# Third Party Support and Risk Costs in Supply Chain Coordination

A Thesis

Submitted to the Faculty

of

Drexel University

by

Kurt A. Masten

in partial fulfillment of the

requirements for the degree

of

Doctor of Philosophy

in

May 2016

## Dedications

This is dedicated to my beloved wife who supported me throughout this endeavor.

Seni seviyorum aşkım.

# Acknowledgements

I would like to recognize my advisor and committee chair, Avijit Banerjee, for his many hours of guidance, assistance, perfectionism, and witty banter. This dissertation and my abilities as a researcher have both benefited greatly from his input. I would also like to thank my other committee members; Seung-Lae Kim, Min Wang, Murugan Anandarajan, Konstantinos Serfes, and Hande Benson. Their participation, thoughtful suggestions, and keen questioning were invaluable to the process.

I am grateful to my wife, Neslihan, for encouraging me to return to academia. Finally, I want to give a special thanks to my parents; my mother for always believing in me and my father for instilling a love of learning.

## Table of Contents

## List of Tables

## List of Figures

# Abstract

## Third Party Support and Risk Costs in Supply Chain Coordination

Kurt A. Masten

It is broadly accepted that supply chain members which can jointly optimize their decisions, using techniques such as joint economic lot-sizing (JELS), will always produce equal or superior total profits than those supply chains which do not cooperate. In addition to increased profits, cooperation offers other established benefits. The majority of research has explored the use of coordination mechanisms (e.g. quantity discounts) to improve on purely competitive (arms-length) arrangements in supply chain purchase contracts. Though the use of these mechanisms can potentially improve profits, they often fail to offer any substantive guidance in implementing the proposed solution. Further, the JELS solution proposals often presuppose a spontaneous and effective coordination effort led by one or both supply chain parties. However, research has shown that very little meaningful cooperation occurs in practice. This thesis proposes and explores the novel use of an expert third party to assist in coordination and cooperation efforts of a contract-based dyadic (supplier-buyer) relationship. It is shown that coordination using a third party can, not only ensure optimal profits for the entire supply chain, but also provide significant contributions to the extant body of knowledge. These benefits include consideration of intangible factors such as neutral arbitration and protection of confidential information. An updated cost model accounts for many costs not typically considered in lot-sizing problems, including the introduction of the seller's costs of commitment and contract costs. Numerical studies via simulation are performed to add insight into the implications of the updated model. Sensitivity and algebraic analyses are included for selected scenarios.

# Chapter 1: Introduction

## 1.1 The Need for Supply Chain Coordination and Cooperation

There is wide agreement among both academics and practitioners that the future of free-market competition lies not in company vs. company, but in supply chain vs. supply chain (Rice and Hoppe, 2001). In such an economy, the inefficiencies of traditional (non-cooperative) relationships consisting of firms that locally maximize profits will put all parties in those supply chains at a disadvantage against supply chains with firms that can jointly maximize profits. There is also broad agreement that firms within a supply chain which can successfully cooperate with upstream or downstream partners will have higher potential profits over firms which adhere to a non-cooperative approach. However, the typical method offered to help achieve higher profits is through the use of a coordination mechanism with the potential profits using joint maximization being held as the "ideal" benchmark. This approach has troubling assumptions and ramifications. First, it assumes that the singular goal of any coordination effort is increased profits. This is not true. Obviously, every for-profit firm wants more profits, but other non-monetary benefits are being increasingly considered by modern firms. Second, it assumes relationships are combative in nature. For example, consider a contract negotiation between two parties, $A$ and $B$. Party $A$, itself in a weak negotiating position, offers a monetary incentive $\$x$ to party $B$, in the hopes of driving it to accept new terms costing $<\$x$ to $B$ and returning $>\$x$ in increased profits back to $A$. This is not cooperation, but advanced negotiation. This brings us to the third and perhaps most troubling ramification, sub-optimality. Any approach similar to the one described above, which is not uncommon, will not only fail to maximize total supply chain profits, but perhaps also fail to garner good will among the participants.

Let us keep focus on a single dyadic link of a larger supply chain which employs the use of contracts for purchase agreements. There are a variety of reasons for contracts, such as securing a fixed-cost supply for the buyer and lot-splitting large batches for the supplier. It is well-established that in the traditional (non-cooperative) buyer-supplier relationship, a strong party will use its strength as leverage to gain better terms and/or price on a contract. In a cooperative relationship, the firms would ideally work together to establish a policy that is mutually beneficial, including the maximization of profits for all members. One well-known cost model requiring cooperation (rather than a coordination mechanism) is joint economic lot-sizing (JELS). This scenario of firms coming together in spontaneous and effective cooperation has, perhaps unsurprisingly, remained elusive in practice despite interest from practitioners. The goal of this thesis is to present the problem in detail, consider previously overlooked aspects of the problem, and propose an implementable solution that addresses the low rate of success of cooperative solutions. Specifically, we propose the novel use of a third party coordinator (3PC) to provide expertise and services to aid in achieving cooperation. It is shown that our proposed solution addresses many of the practitioner's concerns that have hindered previous efforts in this regard.

In the first chapter, a general background is provided along with detailed information on the scope and assumptions of the problem and the proposed solution. An illustrative example and some notes on the need for a more complete cost accounting methodology are outlined as well.

In the second chapter, we review the relevant extant literature on third parties in supply chains and joint economic lot-sizing (JELS) models. Also in this chapter, we discuss the related literature on quantifying risks, both to the buyer and the seller, for inclusion in the proposed models. The literature review concludes with an examination of the possible legal implications for close coordination between supply chain members.

The next chapter is devoted to examining traditionally unquantified risk costs, such as the opportunity cost of commitment to a contract. Updated cost models including these costs are provided for the buyer and the supplier. A numerical example, for illustrating and examining the concepts developed is provided.

The following chapter focuses on the role, limitations, and consequences of using a third party as a supply chain coordinator. An updated JELS model with a third party is presented and various payment options are discussed. Finally, this chapter includes a set of numerical experiments, along with some selected sensitivity analyses.

The fifth and final chapter concludes this thesis with a summary and closing thoughts with some potential extensions and possible future research areas.

## 1.2 Finite Contracts and Infinite Horizon Models

Infinite horizon models as a commonly used research approach offer many advantages. They often result in ease of analysis and interpretation, and are usually easier to solve implicitly. However, they are rarely realistic. They are especially unrealistic when contracts and legal issues are involved. Gone are the days of forecast based “push” ordering systems. Buyers today desire small deliveries at mass-produced prices. To satisfy both requirements, suppliers must often split large production batches into multiple, smaller deliveries. In turn, the supplier will require a commitment from the buyer to purchase one or more of these large production batches to ensure that all parts produced are sold. These commitments require contracts, which are necessarily of finite duration. Although finite, all contracts considered herein, unless noted, are of arbitrary length to be determined at the time of optimization.

We will assume that the item's demand is stationary and is not expected to end in the foreseeable future. Should a required contract length be known before the optimization (and thus the contract signing), such as the case with end-of-lifecycle and planned design changes, this can be included as an additional constraint in the optimization model, without loss of generality. Indeed, this is likely to simplify the solution process. The optimization objective remains the minimization of the average total relevant supply chain cost per time unit, the same as infinite horizon models.

## 1.3 Why Introduce a Third Party?

It is a well-accepted fact that firms in a supply chain which can successfully coordinate their actions and decisions will produce equal or higher profits than those that maintain a more traditional (arms-length or competitive) relationship (Jeuland and Shugan, 1983; Lee et al., 1997; Park, 2005; Vereecke and Muylle, 2006; Van der Vaart and van Donk, 2008; Cao and Zhang, 2010; Prajogo and Olhager, 2012). As mentioned above, this thesis explores the novel addition of an independent and neutral third party coordinator (3PC) to assist in coordinating a dyadic (buyer-supplier) supply chain relationship. The scope of this research is limited to dyadic relationships since the vast majority of coordination attempts in practice are of this variety (Storey et al., 2006). The reasons underlying the need for this third party can be seen by investigating the reasons why coordination efforts often fail.

Collaboration efforts fail for a variety of reasons. Some cite concerns over confidential information being shared (Kelle and Akbulut, 2005), especially if a supplier also works with a competitor (Storey et al., 2006; Fawcett and Magnan, 2002). Other collaboration efforts, even those that seem to be working adequately, fail when there is a change in personnel, such as a purchasing agent that has left the firm (Frankel et al., 2002). Some efforts fail, quite paradoxically, due to a concern that close collaboration might be a first step towards an undesired merger or buy-out (Sabath and Fontanella, 2002). Even something as seemingly simple as a lack of a formalized collaboration agreements has caused numerous efforts to be unsuccessful (Daugherty et al., 2006). A neutral third party could help overcome these hurdles, as well as provide other potential benefits, such as conflict resolution, disruption mitigation, and coordination expertise. For an example of a hurdle crossed, through the use of a 3PC, the buyer and supplier are not required to share sensitive information with the other party, but only to the 3PC, which will ensure confidentiality. Hence, the buyer and the supplier may be less reluctant to cooperate.

Neutral third parties are not a new concept. Indeed, they are regularly employed in various circumstances such as conflict resolution, escrow, or peer-reviewed academic research. They may act as a mediator, assisting with a solution using persuasion or logic to converge to a solution agreeable to both sides. Alternatively, the role may be that of an arbitrator, which is essentially a mediator with the authority to enforce an agreement that may not be acceptable to both sides. Such a third party may simply be a trusted liaison, offering a line of communication between disgruntled parties. Finally, its role may be as an expert consultant providing expertise and guidance, while considering or investigating competing claims. Reviewing this list, we see that all of these might be needed at some point between a supplier and buyer in a supply chain. Currently, firms must peacefully, coercively, or perhaps, even through legal means, work out all aspects, agreements, and disagreements of their relationship. Smooth, efficient handling of all collaboration requirements may be too much to expect without any expert outside help.

Individuals have seemed to grasp what firms struggle to understand. Imagine a couple, currently living in a rental, on the market for a first new house. They meet someone at a party who has just secured a new job in another city. The person with the new job is anxious to move and offers a good price to the couple. The couple loves the home and location and makes a counter-offer. The offer is close, but a bit less than what the seller wants. The couple writes up a contract from a template they find on the internet. The seller, who has no experience selling a house, is uncomfortable with all of this and suggests they hire someone to help make the transaction. The buyers agree on using a local real estate agent with years of experience to assist with the transfer. The realtor with dual agency rewrites the contract, adds conditions to the sale, and convinces the buyers to increase the price slightly to come above what the seller could get from someone else, but still less than the buyers would pay to a seller with more time. The process is streamlined and the deal goes through quickly as everyone involved has clear expectations and is spearheaded by an experienced third party.

Scenarios similar to the one described above are certainly not uncommon. Yet, if they had acted like the majority of firms, they would have insisted on trying to work things out by themselves. Expectations of firms can differ greatly, possibly with undesirable consequences later on, including the loss of future business opportunities. Considering that many businesses are already using third parties to assist with logistical needs, it is not a giant leap to have a third party assist with the numbers, purchase contracts, and actions behind those logistics.

## 1.4 General Background and Scenarios of Interest

Today's complex supply chains are commonly viewed as a series of firms, factories, or agents, together transforming raw materials at one end of the chain to a product or service delivered to a customer at the other end. We fully expect that each and every one of these firms along the supply chain will attempt to maximize its own profits. To accomplish this, a firm will try to minimize its own relevant costs, while maintaining standards of quality and customer service. It is well known that such attempts are likely to lead to suboptimal performance of the whole system. One proven method to maximize overall supply chain profits is supply chain coordination (SCC). We note here that "supply chain coordination" can be a somewhat vague term that now encompasses many different facets of study, including research on areas such as coordination mechanisms, coordination roles, and empirical studies. Additionally, the focus of research may be on internal coordination (among or between functional areas of a single firm, or "intra-firm") or external coordination between independent buyers and suppliers ("Inter-firm").

In this research, we are interested in a specific, but common, scenario where there is a single supplier and a single buyer which enter into a binding contract for a specified quantity of parts to be delivered with lot-splitting as an option to lower total supply chain costs. This process is sometimes referred to as SSMD (single-setup-multiple-delivery) (Kim and Ha, 2003). Besides the empirical evidence of practitioner interest in SSMD, commonly cited mathematical justifications for this approach include a higher carrying cost for inventory for the buyer and greater setup costs for the supplier. The supplier will make every reasonable effort to match the buyer's realized demand, but is limited by its production rate. One of the two firms may be in a stronger negotiating position and may choose to use it to maximize its own profit. Alternately, the firms may agree to work together to design a contract that minimizes the entire supply chain's average total relevant cost per time unit. If applicable, the joint profit is split through negotiation or based on industry customs via some external mechanism or through the help of a third party. The length of the contract time is dependent on the values of the decision variables in the optimal solution. In fact, the contract size, and thus the contract length, is an important decision variable in our model.

### 1.4.1 The Archetypal Scenario

The base scenario consists of two profit-maximizing firms that are potentially willing to work together to improve total joint performance (profit) of the supply chain. These two firms consist of an upstream supplier and a downstream buyer. The firms do not compete with each other and will share all relevant information such as holding cost rates, tooling costs, demand, and production rates if they decide to work together. Using the shared information, the buyer and supplier can minimize the average joint total relevant cost over the planning horizon. Note that since shortages and backorders are not permissible, cost minimization is equivalent to profit maximization. If collaboration fails, the party in the stronger bargaining position will dictate its preferred decisions and the other party will optimize what it can given the stronger party's dictated values. The critical decision variables in this cost minimization problem are the total number of deliveries over the life of the contract ($n$), the quantity of each delivery ($q$), and the number of deliveries per production batch ($m$). The resulting contract size, $nq$, is simply the product of the total number of deliveries and the quantity of each delivery. Similarly, the supplier's production batch size is simply $mq$, the product of the number of deliveries per batch and the size of a single delivery. Further, to ensure that the supplier is not left with excess (and unpaid for) inventory at the end of the contract, a constraint is added: $n/m \in \mathbb{Z}^+$. No assumption is made on additional business between the two firms, but contracts are only made for single parts and only one contract may be active on a part at a time. There may be significant tooling or setup costs for a part, so the supplier is interested in a purchase commitment from the buyer. The supplier also needs the freedom to produce very large batches to minimize long-run production costs, but needs a contract to ensure that it is not left with unusable inventory should the buyer attempt to renege on the contract during its execution. The buyer is interested in a steady lean supplier, willing to spread out delivery of large production batches via small but frequent deliveries. Occasionally, the buyer may be interested in using a contract for purposes other than lot splitting. For example, this buyer may want to “lock in” a particular fixed price for the duration of the contract on parts known to have high price volatility (see Section 3.3 for an in-depth discussion). The exact process for determining the best decision variables will depend whether the firm in the stronger negotiating position will use that leverage or if both parties are willing, instead, to work together jointly. Three possible scenarios that thus arise, are discussed next.

### 1.4.2 Three Scenarios of Interest

There are three specific scenarios that we are particularly interested in exploring:

1. A non-cooperative supply chain where the buyer has a stronger negotiating position (“Strong Buyer” or SB)

2. A non-cooperative supply chain where the seller has a stronger negotiating position (“Strong Seller” or SS)

3. A cooperative supply chain where either the buyer or seller would traditionally enjoy a stronger negotiating position, but instead employ the services of a third party to assist in cooperation and arriving at jointly optimal contract decisions (“Third Party Coordinator” or 3PC)

For brevity, we will refer to each scenario by only its defining participant: SB, SS, or 3PC. In both of the first two scenarios, SB and SS, the stronger party will fully use its leverage to directly minimize its own costs when making decisions. This will offer us “worst case” results when considering total supply chain costs. These will also provide baselines of comparison for the third scenario, 3PC. In practice, we expect a weaker buyer or seller to offer incentives, such as quantity discounts, to help align

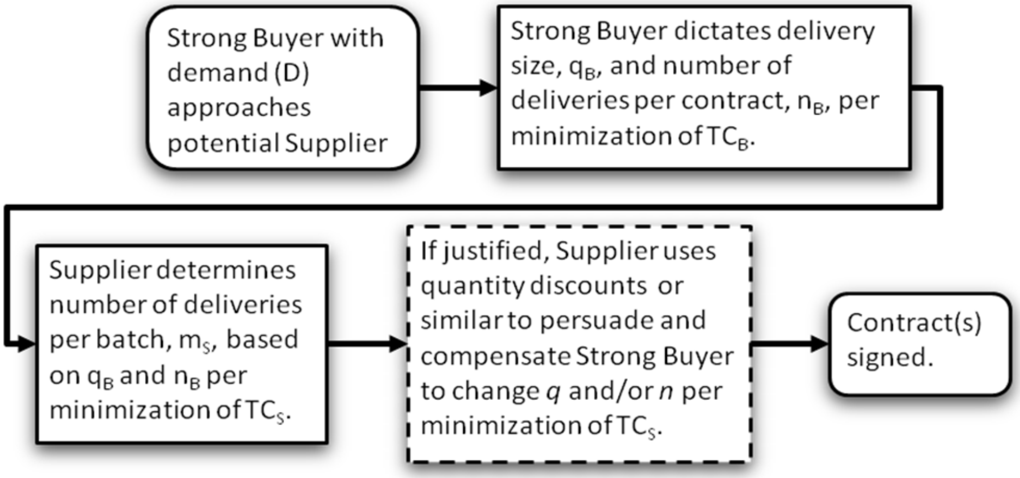

Figure 1.1: Sequence of Events for a Supply Chain with a Strong Buyer (SB)

the stronger party with its own preferred terms, thus lowering the cost for the overall supply chain. These mechanisms can be viewed as a non-cooperative reaction to a non-cooperative player (SB or SS), and are fitting for an arms-length contract. Non-cooperative coordination mechanisms such as these are outside the scope of this thesis. In contrast, the approach discussed here applies to firms desiring a closer, more collaborative, relationship. Additionally, the 3PC scenario guarantees us jointly optimized decisions, potentially providing the "best case" minimal cost results (given the conditions discussed later).

To help clarify the sequence of events in each of the three scenarios of interest, flowcharts are provided in Figures 1.1, 1.2, and 1.3.

In these figures, dotted items indicate the weaker party's logical response to a stronger party's dictated contract terms. These are outside the scope of the current research but provided here for completeness. For details on the $L_S$ term, see Section 3.3.

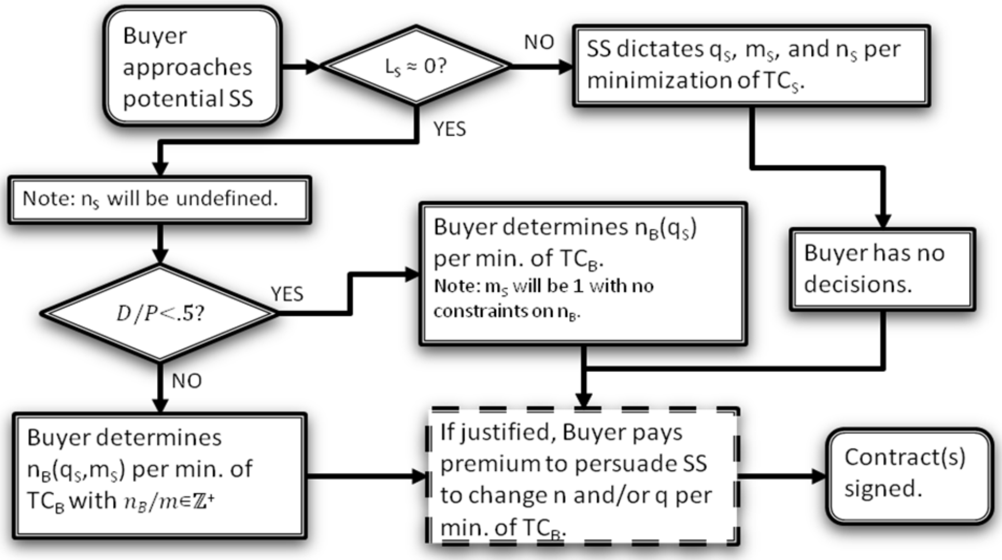

Figure 1.2: Sequence of Events for a Supply Chain with a Strong Supplier (SS)

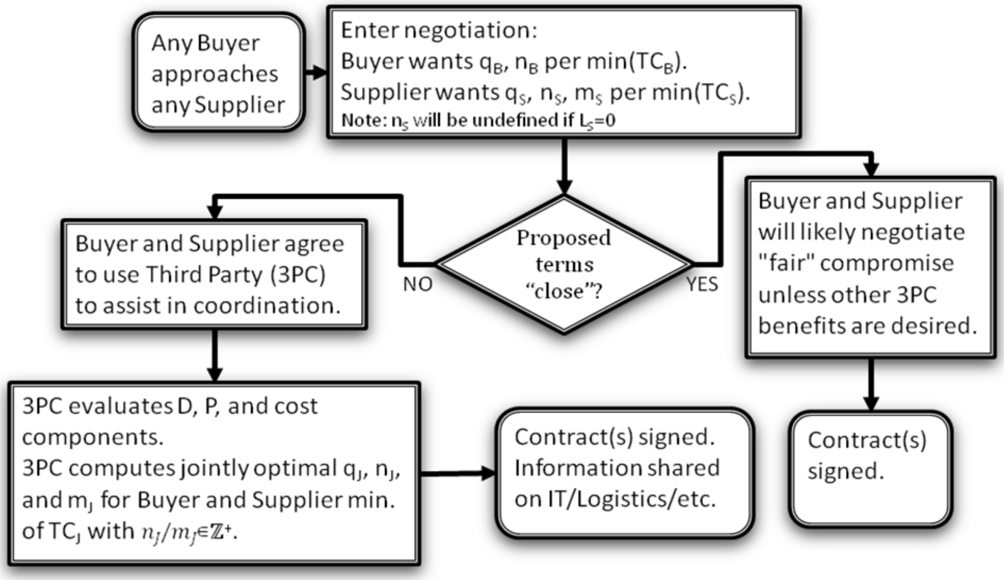

Figure 1.3: Sequence of Events for a Supply Chain Utilizing a Third Party Coordinator (3PC)

### 1.4.3 Common Assumptions for all Scenarios

For clarity and ease of reference, a numbered list of assumptions used throughout this thesis is presented here:

1. Scope is limited to dyadic relationships.
2. Under deterministic market demand each party's revenue is fixed and the goal of each player is to maximize its own operating profit per time unit.
3. No planned stockouts or backorders are allowed.
4. All players are rational and are either risk-averse or risk-neutral (i.e. not risk-seeking).
5. Independence of and no superadditivity among risk, collaboration, coordination, or competition effects.
6. Possible jointly optimal cooperative policies are a superset of possible non-cooperative policies.
7. Typical and commonly accepted assumptions for model parameters:
    (a) $P > D$ with both deterministic (Production rate greater than demand rate.)
    (b) $C_B > C_S$ with both deterministic (Part cost to buyer is higher than final part cost to supplier.)
    (c) $A_S > Z_B$ with both deterministic (Supplier's setup cost is greater than buyer's per-delivery cost.)
8. Supply chain agreements enforced by purchase contract.
9. Payments are made on-time (i.e. no credits or penalties considered).

10. Lot-splitting is allowed to facilitate small delivery quantities.
11. Supplier not forced to hold excess stock at the end of the contracted period.
12. Inflation is either negligible or factored into each payment so that the time-value of money is not taken into account (i.e. no discount factors).

Assumption 1 defines the focus of the research to "Supplier/Buyer" relationships. To avoid confusion, this terminology will be universally preferred over alternative pairs of dyadic descriptors such as "Manufacturer/Supplier" or "Seller/Reseller". Further, unless otherwise noted, we will assume that the supplier is also a manufacturer with limited capacity that produces the item in question in batches. However, without loss of generality, this could in practice be a middleman that purchases rather than manufactures directly. This limiting of scope to dyadic relationships is justifiable since true multi-echelon relationships rarely exist in practice (Fawcett and Magnan, 2002). Assumption 2 merely states that all players are motivated by maximization of their own profits. Assuming fixed revenue, no stockouts, and no backorders (assumption 3), we will utilize the common simplification of achieving maximum profit by minimizing cost. Assumption 4 declares that all players will behave in a predictable (rational) manner and will act in accordance with preserving their long-term viability (not risk-seeking). We state that superadditivity is not allowed in assumption 5. This is both realistic and required as a basis of later inferences. Additionally, we assume independence between risk costs since interaction effects are expected to be negligible. In the unusual case that a large interaction is expected, additional or combination of terms can be considered. In assumption 6, we state that jointly cooperative policies are a superset of non-cooperative policies. This can be easily justified if we recognize that in an arms-length or traditional coordination mechanism (e.g. quantity discount) scenario, individual players limit possible policies based on their own profit (cost) requirements while in a jointly coordinated scenario, a centralized decision maker has no such restrictions on policy creation and can always consider every possible non-cooperative policy when minimizing costs. Assumption 7 lists various common and apparent assumptions on the nature of the parameters used in the cost model. Production rate must be higher than demand rate to ensure feasibility. A rational supplier will pass on the part costs plus its own margin on all sold items, making the part cost higher to the buyer than the supplier. Note that there is no assumption placed on $h_B$ and $h_S$ since there is no *a priori* justification that the supplier's holding cost per unit per time unit ($h_S$) *must* be less than the buyer's analogous cost per unit per time unit, $h_B$. However, it is commonly assumed that as we move up a supply chain towards raw materials, fewer value-added steps and holding cost rate components (e.g. labor) are invested into the parts; thus we *expect* but do not require $h_B > h_S$. The last in the list under assumption 7 tells us that the supplier's cost of setup is greater than the buyer's contract cost, another common and intuitive assumption. Assumption 8 states that a contract will be the vehicle employed to enforce agreements between the players in the supply chain coordination. We further assume that there is no predefined time unit for this contract (which is determined by the decision variables) and that any arbitrary addition can be added to this contract to stipulate the terms of the negotiation. Assumption 9 informs us that monetary transfers happen on-time and in such a way that the time-value of money is not of concern to any player. To reflect the needs of modern supply chains, we will assume (as stated in assumption 10) that each production batch may be split into multiple delivery lots (i.e. lot-splitting). Assumption 11 details that a rational supplier will not agree to a production schedule that could potentially leave it with unsold parts at the end of the contract. Of course, this is a conservative assumption and may be dropped if negotiated (and compensated). This assumption is addressed in all presented models and numerical examples by enforcing a requirement that there be an integer ratio of deliveries to batches ($^n/_m \in \mathbb{Z}^+$). Simply put, there should be an integer number of production runs per contract. This constraint will guarantee an even "matching out" of part deliveries with part production. The final assumption allows us to disregard inflationary factors. This is equivalent to dealing only with "today's dollars" at the time of contract signing. In practice, an agreement can stipulate appropriate inflationary correction factors during contract execution, without affecting any results or conclusions from this research.

