MANAGING SUPPLY CHAIN SUSTAINABILITY
THROUGH MICROFINANCE AND RECYCLING

A Dissertation in
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by
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ABSTRACT

As environmental laws and regulations tighten and the expectations for social responsibility of manufacturers rise, the conventional supply chain has responded by incorporating economic, environmental, and social content. In response to the demand for an increased social aspect of a sustainable supply chain, this study proposes the concept of supply chain microfinance (SCMF) as a financial sustainability solution to the problem of high interest rates in microfinance.

Based on a minimum interest rate obtained from a Black-Scholes debt (BSD) model, this study first develops scenario-based stochastic microcredit contract models to calculate a proper interest rate that minimizes both the risk of adverse selection and the risk of moral hazard. The suggested models also include financial statement analysis through financial ratios to reflect the unique characteristics of the microfinance business environment.

Next, this study formulates the concept of SCMF as a Stackelberg game model in the framework of a newsvendor problem for three entities, a manufacturer, a supplier, and a bank, based on the concept of SCMF. In the model, the manufacturer as a leader decides on an optimal order quantity and an optimal interest rate of a microcredit loan to a supplier. In a fair price trade, the supplier as a follower decides on an optimal wholesale price. The bank as a sub-leader decides on an optimal interest rate for a bank loan to the manufacturer.

To investigate the financial sustainability and outreach of MFIs in terms of interest rate and default rate, this study employs an interest rate premium methodology for the evaluation of microcredit interest rates, along with a default rate premium methodology for the evaluation of microcredit default rate. To employ the Black-Scholes (BS) model to calculate microfinance institutions’ (MFIs) default rates, this study preliminarily tests the validation of MFIs’ asset
values and default rates of geometric Brownian motion (GBM) using the Ryan-Joiner test and the chi-square test on two-way tables.

Finally, to address the environmental aspects of a sustainable supply chain, this study conducts a life cycle analysis of energy usage and air emissions of two types of carpet, wool carpet and nylon carpet. In the first step, the analysis estimates the total energy requirement and carbon dioxide emissions (CO₂) in the carpets’ six life cycles -- raw material acquisition, raw material production, product manufacturing, product installation, product use, and product recycling -- along with transportation in a sustainable supply chain.
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Chapter 1

Introduction

In the recent global business environment, environmental laws and regulations have tightened in response to governmental and citizen awareness of global environmental issues. At the same time, the expectations for social responsibility of corporations have risen. In response to these trends, corporations have made efforts to procure environmentally-friendly raw materials, to manufacture environmentally-friendly products, and to recycle and reuse post-consumer products from the customers. In addition to the environmental concerns raised in recent years, the business trend has reflected an increasing concern for the social content in the supply chain. The concept of corporate sustainability management has become a new business paradigm in today’s economy. This new paradigm expands the conventional supply chain further to contain a sustainable supply chain, which incorporates economic, environmental, and social content in the supply chain.

1.1 Background

In the highly competitive and ongoing globalization of the business environment, business leaders have realized that economic growth and success can be enhanced by their efforts on both environment and social values (Stead et al., 2008). These leaders have come to believe that the competitiveness of a supply chain can only be achieved through corporate sustainability which simultaneously pursues economic, environmental, and social values. This belief originated from the concept of the triple bottom line developed by Elkington (1998).
The triple bottom line approach simultaneously considers and balances economic, environmental, and social dimensions from a microeconomic standpoint. In other words, companies take actions that not only positively impact the natural environment and society, but which also lead to long-term economic benefits and competitive advantages in the future (Carter and Rogers, 2008).

In addition to stringent environmental regulations put in place by governments, a number of customers have expressed significant concerns about the health, safety, social, and environmental impact of the goods and services they purchase. This central concept, called corporate sustainability, has become a fundamental principle of smart management in the search for sustainable competitive advantages for companies (Savitz and Weber, 2006). By incorporating this new concept into their business strategies (Ahn et al., 2008), leading corporate now expend more efforts on both environmental and social values to enhance business competitiveness in terms of economic growth and success (Stead et al, 2008).

As the demand for new types of products escalates, companies are called to supply sustainable products and services to satisfy the ethical customer. In other words, companies are required to become increasingly flexible and responsive in order to modify the existing supply chain or to develop new ones in order to fulfill customer demand. This leads to an increased focus on creating a sustainable supply chain.

Sustainable supply chain is defined as not only all activities contributing to a supply chain’s economic value, but also responsibilities to all members in the supply chain, societies, and environments by continually improving a supply chain’s value with managerial innovation. The economic value in sustainable supply chain is represented as supply chain profitability obtained by the difference between revenue generated from the customers and total costs including environmental, social, and conventional costs in the supply chain.

The environmental value of sustainable supply chain is represented as eco-efficiency.
To achieve eco-efficiency, companies should produce and deliver competitively-priced merchandise and services which fulfill customers’ demands, while progressively decreasing environmental impacts and increasing efficient resource usage through the life-cycle of products (Schmidneiny, 1997). The social value in sustainable supply chain is represented as social-effectiveness, which can be achieved by companies’ increasing strategic approaches to incorporate social responsibility for their merchandise and services.

After the enormous success of ACCION in Brazil and the Grameen Bank in Bangladesh in the 1970s, the concept of microfinance has risen as a new promise for alleviating poverty and improving the limited access to financial services for the poor in both developing and underdeveloped countries. Microfinance provides the underprivileged with not only financial services, such as collateral-free loans, savings, insurance, but also social services, such as health care and education (Sengupta and Aubuchon, 2008).

Motivated by the success of microfinance institutions, corporations have begun to see microfinance as one of their strategic approaches to incorporate social responsibility into their merchandise and services through collaboration with raw material suppliers and manufacturers. For example, corporate leaders realize that in Afghanistan there are potential economic opportunities for the impoverished rural population. The livestock sector of Afghanistan, particularly in wool production, had the world’s competitive lead until the late 1970s. However, conflicts and natural disasters there caused devastation to agricultural land and production capacity in rural areas. Subsequently, the lack of financial resources and infrastructure resulted in most of the wool produced being traded at non-fair prices and exported as raw wool. As illustrated in the Afghanistan wool example, microfinance has the potential to simultaneously improve companies’ social responsibility and supply chain performance.

Although MFIs have had success in alleviating poverty, they do have challenges. Generally, MFIs face high levels of poverty, information asymmetries, incentive incompatibilities,
and imperfect mechanisms of contract enforcement in underdeveloped countries (Conning and Udry, 2007). In those business environments, interest rates do not perfectly represent the lender’s opportunity costs of loans and do not increase the lender’s profits as in a traditional financial market. Therefore, the inevitable high interest rates, along with default rates are considered principal problems in microfinance.

The net result is that a poor supplier with non-financial resource has only one financial resource, a microcredit loan from MFIs at an average value of a 38% interest rate. Unapproachable interest rates cause MFIs difficulty in maintaining the financial sustainability of the institutions and increasing outreach toward particular clientele.

1.2 Research Objective

In the social perspective of a sustainable supply chain, this paper considers SCMF as a financial sustainability solution to high interest rates. Incorporating supply chain finance (SCF) into microfinance, the concept of SCMF has emerged. In a SCMF scheme, a corporation provides a raw material supplier with a microcredit loan at a low interest rate, thereby increasing corporate social responsibility (CSR) while decreasing the supply risk by securing a consistent supply of raw materials (Norell and Brand, 2012). On the other hand, the supplier increases the revenue for raw materials at fair trade by reducing the number of levels in the marketing structure (Alexander and Alexander, 1991).

As shown in Figure 1.1, SCMF has three entities: a bank, a manufacturer, and a supplier. In a SCMF scheme, a manufacturer attracts an investment \( (I_B) \) from a bank at a low interest \( (R_B) \), and lends the investment \( (L_M) \) to a poor supplier at a relatively low interest rate \( (R_M) \) through MFIs. In reality, the manufacturer cannot lend the investment directly to the supplier due to various associated costs. In this case, the manufacturer uses the MFI as an intermediate agent by
paying related loan processing costs ($L_{pc}$). The supplier makes a repayment with the equivalent value of raw materials to the manufacturer. Since the manufacturer also reaps the intangible benefit of CSR, the manufacturer does not charge any extra interest rate to the MFI.

![Supply Chain Microfinance Network](image)

**Figure 1-1. A Supply Chain Microfinance Network**

In this study, two methodologies, a stochastic microcredit contract model and a Stackelberg game model, are used to calculate an appropriate interest rate in a SCMF scheme. In the stochastic microcredit contract model, a group case is developed to obtain a proper interest rate based on the concept of SCMF. A BSD model is employed to estimate a minimum interest rate for the microcredit contract models.

At the second stage, multi-level Stackelberg game formulations are developed to obtain a proper interest rate in the microfinance business environment. In the game model, the manufacturer as the leader makes a decision on the interest rate ($R_M$) of a microcredit loan ($L_M$) to a supplier, and the supplier as the follower makes a decision on the raw material price. In addition, the bank makes a decision on the interest rate ($R_B$) of an investment ($I_B$) to the manufacturer.

Next, to analyze MFIs’ microcredit interest rates, this study employs a simple methodology for the evaluation of the microcredit interest rates proposed by Muhammad Yunus (2007) based on an interest rate premium. In a similar way, this study also proposes a new methodology, a default rate premium, for the evaluation of the microcredit default rates. Furthermore,
this study employs the Black-Scholes (BS) model to calculate MFIs’ default rates based on the main underlying assumption that the underlying value of each MFI follows a GBM process.

Finally, in the environmental perspective of a sustainable supply chain, this study examines two types of carpet, a wool carpet and a nylon carpet, in terms of energy requirements and greenhouse gas (GHG) emissions in the carpets’ six life cycles: raw material extraction, raw material production, product manufacturing, product installation, product use, and product recycling.

1.3 Thesis Outline

This study is organized into seven chapters. In Chapter One, the background and the objective of this research are presented. Chapter Two provides a review of the literature on microfinance in terms of particular characteristics -- adverse selection, ex-ante and ex-post moral hazard -- on game theory in terms of a newsvendor problem, closed-loop supply chain. These reviews are intended to provide an overview of the current research trends in the relevant topics. In Chapter Three, a stochastic microcredit contract model in a SCMF scheme is presented, along with a BSD model. In Chapter Four, multi-level Stackelberg game formulations are presented, along with decisions on the interest rate of a microcredit loan, the wholesale price of a raw material, and the interest rate of a bank’s investment. In Chapter Five, the interest rate premium and the default rate premium are presented, along with the BS model. In Chapter Six, the life cycles of a wool carpet and a nylon carpet are examined in terms of energy requirements and greenhouse gas emissions. Finally, the conclusion of this research and the future research plan are discussed.
Chapter 2

Literature Review

In this chapter, relevant research on microfinance, SCMF, MFI sustainability, and environmental supply chain is discussed. The review encompasses two main areas: microfinance and supply chain. A scan of the literature on the topic of the microfinance contract suggests that most of the relevant research has broadly focused on the effectiveness of a variety of lending mechanisms under group setting aimed at eliminating adverse selection and moral hazard, from a theoretical to an empirical perspective. Most empirical studies have attempted to verify the claims of the proposed theoretical models with real data. In addition, a review on sustainability and outreach of MFIs is conducted. On the other hand, a review of relevant literature on SCMF indicates that little fundamental research has been conducted in that field. Thus, the review on SCMF focuses on the literature on financial decisions in the supply chain. Finally, a review on environmental supply chain is conducted.

2.1 Microfinance

Since the concept of CSR appeared in the early 1960s, corporations have increasingly had to consider environmental and social dimensions as a part of their supply chain issues. Despite the growing interest in sustainable supply chain in practice, there has not been much research conducted in this regard, compared to conventional supply chain. The review indicates that little fundamental research has been conducted in either the social aspect of sustainable supply chain or SCMF. Therefore this review will focus on the literature on microfinance, adverse selection and moral hazard.
2.1.1 Adverse Selection

In a microfinance market, information asymmetries usually occur because the lender does not have any knowledge of the actions or the types of the borrowers. In the presence of asymmetric information, MFIs encounter the adverse selection problem which arises when the lender is unable to distinguish the risk type of the borrowers.

Several studies propose that a group formation process mitigates the adverse selection problem. For example, Van Tassel (1999) examines the endogenous formation of homogeneous groups under imperfect information. This study demonstrates that joint liability can be used as a screening tool to distinguish agent types by inducing endogenous group formation and self-selection among members of the group.

Ghatak (1999) investigates how the borrower’s self-selection process increases repayment rates and welfare by mitigating the adverse selection problem. This study shows that the positive assortative matching process can occur in group formation if each borrower has perfect information on the risk of others’ projects. Similarly, Guttman (2008) analyzes the relationship between social capital and repayment performance. This study shows that the positive assortative matching mechanism can mitigate an adverse selection problem without any involvement of dynamic incentives.

On the other hand, several studies demonstrate that a particular lending mechanism can mitigate the adverse selection problem. For example, Daripa (2008) uses a simple-budget-balanced mechanism to demonstrate that both the adverse selection problem and the moral hazard problem can be overcome by pricing the participation of the lower risk borrowers in investment through a transfer from higher risk to lower risk borrowers, as well as by distinguishing between investors and non-investors.
Using a mechanism design approach, Karim (2009) shows that a joint liability mechanism and the cross-reporting lending mechanism can decrease or remove the adverse selection problem through peer selection and peer screening in a microfinance market. Batabyal and Beladi (2010) show how a particular signaling device, self-financing, mitigates adverse selection-related problems between MFIs and borrowers by forcing a borrower to choose a high-quality project.

2.1.2 Moral Hazard

In the presence of asymmetric information, if the lender is unable to provide the borrower with enough incentives to undertake actions conducive to the generation of sufficient capacity to repay, the ex-ante moral hazard occurs before the lender realizes the returns of the productive activity. On the other hand, the ex-post moral hazard occurs after the lender realizes the returns of the productive activity. If the lender is unable to enforce repayment, the borrower prefers not to repay the loan and may strategically default.

Most literature concerning moral hazard problems deals with peer selection and joint liability because under joint liability, peer monitoring plays an important role in preventing group members’ strategic default via social sanction (Katchova et al., 2006).

Stiglitz (1990) shows that a group contract with a peer monitoring mechanism can mitigate the ex-ante moral hazard problem by creating incentives for group members to observe the group member’s project choice. Further, in the homogeneous groups of the Grameen Bank, Varian (1991) shows that the lender may have almost perfect information on borrower types through the peer screening effect.

Besley and Coate (1995) demonstrate that there is a positive effect of joint liability using social sanctions as the incentive to make a repayment for any group member who cannot
repay his loan through a strategic repayment game. In addition, the study suggests that social collateral is an important mechanism to guarantee the performance of repayment. Armendariz de Aghion (1999) considers the optimal design of collective credit agreements with joint liability in terms of optimal group size and monitoring mechanisms. The study also shows that joint liability mitigates the strategic default problem in group contracts.

Chowdhury (2005) examines the effects of sequential financing and lender monitoring schemes on group lending contracts in terms of repayment rate, using a simple game model of group lending based on peer monitoring and ex-ante moral hazard problem. The study concludes that either sequential financing or a combination of lender monitoring and joint liability mitigates the moral hazard problem.

By extending Stiglitz’s model (1990), Ghatak and Guinnane (1999) demonstrate that the joint liability mechanism overcomes the adverse selection problem by positive assortative matching, the ex-ante moral hazard problem by peer monitoring, the costly state verification problem by lower audit cost, and the enforcement problem by strong sufficient capital based on strong social ties.

Aniket (2006) employs a principal-agent model of two-member groups to analyze the impact of various monitoring mechanisms on the range of socially viable projects. The study finds that the increased efficiency of monitoring mechanisms does not significantly change the agent’s rent under either sequential group lending or static group lending.

Cason et al. (2008) employ controlled experimental methods to gain a better understanding of specific aspects of group lending schemes under ex-ante moral hazard and peer monitoring. The study shows that group lending contracts with a lower monitoring cost among borrowers encourage lending activities and increase repayment rates. Gine et al. (2010) conduct experimental economic games to examine how dynamic incentives in individual and group
contracts influence investment decisions in Peru. The study shows that any loan contract with dynamic incentives decreases the rate of risky project choice and default.

In contrast to theoretical literature on microfinance, several researchers try to find empirical evidence of how microfinance actually mitigates existing information asymmetries using related real data. For instance, Karlan et al. (2007) develop a new market field experiment methodology to identify the existence of any adverse selection and moral hazard in South Africa. In their experiment, information asymmetries are identified by randomizing an initial offer interest rate, a contract interest rate, and a dynamic repayment incentive. In addition, the existence of moral hazard is identified by using the response of repayment behavior with respect to the dynamic repayment incentive.

Further, Ahlin and Townsend (2007) explicitly conduct direct empirical tests from four theoretical models of joint liability group lending in the presence of adverse selection, moral hazard, and social sanctions in Thailand. Based on these models, the study finds that repayment performance is negatively associated with higher levels of relatedness and sharing within groups and with higher levels of joint liability. Similarly, using a field experiment in the Philippines with a randomized control trial, Gine and Karlan (2007) show there is no strong statistical evidence of a decreasing default rate by screening and monitoring mechanisms in both individual and group contracts.

2.2 Supply Chain Microfinance

Since the concept of CSR appeared in the early 1960s, corporations have increasingly had to consider environmental and social dimensions as a part of their supply chain issues. Despite the growing interest in sustainable supply chain in practice, there has not been much research conducted in this regard, compared to conventional supply chain. The review indicates that little
fundamental research has been conducted in either the social aspect of sustainable supply chain or SCMF. Therefore this review will focus on the literature on microfinance, adverse selection and moral hazard.

Since SCMF is a relatively new concept in both theory and practice, a review of relevant literature indicates that little fundamental research has been conducted in SCMF. Therefore, this review focuses on the literature on financial decisions in supply chain. Despite the growing interest in the concept of SCF in recent years, there has not been much research conducted in this regard, compared to operational decisions issues in supply chain.

In an early study regarding a newsvendor problem, Buzacott and Zhang (2004) incorporate asset-based financing into production and inventory decisions to examine the relationship between financial and operational decisions. The study formulates a newsvendor problem to decide the optimal amount of loan and order quantity with a loan amount limit constraint at a given interest rate. The study suggests that a sufficiently low interest rate motivates the wealthy retailer to order more with taking a bankruptcy risk. On the other hand, the asset-based loan limit prohibits the poor retailer to make a larger order.

In contrast to other studies, the study of Dada and Hu (2008) is the only work considering an interest rate in a financing newsvendor problem. The authors employ the inventory procurement problem of a financially-constrained newsvendor to calculate the required amount of loan at a given interest rate to finance additional procurement under stochastic seasonal demand. The problem is presented by a Stackelberg game model with the bank as a leader and the newsvendor as the follower under default risk. The study demonstrates that only an appropriate interest rate motivates the newsvendor to finance the additional procurement.

Lai et al. (2009) investigate the efficiency of supply chain on three operational schemes: preorder mode, consignment mode, and the combination of the two modes. To test the impact of financial constraint on the three schemes, the study employs a Stackelberg game model with the
supplier as a leader under inventory risk. The study shows that the supplier prefers the consignment order over the other two modes without a financial constraint. With a financial constraint, the supplier prefers the preorder mode up to a certain point, while the combination of modes shows the most efficient performance.

Considering capital cost, Phohl and Gomm (2009) propose a conceptual framework of SCF, along with a mathematical model of SCF based on a principal-agent theory. The proposed framework consists of three entities: actors, objects, and levers. The study considers assets and net working capital as actors, primary and supportive members as objects, and duration, volume, and capital cost rate as levers in the framework. The study analyzes the financing activities across supply chain and the impact of capital cost on supply chain by calculating the maximum rate of return over the level and cost of information.

In the presence of a budget constraint, Caldentey and Haugh (2009) compare a flexible wholesale price contract with a flexible wholesale price with hedging, using a Stackelberg game model. The numerical result shows that the producer as a leader prefers the flexible contract with hedging to the flexible contract without hedging. On the other hand, a retailer as a follower prefers the flexible contract with hedging depending on the retailer’s budget.

To study the supply chain coordination, Lee and Rhee (2010) investigate the impact of trade-credit on four supply chain coordination mechanisms: wholesale quantity discount, buyback, two-part tariff, and revenue-sharing using a newsvendor framework. In the presence of a positive inventory financing cost, the revenue-sharing mechanism is the least profitable contract. The study also demonstrates that a supplier’s trade credit financing increases joint supply chain profit rather than direct financing due to the pooling effect of default risks.

To investigate the relationship between a wholesale price and a bankruptcy risk, Kouvelis and Zhao (2011) consider a bankruptcy cost in a wholesale price contract with a capital-constrained retailer using a Stackelberg game model based on the newsvendor problem. The
study calculates the optimal order quantity for the retailer and the optimal wholesale price for the supplier under stochastic demand. The study demonstrates that the supplier’s wholesale price is increased in response to the growth of the retailer’s wealth under the retailer’s bankruptcy risk.

To compare the trade-off between two financing schemes, Caldentey and Chen (2011) investigate a newsvendor problem using an internal financing scheme in terms of a procurement contract and an external financing scheme. The study uses a Stackelberg game model with the supplier as a leader and the budget-constrained retailer as a follower to calculate the optimal level of the budget in two financing schemes. The study demonstrates that both the supplier and the retailer prefer internal financing to external financing. In the case of internal financing, the supplier always gets the maximum reward, but the retailer does so only under critical budget level.

To study the trade-off between an independent decision and a joint decision, Srinivasa Raghavan and Mishra (2011) consider a newsvendor problem with a cash constraint to investigate the relationship between the lender’s profit and the borrower’s cash position at the next level of the supply chain. In the perspective of a lender, the study compares a joint decision on the loan amount with an independent decision for both a manufacturer and a retailer. As long as one of the lender, manufacturer, or retailer has proper low cash, the result shows that the joint decision benefits all.

Using a supplier early payment discount scheme, Kouvelis and Zhao (2012) again consider the newsvendor problem under a trade credit contract using a Stackelberg game model. The study obtains the optimal order quantity for the capital-constrained retailer and the optimal wholesale price for the capital-constrained supplier in the presence of bankruptcy risks. The results show that the retailer prefers supplier financing to bank financing under an optimally structured trade credit contract, along with the improvement in both the supplier’s profit and supply chain efficiency.
By including an on-line market, Chen et al. (2013) analyze pricing policies for a manufacturer in both a traditional and an Internet channel and for a retailer in a traditional channel, using Nash and Stackelberg games. The study shows that improving brand loyalty increases the profits of the manufacturer and the retailer. In addition, the increased service value enhances the profits of the retailer by mitigating the threat of the Internet channel, to a certain extent.

