under Channel Rebates with Sales Effort Effects"

Management Science, Vol. 48, No. 8 (Aug., 2002), pp. 992-1007

[59] Barnes-Schuster, D., Y. Bassok, R. Anupindi. 2002. Coordination and flexibility in supply contracts with options. Manufacturing Service Oper. Management 4(3) 171- 207.

[60] Bernstein, F., and A. Federgruen, 2005, Decentralized Supply Chains with Competing Retailers under Demand Uncertainty, Management Science, 51(1), 18-29

[61] Tayur, S., R. Ganeshan, and M. Magazine, editors. Quantitative models for supply chain management. Kluwer Academic Press, Boston, 1998.

[62] Cachon, G. P., Supply chain coordination with contracts. In S. Graves and A. de Kok, editors, Handbooks in Operations Research and Management Science, Vol. 11: Supply Chain Management: Design, Coordination and Operation, pages 229–339. Elsevier B.V., Amsterdam, The Netherlands, 2003.

[63] Lariviere , M. 1999. Supply Chain Contracting and Coordination with Stochastic Demand. S. Tayur, M. Magazine, R. Ganeshan, Eds. Quantitative Models of Supply Chain Management, Kluwer Academic Publishers, Boston, MA.

[64] Sahin, F., E.P. Robinson. 2002. Flow Coordination and Information Sharing in Supply Chains: Review, Implications, and Directions for Future Research. Decision Sciences 33(4) 505-536.

[65] Roundy, R., 98%-effective integer ratio lot-sizing for one-warehouse multi-retailer systems. Management Science, (31):1416–1430, 1985.

[66] Maxwell, W. and J. Muckstadt. Establishing consistent and realistic reorder intervals in production distribution systems. Operations Research, 33(6):1316–1341, 1985.

[67] Naddor, E., Inventory Systems. Wiley, New York, 1966.

[68] Naddor, E., Optimal and heuristic decisions in single and multi-item inventory systems. Management Science, 21(11):1234–1249, 1975.

[69] Atkins, D. and P. Iyogun. Periodic versus "can-order" policies for coordinated multi-item inventory systems. Management Science, (34):791–796, 1988.

[70] Eynan, A. and D. Kropp. Periodic review and joint replenishment in stochastic demand environments. IIE Transactions, 30(11):1025–1033, 1998.

[71] Rao, U., Properties of the periodic review (R, T) inventory control policy for stationary, stochastic demand. Manufacturing and Service Operations Management, 5(1):37–53, 2003.

[72] Cachon, G. P., Managing supply chain demand variability with scheduled ordering policies. Management Science, 45(6):843–855, 1999.

[73] Tsay, A., Agrawal N., "Channel Dynamics under Price and Service Competition," Manufacturing & Service Operations Management, 2(4):372-391. 2000

[74] Bichescu, B. C., “Performance Analysis of Decentralized Supply Chains: Considerations of Channel Power and Subcontracting,” PhD thesis, the University of Cincinnati, 2006

[75] Lariviere, M. A., E. L. Porteus, “Selling to the Newsvendor: An Analysis of Price-Only Contracts”, MANUFACTURING & SERVICE OPERATIONS MANAGEMENT, Vol. 3, No. 4, Fall 2001, pp. 293-305

Appendix A: Waste Cooking Oil Sampling Exercise

An overview of the study

This study aims to explore the possibility of producing biodiesel from a low-grade feedstock, such as waste cooking oil (WCO) derived from the household sector. Biodiesel is a clean and cheap fuel and have many benefits to the society and the environment. Thus we are going to study the feasibility of its application in Singapore. For this reason, we need to gather the following information for our study:

- Approximate volume of WCO generated by the households;
- The type and brand of the oil which they usually use; and
- The number of times the oil is re-used.

The data from this exercise will help us gather an accurate estimate of waste cooking oil volume and quality generated nationwide.

Please read the guidelines outlined below, follow the instructions and fill-in the attached record sheet for duration of one month.

The guidelines

Please follow the four steps:

1- When you deem the cooking oil is not suitable anymore for re-use in cooking, pour it in the designated container;

2- Read the cooking oil level in the graduation of the bottle;

3- Fill in the required data in the record sheet (i.e. date of disposal, level of oil, type and brand of oil, and number of times of re-use); and

4- Continue the practice for one month.

Final comments (Please answer in the space provided)

After one month, when the procedure is finished, please answer the following questions.

1- Did you have any difficulty collecting waste cooking oil? Please explain in more detail.

_____

2- Do you have any suggestion to further improve the collection system? Please explain in more detail.

_____

3- Now that you have experienced collecting waste cooking oil for a month, are you still willing to continue for a longer time if the government starts a comprehensive project on waste cooking oil collection from households? If not please explain why.

_____

WASTE COOKING OIL USE RECORD SHEET

SN	Date	Level of oil	Type of oil (as seen on label)	Brand of oil (as seen on label)	Number of times the oil was reused
Ex	20 Sept 2007	120	Canola Oil	Naturel	2
1					
2					
3					

Name: _____

Address: _____

What is the type of the house you are living in?

HDB ☐ Condominium ☐ Private House ☐

How many people are living in your house? _____