## 1.5 More Comprehensive Cost Accounting

Traditionally, joint economic lot-sizing (JELS) problems account for holding costs ($h_B$, $h_S$), per-shipment transportation/receiving costs ($Z_B$, $Z_S$), per-batch setup costs for the supplier ($A_S$), and one-time contract costs to the buyer ($A_B$). With the early assumptions of short-term or small-volume contracts, the model seemed appropriate. There are a few problems with this model that become clear after removing such assumptions. First, the model ignores any one-time contract costs to the supplier. The probable reason for this is it would introduce a new decision variable to the supplier, making implicit mathematical solutions cumbersome. Next, without a cost that increases with the length of the contract, the contract quantity for any unbounded contract will increase without limit as fixed costs are minimized with longer commitments. Experience and logic tell us that this is unreasonable and unrealistic, so something needs to added to the model to address this. These factors are known as the "costs of commitment". Some recent models have added a buyer's cost of commitment ($L_B$), but no analogous cost has been introduced for the supplier.

### 1.5.1 Costs of Commitment

Prices are often volatile in industry, especially those reliant on commodities. Contracts set prices for the length of the contract. We will assume that inflation costs are either negligible or accounted for in the terms of the contract. Depending on the business environment, perhaps we might expect slow, quick, or unpredictable advances in technology that would lead to price decreases. In more volatile markets, such as those closely tied to commodities, the buyer may wish to lock in a longer contract to take advantage of current low prices. This represents the second of two cases in the scope of this paper where we might expect a negative component to the commitment cost. In practice, this is often viewed as a “switching cost”, where the commitment is considered the normal relation and a potential deviation or defection is considered a cost.

The cost minimization objective naturally entails balancing the costs of the supplier with the costs of the buyer. The commonly accounted costs include setup costs, delivery costs, ordering costs, and some opportunity costs. However, the only opportunity cost typically included in existing research is the opportunity cost of capital, which can be estimated based on factors such as returns on investment (ROI) or interest rates. On the other hand, estimating the cost of contract commitment, a frequently forgotten opportunity cost, can be much more complicated. Various factors play a potential role in estimating the true cost of committing to a contract. An obvious upper limit to this cost is the complete loss of all contracted funds and perhaps some associated administrative, logistical, disposal costs, and legal fees. On the other extreme, the lower limit to this cost is zero. Indeed, this is what is typically assumed in much of the extant literature. The problem with the latter assumption is that the only way for this commitment cost to actually be zero, or even negative with price-locking, is if there is no cost or loss associated with creating or breaking contracts, including, for example, discarding unusable product or tooling cost liability. If we keep this assumption, but include net positive one-time costs to the buyer, our only conclusion when minimizing the average cost per unit will be to commit to an infinite contract, a clear contradiction that has previously been mentioned (Kelle et al., 2003, 2009). Researchers have included other assumptions or limits to ensure the mathematical tractability of the model and to obtain optimal solutions implicitly. These simplifications are often based on time or lot-size (Huang, 2004). A more realistic model without these simplifications requires consideration of the cost of commitment, which is a goal and motivation for this research.

### 1.5.2 Buyer's Commitment Cost Example

An intuitive starting point for considering the cost of commitment can be understood from the following hypothetical scenario. Consider a buyer, an OEM, which makes electrical panels, contacts a manufacturer of custom switches to provide parts for a new design. Prototypes are produced and all engineering specifications are finalized and released. Other functional areas such as Quality Control and Manufacturing are confident of the new product. Marketing realistically anticipates demand of 10,000 panels a year, with each panel requiring one highly customized switch. As part of the normal new product launch, the buyer's purchasing agent meets the salesperson for the switch company to negotiate a contract. To cost-effectively produce the large quantities of switches required, the supplier requires some very expensive tooling, but is willing to waive the normal tooling cost, if the buyer agrees to a five (5) year commitment. The buying agent, having met with all the various concerned functional managers, is quite confident that this will be fine, since the typical product life cycle in this industry is about 10 years. The contract is signed and deliveries begin as scheduled. One year later, new federal regulations are rushed in place after a few unrelated, but high-profile, accidents. However, the unique switch fails to meet the new regulations as currently designed, so a major redesign is required. The switch producing company is not capable of producing the newly redesigned switch. The OEM is still committed to 40,000 undelivered switches on the contract that they cannot possibly use. Depending on the terms of the contract, this sudden end of demand potentially leaves the buyer "on the hook" and potentially responsible for all parts remaining on the contract (produced or not) and could become a very large cost to the buyer. This is one realization of the cost of commitment and is discussed in detail in Chapter 3. Had the buying agent accounted for the probability of a sudden end of demand, there would be a cost associated with each additional unit committed to and the buying agent might prefer to pay for some or all of the tooling up-front rather than commit to a longer contract.

### 1.5.3 Supplier's Commitment Cost Example

Let us revisit the switch example presented above. As before, a buyer commits to a five (5) year contract of 10,000 switches per year. However, in this scenario, no federal regulations are changed which cause an end of demand event to the buyer. Rather, let us suppose that the unique switch requires the use of tellurium, a "rare earth" metal with historically stable prices. Tellurium is also used in high-efficiency solar panels, which were not very common at the time the contract was made. After a quick and significant shift to "green" technologies by many countries and individuals, the demand for high-efficiency solar panels has soared. As a result, the price of tellurium has more than doubled in the first two (2) years of the contract. The supplier can still make the switches, but now makes no money and will soon lose money for every switch it ships. If the supplier had balanced the potential costs of committing to a larger contract with the benefit of guaranteed business, it might have made concessions to the buyer to split the high tooling costs rather than use it as leverage to gain a longer commitment.

## 1.6 Illustrative Example

In order to demonstrate the financial need and benefit of a joint optimization, attainable through use of a 3PC, an illustrative case is now presented. In this illustrative example, we will examine the ramifications of having a supplier in an extremely strong negotiating position that can set the terms of the contract. The following parameter values are used for the example:

Table 1.1: Illustrative Scenario Parameters

| Parameter | Value |
|---|---|
| $P$ | 4000 units per year |
| $D$ | 2500 units per year |
| $Z_B$ | \$22.5 per shipment |
| $A_B$ | \$125 per contract |
| $C_B$ | \$10 unit cost |
| $r_B$ | 0.125 per year |
| $L_B$ | 0.03 per year |
| $Z_S$ | \$22.5 per shipment |
| $A_S$ | \$150 per production batch |
| $C_S$ | \$4 unit cost |
| $r_S$ | 0.1 per year |
| $L_S$ | 0.03 per year |
| $h_B$ | $= r_B * C_B$ |
| $h_S$ | $= r_S * C_S$ |

Extended parameter descriptions may be found in Appendix A. An expository discussion on the parameters $L_B$ and $L_S$ may be found in Section 3.3. All dollar amounts may be assumed to be in 1000's.

By examining each party's optimal decisions for number of deliveries per contract ($n$) and number of deliveries per batch ($m$) for a given delivery quantity ($q$), we can calculate the resulting costs for the buyer, the supplier, and the combined (joint) cost. The presentation of the models and their results used to calculate these costs is left to a later section.

Given the above described scenario, the strong supplier of this supply chain will create a contract with $q=873$, minimizing its annual cost at \$559. However, this quantity forces the buyer to deviate greatly from its preferred delivery quantity of 294, resulting in an apparent cost increase of \$243 per year. Even if the buyer was in a position to offer a per unit price premium (a relatively unheard of practice) to incentivize a change in $q$, the buyer would still have no knowledge of the supplier's internal cost structure and can only guess at acceptable incentives for the Strong Supplier.

Alternatively, if the two parties agree to the services of a neutral third party (3PC), the internal costs, still confidential from the other party, can be jointly optimized by the 3PC to provide the optimal decision variables based on the total costs. The 3PC will set the supply chain's decision variables to the jointly optimal settings ($q=396$, $n=4$, $m=4$), resulting in a joint cost of \$1437. This 11% savings (\$173) is split between the parties via extra payment from the buyer to supplier. Pareto optimal payments from buyer to supplier range from \$53.5 (supplier minimum to accept) to \$226.5 (buyer maximum to give). We expect the third party coordinator to take a portion of these savings as remuneration with the remainder split between buyer and supplier. For example, using actual dollars, with a fee set at 10% of savings and

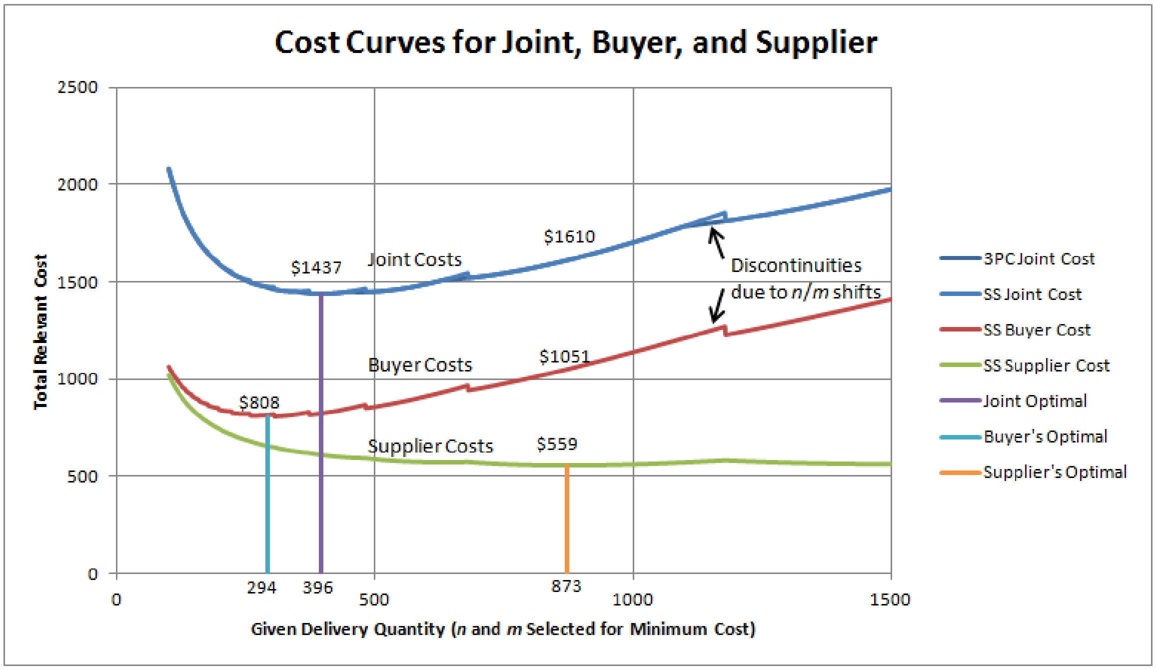

Figure 1.4: Illustrative Cost Curves for Selected Scenario with a Strong Supplier (SS)

agreement to evenly split savings, the 3PC would be paid \$17,300 with the buyer and supplier each receiving \$77,850 additional profit. The disbursement of funds is detailed in Table 1.2.

If we expand this illustrative example to include the reverse situation of Strong Buyer, we can compare the various scenarios. Table 1.4 summarizes the optimal $q$, $n$, and $m$ and related results for three possible scenarios: SB, SS, and 3PC. Note that the 3PC policy has the lowest total cost, as expected. In this example, the jointly optimal $q$, $n$, and $m$ (as well as $nq$ and $mq$) are all bounded by the SB and SS optimal decisions, which is common, but certainly not guaranteed. We can also note that this example reflects the classical case of a buyer that desires multiple small deliveries and a supplier that prefers fewer, but larger, deliveries.

Table 1.2: Strong Supplier Costs (Benefits) in \$1000's After Joint Optimization with 3PC

| Total Costs | Strong Supplier | Jointly Optimal | Difference | Side Payment | Net |
|---|---|---|---|---|---|
| Buyer | 1051 | 824.5 | (226.5) | 148.65 | (77.85) |
| Supplier | 559 | 612.5 | 53.5 | (131.35) | (77.85) |
| 3PC | - | - | - | (17.3) | (17.3) |
| Supply Chain | 1610 | 1437 | (173) | - | (173) |

Table 1.3: Strong Buyer Costs (Benefits) in \$1000's After Joint Optimization with 3PC

| Total Costs | Strong Buyer | Jointly Optimal | Difference | Side Payment | Net |
|---|---|---|---|---|---|
| Buyer | 808 | 824.5 | 16.5 | (30.45) | (13.95) |
| Supplier | 660 | 612.5 | (47.5) | 33.55 | (13.95) |
| 3PC | - | - | - | (3.1) | (3.1) |
| Supply Chain | 1468 | 1437 | (31) | - | (31) |

Table 1.4: Optimal Decision Variables and Related Results

| Optimal | SB | SS | 3PC |
|---|---|---|---|
| $q$ | 294 | 873 | 396 |
| $n$ | 5 | 2 | 4 |
| $m$ | 5 | 2 | 4 |
| $nq$ (Contract Size) | 1470 | 1746 | 1584 |
| $mq$ (Batch Size) | 1470 | 1746 | 1584 |
| Contract Length (Years) | 0.59 | 0.70 | 0.63 |
| Total Cost (\$) | 1468 | 1610 | 1437 |
| % Coordination Savings | 2.1% | 10.7% | - |

# Chapter 2: Literature Review

The literature review is split into four sections. The first section addresses literature covering the justification, roles, and benefits of third-party coordination. The next section covers the literature establishing and supporting the general model to be used throughout this thesis. The third section begins with the foundations of supply chain risk and is further divided into two parts: the first covers literature discussing opportunity and flexibility costs affecting the buyer while the second part looks at the literature alluding to the costs affecting the supplier. The fourth and final section explores the literature recognizing the oft-overlooked potential legal issues involved with the close coordination of a buyer and supplier. The scope of this last section will be limited to laws of the United States.

## 2.1 Third Party Coordination of the Supply Chain

In the same paper in which the JELS model is introduced, Goyal (1977) proposes a method for sharing between a buyer and supplier, the increased supply chain profit. The method shown is to allocate the new costs in proportion to the respective non-cooperative solution costs, with a side payment based on the actual costs observed in the joint solution. In the numerical example given by Goyal, the joint costs are reduced from 925.71 to 881.82 via jointly optimal decisions. Details from the example are replicated and expanded below in Table 2.1.

Although at first it appears a fair disposition of costs, a few problems with this methodology are soon apparent. First, even though a strong buyer is assumed, using the proposed proportionality method, the bulk of the savings are passed to the supplier since the supplier in this example has inherently higher costs in the non-

Table 2.1: Goyal's Method of Splitting Profit Gains

| Category | Supplier | Buyer | Total |
|---|---|---|---|
| Non-cooperative Costs (Strong Buyer Assumed) | 657.41 | 268.30 | 925.71 |
| Cost as a % of Total | 71.02% | 28.98% | 100% |
| Cooperative "Allowed" Cost per Goyal's Method | 626.24 | 255.58 | 881.82 |
| Realized Costs with Joint Optimal | 563.49 | 318.33 | 881.82 |
| Side Payment to Match "Allowed" Costs | -62.75 | +62.75 | |
| Realized Net Savings | 31.17 | 12.72 | 43.89 |

cooperative scenario. Second, in a non-cooperative scenario where the buyer is presumed to be the strong player that will attempt to minimize its own costs, the supplier, as it increasingly deviates from its optimal, will be saddled with ever higher costs, further increasing this percentage. Finally, firms with high costs (or, more cynically, *reporting* high costs) are rewarded with a larger percentage of the savings. This might present a conflict of interest or perhaps a disincentive to find cost savings which will then be shared with the other "undeserving" party. This allows us to consider the absurdity of a scenario with a very strong buyer purchasing goods from a supplier with high costs where the strong buyer only receives a small fraction of the gains from coordinating after going to the trouble of coordinating and divulging its cost structure to the supplier. Further, the buyer, if it is foolish enough to agree, would have almost no incentive to reduce receiving, ordering, or holding costs, as the vast majority of these savings (if shared) would go directly to the supplier!

Due to concerns such as these, sharing the additional profit in a supply chain via coordination was also examined by Jeuland and Shugan (1983) and extended by Weng (1995). Jeuland et al. discuss a few possible methods of splitting this profit, including bargaining and quantity discounts after negotiation. The authors note that cooperation will yield the highest possible total profit, but assume this can only be possible with joint ownership (vertical integration) or the presence of a centralized decision maker. The concept of a centralized decision maker is then ignored. In a taxonomy of recent coordination models, Sarmah et al. (2006) observe that a mechanism for the sharing of added profits is rarely included. They also note that most of the studied models assume complete information sharing between parties and ignore issues such as conflict resolution.

Some of the literature has investigated or assumed that the stronger party will act as the centralized decision maker. Not many works have considered an outside decision maker. One notable paper that has considered a third party is Bitran et al. (2007) where the authors propose hypothetical “maestros” and “mini-maestros” to help coordinate the supply chain. They cite some case studies of firms currently filling the role. However, upon closer inspection, these firms turn out to be little more than middlemen that can source inventory from multiple suppliers as needed to provide extra flexibility. Another study of note is Zacharia et al. (2011), who look at the increasing roles played by third party logistics providers (3PLs).

The majority of the supply chain coordination (SCC) and supply chain integration (SCI) literature approaches the problem as either a “hard numbers” numerical/mechanism based problem or as a “soft savings” empirical problem. This is supported by numerous reviews and taxonomies that have failed to find almost any research that crosses categories (Benton and Park, 1996; Thomas and Griffin, 1996; Maloni and Benton, 1997; Munson and Rosenblatt, 1998; Goyal and Gupta, 1989; Kanda et al., 2008; Arshinder et al., 2011). The analytical supply chain coordination literature rarely uses empirical support for anything more than motivation, while most of the empirical research glosses over quantification and division of coordination savings, choosing to focus instead on the less tangible benefits. These “soft” benefits are numerous and well established by multiple sources (Park, 2005; Vereecke and Muylle, 2006; Van der Vaart and van Donk, 2008; Cao and Zhang, 2010; Prajogo and Olhager, 2012). They therefore deserve consideration in coordination policies.

Despite both quantitative and qualitative justifications that should be increasing coordination, multiple studies have found surprisingly low success rates of firms attempting some form of integration (Sabath and Fontanella, 2002; Storey et al., 2006; Bititci et al., 2007). For example, Sabath and Fontanella (2002) found that only 17% of companies employ SCI practices. In a joint survey by Supply Chain Management Review and Computer Sciences Corporation (SCMR), it was reported that 44% of the sample had structures in place to facilitate buyer-supplier coordination and collaboration. However, only about 35% of such initiatives were classified as at least “moderately successful”. Further, research has shown that some company cultures have the effect of discouraging individuals from attempting collaboration (Ireland and Bruce, 2000; Barratt and Green, 2001). Finally, as assumed in almost all of the coordination mechanism-based literature, there exist powerful firms that will be non-cooperative partners, using their power to unilaterally gain at the expense of the other party (Simatupang and Sridharan, 2002). In some of these cases, where there is no prospect of cooperation, the available mechanism-based policies (e.g. quantity discounts) may need to be used. However, this appears to be the exception rather than the rule, since collaboration is a high priority goal for many managers (Fawcett and Magnan, 2002; Wognum and Faber, 2002).

The reasons for these collaboration failures are varied, but a few causes are cited multiple times. One is a lack of a clear leader of the supply chain. Another oft-cited reason is low managerial ability or understanding (Lambert and Cooper, 2000; Ballou et al., 2000; Simatupang and Sridharan, 2002; Holweg et al., 2005) or experience (Fisher et al., 2000). Often, there are conflicting incentives and processes between the members. Firms that are usually only concerned with profits find it difficult to transition to a collaborative focus where compromise and trust must be given a value not directly reflected in the product cost (Barney and Hansen, 1994; Khanna et al., 1998; Das and Teng, 2000). Other times, firms are victims of their own efficiency. Larger firms, those that would benefit most from a successful joint venture, typically have many divisions and functional departments, many of which need to come together for a successful collaboration effort. This complexity and size of organization can, paradoxically, hinder cooperation (Gerwin, 2004; Fawcett et al., 2012). When coordination fails, parties will usually resort to what they know best, non-cooperative arrangements (Zand and Sorensen, 1975; Lehoux et al., 2011). Simatupang and Sridharan (2002) outline how a more powerful supply chain member will use its leverage to the detriment of the supply chain as a whole. Ryall and Sampson (2006) find in a study of 52 alliances that many firms have used legally unenforceable clauses in contracts. However, they also find that these clauses, which offer no true legal or monetary protection from a partner's opportunism, lay out expectations and act as a blueprint and facilitator of cooperation.

The business need for a third party to assist in the coordination of the supply chain members was established in an article by Bitran et al. (2007). The authors propose hypothetical "maestros" and "mini-maestros" to assist in the coordination of the supply chain. They are characterized as neutral third parties with the power to control supplier selection as needed. They include references to a few case studies of companies currently playing such a role. However, even if this third party had the ability to hold parts inventory from one or more suppliers, some recent studies (Ton Hien Duc et al., 2010; Hassanzadeh et al., 2014) have shown that a 3rd party warehouse does not mitigate the bullwhip effect, a typical coordination goal. This thesis will presume efforts that are more in line with the type of point-of-sale information exchange explored by Metters (1997); the implementation of which can readily be assisted via third party intervention.

## 2.2 The Current Joint Model

The joint economic lot size problem, later referred to as just JELS or JELP (Banerjee, 1986a), was first proposed by Goyal (1977). Goyal uses a simple lot-for-lot model which ignores the production rate (by assuming negligible production or purchasing time) when calculating the average supplier holding cost. The goal in this integrated model is to minimize the total variable cost by calculating the optimal time between orders ($t$*) and the optimal number of orders per set-up ($K$*). The optimal time between orders is solved from the first order conditions as a function of $K$ (see below). Goyal suggests an iterative search solution with *K(t*)=1,2,3...* to find the lowest joint total relevant cost (JTRC), and then using this to find *t**. The remaining parameters have been updated to be consistent with the notation adopted in this thesis.

$$JTRC = \sqrt{2D(Z_B + A_S/K(t*))[h_B + (K(t*) - 1)h_S]} \tag{2.1}$$

$$t* = \sqrt{\frac{2(Z_B + A_S/K(t*))}{D[h_B + (K(t*) - 1)h_S]}} \tag{2.2}$$

An interesting difference in this model to current models is that the solution here is solved as an optimal time between orders, rather than optimal order quantities (which is now standard). Of course, if we assume a deterministic demand rate, the optimal time between orders approach yields equivalent results with $t* = {}^{q_J}/_{D}$. Also of interest is the concept of splitting a production lot into an integer number of deliveries. Being an infinite horizon problem, there is a presumption that future orders will always be placed. This is certainly *not* a conservative assumption, as this offers no disincentive to overproduction by the supplier, which may leave unsellable product in their inventory, which then becomes an unaccounted for cost in the model. However, if the buyer commits to the optimal $K$ orders at the beginning of production, this risk is negated. This commitment and its associated costs will be discussed in much more detail later.

The more modern joint model, based on finding optimal order quantities, was introduced by Banerjee (1986a) as a lot-for-lot policy with a finite production rate and extended by Goyal (1988) to allow for multiple orders per production set-up. Unfortunately, this model assumes somewhat unrealistically that all production be completed at the manufacturer before the first delivery can be made. This deficiency was rectified by Lu in a very generalized solution allowing for multiple buyers and shipments before the production run was complete (Lu, 1995). At roughly the same time as Banerjee's JELS model, Monahan (1984) showed the optimal discount policy to coordinate a lot-for-lot, infinite horizon model. Again, rather unrealistically, this model assumes the supplier has instantaneous production capabilities and, therefore, no carrying costs. Banerjee (1986b) showed his model to be a generalization of Monahan's model. Joglekar (1988) generalized Monahan's model for both finite production and multiple orders per setup. Although arrived at by different methods, for a single-buyer, single-supplier scenario with equal sized shipments, Joglekar's and Lu's models are equivalent. This can be seen by comparison of the provided vendor's average inventory level, the most critical addition to these models, detailed in Table 2.2.

Additional costs and just-in-time (JIT) lot-splitting are added to the model by Banerjee and Kim (1995) and Kim and Ha (2003). Hill (1999) later provides the optimal production and shipment policy for the single-buyer, single-supplier JELS model with arbitrary shipment sizes. An example of a solution with arbitrary shipment sizes

Table 2.2: Equivalence of Vendor's Average Inventory in Two Models

| | Lu, 1995 | Joglekar, 1988 |
|---|---|---|
| Presented | $\frac{D}{2}T\left[1+\left(\frac{2D}{P}-1\right)k-\frac{D}{P}\right]$ | $\frac{q}{2}\left[(m-1)-(m-2)\frac{D}{P}\right]$ |
| Substitution | $T=\frac{mq}{D}$, $k=\frac{1}{m}$ | |
| Expansion | $\frac{D}{2}\frac{mq}{D}\left[1+\left(\frac{2D}{P}-1\right)\frac{1}{m}-\frac{D}{P}\right]$ | $\frac{q}{2}\left[(m-1)-(m-2)\frac{D}{P}\right]$ |
| Simplification | $\frac{mq}{2}\left[1+\left(\frac{2D}{mP}-\frac{1}{m}\right)-\frac{D}{P}\right]$ | $\frac{mq}{2}\left[(1-\frac{1}{m})-(\frac{D}{P}-\frac{2D}{mP})\right]$ |
| Equivalency | $\frac{mq}{2}\left[1-\frac{D}{P}-\frac{1}{m}+\frac{2D}{mP}\right]$ | $\frac{mq}{2}\left[1-\frac{D}{P}-\frac{1}{m}+\frac{2D}{mP}\right]$ |

is a policy for four deliveries of sizes 100, 300, 500, and 800 spaced by 3, 9, 15, and 24 days, respectively. However, the author admits that the resulting policy with arbitrary sizes is "less likely to be of practical interest." This concern is exacerbated by the general move away from "push" systems to pull-based JIT systems where small, but steady and predictable material flow is valued over small cost savings. In the scope of this thesis, the next significant addition to the standard JELS model arrived in 2003, when Kelle et al. (2003) introduced a new cost factor ($L_B$) to account for the opportunity and flexibility cost to a buyer for the purchase commitment, discussed next.