Focusing on a credit capacity, Yan and Sun (2013) design a SCF system with a manufacturer as the leader, a commercial bank as sub-leader, with a financially-constrained retailer using a multi-level Stackelberg game model under demand uncertainties. The study analyzes the optimal wholesale price for the manufacturer, the optimal credit line for the commercial bank, and the optimal order quantity for the retailer. The study concludes that a suitable financing scheme with limited credit is an effective incentive for the capital-constrained retailer to order more. In addition, the study demonstrates that the wholesale price contract with finite loans scheme coordinates the supply chain.

### 2.3 Microfinance Institution Sustainability

Since the debate between the financial sustainability and outreach of MFIs in the 1990s, MFIs have increasingly had to consider both profit maximization and social mission as part of their operations. Increasing outreach to the poor cannot be achieved without solid financial sustainability of MFIs. Despite the growing emphasis towards sustainability and outreach, there has not been much research conducted in this regard.

Cull et al. (2007) conduct empirical tests for 124 MFIs in 49 countries to gain a better understanding of specific aspects of financial performance and the depth of outreach. The study shows that an individual contract-based MFI makes better profits compared with a group
contract-based MFI. The study also shows that an individual contract-based MFI increasingly focuses on wealthier clients and dramatically lowers the fraction of both poor and female clients. The study also shows that a high level of fees does not guarantee a high profit.

Hermes et al. (2010) investigate the relationships of the trade-off between sustainability and outreach by analyzing 435 MFIs from 1997 to 2007. The study measures sustainability in terms of cost efficiency and the depth of outreach in terms of the average loan balance, average saving balance, and percentage of women clients. The study indicates that efficient operations in MFIs are helpful for improving financial sustainability. The study shows that MFIs show less efficient performance when the MFIs have lower average loan balances and a greater number of female clients. The study concludes that there is a negative correlation between outreach and efficiency of MFIs.

Cull et al. (2010) investigate how prudential regulation and supervision affect sustainability and outreach of MFIs, using the data of the largest 245 MFIs. The study shows that supervision increases an MFI’s average loan balance and decreases the fraction of female clients. Social mission-oriented MFIs significantly reduce their profitability without adjusting loan sizes and fraction of women clients under supervision.

Hudson and Traca (2010) examine how subsidy affects the efficiency of MFIs, based on microfinance rating data of 100 MFIs. The study indicates that the subsidy intensity positively affects the efficiency of MFIs under a certain level. Wydick et al. (2010) employ an elasticity of social imitation to investigate the determinants of outreach of MFIs. The study provides evidence that the magnitude of the social network, such as a church network, plays an important role in the breadth and depth of outreach.

In summary, the literature review shows a relationship between sustainability and outreach of MFIs. It is clear that a marginal increment of financial sustainability in terms of profit creates a marginal reduction of outreach of MFIs. However, it is difficult to determine how a
marginal increment of outreach affects a marginal improvement of financial sustainability in microfinance.

2.4 Environmental Supply Chain

Since the middle of the 1990’s, as environmental-consciousness has increased and regulations have tightened, reverse logistics system design and modeling have become important tools. In global markets, the concept of reverse logistics has been expanded to environmental or green supply chain management (Beamon, 1999). The environmental or green supply chain is also referred to as the closed-loop supply chain.

Environmental supply chain management is defined as the set of policies, actions, and relationships related to the design, acquisition, production, distribution, use, reuse, and disposal of the firm’s goods and services in a natural environment (Zsidisin and Siferd, 2001). The research issues on the reverse logistics are categorized into three areas: production planning, distribution planning, and inventory control (Fleishmann et al, 1997).

In one of the studies about location problems for reverse logistics systems, Bloemhof-Ruwaard et al. (1996) consider the two-level capacitated facility location problem, encompassing the capacitated distribution and waste disposal problem. The study develops a deterministic capacitated mixed integer programming (MIP) model to minimize fixed costs for opening plants and waste disposal units, and variable costs related to the location of capacitated waste-disposal plants and the flow of waste. The study utilizes two types of relaxation, linear and Lagrangian, to generate lower bounding and upper bounding procedures.

Like the previous research concerned with reuse activity on a particular functional activity, Spengler et al. (1997) also propose two mixed integer linear programming (MILP) models for the recycling of industrial byproducts and the dismantling and recycling of products at
the end of their life cycle. The study develops two models based on the multi-stage capacitated warehouse location problems to support the decision on process locations, capacities, input materials and process chains. The first model is a linear dismantling problem. The second is a linear recycling problem. The developed models are validated with an iron and steel industry application using a hierarchical tree approach. A numerical example illustrates cost savings by 20%.

As a case study, Barros et al. (1998) develop a multi-level capacitated warehouse location problem as a MIP model for the configuration of an optimal sand recycling network. The model determines the location, number and capacities of regional depots for sorting the sand according to its pollution level, and treatment facilities to clean polluted sand. The study proposes a heuristic approach based on a linear programming (LP) relaxation and iterative rounding approach. The numerical example shows the proposed heuristics approach considerably reduces the computational effort.

To analyze the logistics network of electronic equipment, Jayaraman et al. (1999) develop a two-stage capacitated discrete facility location model as a MILP subject to the number of processing facilities and storage capacities at the processing facilities and at reuse sites. The model determines the optimal number and locations of remanufacturing facilities, and the transshipment, production, and stocking of the optimal quantities of the remanufacturing products and cores. The model is solved for different supply and demand scenarios.

In a case study of carpet recycling logistics networks, Realff et al. (1999) develop a multi-period, three-stage capacitated discrete facility location model with deterministic supply and demand. The network consists of potential collections sites, potential sorting facilities, potential processing facilities, and reuse sites. The study investigates the influence of distributed sorting operations on the configuration of the network and feasibility of recycling. The numerical example proves that volume is a major factor for the network layout.
In a theoretical investigation of the synergy between the forward and the reverse chain, Fleischmann (2000) considers a network consisting of manufacturing facilities, distribution and collection centers, and customer sites. The study formulates the network as a two-stage uncapacitated discrete facility location model in a closed-loop supply chain. Comparing the sequential and integrated network approaches on two case studies, the researcher observes that the use of an integrated network design approach is more beneficial if the forward and reverse channels have different characteristics with respect to geographical distribution configuration and cost structures.

Considering the disposition of end-of-life home appliances, Shih (2001) develops a mixed integer programming model to optimize the infrastructure design and the reverse network flow for the recycling of electrical appliances and computers. The model minimizes the total cost including transportation costs, operating costs, fixed investment costs for new facilities, final disposal costs, and the sales revenue of reclaimed materials. The study analyzes the model on various scenarios by changing take-back rates and operating conditions.

One of the examples of modeling the life cycle of a production system is the Chandra and Kumar (2002) study using a bi-criteria MILP model for a reverse production system design. The study proposes three generic models for implementing inventory decision rules in the textile supply chain. The study observes that the geographic location of processing facilities plays an important role in network economics and suggests the subdivision of recycling tasks to avoid the shipment of low value material as an effective strategy for carpet recycling. The study concludes that the overall economic feasibility of recycling is strongly related to the volumes that can be expected from investments in the collection infrastructure.

For the collection cost effect of used products, Savasken et al. (2004) investigate the appropriate reverse channel structure for collecting used products in a closed-loop supply chain to determine the most effective undertaker of product collection activity. The study considers three
options of collection activity: (i) direct collection from customers, (ii) incentives to existing retailers, and (iii) subcontracts with a third party. The study develops a decentralized decision-making system incorporating the three options. The result indicates the most effective collection activity is to provide suitable incentives to the agent closer to the customer.

Nagurney and Toyasaki (2005) consider several independent agents in electronics recycling systems to study the individual behavior of acquisition and flow decisions. The study develops an integrated framework for the modeling of the reverse supply chain management of electronic waste. For balancing e-cycling in the multi-tier supply chain process, the study proposes an e-cycling network equilibrium model which provides qualitative properties of the equilibrium pattern of material flows and prices. The developed model is solved using the algorithm proposed by Nagurney and Toyasaki (2005).

Sheu et al. (2005) propose an integrated logistics operational model incorporating cross-functional product logistics flows and used product reverse logistics flows in a green supply chain. The study categorizes supply chain members in two groups: manufacturing supply chain members and used product reverse logistics chain members. After identifying critical activities and related operational requirements of the integrated model, the study formulates a multi-objective function to seek equilibrium solutions with the objective of maximizing a systematic net profit subjective to operational constraints. Results from a numerical example shows that the proposed model enhances net profits by 21.1%.

For a more realistic and accurate analysis, Ravi et al. (2005) incorporate balanced scorecard (BSC) and analytic network process (ANP) for reverse logistics operations for end-of-life computers. The study utilizes the ANP to structure the dimensions of reverse logistics based on four perspectives from the BSC. The study provides a holistic framework for the selection of an alternative for the reverse logistics operations for end-of-life computers by linking financial and non-financial, tangible and intangible, internal and external factors.
Since uncertainty is an important characteristic of modeling a product recovery network on a strategic level, Listes and Dekker (2005) develop a three-stage mixed-integer stochastic programming model for maximizing the expected profit of the reverse logistics network. The first stage considers supply uncertainty by making initial location decisions. The second stage considers capacity constraints by making a strategic decision of whether additional facilities are required to open or not open. The last stage considers demand uncertainty by making product flow decisions. The model is applied to a representative case study on the collection, recycling, and reuse of sand from demolition sites in the Netherlands.

To integrate remanufacturing and reverse logistics into one model, Srivastava and Srivastava (2006) develop a conceptual model and an integrated modeling framework which utilize product ownership data, average life cycle of products, past sales, forecasted demand and the likely impact of environmental policy measures to estimate returned product flows in several secondary markets for different product types. The numerical example shows that the estimation of returns is an important factor in logistics network design by investigating the impact of quality, quantity, and timing of returns of the overall profits.

In a case study conducted in Germany, Schultmann et al. (2006) study how to incorporate reverse material flows into forward logistics. The study formulates reverse logistics aspects as a vehicle routing planning problem for end-of-life vehicle treatment. Based on the planned locations of the reprocessing facilities, the model is formulated to minimize the total length of all routing distances in reverse logistics, while considering the corresponding number of dismantlers to be served per collection period.

For the multi-echelon reverse logistics problem involving product returns, Min et al. (2006) investigate the relationship between the desirable holding time for the consolidation of returned products and the number and location of initial collection points in a multiple time horizon. The study formulates a reverse logistics problem from customers to collection points in a
mixed integer nonlinear programming model to determine the exact length of holding time for the spatial and temporal consolidation at the initial collection points, while minimizing total costs related to consolidation and transportation. To obtain good feasible solutions, the study proposes multiple steps of heuristics based on a genetic algorithm. However, their models did not take into account temporal consolidation issues in a multiple planning horizon.

As a simple case study, Mostard and Teunter (2006) consider the newsvendor problem for reusing undamaged returned products from customers with more general demand-return relationships. The study develops a simple closed-form equation which generates the optimal order quantity given the different demand distributions in a single period using a distribution-free heuristic. The proposed equation is applied to a large catalogue mail order retailer case with real data and proves its capability of performance in most realistic cases.

Vlachos et al. (2007) employ a system dynamics methodology for strategic remanufacturing and collection capacity planning in reverse supply chains. The model formulates the operations system including capacity considerations and environmental protection policies. The simulation model is tested on various scenarios in single product recovery operations to determine efficient collection policies and long-term operation policies. The study specifically analyzes the influence of several factors such as the green image effect, failure percentage of the collected products, addition of remanufacturing capacity, and addition of collection capacity in terms of economical scale. However, the model does not incorporate the concept of a limited product life cycle or issues related to capacity contraction.

Easwaran and Üster (2009) formulate a network design problem as a MILP model to determine the optimal location of collection centers and remanufacturing facilities with the objective of minimizing total costs related to fixed and variable operational facility and transportation costs. To improve performance of the solution algorithms in terms of both solution quality and time, the model is solved using the Benders decomposition solution approach.
incorporating two tabu search heuristics: sequential and random neighborhood search procedures and Benders cuts.
Chapter 3

A Microcredit Contract Model

Based on the concept of SCMF, this chapter develops scenario-based stochastic microcredit contract models for a group case to calculate a proper interest rate. The minimum interest rate of the microcredit model is estimated by a BSD model based on a borrower’s equity. The stochastic microcredit model also considers financial statement analysis through financial ratios.

3.1 Introduction

Since the concept of CSR appeared in the early 1960s, corporations have increasingly had to consider environmental and social dimensions as a part of their supply chain issues. Despite the growing interest in sustainable supply chain in practice, there has not been much research conducted in this regard, compared to conventional supply chain. The review indicates that little fundamental research has been conducted in either the social aspect of sustainable supply chain or SCMF. Therefore this review will focus on the literature on microfinance, adverse selection and moral hazard.

In the recent business environment, global business leaders in organizations such as Shell, Philips, BASF, and Toyota have realized that business competitiveness in the future will not be achieved purely by financial performance (Beamon, 1999). These leaders have come to believe that business competitiveness can only be achieved through corporate sustainability which simultaneously considers economic, environmental, and social values. This belief encourages leaders to expend their efforts on both environmental and social values to enhance economic growth and success (Stead et al., 2008). Motivated by the success of MFIs, companies
saw opportunities to collaborate with suppliers concerning a sustainable raw material supply for manufacturers and sustainable economic growth for impoverished raw material suppliers.

After the enormous success of the Grameen Bank in Bangladesh in the early 2000s, the concept of microfinance emerged as a new promise for alleviating poverty and improving the limited access to financial services by offering small loans with no pledged collateral requirement to the poor in both developing and underdeveloped countries. As microfinance has grown and expanded, MFIs have increased outreach toward particular clientele, while keeping the financial sustainability of the institutions (Hartarska, 2002). MFIs provide the underprivileged with not only financial services, such as saving and insurance, but also social services, such as health care and education (Sengupta and Aubuchon, 2008).

As the demand for CSR escalates, companies have begun to consider microfinance as one of their strategic approaches to incorporate social responsibility into their merchandise and service. For example, the livestock sector of Afghanistan, particularly in wool production, was among the world’s competitive nations until the late 1970s. $69 million of pastoral production, about 43% of total agricultural exports, was exported in 1970 (Barfield, 2004). However, the conflicts and natural disasters have devastated agricultural land and production capacity in rural areas in Afghanistan.

Since Afghanistan had competitive strengths in the livestock sector in the past, this sector can be a potential industry for the impoverished rural population. However, the livestock sector has neither the available finance nor infrastructure to produce a large quantity of high quality livestock and develop potential markets. Subsequently, the lack of financial resources results in most of the wool produced being traded at non-fair prices and being exported as raw wool.

The Afghanistan wool example shows how microfinance has the potential to simultaneously improve companies’ social responsibility and supply chain performance. For
instance, if the rural farmers would produce a large share of high quality wool, they would generate more income by selling the wool at fair prices in secured market and by raising more sheep in a better environment. At the same time, manufacturers would benefit from product quality enhanced by more reliable sources of raw material and from lower sourcing costs enhanced by increased operating efficiencies. These efforts are critical not only because of the desirability of sustainable wool sources for manufacturers in the supply chain, but also because of the potential for rural poverty alleviation. The pros and cons of each entity in SCMF are summarized in Table 3-1.

Table 3-1. The Pros and Cons of each Entity in SCMF

<table>
<thead>
<tr>
<th>Entity</th>
<th>Pros</th>
<th>Cons</th>
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| Manufacturer | • Increasing revenues of products through CSR  
• Decreasing supply risk of raw materials | • Increasing raw material costs at a fair trade |
| MFIs | • Increasing outreach of MFIs | • Decreasing revenue from a loan portfolio |
| Supplier | • Increasing revenues of raw materials at a fair trade  
• Securing a market by continuous supply of raw materials  
• Granting access to capital | • Depending heavily on a manufacturer |
| Bank | • Increasing financial revenues through an investment | • Losing other investment opportunities |

In general, MFIs operate in underdeveloped countries which have features of high levels of poverty, information asymmetries, incentive incompatibilities, and imperfect mechanisms of contract enforcement (Conning and Udry, 2007). In those business environments, the interest rate does not perfectly represent the lender’s opportunity costs of loans and does not increase the lender’s profits as in a traditional financial market. Due to the unique features of microfinance, a high interest rate is inevitable. Indeed, the high interest rate is considered one of the principal
problems in microfinance. An unapproachable interest rate makes MFIs experience difficulty in increasing outreach toward particular clientele while maintaining the sustainability of the institutions.

In this paper, the concept of SCMF is presented as a financial sustainability solution to decrease high interest rates. SCMF incorporates the concept of SCF into microfinance to provide a raw material supplier with a loan at a low interest rate. Through SCMF, the company increases CSR by granting the supplier access to capital and market (Gaspar, 2003). The company also decreases the supply risk by securing a consistent supply of raw materials (Norell and Brand, 2012). In addition, the suppliers increase the revenue of raw materials at fair trade by reducing the number of levels in the marketing structure (Alexander and Alexander, 1991).

As shown in Figure 3.1, SCMF has three entities: a bank, a manufacturer, and a supplier. In impoverished underdeveloped countries, a poor supplier with no financial resources normally would have little chance to borrow a loan from a bank because of his or her low credit score. As a result, a poor supplier would have only one financial resource, a microcredit loan from MFIs at a high interest rate, in order to invest in the borrower’s own project.

In contrast, in the SCMF model, to decrease the average value of a 38% interest rate in microfinance, a manufacturer attracts an investment ($I_b$) from a bank at a low interest ($R_b$), and lends the investment ($L_d$) to a poor supplier at a relatively low interest rate ($R_l$) through MFIs. In reality, the manufacturer cannot directly lend the investment to the supplier due to various prohibitive costs. In this case, the manufacturer uses the MFI as an intermediate agent by paying related loan processing costs ($L_{pc}$). If the supplier’s project is successful after an investment from the manufacturer, the supplier makes a repayment with the equivalent value of raw materials to the manufacturer. Through SCMF, the manufacturer also reaps the intangible benefit of CSR. Thus, it is assumed that the manufacturer does not charge any extra interest rate to a MFI.
In this study, based on the concept of SCMF, stochastic microcredit contract models for a group cases is developed to obtain a proper interest rate in the microfinance business environment. In addition, a BSD model which estimates a minimum interest rate of the microcredit contract models is employed.

The rest of the paper is organized into four sections. Section two provides a review of the relevant literature on microfinance loan contracts and sustainable supply chain. In section three, scenario-based stochastic mathematical models of a microcredit contract are presented, along with the BSD model. In section four, numerical examples through the Afghanistan wool case are presented with discussion. Finally, the conclusion is provided in section five.

3.2 Mathematical Formulation

The objective of this study is to design relevant microcredit contract models which are able to provide an appropriate interest rate based on the concept of supply chain microfinance. In the first stage, this study uses one of the credit risk models, the BSD model, to calculate a minimum interest rate for microcredit loans. In the second stage, two types of individual and
group stochastic microcredit contract models are developed by incorporating the minimum interest rate from the BSD model.

### 3.2.1 The Black Scholes Debt Model

This section reviews the BSD model. In the early 1970s, one of the most important developments in finance, the Black Scholes option pricing (BSOP) model, was developed under the assumption that that the value of the firm $S$ follows standard GBM with constant drift $\mu$ and volatility $\sigma$ of firm value returns, $dS = \mu S dt + \sigma S dB$, where $dB$ is an increment of a standard Wiener process.

When equity is viewed as a call option, the BSOP model can be transformed into the BSD model to value equity as an option (Damodaran, 2012). The BSD model considers the equity of the firm $E$ as a European call option on value of the firm $S$ and face value of outstanding debt $K$ due at maturity $T$. The BSD model for the price at time zero of a call option on a non-dividend paying stock is as follows (Damodaran, 2012).

$$E = SN(d_1) - Ke^{-rT}N(d_2)$$  \hspace{1cm} (3.1)

where $d_1 = \frac{\ln(S/D) + (r + 0.5*\sigma^2)T}{\sigma\sqrt{T}}$ \hspace{1cm} (3.2)

and $d_2 = d_1 - \sigma\sqrt{T} = \frac{\ln(S/D) + (r - 0.5*\sigma^2)T}{\sigma\sqrt{T}}$ \hspace{1cm} (3.3)

The term $SN(d_1)$ is the expected value of the firm, and the term $Ke^{-rT}$ is the present value of the principal outstanding debt due at maturity. The term $N(d_2)$ is the probability of the firm being solvent at maturity where $r$ is a risk-free interest rate and the term $N(d)$ is cumulative standard normal distribution function (Charitou et al., 2013).
The value of the outstanding debt is directly calculated using Equation (3.1) as follows in Equation (3.5):

\[ D = S - E \]  \hspace{1cm} (3.4)

Finally, the interest rate on debt is calculated using Equation (3.4) with a face value of outstanding debt as follows:

\[ R = \left( \frac{K}{D} \right)^{\frac{1}{T}} - 1 \]  \hspace{1cm} (3.5)

In the BSOP model, equity return volatility is easily estimated from historical stock return data as follows:

\[ \sigma = \text{std} \left( \log \left( \frac{Q_t}{Q_{t-1}} \right) \right) \]  \hspace{1cm} (3.6)

where \( \text{std} \) represents standard deviation and \( Q_t \) represents stock prices.

### 3.2.2 A Microcredit Contract Model

In this section, the scenario based stochastic model for a group microcredit contract with one lump payment at maturity is provided. It is assumed that there are four different types of borrowers: a renewal female borrower, a renewal male borrower, a new female borrower, and a new male borrower. The yield uncertainty is brought into the models through a scenario approach. Due to the similarity between an individual contract and a group contract, only the group microcredit contract model is provided in this paper. In the perspective of the manufacturer, the stochastic model for a group microcredit contract appears below. Since the manufacturer does not earn any financial earning from a MFI except CSR, the general supply chain microfinance network can be simplified as in Figure 3.2.
3.2.2.1 Objective Function

In this study, it is assumed that the manufacturer acts as a lender on behalf of MFIs under the simplified supply chain microfinance network. Thus, as shown in Equation (3.7), the objective function of the scenario-based stochastic model is to minimize a loan interest rate \( LR \) over all scenarios in order to increase the outreach and the financial sustainability of the manufacturer. In general, the lower the interest rate of a loan, the higher the borrowers’ accessibility, with lower default cases.

\[
\text{Min } \sum_j LR_{j,t} \quad \forall t, l \tag{3.7}
\]

3.2.2.2 Asset Constraints

Equation (3.8) shows the cash balance constraint of the manufacturer, which consists of cash earning (CE), financial liability balance (FLB), loan balance (LB), and asset balance (HB), production revenue (PR), and production cost (PC).

\[
C_i^t = CE_i^t + FLB_i^t + LB_i^t + PR_i^t - HB_i^t - PC_i^t \quad \forall t, l \tag{3.8}
\]
Equation (3.9) represents cash earnings in a previous time. Equation (3.10) is financial
liability balance constraints, including a financial investment from a bank in a current time and a
financed investment with interest in a previous time. Equation (3.11) is a loan balance constraint
which is calculated by subtracting the summation of a loan in a current time from the summation
of a loan with a loan yield and a loan processing cost in a previous time. A loan processing cost is
assumed to be 25% of a loan based on the First MicrofinanceBank (FMFB)-Afghanistan.

\[ CE_t^l = C_{t-1}^l CR_{t-1}^l \quad \forall t, l \] (3.9)

\[ FLB_t^l = FL_t^l - FL_{t-1}^l FLR_{t-1}^l \quad \forall t, l \] (3.10)

\[ LB_t^l = \sum_j \gamma_{j,t-1}^l L_{j,t-1}^l (LR_{j,t-1}^l + LPC_{j,t-1}^l) - \sum_j L_{j,t}^l \quad \forall t, l \] (3.11)

To increase the manufacturer’s financial sustainability, this model employs buy and sell
decisions on secured assets through asset balance constraints. By investing available cash into
secured assets, the manufacturer can assure the financial sustainability in the loan default cases by
the suppliers. Equation (3.12) is an asset balance constraint, which states the summation of an
amount of holding secured asset with an asset yield at the previous period and an amount of
secured asset purchased at the current period less an amount of secured asset sold at the current
period.