The literature on JIT is well-established, going back many years and dealing with many topics. Supply chain coordination (SCC) has also received much attention in the last 25 years. A cursory search of the literature produced approximately 1000 articles referring to both JIT and supply chain coordination. Adding "opportunity cost" to the search yields fewer than 50 papers, with most of these addressing the opportunity cost of lost sales and holding inventory or cost of capital. Relatively few papers can be found which address the opportunity cost of commitment in JIT based supply chain coordination. The most notable of these is the above mentioned Kelle et al. (2003), which introduces the concept of a buyer's opportunity cost into the JELS model and is a major motivation for this research. This concept solves a mathematical quandary in the model, which would otherwise drive the joint optimal contract quantity to infinity. Huang (2004), using work based on Salameh and Jaber (2000) as well as Kim and Ha (2003), incorporated random yield into the optimal decision, but without consideration to the above mentioned buyer's commitment cost. Kelle et al. (2009) combines Huang's random yield consideration with the opportunity cost concept of Kelle et al. (2003). Cachon (2003) thoroughly explored SCC with contracts for profit maximizing individual firms, but not in cooperative, jointly optimized environments such as the one discussed here.

## 2.3 Supply Chain Risks and Mitigations

Before examining particular supply chain risks unique to either the buyer or supplier, it is helpful to establish a framework and perspective of *all* supply chain risks. An abundant and robust literature exists which examines risks and their mitigation in the supply chain (see for e.g. Svensson (2002); Jüttner et al. (2003); Tang (2006); Colicchia and Strozzi (2012)). In 1997, one of Toyota's critical suppliers was badly damaged by fire and was unable to supply parts for a long period. This forced a shutdown at some of Toyota's plants for two weeks with estimated lost sales of 70,000 vehicles and $195 million in cost (Nakamoto, 1997; Norrman and Jansson, 2004). Chopra and Sodhi (2004) provide a chilling example of two telecom companies, Nokia and Ericsson, which took different supply chain approaches with drastically different results. Nokia employed a traditional multiple supplier approach while Ericsson took what would be considered by most, a more modern, single-sourcing approach.

A catastrophic fire at a supplier's plant stopped production at a common supplier to both firms. Nokia quickly switched to alternate suppliers with little loss while Ericsson experienced $400 million in lost sales. Naturally, the stoppages carried forward in the supply chain to the final retailers. Ericsson suffered losses as both buyer and supplier. The authors go on to point out that most firms have plans to address frequent low-impact disruptions, but many have no plans for rare high-impact events such as the catastrophic fire mentioned above. Ericsson's reaction and corrections after this event are outlined in a paper by Norrman and Jansson (2004). Inventory is a common buffer for the prior type of risk, but of course it is unrealistic to expect a firm such as Ericsson, selling a short lifecycle product, to hold on to $400 million (or more) in excess inventory ("just-in-case"). Therefore, other measures are required. Examples involving bankruptcy, earthquakes, floods, labor strikes, and even terrorism are common. Chopra and Sodhi (2004) and Tang and Tomlin (2008) list categories of risks and common mitigators for each. These were supplemented with information from the above taxonomies, combined, and recompiled to Table 2.3.

Looking down the "Mitigators" column, we can see a common theme for many of the categories: using a mix of flexibility, capacity, and inventory to handle short to medium term risks and redundancy or ad-hoc solutions in the case of catastrophic or financial problems. "Stress testing" or "what if" thought experiments are offered as a tool to help address and minimize risks. Another interesting observation is that capacity and inventory are both risks *and* mitigators. However, they are also mitigators to each other, but this still logically implies that most suppliers will have to choose to accept at least some inventory *or* capacity risk.

Jüttner et al. (2003) propose a framework for approaching supply chain vulnerability and risk management. They simplify the common strategies for risk mitigation into four broad categories: avoidance, control, cooperation, and flexibility.

Table 2.3: Categories of Risk and Their Mitigators

| Risk Category | Example(s) | Common Mitigator(s) |
|---|---|---|
| Delay | Shipping or Order Delays | Capacity and Inventory (Balancing and Buffers) |
| Disruption - Natural or Man-Made | Natural Disasters, Strikes | Redundant Suppliers |
| System (IT) | Computer Virus | Frequent Backups |
| Demand - Forecast Errors | Bullwhip Effect, Unanticipated Demand | Lean, JIT, Information Sharing, CPFR, Inventory |
| Demand - Pricing Errors | Mismatched Inventory to Demand | Flexible Pricing |
| Intellectual Property | Proprietary Information Lost | Own and Maintain Equipment at Buyer |
| Procurement/Supply Cost | Exchange Rate Change, Price Increases | Financial Hedges, Contracts |
| Receivables | Customer Default on Credit | Large Customer Base |
| Inventory | Obsolescence, Perishables | Pooled Inventory, Fewer SKUs, Postponement |
| Capacity | Excess Capacity (and Capital Investment) | Flexibility (Overlapping Resources) |
| Capability/Process | High Defect Rate | Statistical Quality Control, Inspection |
| Supply Commitment | Long Lead Time Prevents Adjustment to Current Demand | Multiple Suppliers |
| Behavioral | Firms Gaming Ordering Systems | Order Visibility, Corrective Actions |

Avoidance-based mitigation is a pass/fail test made prior to any cooperation efforts. Control-based mitigation options encompass many forms of tweaking the major decision variables in a supply chain, ranging from vertical integration and inventory buffering to capacity buffers and contract stipulations. Cooperation-based mitigation options include joint efforts focusing mainly on information sharing and visibility. Flexibility-based mitigators typically resort to production postponement and sourcing options.

### 2.3.1 Risk Costs Unique to the Buyer

Kelle's 2003 model allows for three decision variables in the model solution, as opposed to the typical two. These variables are $n$, the number of deliveries per contract, $m$, the number of deliveries per production batch and $q$, the size of a delivery. Thus, the size of a contract is $nq$ and the size of a production batch is $mq$. Previous models, based on an infinite horizon, typically assumed either $n$=*1* (lot-for-lot or generalized with $m \geq 1$) (Banerjee, 1986a; Goyal, 1988), $n$=$m$ (lot splitting or "single setup, multiple deliveries" (SSMD)) (Hill, 1997; Kim and Ha, 2003), or an arbitrary limit such as time (e.g. annual) or quantity (e.g. 5000 units per contract). Kelle notes that without a cost on undelivered goods, the size of the contract (when $n$ is not restricted) will approach infinity since average order costs are minimized as $n \to \infty$ (Kelle et al., 2009). Since an infinite contract is obviously unrealistic and mathematically intractable in a finite (albeit arbitrary) horizon problem, Kelle adds a cost that is proportional to ordered product not-yet-delivered, denoted $L_B$. There is a similarity between this order commitment cost and the cost of capital. Rather than a cost of capital committed to on-hand inventory, $L_B$ reflects the cost of future capital tied to the commitment of units-yet-to-be-delivered (Kelle et al., 2007). Huang (2004) added random yield consideration to the JELS model without consideration of $L_B$.

Kelle et al. (2009) added the $L_B$ commitment cost to Huang's model. This cost is more recently discussed by Masten and Banerjee (2014) and Masten and Kim (2015). An intuitive next step is to consider the supplier's cost of commitment (denoted as $L_S$ for consistency).

### 2.3.2 Risk Costs Unique to the Supplier

The literature focused on opportunity and flexibility costs to the supplier is extremely sparse; but there is some relevant research in the area. Van der Vaart and van Donk (2008) highlight in a review of empirical literature that the supplier's perspective is largely ignored in the existing literature. As an exception to this, Hill et al. (2009), investigate the effect of a buyer violating expectations and eroding trust in the buyer on the part of the supplier. They also found that this erosion of trust was not always apparent to the buyer. Wuyts and Geyskens (2005) discuss the value of a contract in discouraging opportunism of a partner. There is also some research, mainly from the accounting literature, which explores the costs of unused capacity (Brausch and Taylor, 1997; Popesko, 2009).

## 2.4 Legality of Close Coordination in the United States

Whenever we consider separate, independent firms working closely together to increase supply chain profits (and thus gaining a certain advantage over the competing supply chains), we need to consider whether we run afoul of any antitrust or anti-competitive laws. Jeuland and Shugan (1983), in a highly-cited work, note that legislation such as the Clayton Act, Sherman Antitrust Act, and other similar laws may actually *increase* prices for the end consumers due to the fact that most of these laws implicitly assume that having many retailers and many suppliers will benefit consumers more than vertical integration can. The authors also note that having multiple competing coordinated supply chains could potentially produce better outcomes for consumers. Perhaps the most important and most discussed legislation is the Robinson-Patman Act of 1936 (Pub. L. No. 74-692, 49 Stat. 1526), which prevents an upstream party from offering different terms to resellers in the same reseller class except for a few special conditions, one of which is when a difference in cost can be justified (Jeuland and Shugan, 1983; Kintner, 1970). Quantity discounts appear to clearly and easily fall under this justification most of the time. However, while it is typically considered acceptable to offer a quantity discount schedule to buyers/resellers, The U.S. Supreme Court found it illegal to offer quantity discounts in cases where only a few very large buyers are capable of taking advantage of highest parts of the discount schedule: "Theoretically, these discounts are equally available to all, but functionally they are not" (*Federal Trade Commission v. Morton Salt. Co.* , 334 U.S. 37 (1948)). The ruling goes into more detail:

> The legislative history of the Robinson-Patman Act makes it abundantly clear that Congress considered it to be an evil that a large buyer could secure a competitive advantage over a small buyer solely because of the large buyer's quantity purchasing ability. The Robinson-Patman Act was passed to deprive a large buyer of such advantages except to the extent that a lower price could be justified by reason of a seller's diminished costs due to quantity manufacture, delivery or sale, or by reason of the seller's good faith effort to meet a competitor's equally low price.

The court's opinion on this matter was reaffirmed as recently as 2006 with *Volvo Trucks North America, Inc. v. Reeder-Simco GMC, Inc.* (546 U.S. 164 (2006)), which is still of obvious concern. However, in that case, the burden and amount of damages was severely limited and a there was a shift in the general tone towards the interpretation of this and other antitrust laws to be more focused on competition rather than competitors. Indeed, there is quite a vocal opposition to the Robinson-Patman Act in the economics literature. Some of this literature claims that enforcement of this act in on the wane for multiple reasons (Blair and DePasquale, 2014), making the typical firm less likely to be acutely aware of its presence or alter its pricing policies in deference to it.

Sellers offering custom or unique parts have no concern from this law since there is only one possible buyer/reseller. There remains an open question as to the legality of a very close coordination and/or cooperation when identical parts are sold both within and outside an agreement of close coordination. There is a potential issue with close information sharing when two competing retailers both share information with a common seller. If this information is visible to the other buyer, this could risk violating antitrust laws (Lee and Whang, 2000).

More than 60 years ago, in a highly-cited article, Spengler (Spengler, 1950) made a well-reasoned argument that vertical integration is inherently *not* anti-competitive and should not be subject to antitrust laws. He argues that horizontal integration and arrangements, not vertical integration, is the possible source of reduction of competition. Further, it has been argued more recently that the competitive advantage gained from supply chain collaboration is insufficient to warrant antitrust litigation (Hoyt and Huq, 2000). Finally, a notable lack of supply chain coordination lawsuits making it to a high court for a violation of antitrust laws should lend some comfort to prospective supply chain partners.

The above review of the literature draws attention to a number of gaps and deficient areas in the extant body of knowledge. For example, few works have seriously considered the benefits that a third party decision maker can contribute to a supply chain's policy decision process. From examining the legal viewpoint, we see the potential regulatory need for protecting sensitive information, a benefit that a third party may provide. Considering the limited research that has been made in regards to commitment and risk costs in JELS models, especially from the supplier's perspective, there is a clear need for further study. We attempt to fill some of these research gaps with the work presented in the following chapters.

# Chapter 3: Quantified Supply Chain Risks and Mitigators

This chapter examines a commonly neglected aspect of JELS models. Called "soft costs" by some and opportunity or commitment costs by others, these risk costs are often ignored in favor of the more easily quantifiable costs such as carrying, inspection, and shipment costs. This is not surprising since it can be difficult to justify costs based on lost opportunities. These costs are often probabilistic or predictive by nature and can be more subjective than objective. For example, predicting the likelihood of disruptive legislative or technological changes may be even more difficult than predicting natural disasters such as hurricanes or floods.

The first section of this chapter discusses the concepts and defines the terminology to be used in reference to supply chain risks. The next portion reiterates the importance of including these costs in any proposed solution. The third section proposes a general framework for the inclusion of any and all known risk costs. The following segment updates the buyer's cost model to include risk costs for the buyer. This section also includes an example quantification for a potential catastrophic demand disruption. The final section updates the supplier's cost model to include risk costs for the supplier.

## 3.1 Concepts and Definitions

Concerns, opportunities, and commitments are all just different applications of the concepts commonly known as risk or probability. A concern is the perceived risk of "something going wrong." This, of course, is an extremely general description that offers little tangible or quantifiable substance. Often nothing more than "gut feelings", concerns may or may not be based on a personal experience or could simply manifest themselves from uneasiness at an unfamiliar situation. One can easily imagine an executive or purchasing agent that openly voices distrust for all small suppliers after suffering the effects from a contract or two that relied on small companies that went bankrupt during a contract. Note that we can fairly quantify the risk of a supply disruption associated with a small supplier, which may be higher than that pertaining to a large supplier; but we can not fairly quantify risk costs biased by personal experience or perception. Likewise, concerns based solely on inexperience or uneasiness need to be similarly discarded.

Unlike general and vague concerns, which are inherently unquantifiable, the opportunity and commitment costs considered below and in the rest of this thesis are assumed to be measurable or can be estimated, based on larger industry trends or by specific research. An opportunity cost is the quantified risk of missing out on "something better" had the contract commitment not been made. For example, imagine a buyer locking in the price of a part at \$100 to later find another supplier that could sell the same part for \$80. The "missed opportunity" for a lower part cost in this example is straight-forward and easily measurable. An analogous opportunity cost is applicable to a supplier that chooses to sell an item at a price below fair market value.

Similarly, a commitment cost is the quantified risk of being committed to parts remaining on a contract, yet-to-be-delivered, should the firm no longer wish to continue the contract for some reason. Possible reasons might include regulatory or technological developments which significantly alter demand for the product or material costs. Mathematically, and perhaps intuitively, there is little need to differentiate between opportunity and commitment costs. Therefore, these terms will henceforth be used interchangeably.

Contract requirements or preconditions, including clauses and stipulations, are an attempt to mitigate or lessen some of these potential losses. For the purposes of this research, if the risk is completely eliminated by legal means, contract clause, insurance or other method, it is no longer a risk that needs to be considered in our model. Periodic costs to mitigate these risks such as insurance premiums or law-firm service retainers may be easily and directly included in the cost minimization process. Unless these costs are dependent on the decision variables, they will not affect the optimality of our decision variables. However, profit sharing schemes using each supply chain member's total periodic cost would be affected, such as the method described by Goyal (1977), which was discussed earlier.

Not only is it important to include opportunity and commitment costs for the sake of fair cost accounting by the supply chain members, it is important to include these costs for mathematical tractability, which is discussed next.

## 3.2 Importance of Considering Opportunity and Commitment Costs

At the beginning of this chapter, proper opportunity and commitment cost accounting was introduced as a matter of fairness and completeness to the model. From a mathematical view, if no increasing cost penalty is assigned to increasing contract sizes in the original JELS models, contract sizes are unbounded. This was shown by Kelle et al. (2003), but is also intuitive when one considers that one-time costs like $A_B$ are minimized by the largest possible contract size if there are no terms which add cost with an increasing number of deliveries or increasing contract size ($nq$). Considering only the holding, delivery, and setup costs, the total relevant cost to the buyer per time unit is:

$$TC_B(q,n) = h_B\frac{q}{2} + Z_B\frac{D}{q} + A_B\frac{D}{nq}, \tag{3.1}$$

which is clearly decreasing in $n$, implying an open-ended contract. Models using this formulation can only avoid the unbounded problem by stipulating a given contract period or quantity. However, if we wish to eliminate this binding and potentially unrealistic assumption, we need to add one or more terms which increase in $n$. But first, it is beneficial to explore some reasons that unbounded contracts rarely if ever exist in practice and to add support and justification for the inclusion of these new terms in the model.

We know that given enough time, almost everything changes. This is true from a cosmic scale all the way down to an ant hill. Narrowing our focus to only supply chain concerns, we know that prices will rise or fall over time based on the season, demand, or even harder to predict events like wars or trade embargoes. Production capacities will change as a supplier invests in new capabilities or accepts contracts from other parties. Technology and innovation will change demand for electronics. Weather events such as droughts in the short-term and climate change in the long-term will affect production capacities. As consumers, we intuitively use these ideas to help determine our purchasing behavior. For example, we may buy less fruit when we know the peak of the growing season is approaching and prices will drop. A very similar example is the ability for consumers to “lock in” natural gas prices. We consider a great many of the same issues, such as: the length of the commitment, the price difference with the common price, the potential for the price to change (up or down) before the end of the commitment period, a value in reducing uncertainty about the future price. These factors are weighed and added up to help us come to a decision.

It is for the above reasons that both parties rightly consider the length of commitment when signing a contract. Currently, this decision is made through a mental calculation of “soft” costs and risks or by a more rigorous mathematical cost accounting or, more likely, through some combination of the two. To transform a "soft" factor into a concrete cost, we need to add terms to our cost model quantifying each factor. Examples and updated cost formulations are given in the following sections.

## 3.3 A Model with Quantified Risks and Benefits

One way in which we can model commitment costs is to imagine the fallout from an undesirable scenario and weigh it by the likelihood that it will happen. In general terms, we can quantify this expected cost (or benefit) of a commitment concern per time unit as follows:

$$E\left[\frac{Risk\,Cost}{Time\,Unit}\right] = \frac{Likelihood}{Time\,Unit} * \frac{Cost\;or\;Benefit}{Occurence} \tag{3.2}$$

or mathematically as:

$E\left[\frac{Risk\,Cost}{Time\,Unit}\right] = L_B V_B(n,q)$ for the buyer and

$E\left[\frac{Risk\,Cost}{Time\,Unit}\right] = L_S V_S(m,n,q)$ for the supplier.

We can interpret $L$ as "likelihood" (i.e. probability) of an event and $V$ as "value" (cost or benefit) of an event. As a basic example, consider a buyer of wooden pallets that is located in a flood prone area. Each year (the relevant time unit), there is a 5% chance of a large flood that will float away or otherwise ruin all on-hand inventory. Pallets are shipped $q$ at a time and cost \$50 each. Combining the probability of a flood with the expected cost of a flood event, we get:

$$E\left[\frac{Flood\,Risk\,Cost}{Time\,Unit}\right] = L_B V_B(n,q) = L_B C_B \frac{q}{2} = .05 * \$50 * \frac{q}{2} \tag{3.3}$$

where $L_B = .05$ and $V_B(n,q) = C_B \frac{q}{2}$ is the value of the buyer's expected on-hand inventory. Note that $V_B(n,q)$ is a generalized value function, with any number of delineations, and $n$ is unneeded in this example. This value term can be updated to reflect additional inputs such as insurance, shipping, and recovery costs as appropriate. The expected flood risk cost as a function of the decision variable $q$ is then added to the total cost calculation to help determine the optimal decision variable values. In this case, with costs increasing in $q$, the inclusion of this cost will tend to push the optimal $q$ lower. In the above example, only $q$ was required, but if we consider a risk that covers multiple deliveries, such as a contract commitment, $n$ would need considered. Similarly, for the supplier, inclusion of $m$ in the value function is required to account for certain risks such as on-hand inventory obsolescence.

Based on our previously stated assumption of independent commitment costs, we can model multiple concerns as a simple summation of individual expected costs, giving us a total risk cost per time unit of:

$E\left[\frac{Total\ Risk\ Cost}{Time\ Unit}\right] = \sum_{i} L_{B_i} V_{B_i}(n, q)$ for the buyer and

$E\left[\frac{Total\ Risk\ Cost}{Time\ Unit}\right] = \sum_{i} L_{S_i} V_{S_i}(m, n, q)$ for the supplier.

By stating the risk cost in this manner, we reduce and generalize any of a host of different possible commitment concerns to a single formulation. This has the added advantage of lending a straightforward interpretation that can be readily adopted by practitioners. In fact, a similar technique known as the Altman Z-score (Altman, 1968) is commonly employed by agents today to assist with contract decisions.

Edward Altman used discriminant analysis on 66 firms to create a “Z-score” that could be used to predict bankruptcy. Much research has since refined and built upon the initial findings to assist practitioners with predicting the likelihood of a supply chain partner’s bankruptcy. Though usually intended for a buyer to judge a potential supplier, there is little stopping a supplier from evaluating a potential buyer. Here, a supplier would judge the per time unit likelihood $L$ of a potential buyer going bankrupt using the Altman Z-score and multiply it by the cost of a bankruptcy event. A potential expected cost for this event is the loss of on-hand inventory plus half of the one-time contract costs, which can be quantified as:

$$E\left[\frac{Risk\ Cost}{Time\ Unit}\right] = L_S V_S(m,n,q) = L_S\left[C_S\frac{mq}{2}\left[1-\frac{D}{P}-\frac{1}{m}+\frac{2D}{mP}\right]+\frac{OTC_S}{2}\right]. \tag{3.4}$$

A recent addition to the literature focused on supply chain disruption is the concept of a focus on Time-to-Recovery (TTR) put forth by Simchi-Levi et al. (2014). Under this approach, specific sources of disruption are ignored in favor of focusing on the recovery process. TTR is the amount of time that is required to resume normal operation after a significant event, such as flooding or a fire. Correction may require, for example, a change in supplier or new machinery. This process is ideally conducted on the entire supply chain to rank the nodes of the network and find the largest potential weaknesses. Should one of those weaknesses be the party to a contract, it is essential to account for that risk to be incorporated in the total relevant costs.

## 3.4 An Updated Cost Model for the Buyer

Generalizing the various costs or benefits of commitment to the above buyer's relevant cost equation produces:

$$TC_B(n,q) = h_B\frac{q}{2} + Z_B\frac{D}{q} + A_B\frac{D}{nq} + \sum_i L_{B_i}V_{B_i}(n,q). \tag{3.5}$$

As an example of this generalized form, we consider a scenario in which a buyer is faced with two costs of commitment. First, the buyer may be liable for unneeded units should the demand end before the contract is completed. Second, the buyer commits to the unit price at the time of the contract commitment and is concerned with a potential change of unit price to $\widehat{C_B}$. From this information, the following equation can be formed from Equation 3.5 above:

$$TC_B(n,q) = h_B\frac{q}{2} + Z_B\frac{D}{q} + A_B\frac{D}{nq} + L_{B_1}C_B\frac{nq}{2} + L_{B_2}(\widehat{C_B} - C_B)\frac{nq}{2}. \tag{3.6}$$

Here, $L_{B_1}$ is the contract commitment cost rate that simply increases the buyer's total relevant cost proportionally with the size of of the contract. The value function describes the monetary value of half of the contract size. This can be interpreted as an insurance cost for the event that, due to unforeseen circumstances, we no longer need the remaining units on the contract. This intuition behind this cost component is described in much more detail below in Section 3.4.1. Similarly, $L_{B_2}$ is the commitment cost (benefit) rate that we will be lose (gain) the opportunity to miss a price decrease (increase) for the remaining portion of the contract. Note that this may be positive or negative depending on the anticipation of the direction of likely price changes. A positive $L_{B_2}$ will tend to lower the buyer's preferred contract length while a negative $L_{B_2}$ will tend to increase it as the buyer wishes to either avoid a unit cost increase or capture a unit cost decrease.

Since a change in unit cost also affects the holding costs, we may for completeness include those potential changes into our value function for $L_{B_2}$. Since $r_B(\widehat{C_B}-C_B)\frac{q}{2}$ is the expected per time-unit increase in holding cost due to a price change of probability $L_{B_2}$, we can incorporate this into the previous equation to produce the following cost equation for the buyer:

$$TC_B(n,q) = h_B\frac{q}{2} + Z_B\frac{D}{q} + A_B\frac{D}{nq} + L_{B_1}C_B\frac{nq}{2} + L_{B_2}(\widehat{C_B} - C_B)\frac{q}{2}(r_B + n). \tag{3.7}$$

If the probability of these events are sizable, a joint distribution may be employed to more accurately reflect the potential costs. However, due to the subjective nature of some of these particular costs, it may be much more appealing to the practitioner to maintain modularity of the equation by assuming a negligible joint probability. In the example above, a catastrophic demand disruption will negate the concern of a future price increase since the remaining contract can be paid off immediately in such an occurrence preventing a future change in price. This might not hold true in the reverse, since a price increase does not logically prevent a demand disruption. Again, a joint probability could address this scenario if it is deemed to be a considerable risk.

### 3.4.1 Example Quantification of $L_B$: Model for End of Demand During Contract Period

In the previous example, $L_{B_1}$ is given simply as the contract commitment cost rate. This is a cost rate that reflects the wariness of buyers in committing to large contract quantities. It also plays an important role mathematically in preventing infeasibility when deciding on the policy decisions for an arbitrarily long contract. Intuitively, it makes sense that a buyer will hesitate before committing to large contracts, and, not surprisingly, this is confirmed by empirical evidence (Kelle et al., 2007). Some of the possible reasons for a buyer's commitment cost have been outlined previously. However, one area in particular, demand disruptions in supply chain coordination, has received little attention (Qi et al., 2004). The remainder of this section is focused on addressing this neglected area by detailing the ramifications to the buyer of a sudden end of demand event during the contract period.

Given a buyer facing the following total relevant cost structure per time unit:

$$TC_B(q,n) = h_B\frac{q}{2} + Z_B\frac{D}{q} + A_B\frac{D}{nq} + L_B C_B\frac{nq}{2}, \tag{3.8}$$

most of the exact parameters are easy to calculate for the practitioner. For example, $Z_B$ may be the transit and incoming inspection costs per delivery and $A_B$ the legal fees for forming a contract. The holding cost per unit, $h_B$, is calculated by multiplying the given wholesale cost, $C_B$, by $r_B$, a well-established number typically provided by the firm's accounting function. However, there is little to no guidance available for an appropriate $L_B$ value. When introduced by Kelle et al. (2003), the only exposition given was explaining that this parameter represents "the cost rate of losing flexibility per unit dollar amount contracted but not yet received." They proceed to use a value of 3% without explanation or justification for it.

Rather than adopting an arbitrary commitment cost rate, it is beneficial to have some basis for this value. This is possible by quantifying a realistic risk of commitment. To do this, suppose a regulatory or design change instantly removes the demand for all undelivered items under contract during the contract's execution. If this happens, the buyer may be held liable for compensating the supplier for all parts remaining on that contract. The consequence is that the buyer will face a cost with some probability (say $p$) or, alternatively, insure against this event. This is a plausible scenario that a practitioner can readily understand.

Given that the buyer can either estimate or know from past events that there is a probability $p$ over the interval of a time unit of an acute end-of-demand (EOD) event, the buyer can add this expected cost to the cost structure when computing the optimal policy decisions. One straightforward interpretation of this $p$ value, assuming an annual basis for costs, is "equally likely throughout the coming year, there is a probability of $p$ for obsolescence of the contracted part." However, since it is not immediately obvious how to correctly account for this cost, an explanation is provided below.

The duration of a contract should no EOD event occur is $\frac{nq}{D}$. For a constant, continuous risk of an EOD event with probability $p$, the duration of the contract is $\frac{nq}{2D}$, half of the contracted quantity. Putting these together, we can find the expected length of the contract:

$$p\frac{nq}{2D} + (1-p)\frac{nq}{D} = \frac{2(nq) - p(nq)}{2D} = \frac{nq(2-p)}{2D}. \tag{3.9}$$

This gives us an expected number of units consumed during the contract:

$$\frac{nq(2-p)}{2D} * D = \frac{nq(2-p)}{2} = nq\left(1 - \frac{p}{2}\right). \tag{3.10}$$

Thus, the number of unconsumed units for the contract is $nq - nq\left(1 - \frac{p}{2}\right) = p\frac{nq}{2}$, with an expected cost of $\overline{C_B}p\frac{nq}{2}$, where $\overline{C_B}$ is the unsalvageable per unit cost ($C_B$ - salvage value) with $0 < \overline{C_B} \leq C_B$ and $0 \leq p \leq 1$. For $\overline{C_B} \approx C_B$, we may also add an implied constraint of $p\frac{nq}{2D} \leq 1$, or equivalently, $nq \leq \frac{2D}{p}$ since a logical buyer would never commit to a contract quantity larger than the expected life of the contracted part. For a small $p$, this would be expected to rarely limit the contract quantity. For a large $p$, the implications and importance of considering an EOD in determining an optimal contract size would be considerable. Of course, this implied constraint does not need to be explicitly added to the mathematical programming since it will already be used in determining an optimal $nq$. Adding the above calculated cost of leftovers to the buyer's total relevant cost equation yields:

$$\begin{aligned} TC_B(q,n) = \\ h_B\frac{q}{2} + Z_B\frac{D}{q} + A_B\frac{D}{nq} + L_BC_B\frac{nq}{2} + \overline{C_B}p\frac{nq}{2} = \\ h_B\frac{q}{2} + Z_B\frac{D}{q} + A_B\frac{D}{nq} + (L_BC_B + p\overline{C_B})\frac{nq}{2}. \end{aligned} \tag{3.11}$$

Should there be very little salvage value (i.e $\overline{C_B} \approx C_B$) as might be expected for unique or custom purchases, we can clearly see the equivalence between $L_B$, the cost of commitment, and $p$, the probability of obsolescence. The important implication of this finding is that many practitioners may not be able to justify an appropriate $L_B$, but may be able to justify a value for a risk of obsolescence, $p$, through either experience or group consensus.

Based on the above analysis, a self-insured company will need to be prepared to pay 100% of the remaining contract costs ($\overline{C_B}\frac{nq}{2}$) with probability of $p$ over each time unit. Or, if insured externally, the buyer will always pay $\alpha p\overline{C_B}\frac{nq}{2}$, where $\alpha$ is the insurer's premium rate and $\alpha > 1$, with the conservative assumption of a profit-seeking insurer.

## 3.5 An Updated Cost Model for the Supplier

A typical accounting of the relevant costs to the supplier is:

$$TC_S(q,m) = h_S\frac{mq}{2}\left[1 - \frac{D}{P} - \frac{1}{m} + \frac{2D}{mP}\right] + Z_S\frac{D}{q} + A_S\frac{D}{mq}, \tag{3.12}$$

which accounts for holding, delivery, and per-batch costs (See e.g. Golhar and Sarker (1992); Banerjee and Kim (1995); Kim and Ha (2003); Kelle et al. (2007); Masten and Kim (2015)). More recently, the concept of a cost of commitment has been discussed and explored for the buyer (Kelle et al., 2003; Masten and Banerjee, 2014). However, there is ample reason to believe that the seller would also be interested in capturing a cost of commitment. For example, a supplier of copper or aluminum ore would surely hesitate before allowing a buyer to "lock in" unusually low prices for an extended time period. Another example would be a supplier that commits to a low-profit product to take advantage of unused capacity, but does not want to lose this capacity in the long-term should a higher-profit product (contract) become available in the future.

The vast majority of the literature referring to a supplier's opportunity cost is in terms of some monetary measure (e.g. lending or trade credits). Kelle and Akbulut (2005) lists and implies some potential hazards for the supplier when cooperating, including the loss of confidential information, investment costs, and losing business from your partner's competitors. Since we allow for offsetting negative costs (benefits), we need to also note the advantages such as point-of-sale (POS) information and

Table 3.1: Example Delineations of $V_{S_i}(m,n,q)$

| $V_{S_i}(m,n,q)$ | Risk Cost Description |
|---|---|
| $C_S\frac{nq}{2}$ | Contract commitment |
| $C_S\frac{mq}{2}\left[1-\frac{D}{P}-\frac{1}{m}+\frac{2D}{mP}\right]$ | Obsolescence of on-hand inventory |
| $(P-D)V_S$ | Excess (unusable) capacity |

simplified financing. Just like the aspects contributing to the cost of commitment for the buyer, most of these are also inherently difficult to quantify.

The supplier's total relevant cost per time unit can be more completely given as:

$$TC_S(m,n,q) = h_S\frac{mq}{2}\left[1-\frac{D}{P}-\frac{1}{m}+\frac{2D}{mP}\right]+Z_S\frac{D}{q}+A_S\frac{D}{mq}+\sum_i L_{S_i}V_{S_i}(m,n,q), \quad (3.13)$$

or with a discrete accounting of one-time costs:

$$\begin{aligned}TC_S(m,n,q) = \\ h_S\frac{mq}{2}\left[1-\frac{D}{P}-\frac{1}{m}+\frac{2D}{mP}\right]+Z_S\frac{D}{q}+A_S\frac{D}{mq}+ \\ OTC_S\frac{D}{nq}+\sum_i L_{S_i}V_{S_i}(m,n,q). \quad (3.14)\end{aligned}$$

Examples of $V_{S_i}(m,n,q)$ are presented in Table 3.1. These represent ad hoc cost structures that can potentially vary by factors such as industry or product.

# Chapter 4: Third Party Coordination of the Supply Chain

Small companies rarely have the time, the resources, the negotiating power, or the desire to implement advanced inventory coordination systems. These small firms may be in a particularly weak negotiating position compared to their much larger trading partners and be forced to accept unfavorable contract terms. Unused capacity or low cash flow may push some to resist any action that may antagonize the other party. Meanwhile, larger firms have the resources and negotiating power required to push for an effective cooperative solution, but it has been shown that firms in a dominant position are more likely to use available leverage to maximize their own individual profits, rather than advocating a jointly optimal policy (Simatupang and Sridharan, 2002). Even firms roughly equivalent in size may hesitate to fully cooperate for various reasons. Protecting proprietary information such as market size is seen as particularly important (Fawcett and Magnan, 2002; Verespej, 2002). The double marginalization problem provides us with a “worst-case” example of this inefficiency in action. In this famous scenario, multiple monopolies (or other price-setting firms) introduce considerable losses and inefficiencies due to the locally-optimizing behavior of the buyer and supplier.

As Cachon (2003) notes, there is much literature on theoretical models but “little guidance on how the theory should now proceed.” As established in Chapter 2, much of the extant coordination literature presupposes either a spontaneous agreement between buyers and sellers to cooperative and collaborate effectively (in models for joint optimization) or a strong party that forces the weaker party to attempt supply chain coordination via some form of mechanism or inducement, such as a quantity discount. Even if both firms wish to cooperate, it is not clear which party should manage the supply chain (Storey et al., 2006).

A practical and novel solution that addresses many concerns and issues is through the introduction and use of a neutral and expert third party coordinator (3PC). A few entities already exist in the marketplace with similar (albeit less grand) goals. These third parties refer to themselves using terms such as "3PL+" or "4PL[1] ". Firms using the 3PL+ moniker typically come from the logistics industry and use a "hands-on" approach to address inventory coordination issues. One popular technique is storing inventories near the shipping points to reduce delivery lag times. Firms called "Fourth-party logistics" or 4PL typically provide outsourcing or consulting services to the members of the supply chain. Larger and famous companies, such as UPS, DHL (Exel), and Con-way (Menlo), have evolved to offer a wide variety of services, including 3PL (third-party logistics), LLP (lead logistics provider), 4PL services, or other ad-hoc solutions (Lieb, 1999; Doll et al., 2014; Lieb and Lieb, 2016). For those supply chain parties that are currently unable or unwilling to cooperate, the use of a third party coordinating expert could allow for an improvement in overall supply chain performance.

The entity acting as a third party coordinator (3PC) may in practice be a 4PL, LLP, or 3PL+. This would potentially require an increase in responsibilities presently administered. However, this evolution of duties from 3PL to 3PC is apparently quite manageable and perhaps even natural, as supported by this shift having already begun at one major 3PL+ (Zacharia et al., 2011). Of course, not all logistics and shipping companies wish to expand their current business to include these new services and the added responsibilities (Fabbe-Costes and Roussat, 2011).

In the first part of this chapter, we expand upon the role that an expert third party would need to play and the responsibilities that need to be assumed by a 3PC.

---

[1] It should be noted that "Fourth Party Logistics" (and 4PL) was once a registered US trademark of Andersen Consulting in 1996 but abandoned in 1998. The usage is now commonly accepted to refer to any fourth party logistics provider.

In the following section, we discuss how limits exist to the range of situations in which gains may be had by adding another, ostensibly unnecessary, profit-seeking participant. Some less obvious consequences of having a third party coordinator are also considered.

The third portion of this chapter lays out the required updates to a current joint model to reflect the more complete cost accounting established in Chapter 3 with the addition of a third party coordinator. This section also explores some of the problems along with a potential solution for third party remuneration.

The next section of this chapter is devoted to a numerical example. In this classical term-by-term investigation, we explore the component influences of the model parameters on the resulting optimals for the three cases of Strong Buyer, Strong Seller, and 3PC (Joint). It is the goal of this numerical example to "open the book" for the much more detailed, simulation-based, numerical analysis and guidance contained in the fifth portion of the chapter.

In the expansive fifth section, we conduct an in-depth simulation covering a great range of potential model parameters. Intuition is coupled with rigorous statistical techniques to establish guidance for buyers, sellers, and third party coordinators.

## 4.1 The Role of a Third Party Coordinator

A large amount of money is wasted each year due to poor policy coordination. By one estimate, these inefficiencies add up to a sizable \$30B (Lee et al., 1997). Of course, capturing all of this would be no easy task, but there is low hanging fruit up for grabs since most organizations have done very little in way of collaboration (Fawcett and Magnan, 2002). So, why hasn't more been done to capture these potential savings?

The answer to this simple question is that there are many concerns preventing or sabotaging cooperation efforts between buyers and suppliers. So, even though there is a desire for more collaboration, a general worry about close collaboration with a possible future competitor or the supplier to a competitor can dampen the desire for coordination (Fawcett and Magnan, 2002). A neutral third party can act as a buffer between the buyer and supplier, acting as both a mental separator, and if needed, physical liaison. This also applies to when either party desires a "buffer" to lessen the possibility of a merger or acquisition due to close collaboration (Sabath and Fontanella, 2002).

Among other "barriers and bridges" to partnership are two important subjects: confidentiality and abuse of power (Kelle and Akbulut, 2005). To address the concern over the sharing of confidential or proprietary information, the 3PC can sign and be bound by a non-disclosure agreement (NDA). This can be done prior to or at the time of formulating the supply chain contract. This, in effect, turns the 3PC into an "information escrow", collecting all of the required sensitive information from both parties, responsible for analyzing and producing recommendations, but not sharing the most sensitive of information of one party with the other party. Giving this confidentiality barrier additional credence, Storey et al. (2006) found that a member of a supply chain is likely to intentionally withhold important information from another member to prevent the latter from being "tipped off" to sensitive information such as promotional campaigns or product launches. To prevent the second barrier, abuse of power, the 3PC is in a unique position to act as a referee and arbitrator. In this position, the third party can push for resolutions and agreements that benefit the entire supply chain, rather than just the dominating supply chain partner.

Another possible barrier to cooperation arises when one or both parties supply false or misleading information to their "partner" in an effort to encourage and reap the benefits of locally-optimal supply chain policies. If this sabotage is left unchecked, it can cause disruptive and undesirable effects (Simatupang and Sridharan, 2002;

Sabath and Fontanella, 2002). A 3PC, provided open-access, can verify all given information to help negate this concern. Additionally, a well-connected 3PC with real-time data can assist in minimizing the bullwhip effect, which can increase profitability by 10% to 30% (Metters, 1997). There are a few 3PL and 4PL firms attempting to enter this role of a neutral third party (Fulconis et al., 2006; Storey et al., 2006; Zacharia et al., 2011), though none to date have responsibilities to the extent suggested here.

Disruption of collaboration efforts due to a change in personnel is a real threat. Collaboration requires trust and is often based on a relationships formed by just a few people, even in large corporations (Frankel et al., 2002). If one of these few people depart his or her position, a collaboration effort could fail. A third party can offer continuity between organizations during personnel changes. Further, a third party can help establish common terminology and expectations, a surprising reason for failure (Daugherty et al., 2006).

With the previously "soft" costs now quantified in the manner described in Chapter 3, a logical extension of the role of a 3PC would be to act as an insurer and/or expeditor in the case of a supply chain disruption or rare event. In this capacity, the 3PC would still determine the jointly optimal decision variable values, but take additional payments or commission to remove some of the risk costs from the joint cost equation. This could also help ensure collaboration since some of the costs, such as risk of a partner's bankruptcy, might be better left out of the contract discussions as these numbers would be a possible focus of scrutiny and contention.

Perhaps the most obvious and easily quantifiable benefit to a third party coordinator is the elimination of the need for coordination mechanisms. These sometimes complicated and often inefficient solutions to supply chain coordination, at best, approach the potential profit gains that are possible with a true jointly optimal policy. They offer no improvements to less quantifiable subjects, such as trust and continuity. Trust is critical for the success of collaboration and is in short supply in modern supply chains (Lee and Billington, 1992; Ireland and Bruce, 2000; Barratt, 2004; Min et al., 2005; Daugherty et al., 2006). On further consideration, many of the barriers to cooperation can be reduced to an issue of trust: trust that your partner will keep sensitive information confidential, trust that your partner will provide you with honest information, trust that both parties have similar expectations, and trust that your relationship won't be affected by a simple personnel change. A 3PC, if seen as a neutral broker, can assist with all of these factors, increasing trust, and increasing the probability of a successful collaboration. However, a supply chain with a third party is not expected to be a utopian paradise. There remains numerous limitations to what can be realistically accomplished with a 3PC, and knowing these limitations could prove helpful.

## 4.2 Limits and Consequences of a Third Party Coordinator

The clearest impediment to the incorporation of a third party coordinator (3PC) into the supply chain structure and making of policy decisions is the potential cost of that third party expert. If a buyer and supplier were capable of ignoring all of the previously mentioned trust issues, had stable personnel, and never needed arbitration services, the two firms could jointly optimize the supply chain decisions to provide maximum profits. However, we know that this rarely happens in practice. So, if the buyer and supplier use the services of a 3PC, remuneration would be expected. This payment would, of course, cut into the increased profits of the supply chain. The only way this is justifiable is if the increase in profits is greater than both the remuneration required for the services of the third party coordinator *and* the increase in profits expected by both the buyer and supplier. After all, coordination efforts always have a cost, quantified or not (Zhao and Wang, 2002). Further, if “arms-length” contracts are sufficient, particularly for non-unique or commodity items, collaboration may not be beneficial enough to justify the effort (Lambert and Burduroglu, 2000; Horvath, 2001).

One more possible complication in considering the use of a 3PC comes from estimating the potential profit gains that are possible with a coordination effort. It could be quite difficult to know *a priori* if there are significant enough gains available to justify the inclusion of a third party. This concern is tempered with the knowledge that such a situation should be quite noticeable in practice. We would expect large discrepancies in the desired policy variables of the buyer and supplier. For example, if the buyer demands 200 deliveries of 100 units each while the supplier would strongly prefer 2 delivers of 10,000 each, we would have a strong indication that the addition of a third party could be beneficial. Sure enough, this concept is borne out by the numerical analysis shown in Section 4.5. Another method for predicting possible savings is through a simple "ABC" style analysis. Efforts can be concentrated on high-value "A" items while low-value "C" items are left to simple devices such as arms-length contracts or vendor managed inventory (VMI) systems. After experience with successful coordination efforts, we would expect firms to move on to "B" items. One possible exception to this methodology might occur in situations where a buyer purchases multiple products from a supplier. In those cases, we could expect broader agreements on collaboration with separate or perhaps modular contracting for each additional purchased item, to gain benefits that come from both collaboration and jointly optimal policy decisions. These multiple product scenarios are, however, beyond the scope of this research.

There are other limits to the value that a 3PC may add. After the initial systems and policy decisions are made, we would expect the daily logistics to be handled as close to shipping and receiving as possible. To prevent becoming an obstacle to communication or smooth operation, we should only desire intervention by a third party for the exceptions, not routine business. Fortunately, those items likely to gain the most from close coordination, “A” and some “B” items, are also the ones that should already be receiving the closest inter-organizational focus. The consequence of this is that after the communication systems are set in place (or improved) with the aid of the 3PC, we are less likely to need the services of that 3PC for common sources of potential disruption, such as design or specification changes or quality issues. These issues can more likely be addressed at the lowest levels before becoming a larger problem.

### 4.3 Quantitative Support and Updated Model

In this section, we update a recent JELS model (Kelle et al., 2007; Masten and Kim, 2015) which in turn was based on work by Kim and Ha (2003), Banerjee and Kim (1995), as well as others. This updated model includes a third party coordinator (3PC) along with the more inclusive cost models introduced in Chapter 3. This new model will be the basis for all further analysis and study in the current research unless otherwise noted. To help quickly reference the foundations of this updated model, the following summary list is presented[2]:

1. Model is for a dyadic relationship between one (1) buyer and one (1) supplier for one (1) item.
2. Without intervention, either the buyer or the supplier will be in a significantly stronger negotiating position.
3. The decision variables of the model are number of shipments in a batch ($m$), the number of shipments in a contract ($n$), and the shipment size ($q$).

---

[2] Note that these are in addition to or reiteration of the common assumptions listed in Section 1.4.3.

4. Total contracted quantity is not fixed and equal to $nq$.
5. Overall contract duration is not fixed and is equal to $\frac{nq}{D}$.
6. Goal is to minimize the average total relevant cost per time unit (TRC), a function of the decision variables: $m$, $n$, and $q$.
7. Choice of $n$ and $m$ is always subject to ${}^{n}\!/_{m} \in \mathbb{Z}^{+}$ regardless of which firm chooses $n$.
8. Metric of coordination success is the percent reduction in per time-unit supply chain costs (i.e. $1 - \frac{TRC_{Joint}}{TRC_{SB}}$ or $1 - \frac{TRC_{Joint}}{TRC_{SS}}$).

While most of the above are self-explanatory, a few items can benefit from further exposition. Item 2 reminds us that, without some outside help, the stronger party will use its negotiating strength to locally minimize costs. Of course, in practice, we would rarely expect a party in a stronger negotiating position to be able to completely dictate all contract terms. We will continue to use the "worst case" of an unquestionably strong party as a consistent point of reference. In item 7, we reiterate that no uncommitted parts will be produced. However, the enforcement of this constraint changes depending on the scenario. The stronger party moves first and only considers the constraint if they have to. For example, a strong buyer will disregard this constraint and freely choose $n$, leaving the supplier with limited options for $m$ in which to comply with the constraint. The metric to measure the supply chain improvement due to the transition from non-cooperative (SB, SS) to cooperative (Joint) is described in item 8. This number, presented as a percentage, reflects the reduction in average total relevant cost per time-unit for the referenced scenario. We now turn our attention to the process and effects of third party remuneration.

### 4.3.1 Payment to the Third Party Coordinator

From Chapter 3, the average total cost per time unit to the buyer if no 3PC is used is

$$TC_B(n,q) = \left[h_B\frac{q}{2} + Z_B\frac{D}{q}\right] + \left[A_B\frac{D}{nq}\right] + \sum_i L_{B_i}V_{B_i}(n,q). \tag{4.1}$$

Similarly, the supplier's total relevant cost per time-unit is

$$\begin{aligned} TC_S(m,n,q) = \\ & h_S\frac{mq}{2}\left[1 - \frac{D}{P} - \frac{1}{m} + \frac{2D}{mP}\right] + Z_S\frac{D}{q} + A_S\frac{D}{mq} + \\ & OTC_S\frac{D}{nq} + \sum_i L_{S_i}V_{S_i}(m,n,q), \end{aligned} \tag{4.2}$$

which includes $OTC_S\frac{D}{nq}$, the amortized one-time contract costs for the supplier.

Therefore, the average joint total cost with payment to a 3PC is

$$TC_J(m,n,q) = TC_B(n,q) + TC_S(m,n,q) + TC_{3PC}(m,n,q). \tag{4.3}$$

Expanding this and adding three possible payment methods to the 3PC, yields

$$\begin{aligned} TC_J(m,n,q) = \\ & \left[h_B\frac{q}{2} + Z_B\frac{D}{q}\right] + \left[A_B\frac{D}{nq}\right] + \sum_i L_{B_i}V_{B_i}(n,q) + \\ & OTC_S\frac{D}{nq} + h_S\frac{mq}{2}\left[1 - \frac{D}{P} - \frac{1}{m} + \frac{2D}{mP}\right] + Z_S\frac{D}{q} + A_S\frac{D}{mq} + \sum_i L_{S_i}V_{S_i}(m,n,q) + \\ & \left[A_{3PC}\frac{D}{nq}\right] + \left[\widehat{A_{3PC}}\right] + Z_{3PC}\frac{D}{q}, \end{aligned} \tag{4.4}$$

where $A_{3PC}$ is a per-contract charge by the third party for services rendered for the coming contract. We observe that $A_{3PC}$ has the same form as $A_B$ or $OTC_S$, letting us conclude that, for our jointly optimal policy decisions, increasing $A_{3PC}$ is indistinguishable from increasing either $A_B$ or $OTC_S$. As an alternative or in addition to the per-contract charge, the 3PC may charge $\widehat{A_{3PC}}$, a periodic payment for services. As an example of this charge, we can picture a third party coordinator charging an annual fee for its services. The last term in the above equation, $Z_{3PC}$, is a per-delivery charge. This might be an intuitive charge for a "3PL+" acting as a 3PC since the fee would be charged as a surcharge on top of the normal delivery charge. From the perspective of a jointly optimal policy, this is analogous to increasing $Z_B$ or $Z_S$. The minimization of this joint cost problem can be readily solved for $n$, $m$, and $q$ using various open-source (e.g. BONMIN) or proprietary (e.g. BARON) solvers. This is a mixed-integer nonlinear programming (MINLP) problem. Assuming reasonable bounds are provided to the solver, computing time is typically negligible.

It is imperative to note that the non-periodic fees for the 3PC, $A_{3PC}$ and $Z_{3PC}$, are both decreasing in $q$ with $A_{3PC}$ also decreasing in $n$. This presents a conflict of interest for the third party coordinator assuming these fees are set ahead of time. Hypothetically, offered a fixed per-delivery fee of $Z_{3PC}$, the 3PC could report a lower than jointly optimal $q$ to increase the frequency of deliveries, thus increasing its own income at the expense of buyer and supplier. Similarly, presented with a fixed $A_{3PC}$, reporting a lower and sub-optimal $n$ would have the effect of shortening the contract period. With the assumption of continued business, the 3PC could charge this fee more often, increasing revenue. Even without the assumption of continued business, lowering $n$ decreases the time and/or effort required. This might go unnoticed if the buyer and supplier still improve their outcomes over the non-cooperative policy. A periodic fee, $\widehat{A_{3PC}}$, would prevent this conflict of interest. Further, if this fee is paid as commission on savings, it would only provide additional incentive to aid cooperation. This idea is explored more in Section 4.3.2.