The manufacturer also makes productions using the raw materials collected from the
suppliers as the repayment of loans. Equation (3.13) and Equation (3.14) are a production revenue
constraint and a production cost constraint, respectively. Since the proposed model needs to
provide a unique solution under considered scenarios, the non-anticipation constraints of
Equation (3.15) for an asset are adopted. The non-anticipation constraints ensure the first stage
decisions will be identical for all scenarios (Zenios, 2008).

\[ HB_t^l = \sum_i H_{i,t-1}^l HY_{i,t-1}^l + \sum_i B_{i,t}^l - \sum_i S_{i,t}^l \quad \forall t, l \] (3.12)
3.2.2.3 Loan Constraints

It is well known that peer monitoring plays an important role in preventing group members’ strategic default via social sanctions under joint liability (Katchova et al., 2006). To prevent the possibility of a strategic default, following the notation of the model proposed by Armendariz de Aghion (1999), the model presented here defines the future benefit that the borrower derives from having access to a future loan opportunity as \( V \) and the cost of social sanction as \( W \), which is imposed on the borrower who makes a strategic default. In addition, the probability of a borrower being monitored is \( 1 - (1 - M)^{N-1} \).

Equation (3.16) is the incentive compatibility constraint of a borrower who makes a repayment. It states that the expected payoff of the borrower who makes a repayment is greater than that of the borrower who makes strategic default.

\[
(BPR_{j,t} - LR_{j,t}^i)L_{j,t}^i + \frac{V_{j,t}^i}{1 + LR_{j,t}^i} \geq L_{j,t}^i - W[1 - (1 - M)^{N-1}] \quad \forall t, i
\]

The loans also have several constraints to ensure the financial sustainability of the manufacturer. Equation (3.17) is the loan availability constraint which states that a total amount of a loan should be less than the particular percentage of a total amount of cash at each period. Equation (3.18) is the loan amount constraint, which states that the total amount of a loan is
greater than the total amount of the total raw material cost because the raw material supplier makes a repayment with raw material to the manufacturer.

$$\sum_j L_{j,t}^l \leq \alpha^t_i C_i^t \quad \forall t, l$$  \hspace{1cm} (3.17)

$$\sum_j L_{j,t}^l \geq \sum_{jp} \sum_{jp} RC_{ip,jp,t}^l VR_{ip,jp,t}^l \quad \forall t, l$$  \hspace{1cm} (3.18)

Equation (3.19) is the loan amount constraint, which states that each borrower has the maximal and minimal amount of a loan which the borrower can borrow. Equation (3.20) is the non-anticipation constraints for a loan, which force the first stage decisions to be identical for all scenarios.

$$CR_i^t \leq LR_{j,t}^l \leq LR_{\text{max}} \quad \forall t, l$$  \hspace{1cm} (3.19)

$$L_{j,t}^l = L_{j,t}^{l^\text{ini}} \quad \forall t, l$$  \hspace{1cm} (3.20)

3.2.2.4 Production Constraints

The main activity of the manufacturer is the production of merchandise for sale. There are several constraints related to production. Equation (3.21) is the raw material mass balance constraint, which states that the summation of total raw material of a product in a previous time should be equal to the summation of the total product produced at each facility in a current time. Equation (3.22) is the production mass balance constraint, which states that the total amount of production at each facility is equal to the total amount of transportation from each facility to each customer. Equation (3.23) is the demand constraint, which states that the total amount of production volume should be equal to the quantity demanded by the customer.

$$VR_{ip,jp,t-1}^l = \sum_{jp} P_{ip,jp,t}^l \quad \forall t, l$$  \hspace{1cm} (3.21)
3.2.2.5 Financial Operation Constraints

As a preliminary stage of measuring whether operating revenues cover both operating and financing costs, referring to the study of Longinidis and Georgiadis (2011), several financial operation constraints of the financial cycle of the manufacturer are modeled in the following equations: Equation (3.24) is an operating revenue (OR) constraint, which represents revenues from product sales (PR), asset yield (HE), cash yield (CE), and loan yield (LE). Equation (3.25) and Equation (3.26) represent asset earnings and loan earnings in a previous time respectively.

\[ OR_t^l = PR_t^l + HE_t^l + CE_t^l + LE_t^l \quad \forall t, l \]  \hspace{1cm} (3.24)

\[ HE_t^l = \sum_i H_{i,t}^l H^l_{i,t} \quad \forall t, l \]  \hspace{1cm} (3.25)

\[ LE_t^l = \sum_j \gamma_j^l L_{j,t}^l (LR_{j,t}^l + LPC_{j,t}^l) \quad \forall t, l \]  \hspace{1cm} (3.26)

In this model, the cost of goods sold is equal to the production cost because all the expenses such as transportation cost, material handling cost, and storage cost are ignored. Thus, the earnings before interest and taxes (EBIT) are calculated as shown in Equation (3.27).

\[ EBIT_t^l = OR_t^l - PC_t^l \quad \forall t, l \]  \hspace{1cm} (3.27)

Equation (3.28) is a net operation profit (NOP) constraint, which is calculated by subtracting interest paid for financed liability (FLIP) in Equation (3.29) from EBIT. Equation (3.30) is the net operating income after taxes (NOPAT), which is calculated by multiplying NOP by a tax rate. Equation (3.31) is an equity constraint which consists of equity at a previous time.

\[ NOP_t^l = EBIT_t^l - FLIP_t^l \quad \forall t, l \]  \hspace{1cm} (3.28)

\[ NOPAT_t^l = NOP_t^l \times T \quad \forall t, l \]  \hspace{1cm} (3.29)

\[ Equity_t^l = NOPAT_t^l - Equity_{t-1}^l \quad \forall t, l \]  \hspace{1cm} (3.30)
and NOPAT. Equation (3.32) is an asset constraint which includes fixed assets, cash, and purchased assets at a current period.

\[
NOP_t^l = EBIT_t^l - FLIP_t^l \quad \forall t, l
\]

\[
FLIP_t^l = FL_t^l FLR_t^l \quad \forall t, l
\]

\[
NOPAT_t^l = (1 - TR_t^l) NOP_t^l \quad \forall t, l
\]

\[
E_t^l = E_{t-1}^l + NOPAT_t^l \quad \forall t, l
\]

\[
A_t^l = FA_t^l + CB_t^l + B_t^l \quad \forall t, l
\]

### 3.2.2.6 Financial Ratio Constraints

In order to reflect the microfinance business environment, referring to microfinance consensus guidelines (CGAP, 2003), the model incorporates some commonly used MFI performance measurements: sustainability and profitability ratios, asset and liability ratios, and efficiency and productivity ratios. Financial ratios will be compared with the targeted financial ratio values from the FMFB.

Sustainability and profitability ratios represent how profitable MFIs manage their operations. Based on the microfinance consensus guidelines (CGAP, 2003), the sustainability and profitability ratios employed in this model are return on equity (ROE), return on assets (ROA), operational self-sufficiency (OSS), and profit margin (PM), as defined in Equation (3.33) through Equation (3.36).

Equation (3.33) is an ROE constraint, which measures how efficiently MFIs manage equity. The ROE is calculated by dividing the net operating income after taxes by total equity. Equation (3.34) is a ROA constraint, which measures how efficiently MFIs operate assets to
generate returns. The ROA is calculated by dividing the net operating income after taxes by total assets.

\[
\frac{NOPAT^i_t}{E^i_t} \geq ROAT^i_t \quad \forall t, l
\]  

Equation (3.35) is an OSS constraint, which states how sufficiently MFIs match their operational costs. The OSS is calculated by dividing operating revenue by the summation of financial expense, loan loss provision expense, and operating expense. Equation (3.36) is a PM constraint, which states how well MFIs make operating revenues after all expenses are paid. The PM is calculated by dividing operating income by operating revenue.

\[
\frac{OR^i_t}{FLP^i_t + LLP^i_t + OE^i_t} \geq OSST^i_t \quad \forall t, l
\]  

\[
\frac{OI^i_t}{OR^i_t} \geq PMT^i_t \quad \forall t, l
\]  

Asset and liability ratios represent how efficiently MFIs manage their assets and repay their liability to generate their sales. Following the microfinance consensus guidelines (CGAP, 2003), the asset and liability ratios incorporated in this model are the yield on gross loan portfolio (YGL), current ratio (CR), yield gap (YG), and funding expense ratio (FE), as defined in Equation (3.37) through Equation (3.40). Equation (3.37) is a YGL constraint, which states how well MFIs have the ability to generate financial revenue in terms of interest, fees, and commissions from the gross loan portfolio. The YGL is calculated by dividing cash financial revenue from loan portfolio by total loan (TL).

\[
\frac{LE^i_t}{TL^i_t} \geq YGLT^i_t \quad \forall t, l
\]
Equation (3.38) is a CR constraint, which states how well MFIs cover their assets and liabilities. The CR is calculated by dividing total assets by financial liability. Equation (3.39) is a YG constraint, which states the difference between actual revenues earned and expected revenues. The YG is calculated by subtracting cash revenue from loan portfolio dividing by the multiplying loan portfolio by expected annual yield (EY) from one. Equation (3.40) is an FE ratio constraint, which states the percentage of interest paid for MFIs’ financed liabilities. The FE is calculated by dividing interest paid on funding liability by loan portfolio.

\[
\frac{A_l^t}{FL_l^t} \geq CRT_l^t \quad \forall t, l
\]  
(3.38)

\[
1 - \frac{CE_l^t}{EY_l^t/TL_l^t} \geq YGT_l^t \quad \forall t, l
\]  
(3.39)

\[
\frac{FLIP_l^t}{TL_l^t} \geq FET_l^t \quad \forall t, l
\]  
(3.40)

Efficiency and productivity ratios represent how efficiently and productively MFIs manage their asset and personnel resources. Following the microfinance consensus guidelines (CGAP, 2003), the efficiency and productivity ratios used in this model are loan officer productivity (LOP), operating expense ratio (OE), and cost per borrower (CPB) ration, as defined in Equation (3.41) through Equation (3.43). Equation (3.41) is a loan officer productivity constraint, which states how efficiently each loan officer covers active clients. The LOP is calculated by dividing the number of active borrowers (NB) by the number of loan officers (NLO).

\[
\frac{NB_l^t}{NLO_l^t} \leq LOPT_l^t \quad \forall t, l
\]  
(3.41)

Equation (3.42) is an OE ratio constraint, which states the average expense per each loan. The OE is calculated by dividing operating expense by loan portfolio. Equation (3.43) is a
CB ration constraint, which states the average cost per each client. The CPB is calculated by dividing operating expense by number of active borrowers.

\[
\frac{OE^l_t}{TL^l} \geq OET^l_t \quad \forall t, l \tag{3.42}
\]

\[
\frac{OE^l_t}{TB^l_t} \leq CPBT^l_t \quad \forall t, l \tag{3.43}
\]

Finally, Equation (3.44) is a non-negative constraint. It states that each purchased, held, and sold asset, loan, financed investment, cash, production amount, and production transportation volume should be positive, not negative.

\[
B^l_{i,j}, C^l_i, F^l_t, H^l_{i,t}, L^l_{j,t}, S^l_{i,t} \geq 0 \quad \forall t, l \tag{3.44}
\]

### 3.3 Numerical Examples

In this case study, it is assumed that there is the world’s leading carpet manufacturer with its commitment to the corporate responsibilities of economic, environmental, and social development through sustainable supply chain. To increase its social responsibility, the company considers purchasing raw materials from the rural poor in Afghanistan. Since Afghanistan is no longer able to contribute a large share of worldwide wool production due to the war and civil strife, the company wants to specifically launch new livestock development and credit support programs for the rural poor in Afghanistan.

The company expects the agricultural microcredit program will improve supply chain performance. For instance, if wool producers benefit from the microcredit program, the producers can reliably provide a good quality of wool to the company by raising sheep in a better environment. Consequently, the company will benefit from product quality enhanced by more reliable sources of raw materials and from lower sourcing costs enhanced by increased operating
efficiencies through a solid relationship between a supplier, the borrower, and a manufacturer, the lender.

The company considers an adequate interest rate as a key factor in the success of a microcredit program in Afghanistan. Thus, to calculate an appropriate interest rate, the proposed mathematical model is applied through real data from FMFB for microfinance ratio targets. The interest rate is calculated through two stages: the BSD model and the scenario-based stochastic microcredit model.

At the first stage, a minimum interest rate is calculated using the BSD model presented in section 3.1. It is assumed that a borrower invests a loan into purchasing sheep. For instance, in Afghanistan, the borrower can buy sheep at $275 and sell the sheep at $446 after one year. Usually, equity return volatility is directly estimated from historical stock return. However, in this case study, sheep are considered as the equity of the borrower.

Since there is no available equity return volatility value of sheep in Afghanistan, the equity return volatility of sheep is estimated from real historical mutton monthly prices from 2007 to 2010 in Afghanistan taken from the Food and Agriculture Organization of the United Nations database. Based on this data, the equity return volatility of sheep is calculated as 0.098 using Equation (3.6). Table 3-2 shows the results of the BSD model. The option value is $184.41, the value of outstanding debt is $261.59, and the interest rate on the debt is 5.03% with 5% of a risk-free interest rate in one year.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equity (S)</td>
<td>$446</td>
</tr>
<tr>
<td>Debt (K)</td>
<td>$275</td>
</tr>
<tr>
<td>Option (E)</td>
<td>$184.41</td>
</tr>
<tr>
<td>Outstanding Debt (D)</td>
<td>$261.59</td>
</tr>
<tr>
<td>Interest Rate (R)</td>
<td>5.03%</td>
</tr>
</tbody>
</table>

Table 3-2. The Results of the Black Scholes Debt Model
Since the majority of the microfinance research tests proposed models of a group loan contract under a group size of two for a convenient and simplified analysis (Ghatak, 1999), in this study, the group contract model employs a standard assumption of the group size of two. In addition, referring to the study of Schreine (Schreiner, 2003), it is assumed that four different types of borrowers have their own strategic default probability as shown in Table 3-3.

Table 3-3. A Default Probability of Each Type of Borrower

<table>
<thead>
<tr>
<th>Type</th>
<th>Borrower</th>
<th>Default Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>New Woman</td>
<td>0.178</td>
</tr>
<tr>
<td>B2</td>
<td>New Man</td>
<td>0.219</td>
</tr>
<tr>
<td>B3</td>
<td>Renewal Woman</td>
<td>0.121</td>
</tr>
<tr>
<td>B4</td>
<td>Renewal Man</td>
<td>0.161</td>
</tr>
</tbody>
</table>

In this study, it is assumed that the company has three products, three plants, and three customers. In addition, the study considers 0.09 m² of wool carpet as a product which requires 0.176 kg of raw wool as raw material. The assumed model parameters related to production are presented in Table 3-4 through Table 3-8. The production sale prices and production costs at plants are shown in Table 3.4 and Table 3.5.

Table 3-4. Production Sale Prices at Plants

<table>
<thead>
<tr>
<th></th>
<th>Product 1</th>
<th>Product 2</th>
<th>Product 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$29.27</td>
<td>$33.27</td>
<td>$31.29</td>
</tr>
</tbody>
</table>

Table 3-5. Production Costs at Plants

<table>
<thead>
<tr>
<th></th>
<th>Product 1</th>
<th>Product 2</th>
<th>Product 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$29.27</td>
<td>$33.27</td>
<td>$31.29</td>
</tr>
</tbody>
</table>

The raw material cost at plants with initial raw material amount at the planning period are shown in Table 3-6 and Table 3-7. The product demands are shown in Table 3-8.
Table 3-6. Raw Material Costs at Plants

<table>
<thead>
<tr>
<th>Material</th>
<th>Material 1</th>
<th>Material 2</th>
<th>Material 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$8</td>
<td>$6</td>
<td>$10</td>
</tr>
</tbody>
</table>

Table 3-7. Initial Raw Material Availability at the Planning Period

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Plant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material 1</td>
<td>96 kg</td>
<td>133 kg</td>
<td>58 kg</td>
</tr>
<tr>
<td>Raw Material 2</td>
<td>120 kg</td>
<td>85 kg</td>
<td>100 kg</td>
</tr>
<tr>
<td>Raw Material 3</td>
<td>65 kg</td>
<td>76 kg</td>
<td>85 kg</td>
</tr>
</tbody>
</table>

The raw material cost at plants with initial raw material amount at the planning period are shown in Table 3-6 and Table 3-7. The product demands are shown in Table 3-8.

Table 3-8. Product Demands

<table>
<thead>
<tr>
<th>Percentage of Customer Demand</th>
<th>Total Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer 1</td>
<td>Customer 2</td>
</tr>
<tr>
<td>Product 1</td>
<td>24</td>
</tr>
<tr>
<td>Product 2</td>
<td>36</td>
</tr>
<tr>
<td>Product 3</td>
<td>10</td>
</tr>
</tbody>
</table>

To investigate how the yield uncertainty of the secured asset and cash affects interest rates, this study considers four scenarios, up-up (UU), up-down (UD), down-up (DU), and down-down (DD) for period one through four as shown in Figure 3-3. These are summarized in Table 3-9 and Table 3-10.
Figure 3-3. A Scenario Tree for a Microcredit Contract

Table 3-9. Asset Yields under All Scenarios

<table>
<thead>
<tr>
<th>Time</th>
<th>Asset</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
<th>Time</th>
<th>Asset</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>Asset 1</td>
<td>1.104</td>
<td>1.104</td>
<td>0.959</td>
<td>0.959</td>
<td>T2</td>
<td>Asset 1</td>
<td>1.116</td>
<td>1.110</td>
<td>0.830</td>
<td>1.166</td>
</tr>
<tr>
<td></td>
<td>Asset 2</td>
<td>0.938</td>
<td>0.938</td>
<td>1.666</td>
<td>1.666</td>
<td></td>
<td>Asset 2</td>
<td>1.102</td>
<td>0.933</td>
<td>0.935</td>
<td>1.167</td>
</tr>
<tr>
<td></td>
<td>Asset 3</td>
<td>0.924</td>
<td>0.924</td>
<td>1.167</td>
<td>1.167</td>
<td></td>
<td>Asset 3</td>
<td>1.102</td>
<td>0.891</td>
<td>0.908</td>
<td>1.203</td>
</tr>
<tr>
<td></td>
<td>Asset 4</td>
<td>1.107</td>
<td>1.107</td>
<td>0.908</td>
<td>0.908</td>
<td></td>
<td>Asset 4</td>
<td>1.125</td>
<td>1.105</td>
<td>0.857</td>
<td>1.206</td>
</tr>
<tr>
<td>T1</td>
<td>Asset 1</td>
<td>1.110</td>
<td>0.975</td>
<td>1.167</td>
<td>1.167</td>
<td>T3</td>
<td>Asset 1</td>
<td>1.304</td>
<td>0.963</td>
<td>1.115</td>
<td>0.795</td>
</tr>
<tr>
<td></td>
<td>Asset 2</td>
<td>0.933</td>
<td>0.898</td>
<td>0.903</td>
<td>1.156</td>
<td></td>
<td>Asset 2</td>
<td>1.203</td>
<td>0.821</td>
<td>1.238</td>
<td>0.830</td>
</tr>
<tr>
<td></td>
<td>Asset 3</td>
<td>0.891</td>
<td>0.873</td>
<td>0.907</td>
<td>1.141</td>
<td></td>
<td>Asset 3</td>
<td>1.195</td>
<td>0.821</td>
<td>1.305</td>
<td>0.875</td>
</tr>
<tr>
<td></td>
<td>Asset 4</td>
<td>1.105</td>
<td>0.925</td>
<td>1.187</td>
<td>0.877</td>
<td></td>
<td>Asset 4</td>
<td>1.295</td>
<td>0.959</td>
<td>1.295</td>
<td>0.855</td>
</tr>
</tbody>
</table>

Table 3-10. Cash Yields under All Scenarios

<table>
<thead>
<tr>
<th>Time</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>1.030</td>
<td>1.030</td>
<td>1.012</td>
<td>1.012</td>
</tr>
<tr>
<td>T1</td>
<td>1.032</td>
<td>1.014</td>
<td>1.030</td>
<td>1.009</td>
</tr>
<tr>
<td>T2</td>
<td>1.034</td>
<td>1.021</td>
<td>1.021</td>
<td>1.007</td>
</tr>
<tr>
<td>T3</td>
<td>1.035</td>
<td>1.027</td>
<td>1.025</td>
<td>1.006</td>
</tr>
</tbody>
</table>

Tax rates under all scenarios are shown in Table 3-11. The manufacturer’s balance sheet at the planning period is shown in Table 3-12. The balance sheet reflects the company’s assets, equity, and liabilities.
Table 3-11. Tax Rates under All Scenarios

<table>
<thead>
<tr>
<th>Tax Rate</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.225</td>
<td>0.225</td>
<td>0.225</td>
<td>0.225</td>
</tr>
</tbody>
</table>

Table 3-12. Balance Sheet at the Planning Period

<table>
<thead>
<tr>
<th>Account</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assets</td>
<td>$6,222</td>
</tr>
<tr>
<td>Current Assets</td>
<td>$10,000</td>
</tr>
<tr>
<td>Total Assets</td>
<td>$16,222</td>
</tr>
<tr>
<td>Equity</td>
<td>$11,290</td>
</tr>
<tr>
<td>Debt</td>
<td>0</td>
</tr>
<tr>
<td>Total Debt and Equity</td>
<td>$11,290</td>
</tr>
</tbody>
</table>

As shown in Table 3-13, the targeted financial ratio values are employed from the FMFB-Afghanistan through MIX Market database in 2013.