#### 4.3.1.1 MINLP for a Strong Buyer Scenario

The strong buyer solves the following MINLP:

$$\begin{array}{ll} \underset{n,q}{min} & TC_B(n,q) \\ subject\ to & n \in \mathbb{Z}^+ \\ & q \in \mathbb{R}^+ \end{array} .$$

The supplier responds by solving:

$$\begin{array}{ll} \underset{m}{min} & TC_S(m,n_B,q_B) \\ subject\ to & m \in \mathbb{Z}^+ \\ & {}^{n_B}/_{m} \in \mathbb{Z}^+ \end{array} .$$

#### 4.3.1.2 MINLP for a Strong Supplier Scenario

The strong supplier solves the following MINLP:

$$\begin{array}{ll} \underset{m,n,q}{min} & TC_S(m,n,q) \\ subject\ to & n \in \mathbb{Z}^+ \\ & q \in \mathbb{R}^+ \\ & m \in \mathbb{Z}^+ \\ & {}^{n}/_{m} \in \mathbb{Z}^+ \end{array} .$$

The buyer has no decisions to make unless the supplier has no commitment cost ($L_{S_i} = 0\ \forall i$), in which case the strong supplier solves:

$$\begin{array}{ll} \underset{m,q}{min} & TC_S(m,q) \\ subject\ to & q \in \mathbb{R}^+ \\ & m \in \mathbb{Z}^+ \end{array} .$$

This leaves the buyer with a choice of contract length by choosing from limited values of $n$:

$$\begin{array}{ll} \underset{n}{min} & TC_B(n,q_S) \\ subject\ to & n \in \mathbb{Z}^+ \\ & {}^{n}/_{m_S} \in \mathbb{Z}^+ \end{array} .$$

#### 4.3.1.3 MINLP for a Third Party Scenario

The third party solves the following MINLP:

$$\begin{array}{ll} \underset{m,n,q}{min} & TC_J(m,n,q) \\ subject\ to & n \in \mathbb{Z}^+ \\ & q \in \mathbb{R}^+ \\ & m \in \mathbb{Z}^+ \\ & {}^{n}/_{m} \in \mathbb{Z}^+ \end{array} .$$

### 4.3.2 Payment to Third Party as a Proportion of Profit Gained

Rather than a per-contract or per-shipment payment, which may not be acceptable to the buyer and supplier due to the potential conflict of interest discussed above, it may be preferable to compensate the third party based on the improvement they offer to the bottom line (i.e. a commission). The weak supplier (or buyer), having the most to gain by moving to a jointly optimal solution, is the party that would likely seek out the assistance of a third party coordinator. The 3PC would first estimate based on any available information whether it is worthwhile to coordinate the supply chain based on some minimum profit criteria (explored further in the numerical analysis). After compensating the strong buyer (or supplier), the 3PC takes a certain percentage of the gain and splits the remainder between the buyer and supplier.

It is important to note the individual non-cooperative models since any joint agreement must provide an improvement to ensure cooperation from the members. Since there is always a cost to collaboration using a third party, which adds to the joint total cost without affecting profit, a collaboration attempt with a 3PC will never perform as well in a cost minimization problem as a joint effort that does not require a third party. However, based on the currently observed low success rate of collaboration, there are significant savings available in cases where a third party makes the difference between a successful collaboration and one that resorts to a classical competitive arrangement.

In consideration of the conflict of interest detailed above, buyers and suppliers would undoubtedly prefer an incentive for the 3PC that is aligned with the success of the cooperation rather than one that incentivizes sabotage. A payment scheme based on the supply chain's total cost reduction is one way to accomplish this. In practice, we would expect the weaker party to seek out the services of a third party. Intuitively, the weaker party might view a change of policy as a savings as opposed to the strong party which could see any change in policy decisions as a cost increase. This would prove especially true if the stronger party, not knowing the extent to which the dictated terms cost the weaker party, discounts the potential side payment. We would expect the contacted 3PC to first make a broad estimate based on all available data, particularly the preferred $m$, $n$, and $q$ of both the buyer and supplier. Should the 3PC estimate adequate potential savings to compensate itself, the buyer, and the supplier, it would agree to offer its services. After an initial side payment to compensate the stronger party for its increased costs at the jointly optimal policy, the third party would take a percentage of the supply chain gains and split remaining improvement between the buyer and supplier. An example of this process is laid out in Section 1.6.

Since any profit-seeking firm, such as a 3PC, invariably demands payment for its efforts, no collaboration that requires the use of a third party can outperform a collaboration that does not require the assistance of an outside player. However, considering the poor rates of collaboration success, significant savings are available where a 3PC becomes the catalyst for a successful collaboration over a supply chain that falls back to a suboptimal competitive policy.

## 4.4 A Numerical Example

The goal of this numerical example is to open the door to the more rigorous numerical analysis presented in Section 4.5. In this section, we shall consider some important relationships among the buyer's and supplier's parameters and their relative effects on contract size, individual costs, joint costs, and potential savings. This will be accomplished by finding the optimal policies in each of the three scenarios of interest (Strong Buyer, Strong Supplier, Third Party Coordinator) over 11 evenly spaced points (10 segments) in the sensitivity ranges described in Table 4.2. These sensitivity figures are produced by holding the denominator constant and varying the numerator of each relationship of interest. Note than an important effect caused by this methodology is a straight line for one the parties (typically the strong supplier). Therefore, in all of the following graphs, it is more important to notice the *relative* distances and trends between lines rather than the absolute figures or trends. Finally, note that in this section we will prefer the term "Joint" over "Third Party Coordinator" or "3PC" to remove possible confusion over remuneration and to emphasize that these differences are inherent to the nature of each scenario and not due to the responsibilities or actions of a particular party. The third party's perspective will be analyzed as part of Section 4.5. To avoid confusion, scenarios will be capitalized (e.g. "Strong Supplier" or "SS" ) while individual firms will be referred to in lower case (e.g. "a strong supplier").

The total relevant cost equations used in this numerical example are:

$$TC_B(n,q) = \left[h_B \frac{q}{2} + Z_B \frac{D}{q}\right] + \left[A_B \frac{D}{nq}\right] + L_B C_B \frac{nq}{2} \tag{4.5}$$

for the buyer, and

Table 4.1: Numerical Example Default Parameters

| Parameter | Default Value | Unit |
|---|---|---|
| $P$ | 40000 | items/year capacity |
| $D$ | 20000 | items/year demand |
| $Z_B$ | 2500 | \$/delivery received |
| $A_B$ | 5000 | \$/contract |
| $C_B$ | 100 | \$/item |
| $r_B$ | 0.15 | holding cost rate |
| $L_B$ | 0.08 | commitment cost rate |
| $Z_S$ | 2500 | \$/delivery shipped |
| $A_S$ | 10000 | \$/batch |
| $C_S$ | 40 | \$/item |
| $r_S$ | 0.15 | holding cost rate |
| $OTC_S$ | 50000 | \$/contract |
| $L_S$ | 0.08 | commitment cost rate |
| $h_B$ | $= r_B * C_B$ | |
| $h_S$ | $= r_S * C_S$ | |

$$TC_S(m,n,q) = h_S\frac{mq}{2}\left[1 - \frac{D}{P} - \frac{1}{m} + \frac{2D}{mP}\right] + Z_S\frac{D}{q} + A_S\frac{D}{mq} + L_S C_S\frac{nq}{2} + OTC_S\frac{D}{nq} \quad (4.6)$$

for the supplier. These equations have the commitment costs in the same format for both the buyer and supplier, expressed as a cost on parts yet-to-be-delivered. One-time costs are included for the supplier. The default parameter values are listed in Table 4.1.

Table 4.3 summarizes the optimal policies for the three scenarios of interest using the default parameters listed in Table 4.1. This provides us with a baseline of comparison for the forthcoming sensitivity analyses. From this summary, we note that the 3PC policy does indeed offer the lowest total cost, as expected. We can also see

Table 4.2: Numerical Example Sensitivity Ranges for Relationships of Interest

| Relationship of Interest | Constant Value(s) | Sensitivity Range |
|---|---|---|
| $L_B/L_S$ | $L_S = 0.08$ | $0.1 - 1.5$ |
| $r_B/r_S$ | $r_S = 0.08$ | $0.1 - 1.5$ |
| $Z_B/Z_S$ | $Z_S = 2500$ | $0.1 - 1.5$ |
| $A_S/(Z_S+Z_B)$ | $Z_S = 2500,\ \ Z_B = 2500$ | $1 - 10$ |
| $C_B/C_S$ | $C_S = 40$ | $1 - 10$ |
| $A_B/OTC_S$ | $OTC_S = 50000$ | $0.1 - 1.5$ |
| $P/D$ | $D = 20000$ | $1 - 10$ |

Table 4.3: Optimal Decision Variables and Related Results with Default Parameters

| Optimal | SB | SS | 3PC |
|---|---|---|---|
| $q$ | 2540 | 12,632 | 3441 |
| $n$ | 2 | 2 | 4 |
| $m$ | 2 | 1 | 4 |
| $nq$ (Contract Size) | 5080 | 25,264 | 13,764 |
| $mq$ (Batch Size) | 5080 | 12,632 | 13,764 |
| Contract Length (Years) | 0.25 | 1.26 | 0.69 |
| TC ($) | 350,394 | 322,456 | 247,043 |
| % Coordination Savings | 29.5% | 23.4% | - |

that the buyer prefers both smaller contracts and smaller deliveries than the supplier. This base case provides us with an interesting example demonstrating that the jointly optimal $n$, $m$, and $mq$ values do not need to be bounded by the SB and SS policy decisions.

### 4.4.1 Sensitivity to $L_B/L_S$

We expect an increase in the commitment cost rates $L_B$ and $L_S$ to shorten the buyer's and supplier's respective desired contract size, $nq$. As expected, this is con-

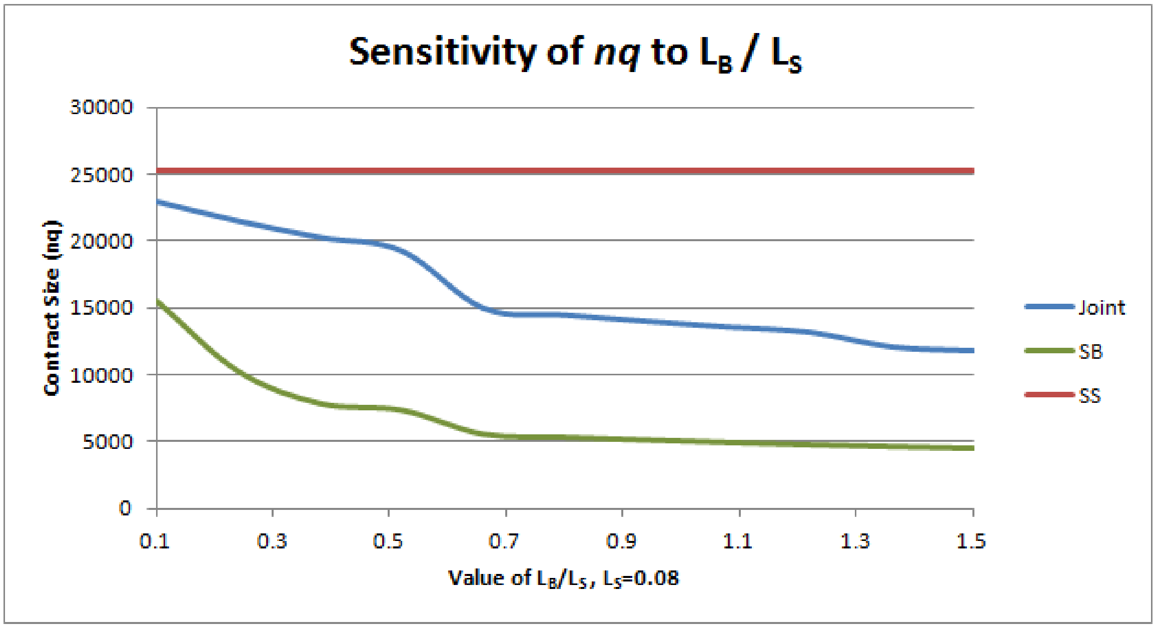

Figure 4.1: Sensitivity of Contract Size ($nq$) to $^{L_B}/_{L_S}$

firmed in our results for the Strong Buyer (SB) case, but also holds for a Strong Supplier (SS) case where $L_S$ increases (not shown). Recall that since $L_S$ is constant in the ratio, the presented optimal policy for SS is not affected, though the relative distances keep interpretability. We can see the contract size for SB quickly decreasing from about 15,000 to 5,000. With a time-unit of one year and a demand rate of 20,000, this represents a decrease of contract length from nine months to three months. This considerable drop results from the buyer's optimal $n$ ($n_B$) quickly dropping from six (6) to two (2) with $q_B$ remaining relatively unchanged, presumably due to the other parameters. Meanwhile, the jointly optimal (Joint) policy for $nq$ ($n_J q_J$) decreases more slowly than for SB due to $n$ decreasing more slowly. We see that when $L_B \ll L_S$ (on left side of graph), the Joint policy is close to the SS policy. As $L_B$ increases past $L_S$, we see $n_J q_J$ begin to approach the optimal policy for SB. In Figure 4.2, the joint total relevant costs (JTRC) for each of the three scenarios are presented. Surprisingly, the total cost curves for SB and SS appear strikingly similar,

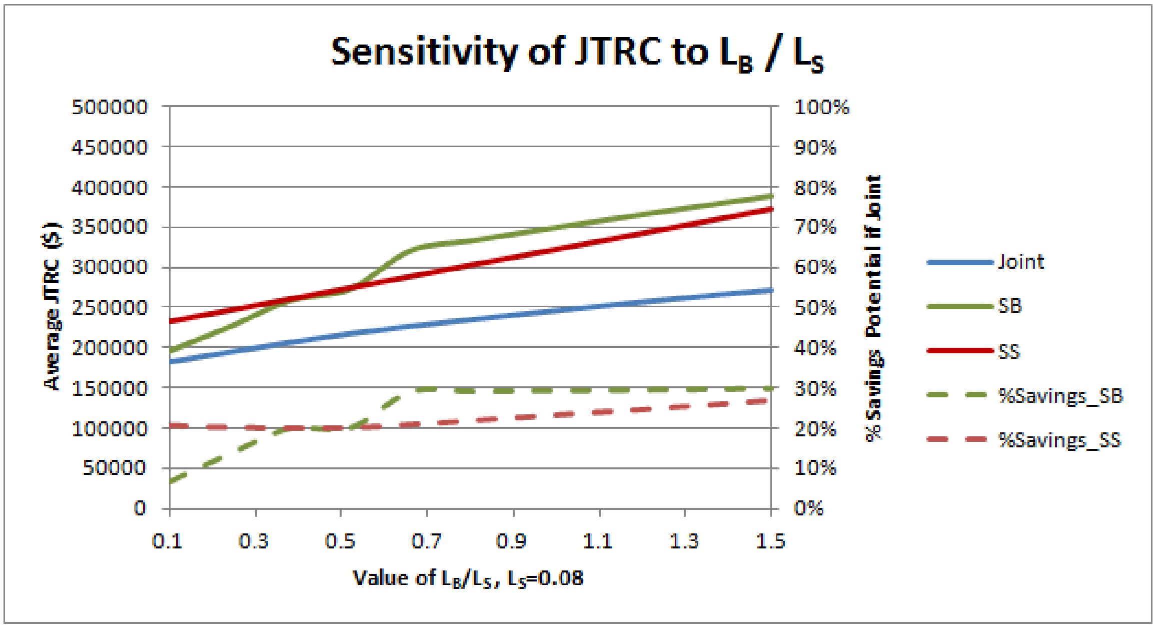

Figure 4.2: Sensitivity of Joint Total Relevant Cost (JRTC) to $L_B/L_S$

with the lines crossing at about 0.5 but otherwise close. The potential savings by moving from SB to Joint (shown in dotted green) increases rapidly before tapering off. This mirrors the quick drop for SB seen in Figure 4.1. The savings are minimal with the a low $L_B$ since the SB policy there most resembles the Joint policy. Figure 4.3 lets us visualize the relative costs of all four possible individual firms and helps explain the apparent discrepancies in the JTRC figure. Again, note that with $L_S$ constant, a strong supplier does not show a cost increase. For both SB and SS, the stronger party updates its optimal policy to minimize its own costs, resulting in huge cost increases for the supply chain at large as the dictated parameters increasingly deviate from the weaker party's optimal numbers.

### 4.4.2 Sensitivity to $r_B/r_S$

We turn our attention to the holding cost rates, $r_B$ and $r_S$. We do not expect any sizable effect on the contract commitment based on the cost rate for on-hand

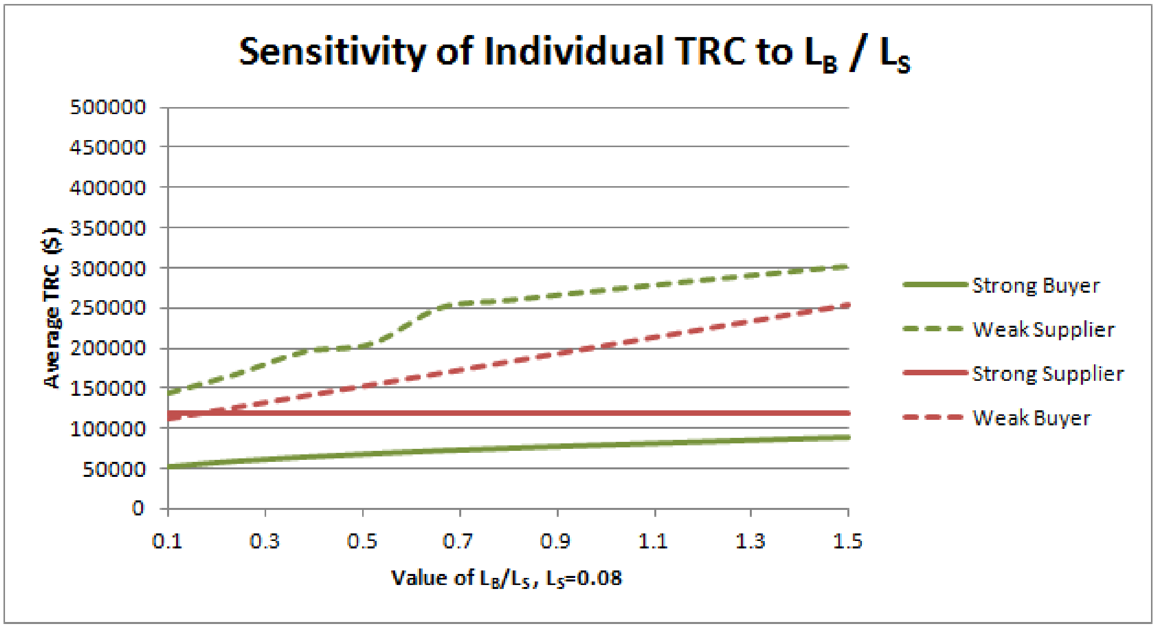

Figure 4.3: Sensitivity of Individual Total Relevant Cost (TRC) to $L_B/L_S$

inventory, and this is confirmed in our results (see Figure 4.4). As before, the $nq$ from the Joint policy is roughly halfway between the SS and SB policies. Intuitively, we expect the buyer to desire more frequent, but smaller, deliveries as $r_B$ increases in order to minimize the holding cost. The supplier has a similar response to a rising $r_S$, and becomes increasingly willing to pay for additional setups to keep on-hand inventory costs at bay (not shown). In Figures 4.5 and 4.6, we can see the savings potential dip as $r_B$ approaches $r_S$. This sudden decrease in costs for the weak supplier is due to the buyer demanding two deliveries of about 2850 units each instead of one delivery of 5000 units. This allows the supplier to split a single batch across two deliveries, creating significant savings despite the slightly increased delivery and holding costs.

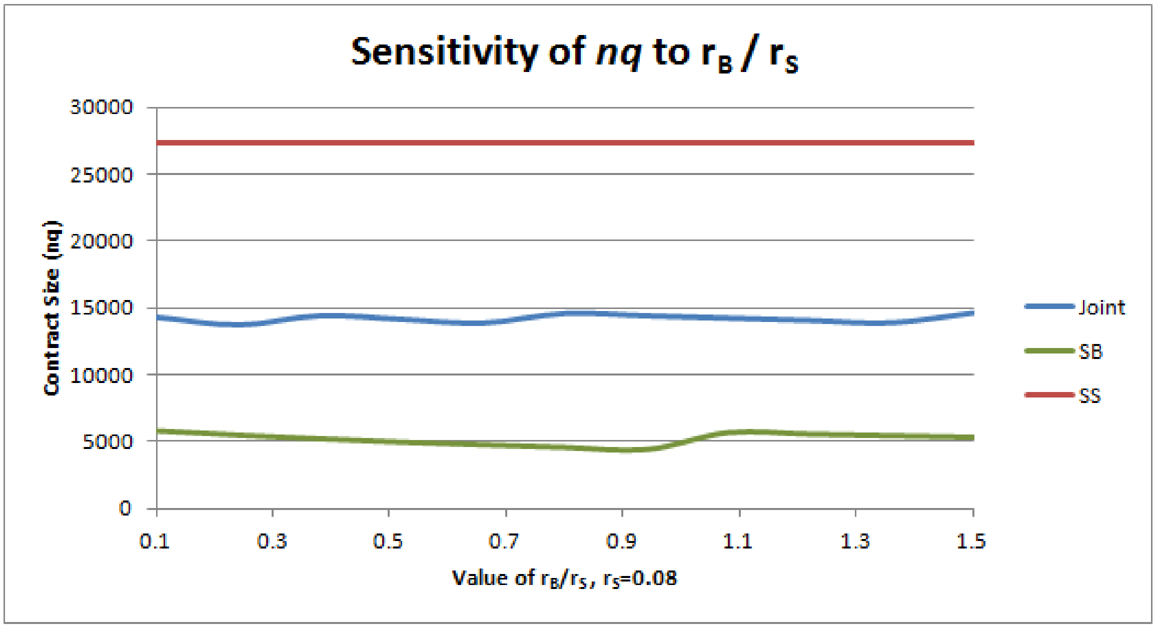

Figure 4.4: Sensitivity of Contract Size ($nq$) to ${}^{r_B}/_{r_S}$

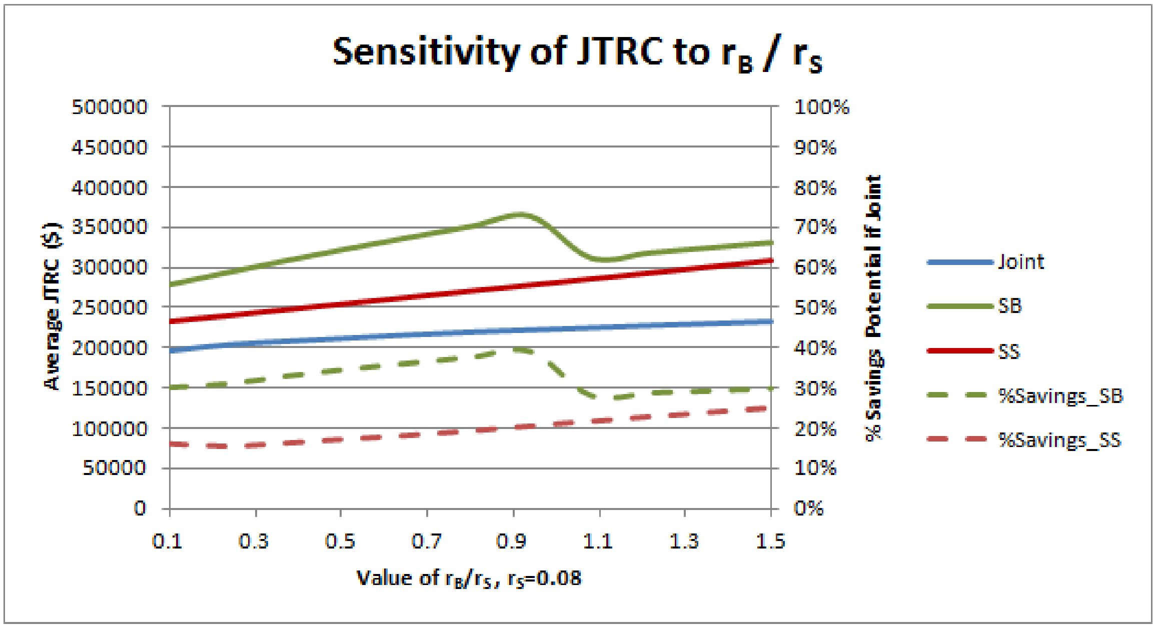

Figure 4.5: Sensitivity of Joint Total Relevant Cost (JRTC) to ${}^{r_B}/_{r_S}$

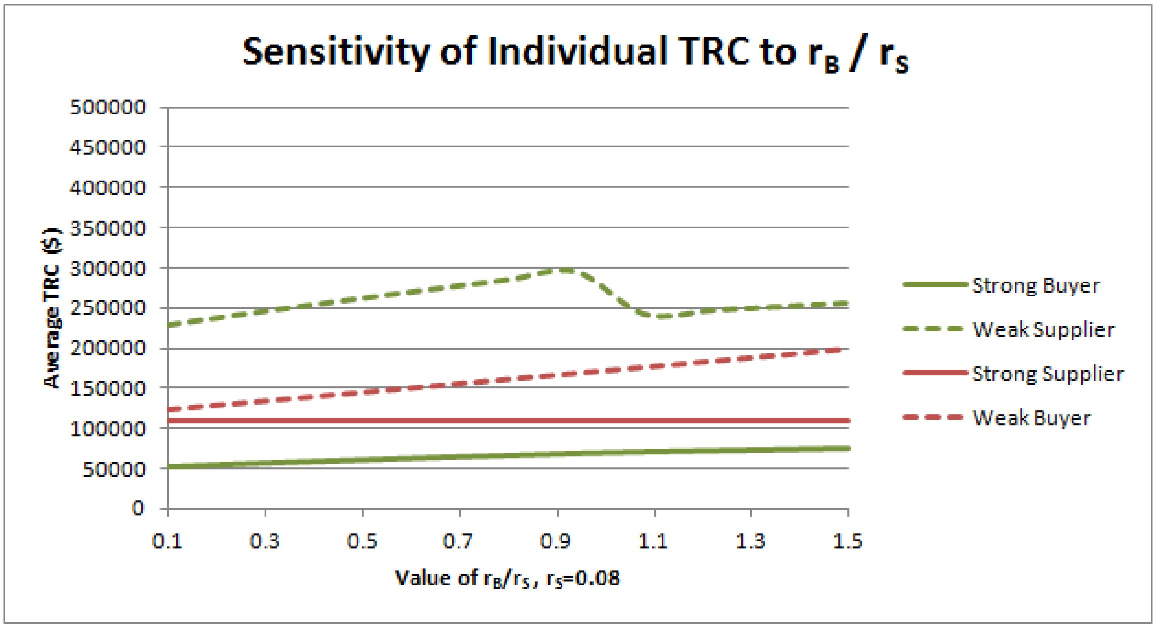

Figure 4.6: Sensitivity of Individual Total Relevant Cost (TRC) to $^{r_B}/_{r_S}$

### 4.4.3 Sensitivity to $^{Z_B}/_{Z_S}$

We do not expect large changes to the contract size due to $^{Z_B}/_{Z_S}$. This is confirmed in our findings. As $Z_B$ increases, the buyer prefers fewer, but larger, deliveries. This naturally aligns the buyer more closely with the supplier, slightly decreasing our potential savings and saving a weak supplier up to \$50,000 in costs per year. However, even at extreme values of $Z_B$, the desired policies do not merge as the buyer will request ever larger $q$ at $n = 1$ while the supplier's minimal cost is at $n = 2$.

We can conclude that our contract sizes, costs, and possible savings are fairly robust to changes in $^{Z_B}/_{Z_S}$.

### 4.4.4 Sensitivity to $^{A_S}/_{(Z_S+Z_B)}$

The ratio $^{A_S}/_{(Z_S+Z_B)}$ represents the supplier's batch cost in relation to the combined delivery costs of both buyer and supplier. We expect large values of $A_S$ to

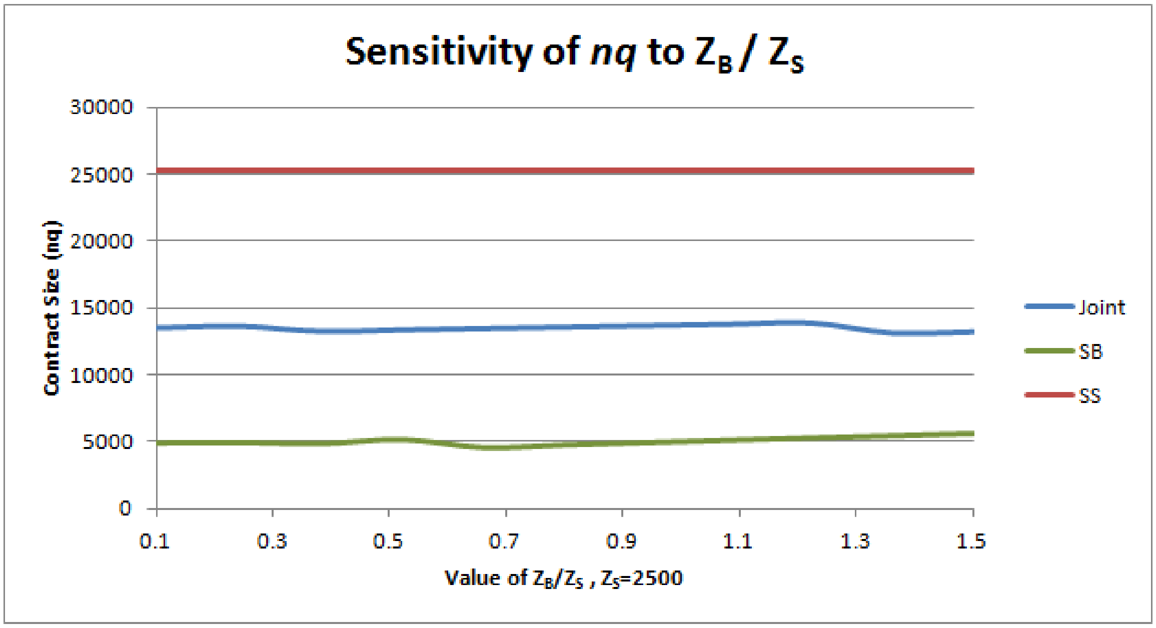

Figure 4.7: Sensitivity of Contract Size ($nq$) to $z_B/z_S$

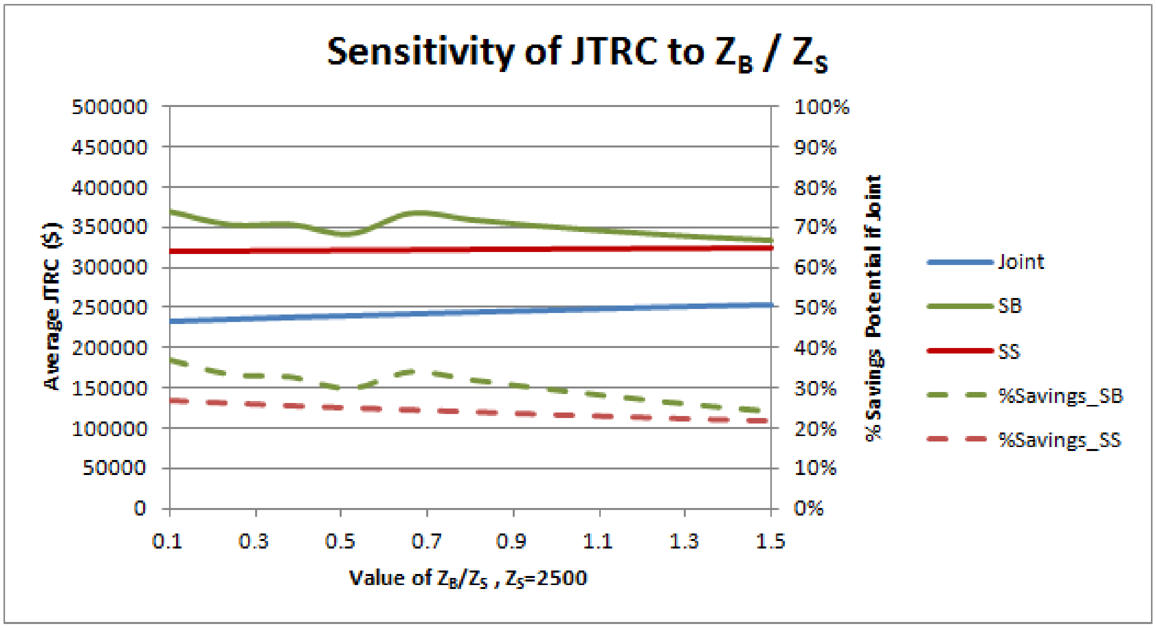

Figure 4.8: Sensitivity of Joint Total Relevant Cost (JRTC) to $z_B/z_S$

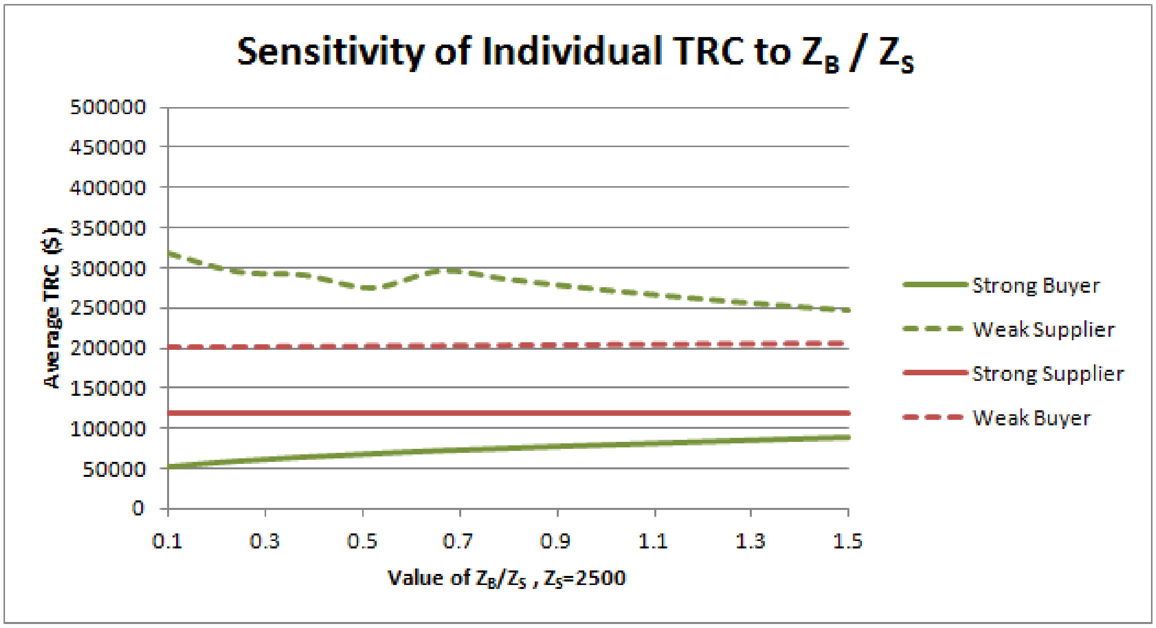

Figure 4.9: Sensitivity of Individual Total Relevant Cost (TRC) to $^{z_B}/_{z_S}$

increase the supplier's preferred $m$ and $q$ since either would entail fewer batch set-ups. In a Strong Buyer scenario, the weak supplier will only have control of $m$. However, with our chosen parameters, even at the lowest value of $A_S$, where a set-up only costs the same as both deliveries, the weak supplier will still choose its highest possible $m$, which is $m = n_B$. Fortunately, from the Joint case, we can still see this increase in $m$, which increases from $m = 2$ at the lowest presented ratio to $m = 5$ at the highest shown sensitivity ratio.

Perhaps surprisingly, we see some considerable fluctuation in the SS value for $nq$ (see Figure 4.10). This variance is due to an increase in $q$ and decrease in $n$ with the resulting $nq$ being the best available (lowest cost) compromise. The optimal Joint contract starts halfway between SS and SB, but moves slowly towards the SS contract size as $A_S$ increases. Interestingly, the Joint policy utilizes $n = 4$ or $n = 5$ for all results even though neither the strong buyer nor strong supplier at any studied ratio desire more than $n = 3$.

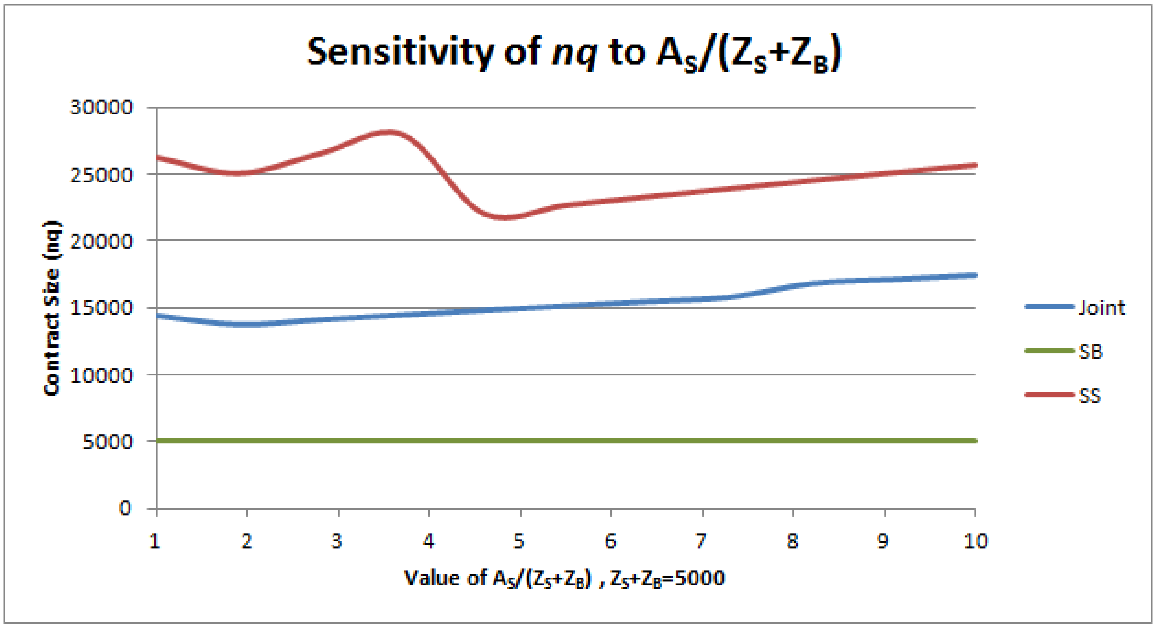

Figure 4.10: Sensitivity of Contract Size ($nq$) to $^{A_S}/_{(Z_S+Z_B)}$

From the joint and individual total relevant costs (Figures 4.11 and 4.12), we see that even a strong supplier can not correct for an increasing batch cost, though a weak supplier will pay much more in comparison. In an SS scenario, $q$ quickly rises, causing a rapid increase in holding costs for a weak buyer.

We conclude that quickly escalating costs to a weak supplier may create significant differences in relative costs and thus potential savings as the batch cost increases. The discrepancy in each party's preferred $q$ at a high ratio ($q_B = 2540$ vs. $q_S = 25716$ at a sensitivity ratio of 10) demonstrates a situation that should trigger alarms in a practitioner's head and signal the possible need for outside assistance.

### 4.4.5 Sensitivity to $^{C_B}/_{C_S}$

At first, it might be easy to dismiss item cost as an exogenous number since the price paid directly for the items is not considered a relevant cost in our equations. However, the item cost is considered twice in our costs, once in the commitment costs,

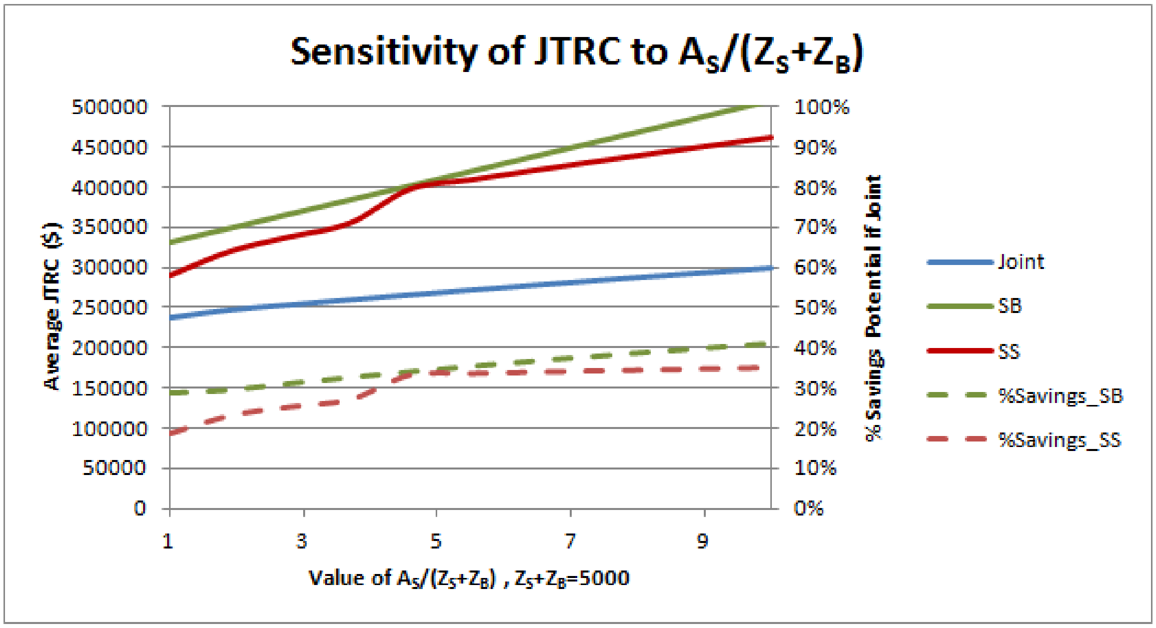

Figure 4.11: Sensitivity of Joint Total Relevant Cost (JRTC) to $^{A_S}/_{(Z_S+Z_B)}$

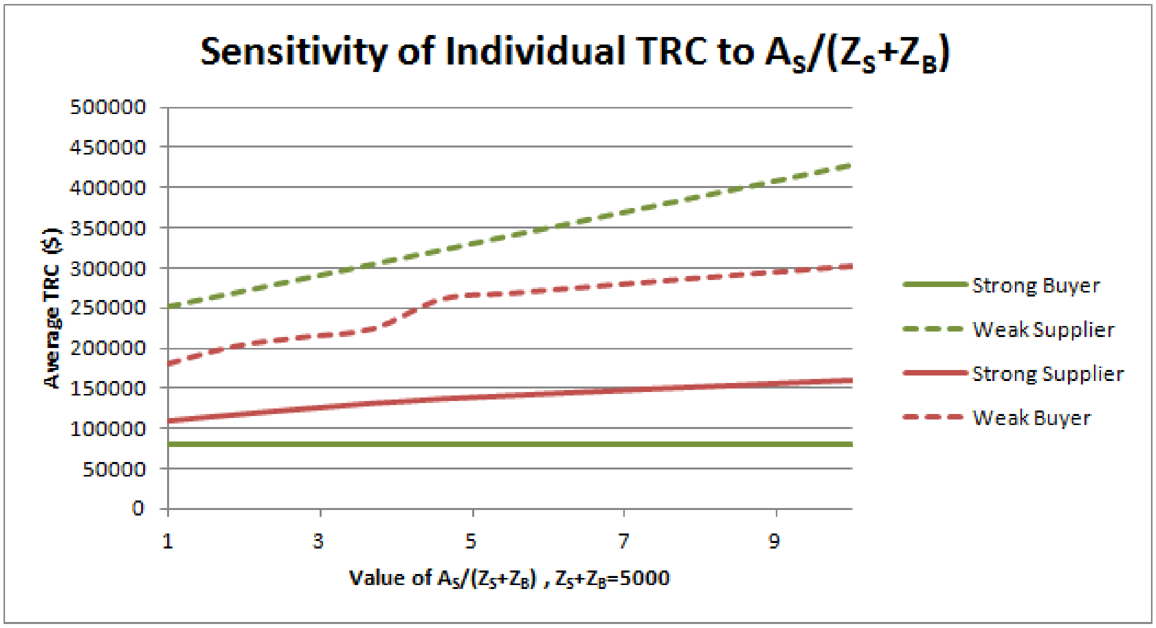

Figure 4.12: Sensitivity of Individual Total Relevant Cost (TRC) to $^{A_S}/_{(Z_S+Z_B)}$

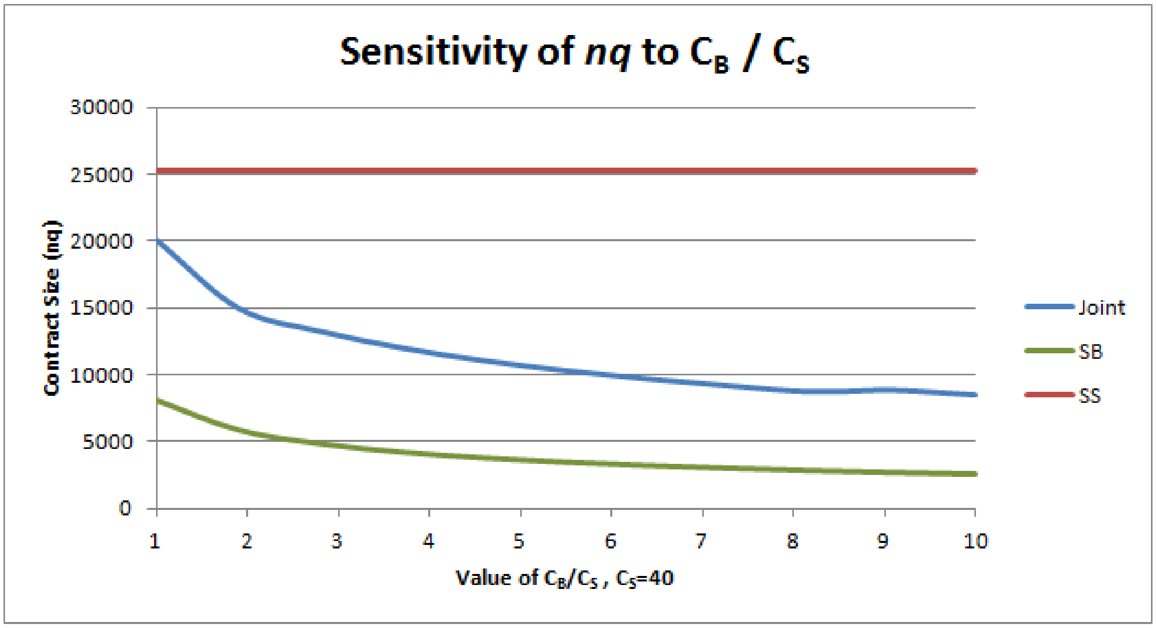

Figure 4.13: Sensitivity of Contract Size ($nq$) to ${}^{C_B}/{}_{C_S}$

but also somewhat hidden in the holding costs. We recall the formulations for the commitment costs and holding costs are $L_iC_i\frac{nq}{2}$ and $h_i = r_iC_i$, respectively. Since $C$ is directly proportional to both our commitment and holding costs, we should expect a large effect from changes in ${}^{C_B}/{}_{C_S}$ and we are not disappointed. In Figure 4.13, we see the optimal Joint contract size rapidly decrease and move from being closer to SS to being closer to SB. This occurs because both the buyer and joint optimal $q$ drops rapidly while $n$ remains unchanged or even, counter-intuitively, increases.

In Figure 4.14, it is shown that the supply chain costs are fairly similar even though all policies differ dramatically. We can see the power of joint optimization in this example as the savings potential increases rapidly with an increasing ${}^{C_B}/{}_{C_S}$. Having a weak buyer's costs increase quickly is not surprising, but what is somewhat surprising is the rapid increase in cost for a weak supplier (see Figure 4.15). This is primarily caused by receiving extremely short contracts from a strong buyer due to the sharp increase in commitment costs. These short contracts force very large

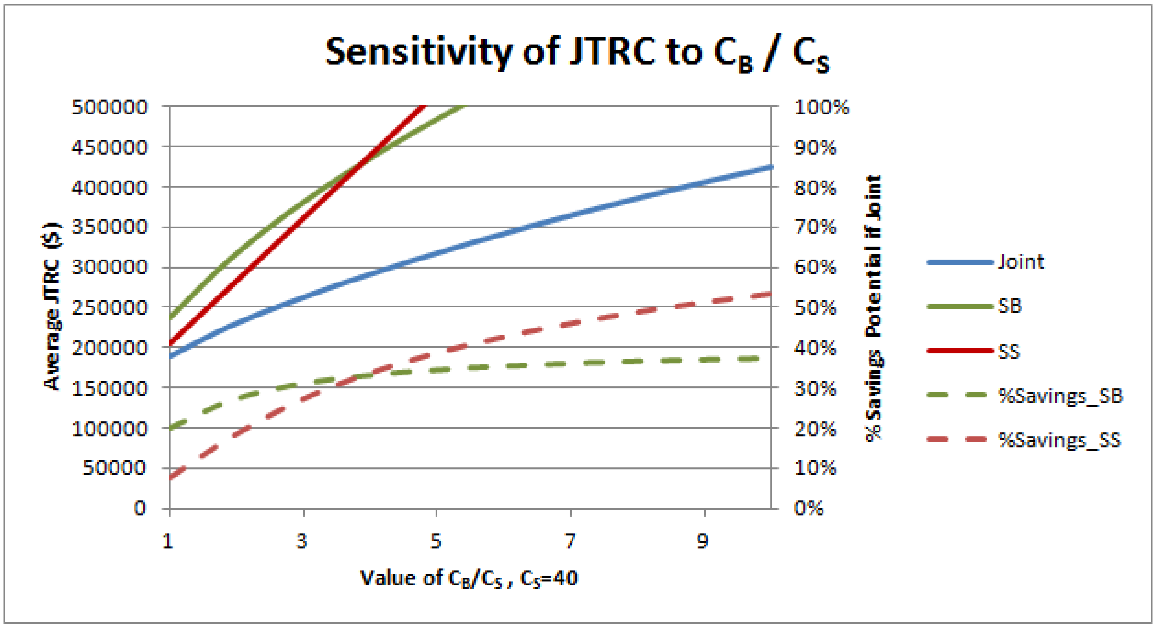

Figure 4.14: Sensitivity of Joint Total Relevant Cost (JRTC) to $C_B/C_S$

contract (e.g. tooling) costs onto the supplier. However, due to the increased profit margin that comes from a large $C_B/C_S$, the net profit for a weak supplier actually increases despite the sharp increase in costs. The opposite is true for a weak buyer, which only faces increasing costs.

### 4.4.6 Sensitivity to $A_B/OTC_S$

In stark contract to the previous ratios, as $A_B$ increases relative to $OTC_S$, the preferred contract quantities begin to converge. Both of these are one-time contract costs such as tooling or legal fees. If $A_B \ll OTC_S$, then we see a buyer that is relatively unconcerned about amortizing up-front costs, and thus chooses a smaller $n$. As $A_B$ approaches $OTC_S$, the buyer prefers a larger n with little change in $q$. In this manner, it is the complement of $L_B$, playing a similar, though opposite, role in our calculation.