Table 3-13. Financial Ratio Target Values

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Value</th>
<th>Ratio</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROET</td>
<td>0.193</td>
<td>YGT</td>
<td>0.0987</td>
</tr>
<tr>
<td>ROAT</td>
<td>0.015</td>
<td>FET</td>
<td>0.0226</td>
</tr>
<tr>
<td>OSST</td>
<td>1.1847</td>
<td>LOPT</td>
<td>52</td>
</tr>
<tr>
<td>PMT</td>
<td>0.1559</td>
<td>OET</td>
<td>0.0758</td>
</tr>
<tr>
<td>YGLT</td>
<td>0.1799</td>
<td>CPBT</td>
<td>173</td>
</tr>
<tr>
<td>CRT</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

At the second stage, incorporating the minimum interest rate obtained from the BSC model, the developed scenario-based stochastic microcredit models are coded in GAMS and solved with CPLEX to determine the optimal interest rate, along with portfolio decisions on secured assets with data derived in Table 3-3 through Table 3-13. The manufactures has a positive cash amount as shown in Table 3-14.
Table 3-14. Cash Amounts under All Scenarios

<table>
<thead>
<tr>
<th>Time</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>$330,909</td>
<td>$330,306</td>
<td>$327,951</td>
<td>$336,323</td>
</tr>
<tr>
<td>T2</td>
<td>$143,824</td>
<td>$119,940</td>
<td>$129,198</td>
<td>$117,335</td>
</tr>
<tr>
<td>T3</td>
<td>$235,800</td>
<td>$240,588</td>
<td>$217,431</td>
<td>$192,748</td>
</tr>
<tr>
<td>T4</td>
<td>$378,045</td>
<td>$370,139</td>
<td>$535,987</td>
<td>$512,400</td>
</tr>
</tbody>
</table>

The proposed model compares the value of ROA and YGL with the real values from FMFB. As shown in Table 3.15 and Table 3.16, the proposed model shows relatively more effectiveness with which the manufacturer uses its total assets to generate revenues due to secured asset portfolio decisions. In addition, the proposed model is relatively more efficient in collecting loans from the supplier due to peer monitoring.

Table 3-15. Return on Asset under All Scenarios

<table>
<thead>
<tr>
<th>Time</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
<th>FMFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0.351</td>
<td>0.351</td>
<td>0.355</td>
<td>0.359</td>
<td>0.0150</td>
</tr>
<tr>
<td>T2</td>
<td>0.414</td>
<td>0.393</td>
<td>0.348</td>
<td>0.390</td>
<td>0.0055</td>
</tr>
<tr>
<td>T3</td>
<td>0.278</td>
<td>0.323</td>
<td>0.254</td>
<td>0.284</td>
<td>0.0162</td>
</tr>
<tr>
<td>T4</td>
<td>0.307</td>
<td>0.306</td>
<td>0.270</td>
<td>0.271</td>
<td>0.0183</td>
</tr>
</tbody>
</table>

Table 3-16. Yields on Gross Loan Portfolio under All Scenarios

<table>
<thead>
<tr>
<th>Time</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
<th>FMFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0.267</td>
<td>0.269</td>
<td>0.287</td>
<td>0.269</td>
<td>0.1748</td>
</tr>
<tr>
<td>T2</td>
<td>0.267</td>
<td>0.269</td>
<td>0.287</td>
<td>0.269</td>
<td>0.1866</td>
</tr>
<tr>
<td>T3</td>
<td>0.267</td>
<td>0.269</td>
<td>0.287</td>
<td>0.269</td>
<td>0.1812</td>
</tr>
<tr>
<td>T4</td>
<td>0.267</td>
<td>0.269</td>
<td>0.287</td>
<td>0.269</td>
<td>0.1713</td>
</tr>
</tbody>
</table>

In Table 3-17, the optimization model provides the best secured asset portfolio strategy for a group case with strategic default case. For example, the best strategy of scenario one is to buy 186 of secured asset one at the period two, 460 of secured asset two at the period three, and 799 of secured asset one at the period four. In addition, the best scenario one is to sell 99 of secured asset two at the period three.
Table 3-17. Decisions on Assets in a Group Contract with Strategic Default Case

<table>
<thead>
<tr>
<th>Time</th>
<th>Asset</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>Asset 1</td>
<td>186</td>
<td>186</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>Asset 1</td>
<td>460</td>
<td>460</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T4</td>
<td>Asset 1</td>
<td>799</td>
<td>835</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table 3-18, the optimal interest rate for each type of a borrower under all scenarios is calculated. In the group microcredit case, under scenario one, each type of borrower has the interest rate of 8.3% over all periods. Under scenario two, each type of borrower generally has the interest rate of 6.4% in period one through period two.

However, each type of borrower’s interest rates is increased from 6.4% to 8% in period three through period four. Under scenario three, each type of borrower generally has an interest rate around 8% over all periods. Finally, under scenario four, each type of borrower generally has an interest rate of 6% over all periods. Comparing an individual microcredit model with the group microcredit model, there is not much difference in terms of interest rate.

Finally, in order to illustrate the benefit of a SCMF scheme, the concept of cash flow bullwhip (CFB) is applied to two cases -- a normal case and a SCMF case. The study of Tangsucheeva and Prabhu (2013) demonstrates that the increase of bullwhip effect causes the increase of CFB effect in terms of the cash conversion cycle (CCC). Based on the study of Tangsucheeva and Prabhu (2013), the components of CCC are defined in Equation (3.45) through Equation (3.48).
Table 3-18. Interest Rates under All Scenarios

<table>
<thead>
<tr>
<th>Time</th>
<th>Type</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
<th>Time</th>
<th>Type</th>
<th>UU</th>
<th>UD</th>
<th>DU</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>B1</td>
<td>0.083</td>
<td>0.64</td>
<td>0.08</td>
<td>0.072</td>
<td>T2</td>
<td>B1</td>
<td>0.08</td>
<td>0.08</td>
<td>0.092</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>0.083</td>
<td>0.064</td>
<td>0.08</td>
<td>0.06</td>
<td></td>
<td>B2</td>
<td>0.083</td>
<td>0.08</td>
<td>0.07</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>0.083</td>
<td>0.064</td>
<td>0.08</td>
<td>0.06</td>
<td></td>
<td>B3</td>
<td>0.08</td>
<td>0.08</td>
<td>0.063</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td>0.083</td>
<td>0.064</td>
<td>0.08</td>
<td>0.06</td>
<td></td>
<td>B4</td>
<td>0.083</td>
<td>0.08</td>
<td>0.097</td>
<td>0.063</td>
</tr>
<tr>
<td>T1</td>
<td>B1</td>
<td>0.083</td>
<td>0.129</td>
<td>0.08</td>
<td>0.06</td>
<td>T3</td>
<td>B1</td>
<td>0.083</td>
<td>0.08</td>
<td>0.08</td>
<td>0.072</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>0.083</td>
<td>0.064</td>
<td>0.08</td>
<td>0.072</td>
<td></td>
<td>B2</td>
<td>0.083</td>
<td>0.08</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>0.083</td>
<td>0.064</td>
<td>0.08</td>
<td>0.06</td>
<td></td>
<td>B3</td>
<td>0.083</td>
<td>0.08</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td>0.083</td>
<td>0.129</td>
<td>0.08</td>
<td>0.06</td>
<td></td>
<td>B4</td>
<td>0.083</td>
<td>0.08</td>
<td>0.08</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Days inventory outstanding (DIO) in a SCMF case are represented in Equation (3.45) as follows:

\[
\text{DIO} = \frac{\text{Average Inventory}}{\text{Cost of Good Sold/365}} = \frac{sI}{(c+e)D/365} = 365 \left( \frac{s}{c+e} \right) \left( \frac{I}{D} \right) \quad (3.45)
\]

where \( s \) is the sale price per unit, \( R \) is the addition revenue per unit from a microcredit contract, \( I \) is the average inventory level, \( c \) is the unit cost, \( e \) is the addition cost per unit from a microcredit contract, \( D \) is the average demand.

When the demand is less than the inventory level, days sales outstanding (DSO) is represented in Equation (3.46) as follows:

\[
\text{DSO} = \frac{\text{Average Account Receivable}}{\text{Revenue/365}} = \frac{(s+R)D}{(s+R)D/365} = 365 \left( \frac{I}{D} \right) \quad (3.46)
\]

When the demand is greater than the inventory level, days sales outstanding (DSO) is represented in Equation (3.47) as follows:

\[
\text{DSO} = \frac{\text{Average Account Receivable}}{\text{Revenue/365}} = \frac{(s+R)I}{(s+R)D/365} = 365 \left( \frac{I}{D} \right) \quad (3.47)
\]

Days payable outstanding (DPO) is represented in Equation (3.48) as follows:

\[
\text{DPO} = \frac{\text{Average Account Payable}}{\text{Cost of Good Sold/365}} = \frac{(c+e)q}{(c+e)D/365} = 365 \left( \frac{q}{D} \right) \quad (3.48)
\]
Based on the study of Tangsuecheeva and Prabhu (2013), the CFB of the SCMF case is represented in Equation (3.49) and Equation (3.50) when the demand is less than the inventory level.

\[
\frac{\text{Var}_{(\text{CCC})}}{\text{Var}(D)} = \left(\frac{365}{\text{Var}(D)} \frac{s}{c + e}\right)^2 \text{Var}\left(\frac{I}{D}\right) + \left(\frac{365}{\text{Var}(D)} \frac{q}{D}\right) \quad (3.49)
\]

\[
\frac{\text{Var}_{(\text{CCC})}}{\text{Var}(D)} \approx \left(\frac{365}{\text{E}(D)} \frac{s}{c + e}\right)^2 \left[\text{Var}(I) \frac{\text{Var}(D)}{\text{Var}(D)} \frac{E(I)}{\text{E}(D)} + \left(\frac{365}{\text{Var}(D)} \frac{E(q)}{D}\right) \right] + \left[\frac{\text{Var}(q) + E(q)^2}{\text{Var}(D) + E(D)^2}\right] \quad (3.50)
\]

In a similar way, the CFB of the SCMF case is represented in Equation (3.51) and Equation (3.52) when the demand is greater than the inventory level.

\[
\frac{\text{Var}_{(\text{CCC})}}{\text{Var}(D)} = \left(\frac{365}{\text{Var}(D)} \frac{s}{c + e}\right)^2 \text{Var}\left(\frac{I}{D}\right) + \left(\frac{365}{\text{Var}(D)} \frac{q}{D}\right) \quad (3.51)
\]

\[
\frac{\text{Var}_{(\text{CCC})}}{\text{Var}(D)} \approx \left(\frac{365}{\text{E}(D)} \frac{s}{c + e}\right)^2 \left[\text{Var}(I) \frac{\text{Var}(D)}{\text{Var}(D)} f(L,p,\rho) + \left(\frac{365}{\text{Var}(D)} \frac{E(I)}{D}\right) + \left[\frac{\text{Var}(q) + E(q)^2}{\text{Var}(D) + E(D)^2}\right]\right] \quad (3.52)
\]

The benefit of a SCMF scheme is illustrated by comparing the CFB of a SCMF case and that of a normal case. When the demand is less than the inventory level, the CFB of a normal case in Equation (3.53) is greater than that of a SCMF case in Equation (3.50) because \((s/c)^2\) is greater than \([s/(c + e)]^2\). By subtracting Equation (3.50) by Equation (3.53), the difference of CFB in two cases is calculated as follows:

\[
\frac{\text{Var}(\text{CCC})}{\text{Var}(D)} \approx \left(\frac{365}{\text{E}(D)} \frac{s}{c}\right)^2 \left[\text{Var}(I) \frac{\text{Var}(D)}{\text{Var}(D)} f(L,p,\rho) + \left(\frac{365}{\text{Var}(D)} \frac{E(I)}{D}\right) + \left[\frac{\text{Var}(q) + E(q)^2}{\text{Var}(D) + E(D)^2}\right]\right] \quad (3.53)
\]

\[
\Delta = \frac{365}{\text{E}(D)} \frac{s^2(2c + e)}{c^2(c + e)^2} \left[\text{Var}(I) \frac{\text{Var}(D)}{\text{Var}(D)} f(L,p,\rho) + \left(\frac{365}{\text{Var}(D)} \frac{E(I)}{D}\right) + \left[\frac{\text{Var}(q) + E(q)^2}{\text{Var}(D) + E(D)^2}\right]\right]
\]

48
When the demand is greater than the inventory level, the difference of CFB is similarly calculated as follows:

\[
\frac{\text{Var}_{\text{a}}(\text{CCC})}{\text{Var}(D)} \approx \frac{(365)^2}{E(D)^2} \left[ \left( \frac{s}{c} \right)^2 + 1 \right] \left[ \frac{\text{Var}(q)}{\text{Var}(D)} + f(L,p,\rho) + \frac{E(I)^2}{E(D)^2} \right] + \left[ \frac{\text{Var}(q)}{\text{Var}(D)} + \frac{E(q)^2}{E(D)^2} \right] \tag{3.54}
\]

\[
\Delta = \frac{(365)^2}{E(D)^2} \left[ \frac{es^2(2c + e)}{c^2(c + e)^2} \right] \left[ \frac{\text{Var}(q)}{\text{Var}(D)} + f(L,p,\rho) + \frac{E(I)^2}{E(D)^2} \right]
\]

The bullwhip effect is considered as one of critical problems in supply chain management. The study of Tangsucheeva and Prabhu (2013) demonstrates that the increase in bullwhip effect causes the increase of CFB effect. With a simple mathematical comparison, this study shows that the SCMF scheme has always decreased CFB effect by \( \Delta \). As shown in Figure 3-4, two types of CFBs are compared over deltas in each case. The CFB of a normal case is always greater than that of a SCMF case. It implies that a SCMF scheme can decrease the effect of CFB. The CFB is increasing as the delta is increasing from 0 to 800. Based on the results of the study of Tangsucheeva and Prabhu (2013), it is possible to conclude that the SCMF scheme can reduce the variance of inventory, the CCC, and the manufacturer's financial cost to some degree.

![Figure 3-4. Cash Flow Bullwhip Effect Over Deltas](image-url)
3.4 Conclusion

In contrast to most microfinance contract models in a static economic environment, this study provides a stochastic scenario-based microcredit contract model for a group case with strategic default under asset and cash yield uncertainty. The developed models provide an optimal interest rate over four different scenarios. To provide a reasonable interest rate, the model considers several features: BSD model, strategic secured asset portfolio decisions, and microfinance ratio target values. First, the model uses the BSD model to calculate a minimum interest rate when a loan is considered a call option. The minimum interest rate guarantees MFIs’ financial sustainability at least. Second, the model considers asset portfolio decisions to increase the institution’s financial sustainability. The increased financial sustainability leads to a decrease in the interest rate needed to be assigned. Finally, the model employs a microfinance ratio target value to reflect a real microfinance business environment. The satisfaction of microfinance ratio targets improves the efficiency and productivity of MFIs. The proposed model could be used an effective credit risk tool in the microfinance business environment.
Chapter 4

A Supply Chain Microfinance Game Model

In this chapter, this study formulates the concept of SCMF as a Stackelberg game model in the framework of a newsvendor problem for three entities, a manufacturer, a supplier, and a bank, based on the concept of SCMF. The manufacturer as a leader decides on an optimal order quantity and an optimal interest rate of a microcredit loan, the bank as a sub-leader decides on an optimal interest rate of a loan to a manufacturer, and the supplier as a follower decides on an optimal wholesale price.

4.1 Introduction

In the recent global business environment, leading business organizations such as Shell, BASF, and Toyota have realized that business competitiveness lies in non-financial performance (Beamon, 1999). Corporate sustainability, which simultaneously considers economic, environmental, and social values, has risen in importance. In response, leading corporations now expend more effort on both environmental and social values to achieve business competitiveness in terms of economic growth and success (Stead et al., 2008). Encouraged by the success of various MFIs over the past decades, several business organizations have sought the potential opportunities to enhance social values by collaborating with suppliers to a sustainable raw material supply for manufacturers and sustainable economic growth for impoverished raw material suppliers.

After the noticeable success of ACCION in Brazil and Grameen Bank in Bangladesh in the early 2000s, microfinance has become a new tool for alleviating poverty and improving the limited access to financial services to the poor in both developing and underdeveloped countries.
While maintaining financial and operational sustainability, MFIs have increased social sustainability toward particular clientele in remote and rural areas by providing both financial resources, such as small collateral-free loans, savings, and insurance, and social resources, such as health care and education, (Sengupta and Aubuchon, 2008).

As the importance of CSR escalates, companies can use microfinance as one of their increasing strategic approaches to incorporate social responsibility into their merchandise and service into their supply chain. For example, Vicuna wool is considered to be among the world’s finest and most expensive fabrics, due to its rarity and the Vicuna’s habitat at over 4000 meters altitude in the Andes. A yard of Vicuna wool is traded at between $1,800 and $3,000, compared to Merino wool at $50 per yard and Cashmere at over $100 per yard.

Due to the high price of its wool, Vicuna are a valuable resource for the impoverished rural population in the Andes. However, the Vicuna wool production industry does not have adequate finance or infrastructure to process a large quantity of high quality wool. The current shearing process of Vicuna is done with inefficient tools, which lowers the quality of the wool. The lack of financial resources results in most of the wool produced in the Andes today being traded at non-fair prices and being exported as raw wool.

The Vicuna wool example shows how microfinance has the potential to simultaneously improve companies’ social responsibility and supply chain performance. For instance, if the Vicuna farmers had adequate resources, they could produce a large share of high quality wool and generate more income by selling the wool at fair prices and by raising more Vicunas in a better environment. On the other hand, manufacturers would benefit from product quality enhanced by more reliable sources of raw material and from lower sourcing costs enhanced by increased operating efficiencies through a solid relationship between supplier and manufacturer. These efforts are critical not only because of the desirability of sustainable wool sources for manufacturers in the supply chain, but also because of the potential for rural poverty alleviation.
In general, MFIs experience difficulty in operation because of high levels of poverty, information asymmetries, incentive incompatibilities, and imperfect mechanisms of contract enforcement in underdeveloped countries (Conning and Udry, 2007). In those business environments, the primary income source of MFIs is the interest earnings of their loan portfolio. For this reason, it has been inevitable to charge high interest to cover the major costs of the microfinance industry. However, inappropriate interest rate is one of the critical issues in increasing outreach toward target clientele in remote and rural areas, while maintaining the sustainability of the institutions at the same time.

In this paper, the concept of SCMF is presented as an innovative approach to decreasing high interest rates. By incorporating the concept of SCF into microfinance, it is believed that a company can provide a raw material supplier with a microcredit loan at a low interest rate. The suppliers increase the income of raw materials at fair trade (Alexander and Alexander, 1991). On the other hand, the company can have benefits of increasing CSR by granting the supplier access to capital and market (Gaspar, 2003). The company also has benefits of decreasing the supply risk by securing a consistent supply of raw materials (Norell and Brand, 2012).

As shown in Figure 4.1, supply chain microfinance consists of a bank, a manufacturer, and a supplier. A poor supplier with no financial resources in undercapitalized countries normally would have no opportunity to obtain a loan from a bank. As a result, a poor supplier seeking capital to fund a project would have no resource but to apply for a microcredit loan from a MFI at a high interest rate which average 38%.

In contrast, in the SCMF model, to provide loans to suppliers at a lower interest rate, manufacturers intercede as middleman. In this scheme, a manufacturer which can get an investment (I_b) from a bank at a low interest (R_b), lends the investment (L_i) to a poor supplier at a relatively low interest rate (R_m) via an MFIs. Due to operational and financial restrictions, the manufacturer cannot directly lend money to the supplier. The MFI acts as an intermediate agent,
with the manufacturer paying related loan processing costs \((L_{pc})\). In reality, the supplier makes a repayment to the manufacturer with the equivalent value of raw materials. Because it also reaps the intangible benefit of CSR, the manufacturer does not charge any extra interest rate to the cooperating MFI.

In this study, based on the concept of SCMF, multi-level Stackelberg game formulations are developed to obtain a proper interest rate in the microfinance business environment. In the multi-level Stackelberg game, the manufacturer as the leader makes a decision on the interest rate \((R_{M})\) of a microcredit loan \((L_{I})\) to a supplier, and the supplier as the follower makes a decision on the raw material price. In addition, the bank makes a decision on the interest rate \((R_{B})\) of an investment \((I_{B})\) to the manufacturer.

The rest of this paper is organized into four sections. Section Two provides a review of the relevant literature on game theory and SCF. In Section Three, a multi-level Stackelberg game model of SCMF is presented along with optimal decision for each entity. In Section Four, numerical examples from the Vicunas wool case are presented with discussion. Finally, the conclusion is provided in Section Five.

### 4.2 SCMF Model

Based on the concept of SCMF, the objective of this study is to design a relevant Stackelberg game model which provides the optimal production quantity and the optimal interest rate for the manufacturer as a lender, the optimal interest rate for the bank as an investor, and the optimal wholesale price for the supplier as a borrower under uncertainty demand.
4.2.1 SCMF Model Description

This section reviews the overview of SCMF, along with the sequence of events and assumptions of the model. A supplier with no financial resources chooses a SCMF method to borrow a microcredit loan from a manufacturer at a relatively low interest rate, compared to that of a conventional microcredit loan. Because the primary income resource of MFIs is the interest earnings of their loan portfolios, it is inevitable to charge a high interest rate to cover their major costs. To satisfy uncertainty demand, the capital-constrained manufacturer provides a microcredit loan and gets the equivalent value of raw material as a repayment at fair trade, along with CSR. Since the manufacturer does not receive any financial earning from an MFI except CSR, the general SCMF network can be simplified as shown in Figure 4-1.

![Figure 4-1. Decisions in a Simplified Supply Chain Microfinance Network](image)

As shown in Figure 4-2, in SCMF, the sequence of events is as follows: At the beginning of a period, the manufacturer provides a SCMF contract to the supplier. At the same time, the manufacturer decides an order quantity (Q) and an associate interest rate of the SCMF contract (R_m). After receiving the investment request from the manufacturer, the bank decides on an interest rate (R_b) for the investment. After accepting the contract, the supplier decides a wholesale price (w) of raw materials.
At the beginning of a period, manufacturer provides a SCMF contract to the supplier.

Manufacturer decides an order quantity and an associate interest rate of the SCMF contract.

After receiving the investment request from the manufacturer, the bank decides on an interest rate for the investment.

After receiving the contract, the supplier decides on a wholesale price of raw materials.

At the end of the period, the supplier repays the loan principal with the associated interest to the manufacturer.

After the manufacturer receives the payment with the associated interest, the manufacturer makes a repayment to the bank.

Figure 4-2. The Sequence of Event

Meanwhile, at the end of a period, the supplier repays the loan principal (I_M) with the associated interest to the manufacturer. After the manufacturer receives the payment with an associated interest, the manufacturer makes a repayment (I_B) to the bank. If the manufacturer cannot make a repayment, the bank liquidates the remaining assets of the manufacturer.