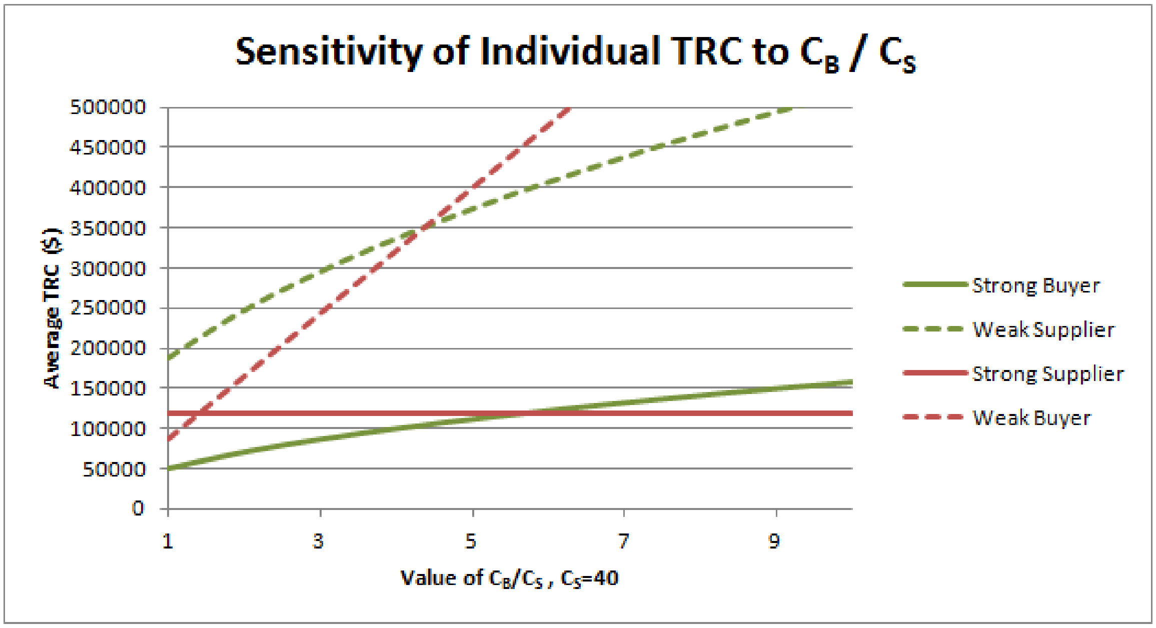

Figure 4.15: Sensitivity of Individual Total Relevant Cost (TRC) to $C_B/C_S$

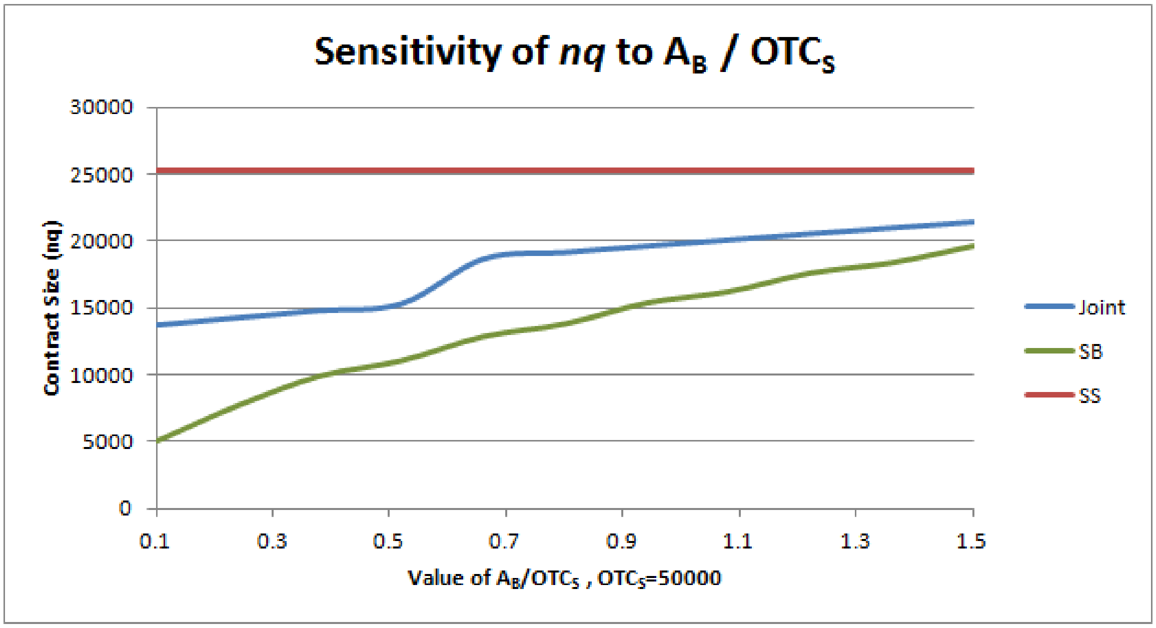

Figure 4.16: Sensitivity of Contract Size $(nq)$ to $A_B/OTC_S$

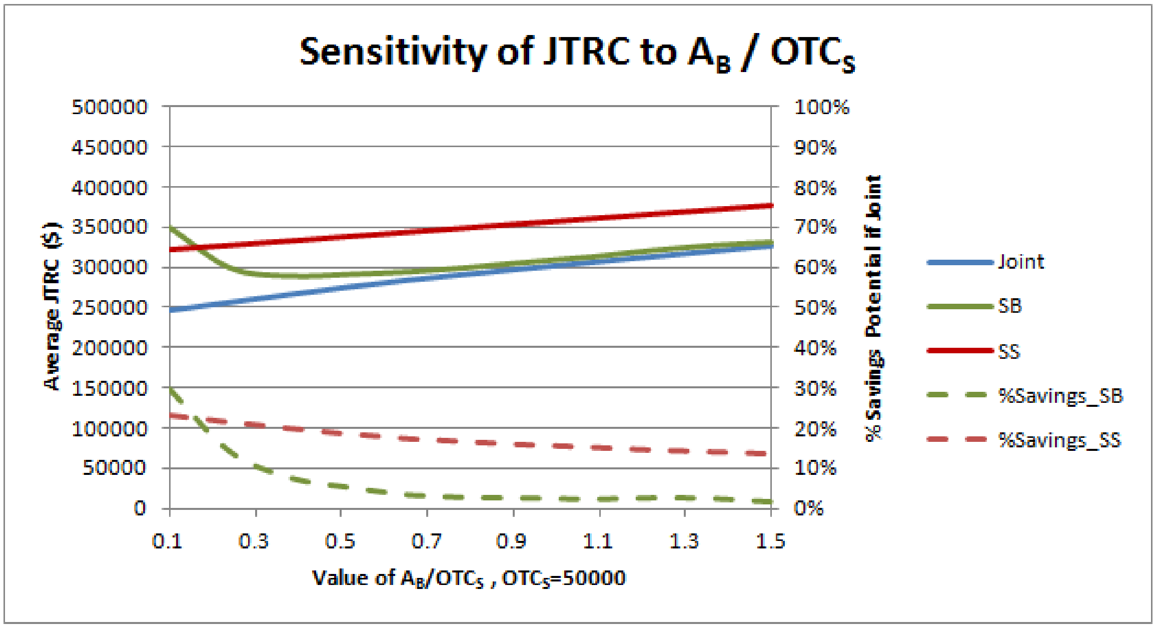

Figure 4.17: Sensitivity of Joint Total Relevant Cost (JRTC) to ${}^{A_B}/_{OTC_S}$

In Figure 4.17, we see that as $A_B$ approaches $OTC_S$, we reach a very efficient Strong Buyer case, with possible savings of only 5% at a 0.5 ratio, continuing down to about 2% when $A_B = OTC_S$. Figure 4.18 shows relatively close-grouped and somewhat parallel lines over most of the sensitivity range, informing us that neither weak party is particularly susceptible to a stronger partner. On the contrary, we observe a rare case where the weak supplier benefits quickly from the rising cost of the strong buyer. This is opposite of what we saw with ${}^{L_B}/_{L_S}$.

### 4.4.7 Sensitivity to ${}^{P}/_{D}$

Our final sensitivity analysis is focused on the ${}^{P}/_{D}$ ratio. As neither demand nor capacity have a logical bearing on contract commitment, it is not surprising to find relatively straight lines in Figure 4.19. The most important ratios to consider here are 1 through 5, which represent demands of 100% of capacity to 20% of capacity,

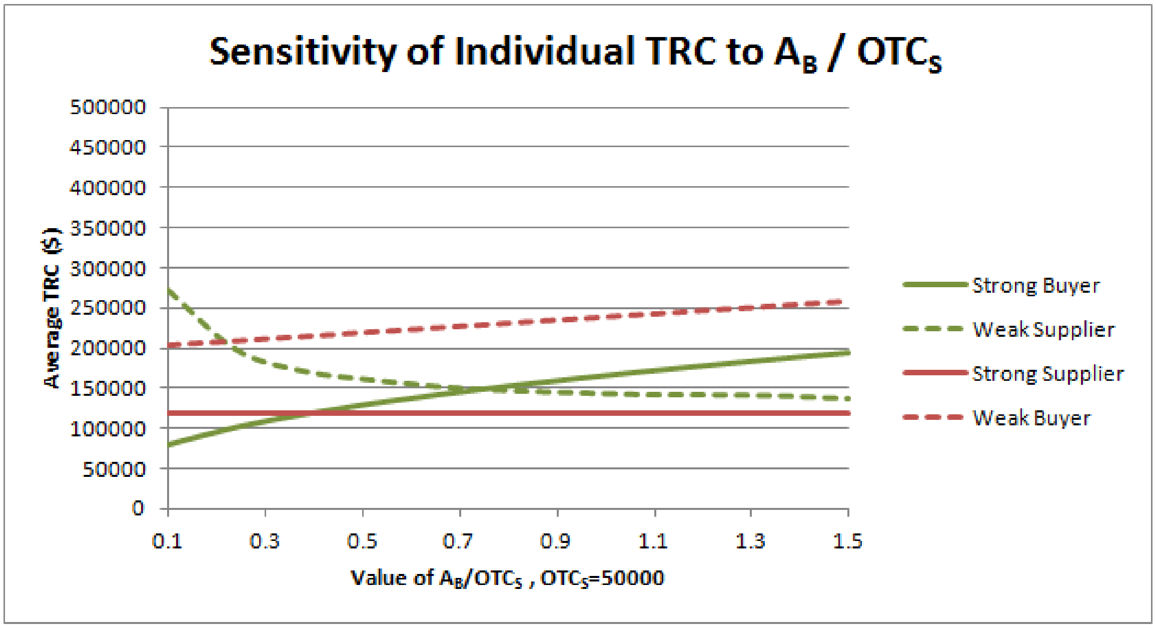

Figure 4.18: Sensitivity of Individual Total Relevant Cost (TRC) to $^{A_B}/_{OTC_S}$

respectively. At less than 20%, we can safely consider the buyer a "small player" for the supplier.

The joint total relevant costs shown in Figure 4.20 show us that there is a switch around 25% of capacity ($^{P}/_{D} = 4$) where the higher costs and savings potential change from the SB case to the SS case. This change coincides with a strong supplier moving to an $n = 1$ policy (to achieve a high $q$) to minimize batch and delivery costs at the slight expense of increased holding costs.

### 4.4.8 Summary of Sensitivity Analyses

The presented sensitivity analyses allow us to better understand some of the fundamental relationships in the model and form some expectations for the numerical analysis in Section 4.5. From the $^{D}/_{P}$ analysis, we do not expect a heavy influence on possible savings unless the $^{D}/_{P}$ ratio is close to 1. This is mostly attributed to the added expense of the supplier that must balance production capabilities with delivery

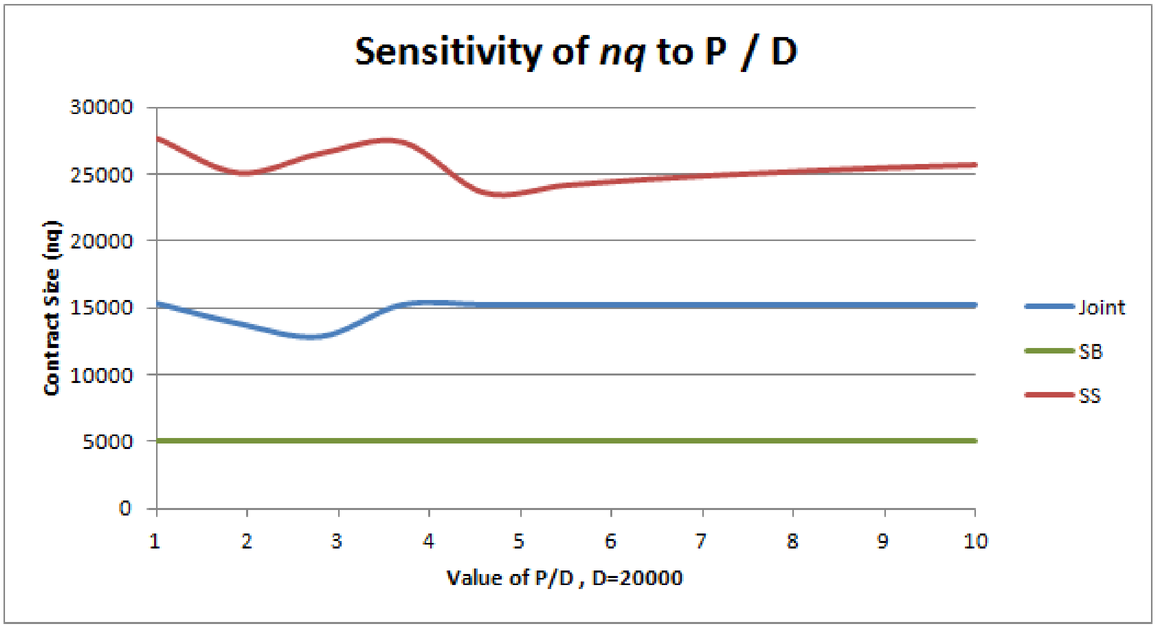

Figure 4.19: Sensitivity of Contract Size ($nq$) to $^P/_D$

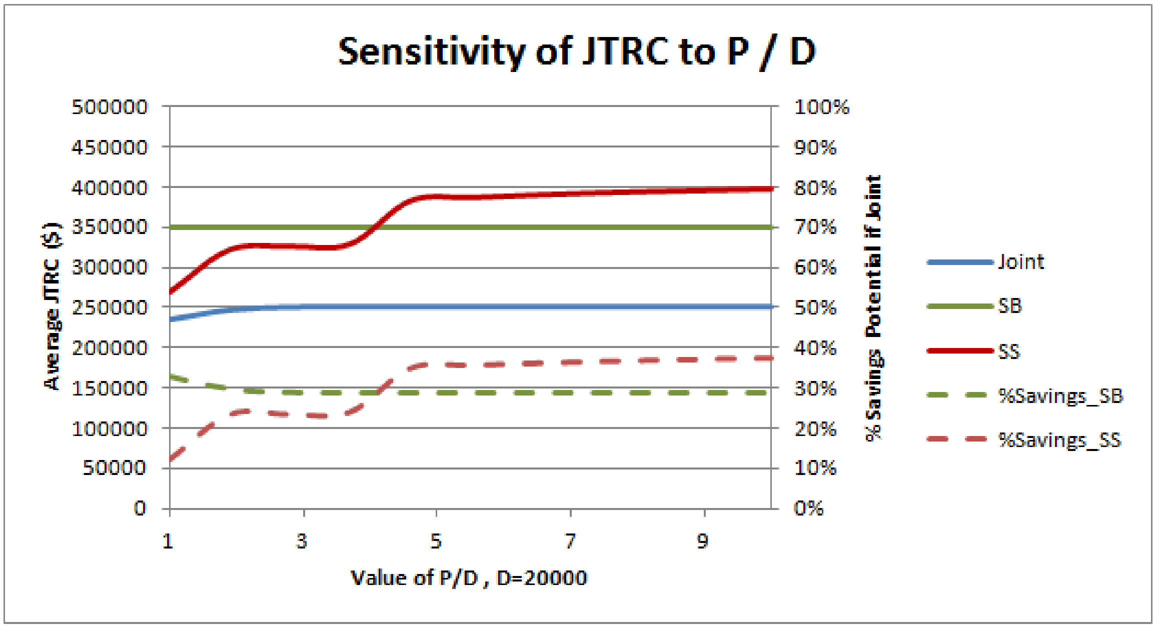

Figure 4.20: Sensitivity of Joint Total Relevant Cost (JRTC) to $^P/_D$

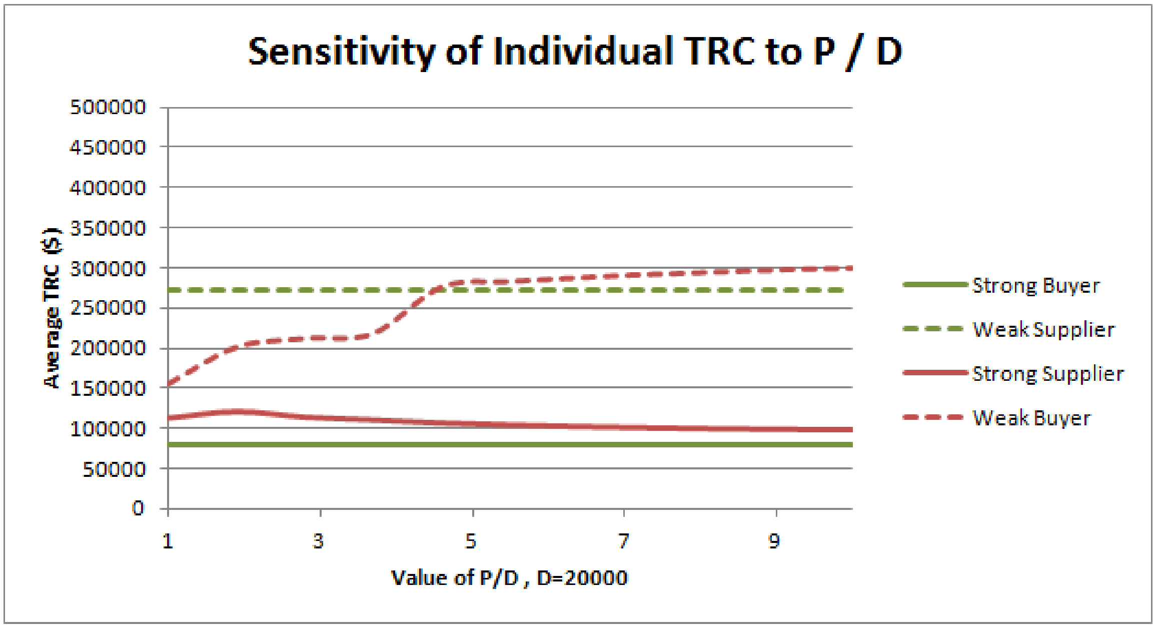

Figure 4.21: Sensitivity of Individual Total Relevant Cost (TRC) to $^P/_D$

promises. This creates a need for increased use of batch splitting. From examining the one-time costs, we can only predict issues if $A_B \ll OTC_S$ and $OTC_S$ in a Strong Buyer scenario. As the part costs diverge, we expect a very fast increase in potential savings, particularly with a strong supplier. The per-delivery costs and capital costs appear to have minimal effect on the possible savings. Finally, from evaluating the relationship of commitment cost rates ($^{L_B}/_{L_S}$), we expect lower savings for a relatively low $L_B$ or a relatively high $L_S$.

## 4.5 Numerical Analysis and Guidance

This section will be divided into four (4) parts. The first part will describe the test setup and methodology for the numerical example. The next portion will interpret the results from the perspective of a strong buyer (SB). The third will interpret the results from the perspective of a strong supplier (SS). The following section will approach the problem from the perspective of a neutral third party. The fifth and final part will attempt to put all the findings together into a cohesive conclusion to help provide insight and guidance. The most critical performance measurement is savings as a percent of total relevant cost by jointly minimizing relevant supply chain rather than individual minimization. This measure is independent of scale and allows us to directly explore the relative impacts of factors without interpretation or adjustment.

### 4.5.1 Test Setup and Methodology

To provide a meaningful numerical example, the scenario parameters were carefully selected to mimic a wide range of plausible scenarios. These are loosely based on the values used by Kelle et al. (2007), but with some notable changes and additions.

Consider a supplier with a production capacity of 40,000 units per time-period. Demand is unclear and may take almost any value up to the production capacity. Buyers pay \$2500 for a domestic delivery ($Z_B$), but twice that for international deliveries. Similarly, contracting costs ($A_B$) are \$5000 for some buyers, but twice that for others. These factors are independent of each other. The supplier has built a reputation on an "everyday low price" of \$100, regardless of order size, and refuses to negotiate price. Holding cost rates are standard across the industry at 15%. The supplier's per-order (with contract and tooling costs), per-batch, and per-unit production costs are constant at \$50,000, \$10,000, and \$40, respectively. Both the buyer and supplier determine commitment cost rates based on a long list of situational factors. These rates range from 0.01 to 0.15. It is unknown which party, buyer or supplier, will be in the stronger negotiating position.

To study this range of possible scenarios, 9900 sample scenarios were created. In each iteration, the demand was increased by four (4), with the remaining parameters determined by the probabilities described above and summarized in Table 4.4. To determine the optimal decision variables for each sample scenario's parameters, the BONMIN solver was deployed via AMPL programming. Optimal decision variables were recorded for three (3) possibilities: an extremely strong buyer, an extremely strong supplier, or perfect cooperation. Generating each set of solutions required approximately 0.5 to 1 second of processing time on an Intel i5-2520M CPU, with all 9900 samples requiring approximately 75 minutes of CPU time. Generous upper bounds and constraints for decision variables were designated to prevent potential solver issues. As expected, no results were found to be bounded by the solver feasibility parameters or constraints. However, it should be noted that this is not guaranteed for all possible parameter choices, as we would expect infeasibility in the case of $L_B = 0$, as discussed at length in the previous chapter.

The main advantage of the above process is a near-complete[3] and even representation of ${}^{D}/_{P}$ ratios while we investigate other factors. This ensures that we can easily and evenly segment the samples for analysis based on different ranges of ${}^{D}/_{P}$ ratios. The supplier numbers (save $L_S$) are kept constant for a similar rationale.

In the first scenario ("Scenario 1"), we vary only $L_B$ and $L_S$ to investigate the "pure" effects of each factor. In the second scenario, we add $Z_B$ and $A_B$ to the analysis, reflecting the situation described at the beginning of the section. The commitment costs in this numerical analysis will be in the same format for both the buyer and supplier, expressed as a cost on parts yet-to-be-delivered. This yields relevant cost formulas of:

$$TC_B(n,q) = \left[h_B \frac{q}{2} + Z_B \frac{D}{q}\right] + \left[A_B \frac{D}{nq}\right] + L_B C_B \frac{nq}{2} \tag{4.7}$$

for the buyer, and

---

[3] Extremely low values of $D$ (<400) were avoided to preserve granularity and prevent other issues as the ${}^{D}/_{P}$ ratio approaches 0.

Table 4.4: Scenario Parameters

| Parameter | Scenario 1 | Scenario 2 |
|---|---|---|
| Description | “$L_B$ and $L_S$ Only” | “Scenario 1 with $Z_B$ and $A_B$” |
| $P$ | 40000 | 40000 |
| $D$ | $\{400, 404, \ldots 4k, \ldots 39996\}$ | $\{400, 404, \ldots 4k, \ldots 39996\}$ |
| $Z_B$ | 2500 | 2500 + 2500 w.p. 0.5 |
| $A_B$ | 5000 | 5000 + 5000 w.p. 0.5 |
| $C_B$ | 100 | 100 |
| $r_B$ | .15 | .15 |
| $L_B$ | Unif(0.01,0.15) | Unif(0.01,0.15) |
| $Z_S$ | 2500 | 2500 |
| $A_S$ | 10000 | 10000 |
| $C_S$ | 40 | 40 |
| $r_S$ | .15 | .15 |
| $otc_S$ | 50000 | 50000 |
| $L_S$ | Unif(0.01,0.15) | Unif(0.01,0.15) |
| $h_B$ | $= r_B * C_B$ | |
| $h_S$ | $= r_S * C_S$ | |

$$TC_S(m,n,q) = h_S\frac{mq}{2}\left[1-\frac{D}{P}-\frac{1}{m}+\frac{2D}{mP}\right]+Z_S\frac{D}{q}+A_S\frac{D}{mq}+L_SC_S\frac{nq}{2}+OTC_S\frac{D}{nq} \quad (4.8)$$

for the supplier, with the joint total cost, $TC_J(m,n,q)$, being the simple addition of the two.

### 4.5.2 Perspective from a Strong Buyer (SB)

Using only a simple breakdown of potential savings by $L_B$ categories of Low_LB (.01-.0249), Med_LB (.025-.049), and High_LB (.05-.15), it is clear that there is a

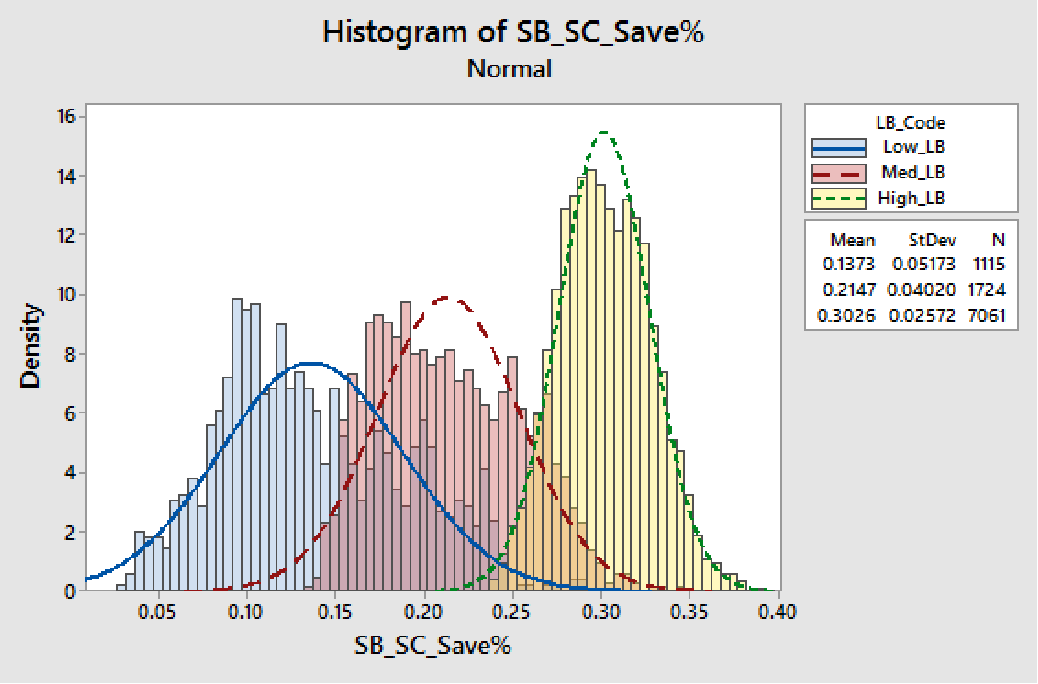

Figure 4.22: Distribution of Supply Chain Savings Percentage by $L_B$ Category

relationship between savings[4] and $L_B$ in Scenario 1. A cubic regression yields $R^2 = 0.717$ with a p-value = 0.000. This relationship is shown in Figure 4.23.

A closer inspection of this scatterplot shows a clearly stepped relationship between supply chain savings and the $L_B$ rate. In fact, these steps occur at conspicuous $L_B$ rates of 0.015, 0.025, and 0.05. These steps also coincide perfectly with a strong buyer's choice of $n$. This is demonstrated in figure 4.24. This "coincidence" might not seem terribly surprising considering that the only factors varying to the buyer in this analysis are demand and $L_B$. However, as these are savings to the entire supply chain, we must remember that we are clearly seeing these steps while the ${}^{D}\!/_{P}$ ratio and the $L_S$ rate, both allowed to vary widely, also play a role to the supplier's costs.