As in the study of Yan and Sun (2013), the proposed model also has several assumptions on information symmetry, production capacity, perfect capital market, risk neutral, and strategic default risk. In the information symmetry assumption, the three entities -- a manufacturer, a supplier, and a bank -- have the same knowledge of each entity’s status except uncertain demand. Second, the manufacturer and the supplier have an unconstrained production capacity to meet the customer’s demand. Third, the capital market is assumed to be perfect, such as no tax, no transaction cost, and no bankruptcy cost. Fourth, the three risk neutral entities make
an effort to maximize their expected profits. Further, the manufacturer and the supplier do not take any strategic default. Finally, for simplicity, it is assumed that the supplier does not have any chance of bankruptcy. For simplicity, in our model, the salvage value of unsold product and a goodwill cost for unmet demand are ignored. The model notation is summarized in Table 4-1.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>Uncertainty demand</td>
</tr>
<tr>
<td>q</td>
<td>Manufacturer’s order quantity</td>
</tr>
<tr>
<td>k</td>
<td>Manufacturer’s bankruptcy threshold</td>
</tr>
<tr>
<td>p</td>
<td>Unit sales price</td>
</tr>
<tr>
<td>c</td>
<td>Unit production cost</td>
</tr>
<tr>
<td>w</td>
<td>Unit raw material price</td>
</tr>
<tr>
<td>e</td>
<td>Unit raw material production expense</td>
</tr>
<tr>
<td>m</td>
<td>Unit raw material production margin</td>
</tr>
<tr>
<td>R_I</td>
<td>Manufacturer’s investment interest rate</td>
</tr>
<tr>
<td>R_B</td>
<td>Bank’s interest rate</td>
</tr>
<tr>
<td>R_M</td>
<td>Manufacturer’s interest rate</td>
</tr>
<tr>
<td>k_M</td>
<td>Manufacturer’s initial working capital</td>
</tr>
</tbody>
</table>

4.2.2 Stackelberg Game Model of SCMF

This study considers a Stackelberg game model of SCMF with three entities, a bank as sub-leader, a manufacturer as a leader, and a supplier as a follower, in a single period based on a newsvendor problem framework. In the model, the manufacturer's uncertainty demand is denoted by a non-negative random variable \( x \). The probability density function of \( x \) is represented by \( f(x) \), cumulative distribution function (CDF) of \( x \) is represented by \( F(x) \), and the complementary CDF of \( x \) is represented by \( F(x) \). Further, the study only considers demand distribution with an increasing failure rate (IFR), which is a common assumption in supply chain literature (Lariviere and Porteus, 2006).
4.2.2.1 Manufacturer’s Decision

In the SCMF scheme, the manufacturer makes decisions on the optimal order quantity and the optimal interest rate of a microcredit loan for the supplier to achieve the expected profit maximization. In the presence of demand uncertainty, the manufacturer places an order of raw materials with the size of $q$ at a cost of $w$ per unit. With the objective of CSR, the manufacturer only considers a poor supplier with no financial resources to produce the raw materials. For this reason, it is necessary provide a microcredit loan at appropriate interest rate $R_M$. In addition, the manufacturer takes all responsibility and risk of the default of a supplier.

At the beginning of the period, depending on the manufacturer’s financial status, the manufacturer borrows a loan $(wq - K_M)^+$ with an interest rate $R_B$ from the bank and provides a microcredit loan $wq$ with an interest rate $R_M$ for the poor supplier. If the manufacturer has enough working capital, the manufacturer may invest the working capital $(K_M - wq)^+$ at the manufacturer’s investment interest rate $R_I$.

At the end of the period, the manufacturer makes the sales profit $(p - c) \min(x, q)$, gets surplus working capital return $(wq - K_M)^+(1 + R_I)$, earns the microcredit interest $wq(1 + R_M)$, and repays the borrowed loan $(wq - K_M)^+(1 + R_B)$. The manufacturer’s expected terminal cash is represented in Equation (4.1) as follows:

$$\pi_M(q, w, R_B, R_M) = E[(p - c) \min(x, q) + (K_M - wq)^+(1 + R_I)$$

$$- (wq - K_M)^+(1 + R_B) + wq(1 + R_M)]^+$$  \hspace{1cm} (4.1)

In this model, there is the manufacturer’s bankruptcy threshold below which the manufacturer cannot repay the bank’s loan with the associated interest, as represented in Equation (4.2). In order to make a profit, the manufacturer needs the order quantity to be greater than the
manufacturer’s bankruptcy threshold \( k < q \).

\[
k(q, w, R_b, R_M) = \frac{[(wq - K_M)^+ (1 + R_b) - (K_M - wq)^+ (1 + R_f) - wq(1 + R_b)]^+}{(p - c)}
\]

(4.2)

The bank expects full repayment when the manufacturer’s revenue is greater than the manufacturer’s cost. Otherwise, the bank liquidates the remaining assets of the manufacturer for a partial payment. Thus, the bank’s expected terminal cash is represented in Equation (4.3) as follows:

\[
\pi_B(q, w, R_b, R_M) = E[\min\{(p - c) \min(x, q) + (K_M - wq)^+ (1 + R_f) + wq(1 + R_M),
\]

\[
(wq - K_M)^+ (1 + R_b)]
\]

(4.3)

As shown in the study of Kouvelis and Zhao (2012), Equation (4.3) can be rewritten as follows:

\[
\pi_B(q, w, R_b, R_M) = E[(p - c) \min(x, q)] + (K_M^+ - wq)^+ (1 + R_f) + wq(1 + R_M)
\]

\[
- E[(p - c) \min(x, q) + (K_M^+ - wq)^+ (1 + R_f) + wq(1 + R_M) - (wq - K_M^+)^+ (1 + R_f)]^+
\]

\[
= E[(p - c) \min(x, q)] + (K_M^+ - wq)^+ (1 + R_f) + wq(1 + R_M) - \pi_M(q, w, R_b, R_M)
\]

(4.4)

In order for the bank loan to be competitively priced, the bank’s interest rate for the manufacturer should bring the same returns from both the loan to the manufacturer and the investment with a risk-free interest rate (Kouvelis and Zhao, 2012). For a competitively priced loan, the bank’s expected terminal cash flow is represented as follows:

\[
(wq - K_M)^+ (1 + R_f) = E[\min\{(p - c) \min(x, q) + (K_M^+ - wq)^+ (1 + R_f) + wq(1 + R_M),
\]

\[
(wq - K_M^+)^+ (1 + R_b)]
\]

(4.5)

By substituting Equation (4.4) into Equation (4.5), the bank’s expected terminal cash flow is represented in Equation (4.6) as follows:

\[
(wq - K_M^+)^+ (1 + R_b) = E[(p - c) \min(x, q)] + (K_M^+ - wq)^+ (1 + R_f) + wq(1 + R_M)
\]
By rewriting Equation (4.6), in case of \( wq > R_M \), the manufacturer’s expected terminal cash can be represented as follows:

\[
\pi_M(q, w, R_B, R_M) = E[(p - c) \min(x, q)] + (K_M - wq)^+ (1 + R_f) + wq(1 + R_M) - (wq - K_M)^+ (1 + R_f) \\
= E[(p - c) \min(x, q)] + wq(R_M - R_f) + K_M(1 + R_f)
\]  

(4.7)

**Proposition 1** Given IFR demand distribution, a wholesale price of raw material, an interest rate of a bank loan, and an interest rate of the manufacturer’s microcredit loan, the unconstrained manufacturer’s optimal order quantity is as follows:

\[
q^* = \bar{F}^{-1}\left(\frac{w(R_f - R_M)}{(p - c)}\right)
\]  

(4.8)

As shown in Equation (4.8), the manufacturer’s optimal order quantity is not influenced by the bank’s interest rate \( R_B \), which shows the same result as the study of Kouvelis and Zhao (2012). Kouvelis and Zhao (2012) explain this result as the capital-constrained manufacturer under bank financing can make an operational decision on ordering without any involvement of financial decisions under a perfect capital market.

To calculate the constrained manufacturer’s optimal order quantity, when the order quantity is greater than the manufacturer’s bankruptcy threshold \( k < q \) and \( wq \geq K_M \), the Equation (4.1) can be rewritten as follows:

\[
\pi_M(q, w, R_B, R_M) = E[(p - c) \min(x, q) + (K_M - wq)^+ (1 + R_f)] \\
- (wq - K_M)^+ (1 + R_B) + wq(1 + R_M)]^+ \\
= E[(p - c) \min(x, q) - (wq - K_M)^+ (1 + R_B) + wq(1 + R_M)]^+ \\
= (p - c)E[\min(x, q)] - (wq - K_M)^+ (1 + R_B) + wq(1 + R_M)
\]  

(4.9)
Since \(k < q\) and \(wq \geq K_M\), Equation (4.5) can be simplified as follows:

\[
(wq - K_M)^\dagger(1 + R_y) = E[\min\{(p - c)\min(x, q) + (K_M - wq)^\dagger(1 + R_y) + wq(1 + R_M),
\]

\[
(wq - K_M)^\dagger(1 + R_y)]
\]

\[
= E[\min\{(p - c)\min(x, q) + wq(1 + R_M), (wq - K_M)^\dagger(1 + R_y)]
\]

\[
= E[(p - c)\min(x, q) + wq(1 + R_M)]
\]

\[
- E[(p - c)\min(x, q) + wq(1 + R_M) - (wq - K_M)^\dagger(1 + R_y)]
\]

\[
= E[(p - c)\min(x, q) + wq(1 + R_M)] - E[(p - c)\min(x, q) - (p - c)k]^\dagger
\]

\[
= (p - c)E[\min(x, q)] + wq(1 + R_M)
\]

\[
- \{(p - c)E[\min(x, q)] - (p - c)E[\min(x, k)]
\]

\[
= (p - c)E[\min(x, k)] + wq(1 + R_M)
\]

(4.10)

By substituting Equation (4.10) into Equation (4.9), the manufacturer’s expected terminal cash can be represented as follows:

\[
\pi_M(q, w, R_y, R_M) = (p - c)E[\min(x, q)] - (wq - K_M)^\dagger(1 + R_y) + wq(1 + R_M)
\]

\[
= (p - c)E[\min(x, q)] + wq(1 + R_M) - (wq - K_M)^\dagger(1 + R_y)
\]

\[
= (p - c)E[\min(x, q)] + wq(1 + R_M) - (wq - K_M)^\dagger(1 + R_y)
\]

\[
= (p - c)E[\min(x, q)] + wq(1 + R_M) - (p - c)E[\min(x, k)] - wq(1 + R_M)
\]

\[
= (p - c)E[\min(x, q)] - (p - c)E[\min(x, k)]
\]

(4.11)

**Proposition 2** Given IFR demand distribution, a wholesale price of a raw material, an interest rate of a bank loan, and an interest rate of the manufacturer’s microcredit loan, the constrained manufacturer’s optimal order quantity in the case of \(k < q\) and \(wq \geq K_M\) is as follows:

\[
q^* = F^{-1} \left[ \frac{w(R_y - R_M)}{(p - c)} \right] \times F(k)
\]

(4.12)
By comparing the manufacturer’s optimal order quantity in a financing case and a non-financing case, it is possible to show how three interest rates interact in terms of an uncertainty demand.

**Proposition 3** Given IFR demand distribution, a wholesale price of a raw material, an interest rate of a bank loan, and an interest rate of the manufacturer’s microcredit loan, the unconstrained manufacturer’s optimal order quantity is greater than that of the constrained manufacturer under a certain condition of the bank’s interest in the case of \( k < q \) and \( wq \geq K_M \). By meeting this condition, the manufacturer can still make an operational decision without any influence of a financial decision.

\[
R_B \leq \frac{R_i - R_M F(k)}{F(k)} \quad (4.13)
\]

**Proposition 4** Given IFR demand distribution, a wholesale price of raw material, and an interest rate of a bank loan, the constrained manufacturer’s optimal interest rate of a microcredit loan in the case of \( k < q \) and \( wq \geq K_M \) is as follows:

\[
R_M^* = \frac{(p - c)\Omega F(k) - q\Omega^2 f(k) + (p - c)[f(q) - \Omega^2 f(k)]}{w^2[q\Omega f(k) - F(k)]} \quad (4.14)
\]

where \( \Omega = \frac{w(R_B - R_M)}{p - c} \)

### 4.2.2.2 Bank’s Decision

In the SCMF scheme, the bank makes a decision on the interest rate for the manufacturer to maximize the expected profit. The bank’s expected terminal cash is represented in Equation (4.3) in the previous section. The bank has two collection options on the loan: the manufacturer’s full repayment or the liquidation of the manufacturer’s remain assets.
**Proposition 5** Given IFR demand distribution, a wholesale price of raw material, and an interest rate of the manufacturer’s microcredit loan, the constrained banker’s optimal interest rate for a bank loan in the case of \( k < q \) and \( wq \geq K_M \) is as follows:

\[
R_B^* = \frac{R_I - R_M F(k)}{F(k)} + \frac{(p - c)(wq - K_M)[f(q) - \Omega^2 f(k)]}{[w^2 F(k) - w(wq - K_M)\Omega f(k)]}
\]  
(4.15)

### 4.2.2.3 Supplier’s Decision

Due to a fair price trade, the supplier makes decisions on the wholesale price for maximizing the expected profit. In the presence of demand uncertainty, the supplier decides a wholesale price \( w \) with a margin of \( m \) at an expense of \( e \) per unit. The supplier’s expected terminal cash flow is shown in Equation (4.16). Similar to the study of Yan and Sun (2013), the optimal wholesale price is obtained as shown in Equation (4.17).

\[
\pi_s(q, w, R_B, R_M) = (w + m - e)q - wq(1 + R_M)
\]  
(4.16)

**Proposition 6** Given IFR demand distribution, an interest rate of bank loan and an interest rate of the manufacturer’s microcredit loan, the constrained supplier’s optimal wholesale price in the case of \( k < q \) and \( wq \geq K_M \) is as follows:

\[
w^* = \frac{(m - e)[F(q) - \Omega^2 qf(k)]}{R_M [F(q) - qf(k)]}
\]  
(4.17)

### 4.3 Numerical Examples

In this numerical example, it is assumed that one of the world’s leading carpet manufacturers considers CSR as a growth engine of its business competitiveness. To increase its
social value, the company seeks to incorporate social responsibility into its merchandise and service as part of its supply chain. In other words, the company collaborates with the rural poor as a raw material supplier, while providing the poor supplier who has no financial resource with a microcredit loan.

Through a SCMF scheme, the company benefits in two ways. First is an elevated social reputation by fair sourcing prices by increased CSR. Second is a good quality of raw material enhanced by more reliable sources of raw materials by increased operating efficiencies through a solid relationship between a manufacturer, the lender and a supplier, the borrower.

Considering the trade-off between financial sustainability and social sustainability, an appropriate interest rate is a key factor in the success of a microcredit program. A high interest rate will cause the company to experience difficulty in increasing its social value. Thus, to calculate an adequate interest rate, the proposed game model is applied through this numerical example.

In the numerical example, the manufacturer expects 5000 units of the estimated demand of a carpet with 1000 units of the estimated standard deviation. In addition, the manufacturer’s bankruptcy threshold is assumed to be 2000 units of the estimated demand of a carpet with 1000 units of the estimated standard deviation. With the manufacturer’s initial working capital of $1000, the manufacturer sells the carpet at $20 per unit with a cost of $5 per unit. On the other hand, the supplier sells the raw material at $12 per unit with the margin of $6 per unit and the expense of $2 per unit.

In the SCMF scheme, with the objective of profit maximization, the unconstrained manufacturer’s optimal order quantity is calculated using Equation (4.1). Given the manufacturer’s investment interest rate $R_i$ of 0.07 and the manufacturer’s interest rate $R_M$ of 0.03, the unconstrained manufacturer’s optimal order quantity is 6853 units with the normally
distributed demand. In the same condition, using Equation (4.12), the constrained manufacturer’s optimal order quantity is calculated as 6865 units with the bank’s interest rate $R_B$ of 0.07. The result shows that there is not much difference between the unconstrained case and the constrained case.

Next, using Equation (4.14), the constrained manufacturer’s optimal interest rate of a microcredit loan is calculated as shown in Figure 4-3 with the normal distribution demand and in Figure 4-4 with the uniform distribution demand, respectively. In the case of the normal distribution demand, the manufacturer’s optimal interest rate is 3.4%. As shown in Figure 4-4, the manufacturer’s interest rate is decreasing as the order quantity is increasing from 5800 units to 6500 units. The graph shows that the order quantity affects the manufacturer’s interest rate for the supplier because the manufacturer makes more profit by selling more products to customer, while decreasing the interest rate for the supplier.

![Figure 4-3. Manufacturer’s Interest Rates under a Normal Distribution](image)

As shown in Figure 4-4, the manufacturer’s optimal interest rate is 4% over the order quantity from 5800 units to 6500 units. In the case of a uniform distribution demand, it is assumed that the company expects the minimum demand of 2000 units and maximum demand of 8000 units.
With the objective of maximizing the bank’s expected profit, the bank also makes a decision on the interest rate for the bank loan. Using Equation (4.15), the bank’s optimal interest rate is calculated as 5.94% when the manufacturer makes an optimal order quantity of 6865 units.

As shown in Figure 4-5, the bank’s interest rate is increasing as the order quantity is increasing from 6500 units to 8000 units. The graph shows that the order quantity affects the bank’s interest rate for the manufacturer because the bank needs to increase the bank’s interest rate as the loan amount is increasing as well as the default risk is increasing.

In a fair price trade, the supplier can make a decision on the wholesale price for the profit maximization. Using Equation (4.17), the supplier’s optimal wholesale price with the normal
distribution demand is shown in Figure 4-6 and the supplier’s optimal wholesale price with the
uniform distribution demand is shown in Figure 4-7.

As shown in Figure 4-6, the supplier’s wholesale price is increasing as the order quantity
is increasing from 5800 units to 6500 units. The graph shows that the wholesale price is
increasing as the order quantity is increasing because the supplier tries to increase the wholesale
price as the demand of raw material is increased to maximize its profit.

As shown in Figure 4-7, the supplier’s wholesale price is increasing as the order quantity
is increasing from 5800 units to 6500 units. Similar to the normal distribution case, the graph
shows that the wholesale price is increasing as the order quantity is increasing with the objective
of supplier profit maximization. The increasing wholesale price suggests that both the
manufacturer and the supplier need to negotiate the wholesale price. Otherwise, the supplier sets
the wholesale price as high as possible to maximize its profit.
In order to assess the appropriateness of the manufacturer’s optimal interest rate, 3.4%, that rate is compared with an interest rate premium in five countries: Afghanistan, China, India, Peru, and Tanzania. Since the actual interest rates of MFIs are not available, this study uses the interest rate premiums based on the MIX Market database. The interest rate premium is equal to the difference between the interest rate and the cost of funds.

As shown in Figure 4-8, the interest rate premiums of all but two MFIs in Afghanistan are greater than the manufacturer’s optimal interest rate, 3.4%. The implication is that most MFIs in Afghanistan focus on the profit maximization mission.

As shown in Figure 4-9, the interest rate premiums of MFIs in China have various interest rate premiums. Some MFIs focus on the profit maximization, as evidenced by their high
interest rate premiums, while others focus on the poverty reduction mission, shown by their low interest rate premiums.

As shown in Figure 4-9, most MFIs in China have a low interest rate premium, which implies that these MFIs focus on the poverty reduction mission.

![Figure 4-9. Interest Rate Premiums in China](image)

As shown in Figure 4-10, most MFIs in India have a low interest rate premium, which implies that these MFIs focus on the poverty reduction mission.

![Figure 4-10. Interest Rate Premiums in India](image)

As shown in Figure 4-11, most MFIs in Peru have a high interest rate premium, which implies that these MFIs focus on the profit maximization mission.
As shown in Figure 4-12, most MFIs in Tanzania have a high interest rate premium, implying that these MFIs focus on the profit maximization mission.

As another way of comparing the manufacturer’s optimal interest rate, 3.4%, the base rate from Reserve Bank of India is employed. The base rate is developed to provide a guideline in determining financial institutions’ benchmark interest rate. In this study, the base rate is modified to apply to the microfinance business environment. The manufacturer’s optimal interest rate is compared with the modified base rates in five countries: Afghanistan, China, India, Peru, and Tanzania. The modified base rate is the summation of the cost of funds, the cost of loan default, and profit margin. The Reserve Bank of India considers 26% as an upper limit which MFIs can assigned.
As shown in Figure 4-13, the base rates of most MFIs in Afghanistan are much greater than the manufacturer’s optimal interest rate, 3.4%. Some of MFIs’ base rates are greater than the upper limit interest rate of MFIs, 26%. The implication is that some MFIs with a high base rate in Afghanistan operate inefficiently and focus on the profit maximization.

![Figure 4-13. Base Rates in Afghanistan](image)

As shown in Figure 4-14, the base rates of MFIs in China have various interest rates. Most MFIs’ base rates are less than the upper limit interest rate of MFIs, 26%. As evidenced by their base rate, most MFIs focus on the poverty reduction mission.

![Figure 4-14. Base Rates in China](image)

As shown in Figure 4-15, most MFIs in India have a base rate, which is less than the upper limit interest rate of MFIs, 26%. Some MFIs focus on the profit maximization mission, as shown by the high base rate, while others focus on the poverty reduction mission.
As shown in Figure 4-16, most MFIs in Peru also have a base rate, which is less than the upper limit interest rate of MFIs, 26%. Some MFIs in Peru operate inefficiently and focus on the profit maximization mission. Other MFIs focus on the poverty reduction mission.

As shown in Figure 4-17, most MFIs in Tanzania have a base rate which is less than the upper limit interest rate of MFIs, 26%. It implies that these MFIs have appropriate interest rates in terms of the base rate.
4.4 Conclusion

This study formulates the concept of SCMF with the manufacturer as a lender and the supplier as borrower as a Stackelberg game model. In the model, the manufacturer as a leader makes a decision on the interest rate of a microcredit loan to a supplier, the supplier as a follower makes a decision on the wholesale price of a raw material, and the bank as a sub-leader makes a decision on the interest rate of a bank loan to a manufacturer. Through the numerical analysis, the study reveals that a SCMF scheme has a potential opportunity to decrease the interest rate of a microcredit loan, which is high compared to loans from regular commercial financial institutions.

With the normal distribution demand, the numerical analysis shows that the manufacturer’s interest rate for the supplier is negatively related to the order quantity. In addition, the numerical analysis suggests that the wholesale price should be decided based on negotiation between the manufacturer and the supplier. By providing an optimal interest rate in a microcredit loan, the proposed model could be an effective tool to simultaneously maintain the financial sustainability and the social sustainability of the manufacturer.
Chapter 5
A Microfinance Institution Sustainability

In this chapter, this study investigates the financial sustainability and outreach of MFIs in terms of interest rate and default rate. This study employs an interest rate premium methodology for the evaluation of interest rates and a default premium methodology for the evaluation of default rates. After the validation of MFIs’ asset values and default rates of GBM, this study employs the BS model to calculate MFIs’ default rates.

5.1 Introduction

After the success of various MFIs over the past decades, microfinance has become a key tool for alleviating poverty and offering financial services to the poor in both developing and underdeveloped countries. MFIs provide the poor with both financial resources such as small loans with no pledged collateral requirement, savings, and insurance, and social services such as health care and education (Sengupta and Aubuchon, 2008).

During the growth of microfinance, MFIs have increased social sustainability by providing additional services to particular clientele in remote and rural areas, while keeping the financial and operational sustainability of the institutions (Hartarska, 2002). As a result, MFIs require more investments to meet the growing demand.

For instance, the World Bank estimates that more than 87% of the vulnerable people still have limited access to financial services in India (The World Bank Group, 2005). Since there is a limit to the amount of investments from donors, it is critical for MFIs to find a way to maintain financial and operational self-sustainability while expanding the breadth and depth of outreach.
MFIs primarily derive income from the interest earnings of their loan portfolios. Thus they have found it necessary to charge high interest to cover their major costs. The average interest rate MFIs charge is 38%, which is high compared to regular commercial financial institutions. A consequence of such a high interest rate is that MFIs experience difficulty in increasing outreach toward target clientele in remote and rural areas.

Along with high interest rates, another principal issue in microfinance is the high default rate. The default rate issue is a major impediment to MFIs increasing their outreach. MFIs experience difficulty in maintaining financial sustainability because they do not have any mechanism of contract enforcement to collect on their loans.

To analyze MFIs’ microcredit interest rates, this study employs a simple methodology for the evaluation of the microcredit interest rates proposed by Muhammad Yunus (2007) based on an interest rate premium. The interest rate premium is calculated by subtracting the cost of funds at the market rate paid by the MFI from the interest rate charged by the MFI. The simple evaluation methodology classifies MFIs into three zones -- green zone, yellow zone, and red zone -- based on the interest rate premium to investigate MFIs’ operations. For instance, if an MFI has fallen into the red zone, the MFI’s main objective is on profit maximization, not on social missions.

Further, to investigate default rates, this study employs the BS model to calculate MFIs’ default rates based on the main assumption that the underlying value of each MFI follows a GBM process. The GBM process has been widely used for describing quantity moves over time with uncertainty, such as in the stock market. As a preliminary stage of using the BS model, this paper first tests whether MFIs’ asset values as the value of MFIs follow GBM, based on the study of Marathe and Ryan (2005).

The rest of this paper is organized into four sections. Section Two provides a review of the relevant literature on the sustainability and outreach of microfinance. In Section Three, the
GBM validation methodology is presented, along with the BS model for a default rate, and the methodology for an interest rate premium evaluation. Section Four presents numerical examples through the Indian MFIs case with discussion. Finally, the conclusion is provided in Section Five.

5.2 Methodology

The objective of this study is to investigate the financial sustainability and outreach of MFIs in terms of interest rate and default rate. In the first stage, this study uses a simple evaluation methodology for microcredit interest rates based on the interest rate premium. In the second stage, as a preliminary to using the BS model, this study tests the validation of MFIs’ asset values and default rates of GBM. In the last stage, this study uses the BS model to calculate MFIs’ default rates.

5.2.1 Microcredit Interest and Default Rate Evaluation

This section reviews Dr. Yunus’s methodology for the evaluation of microcredit interest rates (Yunus, 2007). Based on an interest rate premium, the methodology analyzes MFIs’ operations and classifies the MFIs into three zones, as shown in Table 5-1. The interest rate premium is equal to the difference between the interest rate and the cost of funds. In microfinance, the interest rate premium is calculated by subtracting the financial expense on loan portfolio dividing by gross loan portfolio from the yield on gross loan portfolio.

\[
\text{Yield on gross loan portfolio} - \frac{\text{Financial Expense on loan portfolio}}{\text{Gross loan portfolio}} = (5.1)
\]
For instance, if a particular MFI’s interest rate premium falls into the green zone, it means that the MFI focuses on the poverty reduction mission. On the other hand, if the MFI falls into the red zone, it means that the MFI focuses on the profit maximization mission.

### Table 5-1. The Categorization of an Interest Rate Premium

<table>
<thead>
<tr>
<th>Zone</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Zone</td>
<td>(\leq 10%)</td>
</tr>
<tr>
<td>Yellow Zone</td>
<td>(\leq 15%)</td>
</tr>
<tr>
<td>Red Zone</td>
<td>(&gt; 15%)</td>
</tr>
</tbody>
</table>

In a similar way, this study proposes a new methodology, a default rate premium, for the evaluation of microcredit default rates. In microfinance, the default rate premium is the difference between the loan loss rate and the cost of loan default. The default rate premium is calculated by subtracting the impairment loan loss dividing by gross loan portfolio from loan loss rate. If the value of the default rate premium has a negative value, it implies that the MFI needs to increase its loan loss allowance to keep the financial sustainability of the MFI. In a contrast case, the MFI can still focus on the poverty reduction mission.

\[
\text{Loan loss rate} - \frac{\text{Impairment loan loss}}{\text{Gross loan portfolio}} = (5.2)
\]

### 5.2.2 Geometric Brownian Motion Validation

This section reviews the validation methodology for the GBM proposed by Marathe and Ryan (2005). GBM, defined as the logarithm of randomly varying quantity, follows Brownian motion in a continuous time stochastic process. In order to follow GBM, the data needs to satisfy two assumptions: normality and independence from past data.
5.2.2.1 Normality

This study uses the Ryan-Joiner test, similar to the Shapiro-Wilk test, to check whether the data is normally distributed by detecting all departures from normality. By comparing the correlation between the predicted normal data with actual data, the Ryan-Joiner test checks normality on a set of data based on what normally distributed data set of a given sample size would be. If the p-value is greater than the level of significance, the null hypothesis of a normal distribution is not rejected. In this case, the data could plausibly be normally distributed. In this test, the hypothesis set is as follows:

\( H_0 \): The distribution is normal
\( H_a \): The distribution is not normal

5.2.2.2 Independence

To test the serial independence of data, the study uses the chi-square test on two-way tables. The test investigates the association between the row and column variables in a two-way table by investigating distributions of categorical variables which differ from one another. If the p-value is greater than the level of significance, the null hypothesis is not rejected. This means that the data could plausibly be serially independent. In this test, the hypothesis set is as follows:

\( H_0 \): There is no association between the variables
\( H_a \): There is some association between the variable
5.2.3 The Black Scholes Model

This section reviews the BS model. In the early 1970s, one of the most important developments in finance, the Black Scholes option pricing model, was developed under the assumption that that the value of the firm \( S \) follows standard GBM with constant drift \( \mu \) and volatility \( \sigma \) of firm value returns, \( dS = \mu S dt + \sigma S dB \), where \( dB \) is an increment of a standard Wiener process.

As shown in Equation (5.3), the BS model stipulates the market value of the firm’s equity \( E \) as a European call option on the value of the firm \( S \) and face value of outstanding debt \( K \) due at maturity \( T \).

\[
E = SN(d_1) - Ke^{-rT}N(d_2)
\]  

(5.3)

where

\[
d_1 = \frac{\ln(S/D) + (r + 0.5 \times \sigma^2)T}{\sigma \sqrt{T}}
\]  

(5.4)

and

\[
d_2 = d_1 - \sigma \sqrt{T} = \frac{\ln(S/D) + (r - 0.5 \times \sigma^2)T}{\sigma \sqrt{T}}
\]  

(5.5)

The term \( SN(d_1) \) is the expected value of the firm, and the term \( Ke^{-rT} \) is the present value of the principal outstanding debt due at maturity. The term \( N(d_2) \) is the probability of the firm being solvent at maturity, and the term \( 1 - N(d_2) \) is the probability of the firm being default at maturity, where \( r \) is a risk-free interest rate and \( N(d) \) is the cumulative standard normal distribution function (Charitou et al., 2013).

As the value of the firm \( S \) follows standard GBM with constant drift \( \mu \) and volatility \( \sigma \) of firm value returns, the future behavior of the value of the firm can be simulated with the current value of the firm \( S_0 \) using Equation (5.6) as follows:
where \( \mu_i = (\mu - 0.5 \times \sigma^2) t \) \hspace{1cm} (5.7)

and \( \sigma_i = \sqrt{\sigma t} \) \hspace{1cm} (5.8)

5.3 Numerical Examples

In this case study, the financial sustainability and outreach of 32 MFIs in India is investigated in terms of interest rate premiums and default rates. The relevant data is obtained through the MIX Market database in 2011 and 2012. In this study, each MFI is considered as one group. At the first stage, the interest rates of 32 MFIs in India are calculated to investigate whether the MFIs focus on their social mission in terms of outreach using Dr. Yunus’ methodology.

The interest rate premium is calculated by subtracting the financial expense per gross loan portfolio from the yield on gross loan portfolio. As shown in Figure 5-1, 31 MFIs fall into the green zone because their interest rate premiums are less than 10%. Only one MFI belongs to the yellow zone because its interest rate premium is between 10% and 15%. No MFI falls into the red zone. Based on this result, it is possible to conclude that the analyzed MFIs are attempting to increase their outreach in breadth and depth.
The default rate premium is calculated by subtracting the loan loss impairment expense per gross loan portfolio from the loan loss rate on gross loan portfolio. As shown in Figure 5-2, 31 MFIs fall into the zone around zero, which implies that MFIs need to consider the trade-off between the profit maximization mission and the poverty reduction mission. The positive value of the default rate premium of the MFIs can focus on a poverty reduction mission because of the financial sustainability of the institutions, whereas the negative value of the default rate premium of the MFIs can focus on profit maximization mission because the institution needs to increase its financial sustainability.
Figure 5-3 illustrates the interest rate premium versus the default rate premium. As shown in Figure 5-4, the MFIs in quadrant one focus on profit maximization mission and the MFIs in quadrant three focus on poverty reduction mission. The MFIs in quadrant three need to attempt to increase profit maximization mission. The MFIs in quadrant two and three need to consider the trade-off between the profit maximization mission and the poverty reduction mission, while considering the institutions’ financial sustainability.

![Figure 5-3. Interest and Default Rate Premiums](image)

![Figure 5-4. Interest and Default Rate Premiums Quadrant](image)

In order to use the BS model, the total value of a firm, the value of the underlying assets, needs to follow GBM. Thus, at this stage, the Ryan-Joiner test and the chi-square test on two-
way tables are conducted to check the normality and independence of the asset values and the default rates of 32 MFIs in India from 2011 to 2012. In both the Ryan-Joiner test and the chi-square test, the log ratio values of the asset values and the default values are tested. First, the normality test is conducted. As shown in Figure 5-5, the null hypothesis of a normal distribution is not rejected because the p-value is greater than 0.1. Thus, it can be concluded that the asset values could be consistent with the lognormal aspect of GBM.

![Figure 5-5. Normal Probability Plot for Assets](image)

For the default rate, as shown in Figure 5-6, the null hypothesis of a normal distribution is not rejected because the p-value is greater than 0.1. Thus, it can be concluded that the default rate values could be consistent with the lognormal aspect of GBM.

By knowing the default rate following GBM, it is possible to simulate default rate paths. By predicting the future behavior of the default rate, MFIs can prepare for the impending default risk. As shown in Figure 5-7, the default rate path is obtained with 0.02648 of drift, 0.0772 of volatility, and 3% of current default rate using Equation (5.4).
Figure 5-6. Normal Probability Plot for Default Rates

Figure 5-7. Interest Default Rate Path

Next, the chi-square test on two-way tables is conducted to check the independence of the asset values and the default rates of 32 MFIs in India from 2011 to 2012. The log ratio values of assets are divided into 4 categories as shown in Table 5-2.

Table 5-2. The Categories of asset values for the Independent Test

<table>
<thead>
<tr>
<th>Categories</th>
<th>Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>From -6 to -3</td>
</tr>
<tr>
<td>2</td>
<td>From -3 to 0</td>
</tr>
<tr>
<td>3</td>
<td>From 0 to 3</td>
</tr>
<tr>
<td>4</td>
<td>From 3 to 6</td>
</tr>
</tbody>
</table>
The null hypothesis of no association cannot be rejected because the p-value, 0.861, is greater than 0.05. It can be concluded that the asset values are independent. Similarly, the log ratio values of default rates are divided into three categories. Since the p-value is 0.495, which is greater than 0.05, the null hypothesis of no association cannot be rejected. Thus, it can be concluded that the default rates are independent.

At the last stage, the BS model is employed to calculate default rates of 32 MFIs in India for 2012. In the BS model, the value of the underlying asset is used for the value of firm $S$, and the book value of the firm’s total liabilities is used for the face value of outstanding debt $K$. The default rates of the 32 MFIs are calculated using Equation (5.1) through Equation (5.3) along with 5% of a risk-free interest rate in one year. As shown in Figure 5.8, the majority of the interest rates generally move between 5% and 6%.

![Default Rates in the BS Model](image)

Figure 5-8. Default Rates in the BS Model

5.4 Conclusion

This study considers the financial sustainability and outreach of MFIs in terms of the interest rate and the default rate. Dr. Yunus’s methodology measures interest rate premiums and
the proposed methodology measures default rate premiums for 32 MFIs in India to analyze whether the MFIs focus on their social mission in terms of outreach.

The results show that the analyzed MFIs focus on increasing their outreach in breadth and depth.

As a validation of GBM, the Ryan-Joiner test is used to test the normality of the underlying asset and the default rate, along with the chi-square test for the independence. Since the data follow GBM, the BS model is used to calculate default rates of 32 MFIs in India for 2012. The primary assumption of the widespread risk models in bonds and equities is that the data set follows GBM. By validating both asset and default data following GBM, this study demonstrates that it is possible to employ risk models for the microfinance industry. By measuring key risks, the employed models could be used to reveal risk potential as well as implement risk strategies for MFIs. Ultimately, the MFIs can simultaneously achieve both financial sustainability and social mission.
Chapter 6

A Life Cycle Assessment

In this chapter, this study conducts a life cycle analysis of energy and GHG emissions on two types of carpet, wool carpet and nylon carpet in the carpets’ six life cycles. In the analysis, this study also provides the detailed energy use and greenhouse emissions for each production and recycling process of a wool carpet and a nylon carpet.

6.1 Introduction

A life cycle energy analysis investigates a product’s impact on the environment in terms of energy through the product’s five life cycles: raw material extraction and processing, product manufacturing, product distribution and retailing, product use, and maintenance and waste management (Hodgson et al., 1997). Using the generic flow diagram for life cycle assessment shown in Figure 6-1, this study examines a life cycle energy and air emission analysis (LCEAA) of two types of carpet, a wool carpet and a nylon carpet, by considering all the energy required and all the GHG emissions produced in the carpets’ six life cycles: raw material extraction, raw material production, product manufacturing, product installation, product use, and product recycling.

As stated above, the study begins with raw material extraction. In this stage, LCEAA examines all required energy and produced GHG emissions related to the extraction of a raw material. In the case of a wool carpet, the study considers raw greasy wool harvesting and transportation to a wool yarn production facility. In the case of a nylon carpet, the study considers caprolactam production and transportation to a nylon yarn production facility.
The second stage is raw material production, in which all required energy and accompanied air emission are measured in the processing of wool yarn from raw greasy wool for a wool carpet and of nylon yarn from the raw material caprolactam for a nylon carpet.

Figure 6-1. Generic Flow Diagram for Life Cycle Assessment (Hodgson et al., 1997)

The third stage is product manufacturing. In this stage, LCEAA examines all energy requirements and accompanied GHG emissions in the manufacture of a wool carpet from wool yarn and a nylon carpet from nylon yarn. This stage also includes transportation to a warehouse and distribution facility. The fourth stage is product installation. This stage considers all the required energy use and produced GHG emissions in installing a wool and nylon carpet as well as transporting the carpet to a customer site. The fifth stage is product use. LCEAA considers energy use and GHG emissions during the use and maintenance of both wool and nylon carpet. The final stage is product recycling. This stage considers all energy use and GHG emissions during the collection and recycling of post custom carpet, as well as the disposal of solid wastes and transportation to a landfill site.

In an alternative analysis method proposed by Crowley et al., the energy use and GHG emissions of a nylon carpet from product manufacturing to the end of life of a post customer product, the life cycle of Interface’s carpet are broken down into four stages: production, installation, use, and end of life (Crowley et al., 2010). Total energy requirements and GHG
emissions at each stage of a carpet life cycle are tabulated in Table 6-1. The production stage uses 94% of the total energy, which accounts for 175.25 MJ/m², and the use stage consumes 3.7% of the total energy, which accounts for 6.28 MJ/m² in the life cycle. More detailed nonrenewable and renewable energy resources at each life cycle stage are tabulated in Table 6-2.

Table 6-1. Total Energy and Emissions in Carpet Life Cycle Stage (Crowley et al., 2010)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>172.25</td>
<td>7.5602</td>
<td>3.34</td>
</tr>
<tr>
<td>Installation</td>
<td>2.74</td>
<td>0.114</td>
<td>2.35</td>
</tr>
<tr>
<td>Use</td>
<td>6.28</td>
<td>0.2806</td>
<td>4.89</td>
</tr>
<tr>
<td>End of Life</td>
<td>1.28</td>
<td>0.0532</td>
<td>-2.17</td>
</tr>
</tbody>
</table>

Table 6-2. Detailed Energy Resources in Carpet Life Cycle Stage (Crowley et al., 2010)

<table>
<thead>
<tr>
<th>Energy Type (MJ/m²)</th>
<th>Non-renewable</th>
<th>Renewable</th>
<th>Life Cycle Stage</th>
<th>Production</th>
<th>Installation</th>
<th>Use</th>
<th>End of Life</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crude oil</td>
<td></td>
<td>Production</td>
<td>50.58</td>
<td>1.53</td>
<td>0</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Hard coal</td>
<td></td>
<td>Installation</td>
<td>25.12</td>
<td>0.23</td>
<td>2.82</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Lignite</td>
<td></td>
<td>Use</td>
<td>0.94</td>
<td>0.01</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Natural gas</td>
<td></td>
<td></td>
<td>70.44</td>
<td>0.83</td>
<td>1.48</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>Uranium</td>
<td></td>
<td></td>
<td>14.89</td>
<td>0</td>
<td>1.35</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Hydropower</td>
<td></td>
<td></td>
<td>1.2739</td>
<td>0.0035</td>
<td>0.1563</td>
<td>0.0103</td>
</tr>
<tr>
<td></td>
<td>Wind &amp; wave</td>
<td></td>
<td></td>
<td>1.1495</td>
<td>0.0003</td>
<td>0.1189</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td>Solar</td>
<td></td>
<td></td>
<td>0.4568</td>
<td>0.0019</td>
<td>0.0041</td>
<td>0.0384</td>
</tr>
<tr>
<td></td>
<td>Geothermal</td>
<td></td>
<td></td>
<td>0.015</td>
<td>0</td>
<td>0.0013</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td></td>
<td></td>
<td>14.945</td>
<td>0.2483</td>
<td>0.63</td>
<td></td>
</tr>
</tbody>
</table>

The study also considers the energy requirements of transportation between each stage in the life cycle of carpet because the energy requirements of transportation vehicles are the most energy intense activity in a closed-loop supply chain (Ciceri, 2011). The study compares two types of a transportation mode: ship and truck. Energy use and air emissions for each transportation mode are shown in Table 6-3.
into the red zone, it means that the MFI focuses on the profit maximization mission.

Table 6-3. Transportation Energy Use and Air Emission (Barber and Pellow, 2008)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy Requirement (MJ/kg km)</th>
<th>Air Emission (kg CO2/kg km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship</td>
<td>0.00014</td>
<td>0.000007</td>
</tr>
<tr>
<td>Truck</td>
<td>0.0052</td>
<td>0.000185</td>
</tr>
</tbody>
</table>

The rest of this chapter is organized into four sections. Section Two provides a review of the relevant literature on the closed-loop supply chain. In Section Three, life cycle assessment is conducted for two types of carpet, a wool carpet and a nylon carpet.

Section Four presents a basic mathematical model of energy and emissions. Section Five presents numerical examples through the Pennsylvania State University (Penn State) case with discussion. Finally, the conclusion is provided in Section Six.

### 6.2 Life Cycle Assessment

In this section, life cycle assessment is conducted for two types of carpet, a wool carpet and a nylon carpet, in a manufacturing process and a disposal process in terms of energy use and GHG emissions.

#### 6.2.1 Life Cycle Assessment for a Wool Carpet

A wool carpet is a nature-friendly carpet, which accounts for 10% of the face fiber market (Subbiah, 2008). A wool carpet is composed of a wool facing, a polymer backing, and limestone filler (Lippiatt, 2000). To investigate the life cycle of a wool carpet, the study considers the mass of 0.09 m² of wool carpet tile whose weight is approximately 1.13 kg.
### 6.2.1.1 Manufacturing Processes for a Wool Carpet

To analyze the raw material acquisition of a wool carpet, the study uses the farming data from the life cycle assessment of the New Zealand Merino industry (Barber and Pellow, 2008). Based on the study of Barber and Pellow, this study uses the average total energy of three types of farms to calculate the energy requirements of greasy raw wool production, as shown Table 6-4. In a similar way, the greenhouse gas emission is tabulated as shown Table 6-5.

The general manufacturing process for a tufted wool carpet is illustrated in Figure 6-2. The manufacturing process consists of four major stages: preparing the yarn, dyeing the yarn, tufting the carpet, and finishing the carpet. According to Lippiatt’s study on a generic wool (Lippiatt, 2000), the brief manufacturing processes of a wool carpet are described as follows. As collected wool is transported to a production facility, the wool is scoured, bleached, dried, carded, and spun to prepare a wool yarn. In the scouring process, raw wool is washed to remove grease and dirt.

<table>
<thead>
<tr>
<th>Farm Category</th>
<th>Total Energy (MJ)</th>
<th>Per Hectare</th>
<th>Per Stock Unit</th>
<th>Per Tone Greasy Wool</th>
<th>Per Tone Wool Top</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive</td>
<td></td>
<td>145</td>
<td>155</td>
<td>11,890</td>
<td>19,980</td>
</tr>
<tr>
<td>Medium Intensive</td>
<td></td>
<td>510</td>
<td>200</td>
<td>13,940</td>
<td>23,425</td>
</tr>
<tr>
<td>Intensive</td>
<td></td>
<td>1775</td>
<td>270</td>
<td>14,425</td>
<td>24,235</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>805</td>
<td>210</td>
<td>13,420</td>
<td>22,545</td>
</tr>
</tbody>
</table>

After the bleaching process, the bleached wool is then dyed, blended, carded, drafted, spun, plied, and twisted. After these processes, wool yarn is produced from raw wool. In the next stage, the wool yarn is then tufted by weaving a wool yarn into the backing with specific densities, patterns, and style of carpet. After the tufting process, the tufted carpet is adhered to the backing.
In the finishing stage, a coating of latex is applied to the underside of the carpet. Finally, a complete wool carpet is completed after the drying process.

Table 6-5. Total Emissions in Different Farm Types (Barber and Pellow, 2008)

<table>
<thead>
<tr>
<th>Farm Category</th>
<th>Total Energy (MJ)</th>
<th>Per Hectare</th>
<th>Per Stock Unit</th>
<th>Per Tone Greasy Wool</th>
<th>Per Tone Wool Top</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive</td>
<td>145</td>
<td>155</td>
<td>11,890</td>
<td>19,980</td>
<td></td>
</tr>
<tr>
<td>Medium Intensive</td>
<td>510</td>
<td>200</td>
<td>13,940</td>
<td>23,425</td>
<td></td>
</tr>
<tr>
<td>Intensive</td>
<td>1775</td>
<td>270</td>
<td>14,425</td>
<td>24,235</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>805</td>
<td>210</td>
<td>13,420</td>
<td>22,545</td>
<td></td>
</tr>
</tbody>
</table>

The technical manual and user guide of building for environmental and economic sustainability (BEES) assesses the life cycle of building products in terms of their environmental impact. Based on BEES data, the energy requirement for the production of 0.09 m² of a wool carpet is tabulated in Table 6-6. The Scouring and Tufting steps require most of the energy in a wool carpet production.

Table 6-6. Wool Carpet Production Energy Requirements (Lippiatt, 2000)

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Requirement</th>
<th>Process</th>
<th>Energy Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scouring</td>
<td>4.5723 MJ/m²</td>
<td>Spinning</td>
<td>Negligible</td>
</tr>
<tr>
<td>Drying</td>
<td>1.4281 MJ/m²</td>
<td>Twisting</td>
<td>0.0753 MJ/m²</td>
</tr>
<tr>
<td>Blending</td>
<td>Negligible</td>
<td>Tufting</td>
<td>9.92 MJ/m²</td>
</tr>
<tr>
<td>Carding</td>
<td>Negligible</td>
<td>Dyeing</td>
<td>1.8689 MJ/m²</td>
</tr>
<tr>
<td>Drafting</td>
<td>Negligible</td>
<td>Finishing</td>
<td>0.2664 MJ/m²</td>
</tr>
</tbody>
</table>

The main inflows and outflows for the production of a wool carpet, from raw wool through wool yarn, are shown in Figure 6-3. In the process of wool yarn production, the original mass of raw wool is decreased by 20% after the scouring process (Lippiatt, 2000). The study considers 0.09 m² of wool carpet with a weight of 1.13 kg. For example, 0.176 kg of raw wool is required to produce 0.14 kg of wool yarn, along with 0.0016 kg of lubricant and 0.9307 L of
water. In a yarn production process, the total energy requirement is 0.1508 MJ, while 0.1024 kg CO₂ of GHG emissions are produced. In the production of 0.09 m² of a wool carpet, 0.14 kg of wool yarn is used, along with 2.5383 MJ of total energy requirement. In the production process, 0.4774 kg CO₂ of GHG emission and 0.0014 kg of solid waste are by-products of a wool carpet.

Figure 6-2. Wool Carpet Manufacturing Processes

Figure 6-3. The Main Inflows and Outflows for the production of a wool carpet
6.2.1.2 Recycling Processing Energy and Emissions for a Wool Carpet

The disposed post-customer product follows several end-of-life routes: reuse, repair, remanufacturing, material recycling, incineration, landfill, and emission or leakage into the environment (Huisman, 2003). The study assumes that the face fiber of disposed wool carpet is remanufactured as a fertilizer and the rest becomes landfill. The collected wool carpet is first shredded into little pieces of wool carpet. Then, the heavier backing is separated through a centrifugal air separation. The separated wool pieces are collected and used as fertilizer. The waste backings are transported to a landfill site. The recycling process of a wool carpet is illustrated in Figure 6-4.

![Figure 6-4. Disposed Wool Carpet Recycling Processes (Subbiah, 2008)](image)

The study of Subbiah’s sustainability study provides the types of equipment used in recycling post consumer carpet, along with an equipment capacity and the power used. Based on Subbiah’s study, the energy requirement for the recycling of a wool carpet is shown in Table 6-7.

Table 6-7. Wool Carpet Recycling Energy Requirements

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Requirement</th>
<th>Process</th>
<th>Energy Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredding</td>
<td>0.0582 MJ/kg</td>
<td>Air Separation</td>
<td>0.0001 MJ/kg</td>
</tr>
</tbody>
</table>
The main inflows and outflows for the recycling process of a wool carpet are shown in Figure 6-5. According to BEES data, a wool carpet consists of 58% of wool face fiber. So, 1.13 kg of a post customer carpet produces 0.6554 kg of wool fertilizer in the recycling process. The recycling process requires total energy of 0.0278 MJ, while producing 0.0229 kg of solid waste and 0.0717 kg of backing waste as a by-product.

![Figure 6-5. The Main Inflows and Outflows for the Recycling of a Wool Carpet](image)

### 6.2.2 Life Cycle Assessment for a Nylon Carpet

A nylon carpet is the most popular commercial carpet in the U.S. Nearly 67% of carpets are manufactured using a nylon face fiber, and 95% of carpets are manufactured using a tufting method (Li, 2007). This study considers a nylon carpet to be composed of a nylon 6 facing, a polymer backing, and limestone filler (Lippiatt, 2000). To investigate the life cycle of a nylon carpet, the study considers the mass of 0.09 m² of a nylon carpet tile whose weight is approximately 1.13 kg.
6.2.2.1 Manufacturing Processes for a Nylon Carpet

According to Li’s study on nylon carpet (Li, 2007), the brief manufacturing processes of a nylon carpet are described as follows. After the raw material, caprolactam, is transported to a production facility, the caprolactam is extruded to produce nylon yarn. To produce a nylon face fiber, the nylon yarn is then tufted. The general manufacturing process for a nylon carpet is illustrated in Figure 6-6.

In the next stage, the nylon yarn is then tufted by weaving a nylon yarn into the backing with specific densities, patterns, and styles of carpet. After the tufting process, the tufted carpet is adhered to the backing. Then, the tufted yarn is steamed, blended, coated, dried, and finished. In the stage of coating the carpet, a coating of latex is applied to the underside of the carpet. After the drying process, a complete nylon carpet is finally produced.

![Figure 6-6. Nylon 6 Carpet Manufacturing Processes (Li, 2007)](image)

Based on Li’s study on life cycle assessment of chemical processes and products (Li, 2007), the total production energy usage of nylon carpet is tabulated as shown Table 8. The main inflows and outflows for the production of 0.09 m$^2$ of nylon carpet with 1.13 kg in weight from caprolactam through nylon yarn are shown in Figure 6-7.
Table 6-8. Wool Nylon 6 Carpet Production Energy Requirement (Li, 2007)

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Requirement</th>
<th>Process</th>
<th>Energy Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrusion</td>
<td>0.8309 MJ/ m²</td>
<td>Steamer</td>
<td>1.6501 MJ/ m²</td>
</tr>
<tr>
<td>Twisting</td>
<td>0.0864 MJ/ m²</td>
<td>Blending</td>
<td>0.2386 MJ/ m²</td>
</tr>
<tr>
<td>Heat Setting</td>
<td>1.0578 MJ/ m²</td>
<td>Coating</td>
<td>1.8657 MJ/ m²</td>
</tr>
<tr>
<td>Warping</td>
<td>0.0535 MJ/ m²</td>
<td>Drying</td>
<td>2.1442 MJ/ m²</td>
</tr>
<tr>
<td>Tufting</td>
<td>0.698 MJ/ m²</td>
<td>Finishing</td>
<td>0.3057 MJ/ m²</td>
</tr>
</tbody>
</table>

In the process of nylon yarn production, 0.0741 kg of caprolactam is required to produce 0.0734 kg of nylon yarn, along with 0.05994 L of water. In a yarn production process, the total energy requirement is 0.6157 MJ with negligible amounts of GHG emission and water emission. In the production of 0.09 m² of a nylon carpet, 0.0734 kg of nylon 6 yarn requires 0.5945 MJ of total energy requirement and 0.0837 L of water, producing 0.2452 kg CO₂ of GHG emissions and 0.0035 kg of solid waste.

Figure 6-7. The Main Inflows and Outflows for the Production of a Nylon Carpet
6.2.2.2 Recycling Processes for a Nylon Carpet

The disposed post-customer nylon carpet is material recycled and becomes landfill. In a material recycling process, the raw material for the nylon yarn, caprolantam, is produced. The depolymerization process of a nylon carpet is illustrated in Figure 6-8. In the course of the depolymerization process, caprolactam is produced as the nylon 6 reacts to a base catalyst such as KOH (Subbiah, 2008).

Figure 6-8. Disposed Nylon Carpet Recycling Processes (Subbiah, 2008)

According to Subbiah’s study, the collected nylon 6 carpet is first shredded into little pieces of nylon carpet. Then the heavier backing is separated through a centrifugal air separation. The separated nylon pieces react with a catalyst in the extruder. In this process, the nylon pieces turn back into caprolactam. Then, the vapor caprolactam is condensed and collected through a vacuum pump process. The collected caparolactam is used as the new raw material for nylon yarn production.

For comparison to the wool carpet case, the energy requirements for the recycling of a nylon carpet is tabulated in Table 6-9, based on Subbiah’s study. The main inflows and outflows for the recycling process of a nylon carpet are shown in Figure 6-9.
Table 6-9. Nylon Carpet Recycling Energy Requirement

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Requirement</th>
<th>Process</th>
<th>Energy Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredding</td>
<td>0.0582 MJ/kg</td>
<td>Condenser</td>
<td>0.1176 MJ/kg</td>
</tr>
<tr>
<td>Air Separation</td>
<td>0.0001 MJ/kg</td>
<td>Vacuum Pump</td>
<td>0.058 MJ/kg</td>
</tr>
<tr>
<td>Extrusion</td>
<td>0.0884 MJ/kg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to Li’s study, 39% of caprolactam is recovered from a nylon carpet. For example, 1.13 kg of disposed nylon carpet produces 0.4407 kg of recovered caprolactam, along with a total energy requirement of 0.3642 MJ and catalyst of 0.0024 kg. In this process, 0.0542 kg of solid waste and 0.1698 kg of backing waste are by-products.

Figure 6-9. The Main Inflows and Outflows for the Recycling of a Nylon Carpet

6.3 An Energy and Emission Mathematic Model

The objective of this model is to estimate the energy requirements and GHG emissions of two types of a carpet, a wool carpet and a nylon carpet. To fulfill this objective, the basic mathematical model of energy and emissions in a sustainable supply chain for a single time period is formulated. Generally, the company uses energy and emits GHG to produce and
transport raw material, intermediate products, and final products, and to transport products between each facility, deliver final products to customers and collect post-customer products.

In production activities, a company has certain energy requirements and GHG emissions related to production at various plants. The variable production energy requirement is all the energy related to raw material, the manufacturing of intermediate products, and final products at plants. The production energy requirement is calculated for all products manufactured at a plant multiplied by a unit energy requirement for each plant.

$$\sum_{i=1}^{I} \sum_{j=1}^{J} EP_{ij} P_{ij}$$

(6.1)

In a similar way, the production GHG emission is calculated for all products manufactured at a plant multiplied by a unit air emission for each plant.

$$\sum_{i=1}^{I} \sum_{j=1}^{J} GP_{ij} P_{ij}$$

(6.2)

In transportation activity, the transportation energy requirement and GHG emission is all the transportation related with product transactions between plant, warehouse, internal distribution center, external distribution center, internal customer, external customer and returned warehouse. For instance, the transportation energy requirement is calculated for all products transferred from plant to warehouse multiplied by a unit energy requirement for each warehouse.

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} EPW_{ijm} QPW_{jmn}$$

(6.3)

In a similar way, other energy requirements of transportation are calculated. The company has a transportation energy requirement when products are transferred from warehouse to internal distribution center or external distribution center.

$$\sum_{i=1}^{I} \sum_{m=1}^{M} \sum_{k=1}^{K} EWD_{ink}^{(1)} QWD_{ink}^{(1)} + \sum_{i=1}^{I} \sum_{m=1}^{M} \sum_{k=1}^{K} EWD_{ink}^{(2)} QWD_{ink}^{(2)}$$

(6.4)
The company has a transportation energy requirement when products are transferred from internal distribution center to internal customer or external customer. 

\[ \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{l=1}^{I} EDC_{ikl}^{(1)} QDC_{ikl}^{(1)} + \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{l=1}^{I} EDC_{ikl}^{(2)} QDC_{ikl}^{(2)} \]  

(6.5)

The company has a transportation energy requirement when products are transferred from external distribution center to internal customer or external customer.

\[ \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{l=1}^{I} EDC_{ikl}^{(3)} QDC_{ikl}^{(3)} + \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{l=1}^{I} EDC_{ikl}^{(4)} QDC_{ikl}^{(4)} \]  

(6.6)

The company has a transportation energy requirement when products are transferred between internal distribution center and external distribution center.

\[ \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{l=1}^{I} EDD_{ikl}^{(1)} QDD_{ikl}^{(1)} + \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{l=1}^{I} EDD_{ikl}^{(2)} QDD_{ikl}^{(2)} \]  

(6.7)

The company has a transportation energy requirement when products are transferred from warehouse to internal distribution center or external distribution center.

\[ \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{o=1}^{O} ECR_{ilo}^{(1)} QCR_{ilo}^{(1)} + \sum_{i=1}^{L} \sum_{k=1}^{K} \sum_{o=1}^{O} ECR_{ilo}^{(2)} QCR_{ilo}^{(2)} \]  

(6.8)

The transportation GHG emission is calculated for all products transferred from plant to warehouse multiplied by a unit air emission for each warehouse.

\[ \sum_{i=1}^{L} \sum_{j=1}^{J} \sum_{m=1}^{M} GPW_{ijm} QPW_{ijm} \]  

(6.9)

In a similar way, other GHG emissions of transportation are calculated. The company has transportation GHG emissions when products are transferred from warehouse to internal distribution center or external distribution center.

\[ \sum_{i=1}^{L} \sum_{m=1}^{M} \sum_{k=1}^{K} GWD_{imk}^{(1)} QWD_{imk}^{(1)} + \sum_{i=1}^{L} \sum_{m=1}^{M} \sum_{k=1}^{K} GWD_{imk}^{(2)} QWD_{imk}^{(2)} \]  

(6.10)
The company has transportation GHG emissions when products are transferred from internal distribution center to internal customer or external customer.

\[
\sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{l=1}^{L} GDC_{ikl}^{(1)} QDC_{ikl}^{(1)} + \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{l=1}^{L} GDC_{ikl}^{(2)} QDC_{ikl}^{(2)} \tag{6.11}
\]

The company has transportation GHG emissions when products are transferred from external distribution center to internal customer or external customer.

\[
\sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{l=1}^{L} GDC_{ikl}^{(3)} QDC_{ikl}^{(3)} + \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{l=1}^{L} GDC_{ikl}^{(4)} QDC_{ikl}^{(4)} \tag{6.12}
\]

The company has transportation GHG emissions when products are transferred between internal distribution center and external distribution center.

\[
\sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{l=1}^{L} GDD_{ikl}^{(1)} QDD_{ikl}^{(1)} + \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{l=1}^{L} GDD_{ikl}^{(2)} QDD_{ikl}^{(2)} \tag{6.13}
\]

The company has transportation GHG emissions when products are collected from internal customer or external customer and transported to returned warehouse.

\[
\sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{l=1}^{L} GCR_{ilo}^{(1)} QCR_{ilo}^{(1)} + \sum_{i=1}^{I} \sum_{l=1}^{L} \sum_{o=1}^{O} GCR_{ilo}^{(2)} QCR_{ilo}^{(2)} \tag{6.14}
\]

In the disposal processing activity, the company has a certain disposal energy requirement and GHG emissions in recycling products collected from customers at returned warehouse. The disposal energy requirement and GHG emission are related to the processing of returned products at the returned warehouse. The disposal energy requirement is calculated for all returned product processed at returned warehouse multiplied by a unit energy requirement for each returned warehouse.

\[
\sum_{i=1}^{I} \sum_{o=1}^{O} EDP_{io} DP_{io} \tag{6.15}
\]
The disposal GHG emission is calculated for all returned product processed at returned warehouse multiplied by a unit energy requirement for each returned warehouse.

\[ \sum_{i=1}^{I} \sum_{a=1}^{Q} GDP_{ia} DP_{ia} \]  

(6.16)

6.4 Numerical Examples

According to a Smarter Carpet Initiative program, Penn State has 30 million square feet of building space covered with 480 acres of carpet. In order to maintain the large areas with carpet, Penn State annually spends $1,125,000 in purchasing approximately 45,000 square yards of new carpet tile. In order to develop a standard for a life cycle of a carpet, from purchasing to removing activity, the collaboration of the Penn State Office of Physical Plant, Procurement Services, and the Smeal College of Business started a Smarter Carpet Initiative program in 2010 (Sustainability.psu.edu). By using the new standard, the Smarter Carpet Initiative program expects total cost savings of 20% (Sustainability.psu.edu).

Since the Smarter Carpet Initiative program does not consider the manufacturing process and the disposal process, this study analyzes the carpets’ six life cycles: raw material acquisition, raw material production, product manufacturing, product installation, product use, and product recycling in terms of energy use and greenhouse gas emission. In order to assess the life cycle of a carpet, the basic model presented in this study is applied to present a numerical example of energy requirements and GHG emissions at Penn State University.
Table 6-10. Total Energy Requirements and Air Emission Production

<table>
<thead>
<tr>
<th>Life Cycle Stage</th>
<th>A Wool Carpet</th>
<th>A Nylon Carpet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy (MJ)</td>
<td>Emission (kg CO₂)</td>
</tr>
<tr>
<td>Raw Material Production</td>
<td>36,437.13</td>
<td>24,727.93</td>
</tr>
<tr>
<td>Product Manufacturing</td>
<td>682,192.11</td>
<td>144,983.21</td>
</tr>
<tr>
<td>Product Installation</td>
<td>107,383.83</td>
<td>88,420.47</td>
</tr>
<tr>
<td>Product Use</td>
<td>246,847.36</td>
<td>183,989.82</td>
</tr>
<tr>
<td>Product Recycling</td>
<td>2,478.75</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

The values obtained for all the energy requirements and greenhouse gas emissions are shown in Table 6-10 and graphed in Figure 6-10 through Figure 6-13. In the numerical example data, in the case of a wool carpet, the final product manufacturing process has the largest energy requirement stage in the life cycle of a wool carpet, where the use process has the second impact and the raw material production process has the least impact on the total energy of the network. For greenhouse gas emission, the use process has the most impact and the final product manufacturing process has the second impact on the total greenhouse emission of the supply chain network.

Figure 6-10. Total Energy Types for a Wool Carpet
In the case of a nylon carpet, the raw material manufacturing process is the largest energy requirement stage in the life cycle of a wool carpet, where the final product manufacturing process has the second impact and the recycling process has the least impact on the total energy of the network. For greenhouse gas emission, the final product manufacturing process has the largest impact and the use process has the second impact on the total greenhouse emission of the supply chain network. Based on the life cycle assessment of two carpets, the results indicate the use process has an opportunity to decrease energy use and to improve the campus’s environmental performance.
6.5 Conclusion

In response to the increasing emphasis on life cycle assessment, this study focuses on the life cycle assessment of two types of carpet, a wool carpet and a nylon carpet, in terms of energy use and GHG emissions, from raw material acquisition to recycled post-use carpet. The analysis specifically evaluates the detailed energy use and greenhouse gas emissions for each production and recycling process of a wool carpet and a nylon carpet. In addition, the carpet supply chain of production-distribution-disposal network is formulated as a LP model to calculate both energy requirements and GHG emissions. The model examines how much energy is required and how much GHG is emitted in a production and recycling process, along with transportation activities. Based on the analysis results, this study estimates the total energy use and GHG emission in the carpets’ six life cycles at the Pennsylvania State University. The results indicate which life cycle stage provides an opportunity to decrease energy use and to improve the campus’s environmental performance. The life cycle assessment of this study can provide information on the detailed energy requirements and GHG emissions, which can be used as a guide to decreasing environmental impact.
Chapter 7

A Conclusions and Future Research

This study considers supply chain sustainability through supply chain microfinance and the life cycle assessment of a carpet supply chain. To fulfill this objective, a stochastic scenario-based microcredit contract model and a Stackelberg game model are developed to obtain an appropriate interest rate for microcredit. Also, a life cycle assessment of a carpet supply chain is conducted to determine energy requirements and greenhouse gas emissions.

At the first stage, in contrast to most microfinance contract models in a static economic environment, this study first provides a stochastic scenario-based microcredit contract model for a group case with strategic default under asset and cash yield uncertainty. The developed model provides an optimal interest rate over four different scenarios while considering several features: BSD model, strategic secured asset portfolio decisions, and microfinance ratio target values.

Considering a loan as a call option, the model first uses the BSD model to calculate a minimum interest rate for the financial sustainability of MFIs.

Second, the model considers asset portfolio decisions as a way to increase an institution’s financial sustainability. The increased financial sustainability helps MFIs to decrease the microcredit interest rate assigned. To reflect a real microfinance business environment, the model employs a microfinance ratio target value meant to improve the efficiency and productivity of MFIs. In the numerical analysis, the study shows that the optimal interest rates through supply chain microfinance are in the range of 6.4% to 8%, considerably lower than the average microfinance interest rate of 38%. Thus, the proposed models could be used an effective credit risk tool in the microfinance business environment.

At the second stage, in order to demonstrate that the concept of supply chain microfinance has an impact on decreasing the high interest rate of normal microcredit loans, this
study formulates an alternative concept: supply chain microfinance, with the manufacturer as a lender and the supplier as borrower, as a Stackelberg game model. In the model, the manufacturer as leader makes a decision on the order quantity and the interest rate of a microcredit loan to a supplier, the supplier as follower makes a decision on the wholesale price of a raw material, and the bank as sub-leader makes a decision on the interest rate of a bank loan to the manufacturer.

Through the numerical analysis, the manufacturer’s optimal interest is 3.4% with the normal distribution demand and 4% with the uniform distribution demand. The study reveals that a SCMF scheme has the potential to decrease the interest rate of a microcredit loan, which is high compared to loans from regular commercial financial institutions. With the normal distribution demand, the numerical analysis shows that the manufacturer’s interest rate for the supplier is negatively related to the order quantity and that the wholesale price should be decided based on negotiation between the manufacturer and the supplier. By providing an optimal interest rate in a microcredit loan, the proposed model could be an effective tool in simultaneously maintaining the financial and social sustainability of the manufacturer.

After showing the effect of supply chain microfinance on decreasing interest rates, the study investigates whether the MFIs will still be financially sustainable with a lower interest rate still. Thus, at the third stage, this study considers both the interest rate and the default rate in terms of the financial sustainability and outreach of MFIs. The study employs an interest rate premium methodology and proposes a default rate premium methodology to analyze whether 32 MFIs in India focus on their social mission in terms of outreach. The results show that the analyzed MFIs focus on increasing their outreach in breadth and depth.

As a preliminary to applying several credit risk models in financial fields, this study validates whether the asset and the default rate follow GBM. As a validation of GBM, the Ryan-Joiner test is used to test the normality of the underlying asset and the default rate, along with the chi-square test for independence. After validating that the data set follows GBM, the BS model is
used to calculate default rates of the 32 MFIs in India for 2012. By validating both asset and default data following GBM, this study demonstrates that it is possible to employ the risk models for the microfinance industry. By measuring key risks and underlying risk derives, the employed models could be effective tools to reveal risk potential as well as implement risk strategies for MFIs. Ultimately, the MFIs can simultaneously achieve both financial sustainability and social mission.

Along with the importance of the financial aspects of microfinance, environmental issues cannot be ignored in the microfinance industry. Because microfinance has a strong relationship with an agricultural production in rural areas, greenhouse gas and energy are considered to be important environmental issues. Thus, at the final stage, this study focuses on the life cycle assessment of a wool carpet and a nylon carpet, in terms of energy use and greenhouse gas emissions, from raw material acquisition to recycled post-use carpet. The carpet supply chain of production-distribution-disposal network is formulated as a linear programming model to calculate how much energy is required and how much greenhouse gas is emitted in a production and recycling process, along with transportation activities. By analyzing the carpets’ six life cycles at the Pennsylvania State University, the study can serve as a guide to decreasing environmental impact by providing information on the detailed energy requirements and greenhouse emissions.

Through this research, it is evident that supply chain microfinance can provide a sustainable solution to the high interest of microcredit, while increasing corporate social responsibility and developing a sustainable relationship between a manufacturer and a supplier. As future research, to reflect a whole business model of a MFI, the proposed microcredit contract model can be extended by incorporating other financial services such as saving and insurance, and social services such as health care and education. In addition, a Stackelberg game model can be made more realistic by being extended into a complex model with a default risk of borrowers.
Various credit risk models can be applied to investigate the financial sustainability and outreach of MFIs. The study mainly focuses on the primary issues of microfinance, interest rate and the default rate. However, it would be more beneficial for a MFI to further extend sustainability and outreach into four categories: sustainability and profitability, asset and liability, portfolio quality, and efficiency and productivity.


Appendix A

Model Nomenclature for a Microcredit Contract Model

Indices

\( i \) = Asset

\( ip \) = Product

\( j \) = Borrower

\( jp \) = Plant

\( l \) = Scenario

\( lp \) = Customer

\( t \) = Time

Parameters

\( A^l_i \) = Asset at stage \( t \) under scenario \( l \)

\( B^l_{i,j} \) = Amount to buy of asset \( i \) at stage \( t \) under scenario \( l \)

\( BPR^l_{j,t} \) = Expected project return of a borrower \( j \) at stage \( t \) under scenario \( l \)

\( BSDIR^l_{j,t} \) = Minimum interest rate of a borrower \( j \) from a BSD model at stage \( t \) under scenario \( l \)

\( C^l_i \) = Cash amount at stage \( t \) under scenario \( l \)

\( CE^l_i \) = Cash earning at stage \( t \) under scenario \( l \)

\( CPBT^l_i \) = Cost per borrower target value at stage \( t \) under scenario \( l \)

\( CR^l_i \) = Cash yield from cash amount at stage \( t \) under scenario \( l \)

\( CRT^l_i \) = Current ratio target value at stage \( t \) under scenario \( l \)
\[ D_{ip,lp,t}^l = \text{Demand of product } ip \text{ from customer } lp \text{ at stage } t \text{ under scenario } l \]

\[ E_t^l = \text{Equity at stage } t \text{ under scenario } l \]

\[ EBIT_t^l = \text{The earnings before interest and taxes at stage } t \text{ under scenario } l \]

\[ EY_t^l = \text{Expected annual yield at stage } t \text{ under scenario } l \]

\[ FA_t^l = \text{Fixed asset at stage } t \text{ under scenario } l \]

\[ FET_t^l = \text{Funding expense target value at stage } t \text{ under scenario } l \]

\[ FL_t^l = \text{Financed investment at stage } t \text{ under scenario } l \]

\[ FLB_t^l = \text{Financial liability balance at stage } t \text{ under scenario } l \]

\[ FLIP_t^l = \text{Interest paid for financed investment at stage } t \text{ under scenario } l \]

\[ FLR_t^l = \text{Interest rate for financed investment at stage } t \text{ under scenario } l \]

\[ H_{i,t}^l = \text{Amount to hold of asset } i \text{ at stage } t \text{ under scenario } l \]

\[ HB_t^l = \text{Asset balance at stage } t \text{ under scenario } l \]

\[ HE_t^l = \text{Asset earning at stage } t \text{ under scenario } l \]

\[ L_{j,t}^l = \text{Amount lent to a borrower } j \text{ at stage } t \text{ under scenario } l \]

\[ LB_t^l = \text{Loan balance at stage } t \text{ under scenario } l \]

\[ LE_t^l = \text{Loan earning at stage } t \text{ under scenario } l \]

\[ LOPT_t^l = \text{Loan officer productivity target value at stage } t \text{ under scenario } l \]

\[ LPC_{j,t}^l = \text{Loan processing cost of a borrower } j \text{ at stage } t \text{ under scenario } l \]

\[ LR_{j,t}^l = \text{Loan yield from loan amount lent to a borrower } j \text{ at stage } t \text{ under scenario } l \]

\[ LR_{\max} = \text{Maximum amount of allowed loan} \]
$NB^l_t$ = Number of active borrowers at stage $t$ under scenario $l$

$NLO^l_t$ = Number of loan officers at stage $t$ under scenario $l$

$NOP^l_t$ = Net operation profit at stage $t$ under scenario $l$

$NOPAT^l_t$ = Net operating income after taxes at stage $t$ under scenario $l$

$OET^l_t$ = Operating expense ratio target value at stage $t$ under scenario $l$

$QPC_{ip,jp,lp}^l$ = Transportation volume of product $ip$ from plant $jp$ to customer $lp$ at stage $t$ under scenario $l$

$OR^l_t$ = Operating revenue at stage $t$ under scenario $l$

$OSST^l_t$ = Operational self-sufficiency target value at stage $t$ under scenario $l$

$ROAT^l_t$ = Return on asset target value at stage $t$ under scenario $l$

$ROET^l_t$ = Return on equity target value at stage $t$ under scenario $l$

$p^l_{ip,jp,t}$ = Unit production sale price of product $ip$ at plant $jp$ at stage $t$ under scenario $l$

$PC^l_t$ = Production cost at stage $t$ under scenario $l$

$PCU_{ip,jp,t}^l$ = Unit production cost of product $ip$ at plant $jp$ at stage $t$ under scenario $l$

$PR^l_t$ = Production revenue at stage $t$ under scenario $l$

$PRU_{ip,jp,t}^l$ = Unit production sale price of product $ip$ at plant $jp$ at stage $t$ under scenario $l$

$S^l_{i,t}$ = Amount to sell of asset $i$ at stage $t$ under scenario $l$

$TL^l_t$ = Total loan at stage $t$ under scenario $l$

$TR^l_t$ = Tax rate at stage $t$ under scenario $l$

$V^l_{j,t}$ = Future access value of a borrower $j$ at stage $t$ under scenario $l$
\( YGT_t^l = \text{Yield gap target value at stage } t \text{ under scenario } l \)

\( YGLT_t^l = \text{Yield on gross loan portfolio target value at stage } t \text{ under scenario } l \)

\( \alpha_t^l = \text{Maximum percentage of allowed asset investment at stage } t \text{ under scenario } l \)

\( \gamma_{j,t}^l = \text{Probability of default of each type of a borrower } j \text{ at stage } t \text{ under scenario } l \)

\( M = \text{Probability of being monitored by peer} \)

\( N = \text{Total number of borrowers} \)

\( W = \text{Social sanction cost} \)
Appendix B

Model Nomenclature for an Energy and Emission Model

Indices

$i =$ Product

$j =$ Plant

$k =$ Internal distribution center

$k' =$ External distribution center

$l =$ Internal customer

$l' =$ External customer

$m =$ Warehouse

$o =$ Return warehouse

Parameters

$DP_{io} =$ Disposal of product $i$ at returned warehouse $o$

$EDP_{io} =$ A unit energy requirement of disposal of product $i$ at return warehouse $o$

$EP_{ij} =$ A unit energy requirement of production of product $i$ at plant $j$

$EPW_{ijm} =$ A unit energy requirement of product $i$ transferred from plant $j$ to warehouse $m$

$ECR_{ilo}^{(1)} =$ A unit energy requirement of product $i$ from internal customer $l$ to returned

warehouse $o$

$ECR_{il'o}^{(2)} =$ A unit energy requirement of product $i$ from external customer $l'$ to returned

warehouse $o$

$EDC_{iki}^{(1)} =$ A unit energy requirement of product $i$ from internal distribution center $k$ to internal
customer $l$

$EDC^{(2)}_{ik} = $ A unit energy requirement of product $i$ from internal distribution center $k$ to external

customer $l'$

$EDC^{(3)}_{ik} = $ A unit energy requirement of product $i$ from external distribution center $k$ to internal

customer $l$

$EDC^{(4)}_{ik} = $ A unit energy requirement of product $i$ from external distribution center $k$ to external

customer $l'$

$EDD^{(1)}_{kk} = $ A unit energy requirement of product $i$ from internal distribution center $k$ to

external distribution center $k'$

$EDD^{(2)}_{kk} = $ A unit energy requirement of product $i$ from external distribution center $k$ to

internal distribution center $k$

$GP_{ij} = $ A unit air emission of production of product $i$ at plant $j$

$GCR^{(1)}_{ilo} = $ A unit air emission of product $i$ from internal customer $l$ to returned

warehouse $o$

$GCR^{(2)}_{ilo} = $ A unit air emission of product $i$ from external customer $l'$ to returned warehouse $o$

$GDC^{(1)}_{ikl} = $ A unit air emission of product $i$ from internal distribution center $k$ to internal

customer $l$

$GDC^{(2)}_{ikl} = $ A unit air emission of product $i$ from internal distribution center $k$ to external

customer $l'$

$GDC^{(3)}_{ikl} = $ A unit air emission of product $i$ from external distribution center $k$ to internal

customer $l$
\( GDC_{ikl}^{(4)} \) = A unit air emission of product \( i \) from external distribution center \( k \) to external customer \( l \)

\( GDD_{kk}^{(1)} \) = A unit air emission of product \( i \) from internal distribution center \( k \) to external distribution center \( k' \)

\( GDD_{kk}^{(2)} \) = A unit air emission of product \( i \) from external distribution center \( k' \) to internal distribution center \( k \)

\( GDP_{io} \) = A unit air emission of disposal of product \( i \) at return warehouse \( o \)

\( GPW_{jmn} \) = A unit air emission of product \( i \) transferred from plant \( j \) to warehouse \( m \)

\( P_{ij} \) = Production of product \( i \) at plant \( j \)

\( QCR_{ilo}^{(1)} \) = Transportation volume of product \( i \) from internal customer \( l \) to returned warehouse \( o \)

\( QCR_{iol}^{(2)} \) = Transportation volume of product \( i \) from external customer \( l' \) to returned warehouse \( o \)

\( QDC_{ikl}^{(1)} \) = Transportation volume of product \( i \) from internal distribution center \( k \) to internal customer \( l \)

\( QDC_{ikl}^{(2)} \) = Transportation volume of product \( i \) from internal distribution center \( k \) to external customer \( l' \)

\( QDC_{ikl}^{(3)} \) = Transportation volume of product \( i \) from external distribution center \( k' \) to internal customer \( l \)

\( QDC_{ikl}^{(4)} \) = Transportation volume of product \( i \) from external distribution center \( k' \) to external customer \( l' \)

\( QDD_{kk}^{(1)} \) = Transportation volume of product \( i \) from internal distribution center \( k \) to
external distribution center $k'$

$QDD_{k,k}^{(2)} =$ Transportation volume of product $i$ from external distribution center $k'$ to internal distribution center $k$

$QPW_{ijm} =$ Transportation volume of product $i$ transferred from plant $j$ to warehouse $m$
Appendix C

Proofs of a Microfinance Supply Chain Game Model

C.1 Proof of Proposition 1

The unconstrained manufacturer’s expected profit function can be rewritten as follows:

\[ \pi_M(q, w, R_B, R_M) = E[(p-c) \min(x, q)] + wq(R_M - R_f) + K_M (1 + R_f) \]

\[ = (p-c) \int_0^q xdF(x) + (p-c) \int_q^\infty qdF(x) + (p-c) + wq(R_M - R_f) + K_M (1 + R_f) \]

\[ = (p-c)q - (p-c) \int_0^q F(x)dx + wq(R_M - R_f) + K_M (1 + R_f) \]

By taking the first-order derivative of \( \pi_M \) with respect to \( q \),

\[ \frac{d\pi_M}{dq} = (p-c) \bar{F}(q) + w(R_M - R_f) \]

By setting the first-order derivative of \( \pi_M \) equal to 0 and rearrange,

\[ (p-c) \bar{F}(q) = \frac{w(R_f - R_M)}{(p-c)} \]

Then, the unconstrained manufacturer’s optimal order quantity is as follows:

\[ q^* = \bar{F}^{-1}\left( \frac{w(R_f - R_M)}{(p-c)} \right) \]

C.2 Proof of Proposition 2

The constrained manufacturer’s expected profit function can be rewritten as follows:

\[ \pi_M(q, w, R_B, R_M) = (p-c)E[\min(x, q)] - (p-c)E[\min(x, k)] \]

\[ = (p-c)q - (p-c) \int_0^q F(x)dx - [(p-c)k - (p-c) \int_0^k F(x)dx] \]
By taking the first-order derivative of $\pi_M$ with respect to $q$ using the Implicit Function Theorem (IFT),

$$\frac{d\pi_M}{dq} = (p - c)\overline{F}(q) - (p - c)\overline{F}(k)\frac{dk}{dq}$$

where

$$\frac{dk}{dq} = \frac{w(R_b - R_M)}{p - c}$$

After substituting $dk/dq$ and setting the first-order derivative of $\pi_M$ equal to 0,

$$\overline{F}(q) = \left[\frac{w(R_b - R_M)}{(p - c)}\right] \times \overline{F}(k)$$

Then, the constrained manufacturer’s optimal order quantity is as follows:

$$q^* = \frac{1}{\overline{F}}\left[\frac{w(R_b - R_M)}{(p - c)}\right] \times \overline{F}(k)$$

### C.3 Proof of Proposition 3

When the unconstrained manufacturer’s optimal order quantity is greater than that of the constrained manufacturer, which implies,

$$\overline{F}^{-1}\left[\frac{w(R_b - R_M)}{(p - c)}\right] \times \overline{F}(k) \geq \overline{F}^{-1}\left(\frac{w(R_I - R_M)}{(p - c)}\right)$$

Since $F(x)$ is strictly increasing and follows IFR, which implies,

$$\frac{w(R_b - R_M)}{(p - c)} \times \overline{F}(k) \leq \frac{w(R_I - R_M)}{(p - c)}$$

By rearranging with respect to $R_b$ as follows:

$$R_b \leq \frac{R_I - R_M}{\overline{F}(k)} \frac{F(k)}{\overline{F}(k)}$$
C.4 Proof of Proposition 4

By taking the first-order derivative of \( \pi_M \) with respect to \( R_M \) using the IFT,

\[
\frac{d\pi_M}{dR_M} = (p - c)\bar{F}(q) \frac{dq}{dR_M} - (p - c)\bar{F}(k) \frac{dk}{dR_M}
\]

By taking the first-order derivative of \( F(q) \) with respect to \( R_M \) using the IFT,

\[
-f(q) \frac{dq}{dR_M} - \bar{F}(k) \frac{d\Omega}{dR_M} + \Omega f(k) \frac{dk}{dR_M}
\]

(C.1)

where

\[
\frac{d\Omega}{dR_M} = -\frac{w}{(p - c)}
\]

\[
\frac{dk}{dR_M} = \frac{1}{(p - c)} \left[ w(R_B - R_M) \frac{dq}{dR_M} - wq \right]
\]

After substituting \( d\Omega / dq \) and \( dk / dq \) into Equation (A.1) and rearranging,

\[
\frac{dq}{dR_M} = \frac{W[\bar{F}(k) - q\Omega f(k)]}{(p - c)[f(q) - \Omega^2 f(k)]}
\]

After substituting \( dq / dR_M \) into \( d\pi_M / dR_M \) and rearranging,

\[
\frac{d\pi_M}{dR_M} = [(p - c)\bar{F}(q) - w(R_B - R_M)\bar{F}(k)] \frac{dq}{dR_M} + (p - c)wq \bar{F}(k)
\]

After substituting \( dq / dR_M \) into \( d\pi_M / dR_M \) and rearranging with respect to \( R_M \), the constrained manufacturer’s optimal interest rate of a microcredit loan is as follows:

\[
R_M^* = \frac{(p - c)w[\Omega \bar{F}(k) - q\Omega^2 f(k)] + (p - c)[f(q) - \Omega^2 f(k)]}{w^2[q\Omega f(k) - F(k)]}
\]

After taking the second-order derivative of \( \pi_M \) with respect to \( R_M \) using the IFT,
\[
\frac{d^2 \pi_M}{dR_M^2} = [(p-c)w + (p-c)\Omega f(k) + w\overline{F}(k)] \frac{dq}{dR_M} - (p-c)f(q) \left( \frac{dq}{dR_M} \right)^2 \\
+ [(p-c)\overline{F}(q) - (p-c)\overline{\Omega F}(k)]
\]

After substituting \( dq / dR_M \) and \( d^2 q / dR_M^2 \) and rearranging, it can be shown \( d^2 q / dR_M^2 < 0 \) if
\[ g_f(k) > \Omega f(k)\overline{F}(k) \]. This implies that the manufacturer’s optimal interest rate of a microcredit loan can be obtained.

C. 5 Proof of Proposition 5

By taking the first-order derivative of \( \pi_B \) with respect to \( R_B \) using the IFT,

\[
\frac{d\pi_B}{dR_B} = (p-c)[\overline{F}(k) - 1] \frac{dk}{dR_B} + (wq - K_M) + w(R_B - R_f) \frac{dq}{dR_B} \tag{C.2}
\]

where

\[
\frac{dk}{dR_B} = \frac{1}{(p-c)}[w(R_B - R_M) \frac{dq}{dR_B} + (wq - K_M)]
\]

By taking the first-order derivative of \( F(q) \) with respect to \( R_B \) using the IFT,

\[
\frac{dq}{dR_B} = -\frac{w\overline{F}(k) + (wq - K_M)\overline{\Omega f}(k)}{(p-c)[f(q) - \overline{\Omega^2 f}(k)]}
\]

After substituting \( dk / dR_B \) and \( dq / dR_B \) into Equation (A.2) and rearranging,

\[
\frac{d\pi_B}{dR_B} = [w(R_B - R_M)(\overline{F}(k) - 1) + w((p-c)w(R_B - R_f))] \frac{dq}{dR_B} + (wq - K_M)\overline{F}(k)
\]

After substituting \( dq / dR_B \) into \( d\pi_B / dR_B \) and rearranging with respect to \( R_B \), the constrained bank’s optimal interest rate of a bank loan is as follows:

\[
R_B^* = \frac{R_f - R_M}{\overline{F}(k)} + \frac{(p-c)(wq - K_M)[f(q) - \overline{\Omega^2 f}(k)]}{[w^2\overline{F}(k) - w(wq - K_M)\overline{\Omega f}(k)]}
\]
After taking the second-order derivative of $\pi_M$ with respect to $R_B$ using the IFT,

$$
\frac{d^2\pi_B}{dR_B^2} = \left[ 2w\bar{F}(k) - w(R_B - R_M)f(k) \right] \frac{dq}{dR_B} - \left( wq - K_M \right) f(k) \frac{dk}{dR_B}
$$

$$
+ w[(R_B - R_M)(\bar{F}(k) - 1) + (R_B - R_f)] \frac{d^2q}{dR_B^2}
$$

After substituting $dq / dR_B$, $dk / dR_B$, and $d^2q / dR_B^2$ and rearranging, it can be shown

$$
d^2q / dR_B^2 < 0 \text{ if } (K_M - wq)\Omega f(k) > w\bar{F}(k).$$

This implies that the bank’s optimal interest rate of a bank loan can be obtained.

**C.6 Proof of Proposition 6**

By taking the first-order derivative of $\pi_s$ with respect to $w$ using the IFT,

$$
\frac{d\pi_s}{dw} = (m - e - wR_M) \frac{dq}{dw} - R_Mq
$$

By rearranging with respect to $w$,

$$
w = \frac{(m - e) - q}{R_M} \frac{dq}{dw} \quad \text{(C.3)}
$$

By taking the first-order derivative of $F(q)$ with respect to $w$ using the IFT,

$$
\frac{dq}{dw} = \frac{\Omega[\bar{F}(k) - \Omega f(k)]}{w[\Omega^2 f(k) - f(q)]}
$$

After substituting $dq / dw$ into Equation (A.3) and rearranging with respect to $w$, the supplier’s optimal wholesale price is calculated as follows:

$$
w^* = \frac{(m - e)[\bar{F}(q) - \Omega^2 qf(k)]}{R_M[\bar{F}(q) - qf(k)]}
$$

After taking the second-order derivative of $\pi_s$ with respect to $w$ using the IFT,
\[
\frac{d^2 \pi_s}{dw^2_S} = -\frac{2\Omega^2[2\Omega F(k) - \Omega^2 qf(k) - qf(q)]}{w^2[\Omega^2 f(k) - f(q)]^2}
\]

If \(2\Omega F(k) > \Omega^2 qf(k) + qf(q)\), then \(d^2 \pi_s / dw^2 < 0\). This implies that the supplier’s optimal wholesale price can be obtained.
VITA

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Jaehun Sim was born as the first son of Dongsub Sim and Philnam Park in Pusan, South Korea. He attends Maria kindergarten, Deasin elementary school, Deasin middle school, Kyungnam high school in Pusan, South Korea. He got a Bachelor of Science degree in Industrial Engineering and Operations Research from the University of California at Berkeley and a Master of Science degree in Industrial and Systems Engineering from the University of Southern California. He is married to Jaehwa Lee and has one son, Jungyun Sim.