---

[4] Note that all saving percentages presented in graphs and tables are in decimal format (e.g. 0.3 = 30%) regardless of categorical label.

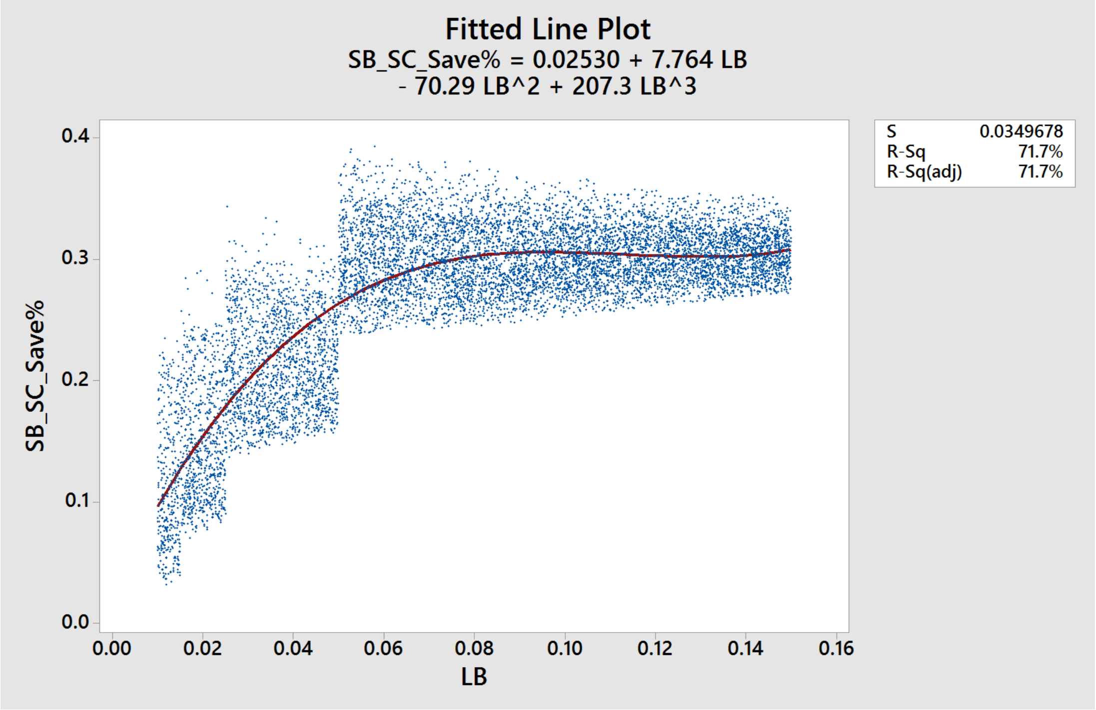

Figure 4.23: Cubic Regression Predicting Supply Chain Savings Using $L_B$

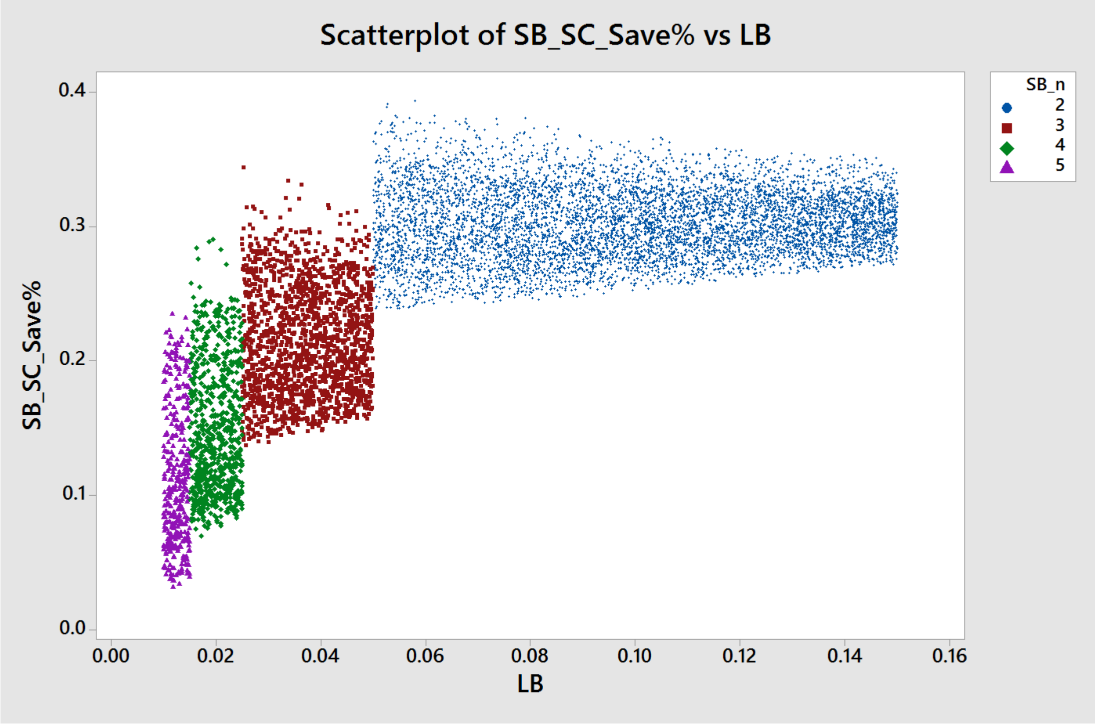

Figure 4.24: Supply Chain Savings Grouped by a Strong Buyer's Optimal Number of Shipments $(n)$

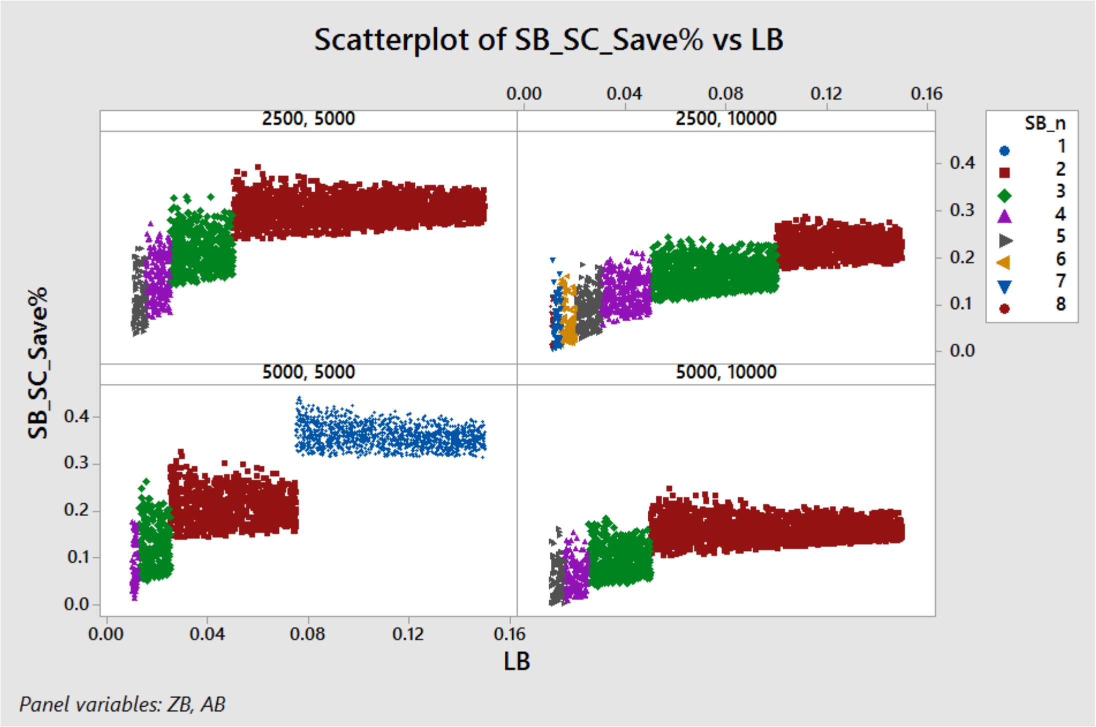

Figure 4.25: Supply Chain Savings Grouped by SB $n$ and Paneled by $A_B$ and $Z_B$

To better understand other factors and interplay between terms that could influence the supply chain savings, we will allow two of the buyer's costs to fluctuate. In Scenario 2, $A_B$ is allowed to take either of two values: 5000 or 10000 and $Z_B$ is also allowed two values: 2500 or 5000. Each of the values has a 50% chance of being used in each run, providing us four potential combinations. The analogous scatterplot to Figure 4.24 is presented in Figure 4.25.

To help explain these results, we can investigate the formulas more closely. Assuming relaxation of the integer constraint, we can calculate the optimal number of deliveries for a strong buyer (SB):

$$\widehat{n_B} = \sqrt{\frac{A_B h_B}{L_B C_B Z_B}} = \sqrt{\frac{A_B}{Z_B}\frac{r_B}{L_B}}. \tag{4.9}$$

From this equation, we predict the $L_B$ cutoffs to be 0.01, 0.0148, 0.0245, 0.048, and 0.133 to produce $\widehat{n_B}$ values of 5,4,3,2, and 1, respectively. These match closely to the observed values of 0.015, 0.025, and 0.05 for $n$ values of 4,3, and 2, respectively. Contrary to the prediction, an $n$ of 1 was not observed in the results after 0.133.

Note from the relaxed optimal solution that the value of $\widehat{n_B}$ will approach $\infty$ as either $L_B$ or $Z_B$ approach 0. However, the intuition concerning these two parameters is completely different. As $L_B$ approaches 0, there is no cost of commitment, therefore the contracted quantity will increase without bound. Conversely, as $Z_B$ (the buyer's receiving cost) approaches 0, the buyer will request ever smaller delivery quantities to minimize holding costs. Thus, $q_B$ will decrease (in practice limited to 1), requiring ever larger $\widehat{n_B}$ to compensate and meet demand.

If only $A_B$ increases, the buyer faces a situation closer to the supplier with high setup costs. This will give lower potential supply chain savings since both parties will want similar terms. This can be seen in Figure 4.25 by comparing the upper-left and lower-right corners, both with the same $A_B/Z_B$ ratio, but the latter with a higher $A_B$. Here, the $n_B$ is the same for a given $L_B$, but the potential savings are cut approximately in half from 26.8% to 13.9%.

If only $Z_B$ increases, the buyer will want more units per delivery due to the receiving cost becoming increasingly important over the relatively decreasing holding cost, leaving fewer deliveries ($n$) required for a given contract length.

From Equation 4.9 above, we would expect an analogous interpretation based on the $r_B/L_B$ ratio. The intuition in this case is rather interesting, since $r_B$ is the holding cost rate of parts-on-hand while $L_B$ is the opportunity cost of parts yet-to-be-delivered. This forces us to balance more deliveries, reducing our need to pay for parts in storage with the commitment cost on parts in future deliveries. In other

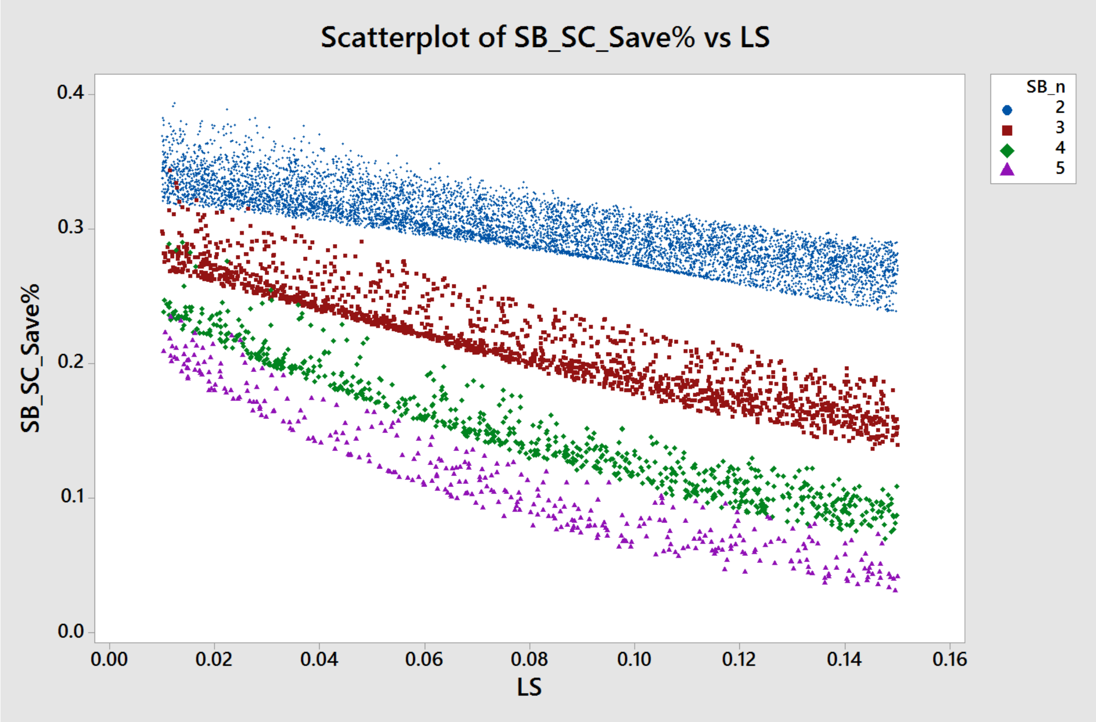

Figure 4.26: Potential Supply Chain Savings against the Supplier's Cost of Commitment ($L_S$) by SB Choice of $n$

words, a higher $r_B$ encourages smaller deliveries, while a higher $L_B$ encourages lesser commitment.

As mentioned above, the total supply chain savings are also contingent upon the supplier's parameters. However, since the supplier's costs, including its cost of commitment has no bearing on a strong buyer's optimal decision variables, the changes in the supplier's parameters can be interpreted as a variance in the potential savings graphs above. This motivates us to explore the effect of an important cost component of the supplier, $L_S$.

In Figure 4.26, we again see, perhaps not surprisingly, the influence of the strong buyer's choice of $n$. We also see that the potential supply chain savings clearly decline as the supplier's cost of commitment $L_S$ increases. The intuition here is that for a

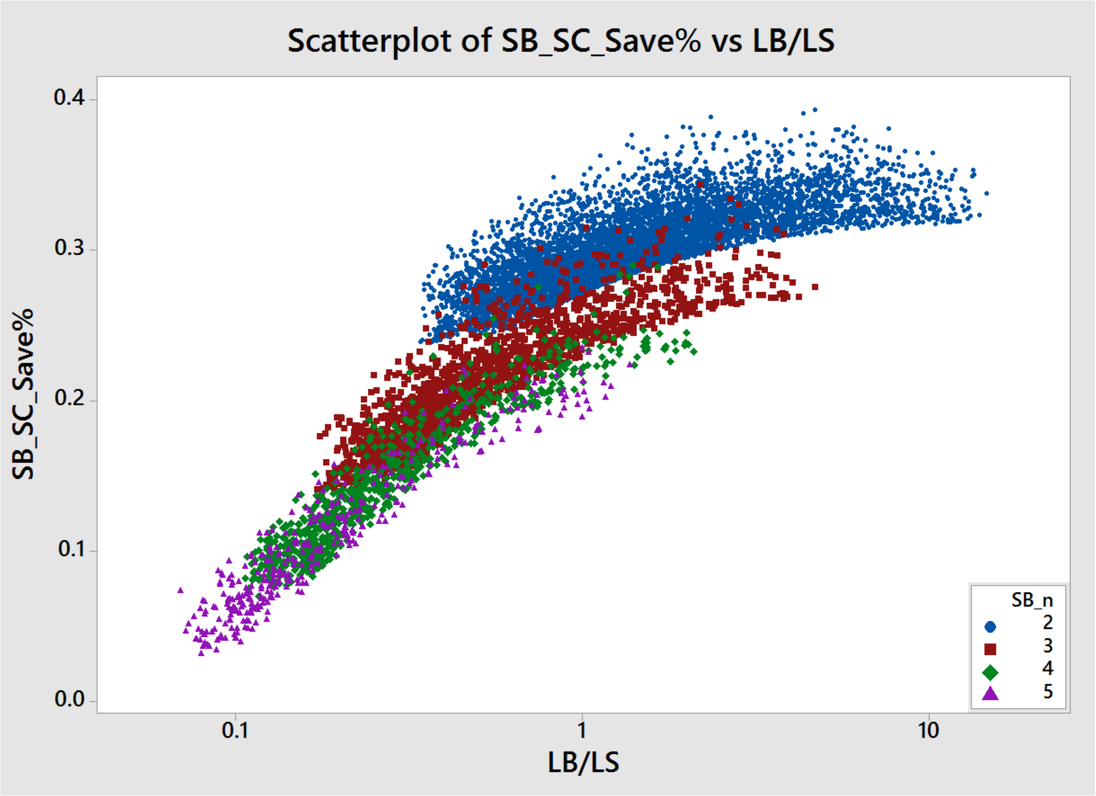

Figure 4.27: Potential Savings against ${}^{L_B}/_{L_S}$ with Log Scale for Scenario 1

given $n$, as $L_S$ increases, the supplier will have goals better aligned with the strong buyer, creating less opportunity for savings.

In Figure 4.27, a fairly linear relationship between potential savings and $log\ ({}^{L_B}/_{L_S})$ is seen. A quadratic regression yields a high $R^2 = 0.86$ with a p-value $= 0.000$. This increases to a very high $R^2 = 0.94$ when combined with knowledge of $n_B$. For ease of interpretation, the $x$-axis rather than the ratio is presented in log scale. Additionally, we observe some clustering based on the strong buyer's choice of $n$, with $n = 2$ being particularly distinct. Putting these insights together, we can conclude that a supplier faced with a strong buyer will have a major incentive to accurately predict the buyer's relative commitment costs. Since $L_S$ and $n_B$ are already known, even a ballpark estimate of $L_B$ should provide a large indicator of potential savings. This

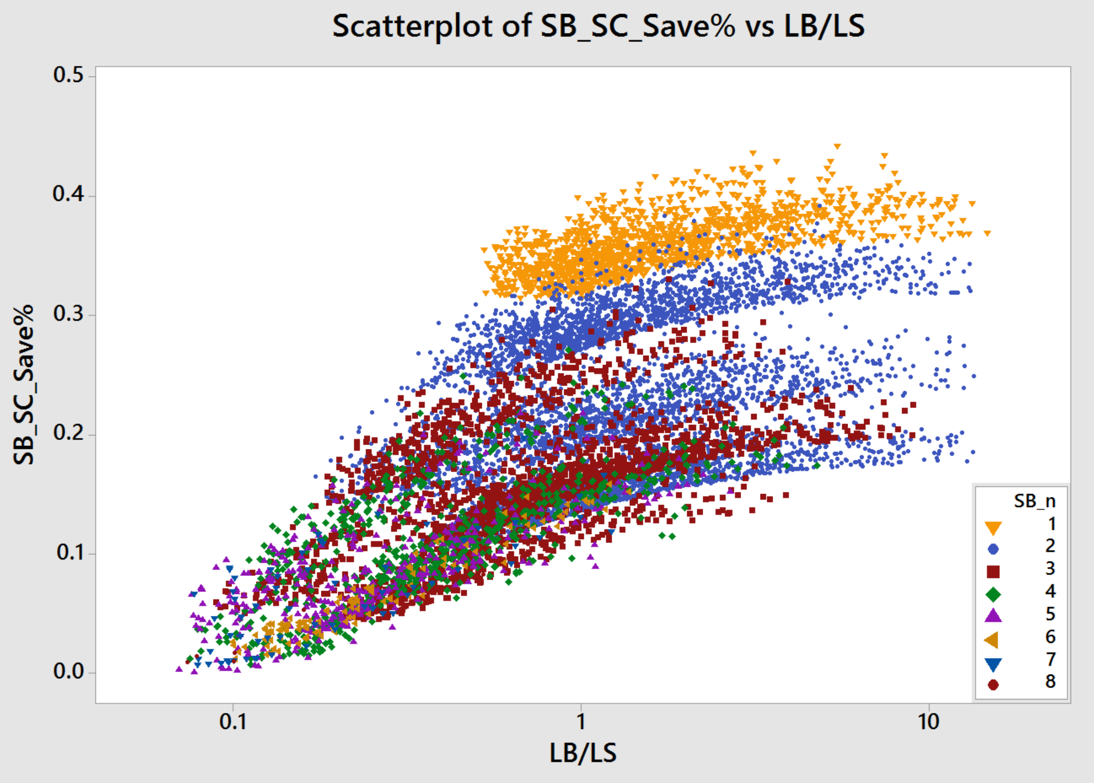

Figure 4.28: Potential Savings against ${}^{L_B}/_{L_S}$ with Log Scale for Scenario 2

holds true, though to a lower extent, in Scenario 2, where $A_B$ and $Z_B$ are each allowed to double in value. The analogous graph for this scenario is shown in Figure 4.28, where $R^2$ has fallen from 0.94 to 0.71 due to the introduction of the varying $A_B$ and $Z_B$.

#### 4.5.2.1 Supplier's Response to Strong Buyer

Since $m$ is the only decision for a supplier faced with a strong buyer, it is beneficial to explore the effects of the buyer's choice of $n$. In Tables 4.5 and 4.6, the cross tabulations of $m$ and $n$ decisions are shown for both scenarios. In the first scenario, we only observe that $n = m$,

Table 4.5: Supplier's Choice of $m$ against Buyer's Choice of $n$ for Scenario 1

| $m \downarrow / n \rightarrow$ | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|
| 2 | 7061 | 0 | 0 | 0 | 7061 |
| 3 | 0 | 1724 | 0 | 0 | 1724 |
| 4 | 0 | 0 | 751 | 0 | 751 |
| 5 | 0 | 0 | 0 | 364 | 364 |
| Total | 7061 | 1724 | 751 | 364 | 9900 |

Table 4.6: Supplier's Choice of $m$ against Buyer's Choice of $n$ for Scenario 2

| $m \downarrow / n \rightarrow$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1372 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1373 |
| 2 | 0 | 5251 | 0 | 74 | 0 | 0 | 0 | 0 | 5325 |
| 3 | 0 | 0 | 1998 | 0 | 0 | 53 | 0 | 0 | 2051 |
| 4 | 0 | 0 | 0 | 646 | 0 | 0 | 0 | 7 | 653 |
| 5 | 0 | 0 | 0 | 0 | 368 | 0 | 0 | 0 | 368 |
| 6 | 0 | 0 | 0 | 0 | 0 | 61 | 0 | 0 | 61 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 63 | 0 | 63 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 |
| Total | 1372 | 5251 | 1998 | 720 | 369 | 114 | 63 | 13 | 9900 |

With a strong buyer, the supplier is only left with deciding on an optimal number of shipments per batch, $m_S$. Therefore, given $n_B$ and $q_B$ by the strong buyer, we can calculate the relaxed optimal $\widehat{m_S}$ for the supplier as follows:

$$\widehat{m_S}(q_B) = \frac{1}{q_B}\sqrt{\frac{2A_S D}{h_S(1 - {}^{D}\!/\!{}_{P})}}. \tag{4.10}$$

The optimal $m_S$ can be found with the following algorithm:

1. If $\widehat{m_S} \geq n_B$, then $m_S = n_B$
2. If $\widehat{m_S} \leq 1$, then $m_S = 1$
3. Otherwise, compute upper and lower candidates for $m_S$
    (a) Upper candidate $m_U$ found by increasing $\widehat{m_S}$ until $\frac{n_B}{\widehat{m_S}} \in \mathbb{Z}^+$
    (b) Lower candidate $m_L$ found by decreasing $\widehat{m_S}$ until $\frac{n_B}{\widehat{m_S}} \in \mathbb{Z}^+$
4. Choose $m_S \in (m_U, m_L)$ based on $min\left(TC_{S|SB}(m_U), TC_{S|SB}(m_L)\right)$

Applying this algorithm to our data, we see the results summarized in Table 4.7. Note that the $m$ values used in the analysis were actually found using the BONMIN solver and not from the above algorithm. However, comparing the solver optimized values against the algorithm results, we find a 100% prediction accuracy, as expected.

If we further breakdown the results from the algorithm (see Table 4.8), we see that usually, but not always, the optimal $m$ will be the candidate closer to $\widehat{m_S}$ . This is due to the nature of the cost function curves and the reason we must test both candidates.

Table 4.7: Summary of Algorithm Applied to Results from Scenarios 1 and 2

| Case | Scenario 1 | Scenario 2 |
|---|---|---|
| $\widehat{m_S} > n_B$ | 9401 | 8907 |
| $\widehat{m_S}$ Increased and $m_U$ Used | 499 | 861 |
| $\widehat{m_S}$ Decreased and $m_L$ Used | 0 | 132 |
| Total | 9900 | 9900 |
| % Matching Algorithm | 100% | 100% |

Table 4.8: Breakdown of Algorithm Usage Applied to Results from Scenarios 1 and 2

| Case | Distance | Scenario 1 | Scenario 2 |
|---|---|---|---|
| $m_S = m_U$ with $m_U - \widehat{m_S} < \widehat{m_S} - m_L$ | Closer | 499 | 778 |
| $m_S = m_U$ with $m_U - \widehat{m_S} > \widehat{m_S} - m_L$ | Farther | 0 | 83 |
| $m_S = m_L$ with $\widehat{m_S} - m_L < m_U - \widehat{m_S}$ | Closer | 0 | 132 |
| $m_S = m_L$ with $\widehat{m_S} - m_L > m_U - \widehat{m_S}$ | Farther | 0 | 0 |
| Total | | 499 | 861 |

### 4.5.3 Perspective from a Strong Supplier (SS)

As discussed in previous sections, a strong supplier observing a cost of commitment ($L_S$) will dictate all decision variables in a contract. The buyer's response comes down to a simple "take it or leave it" decision. This leads to potentially gigantic cost savings opportunities in the supply chain due to the large inefficiencies introduced. In this section, we will examine the nature and interactions of the parameters onto the potential supply chain savings. We will predominately focus on the results from Scenario 1 as the differences in cost will have no effect on a strong supplier's decisions. Only significant differences between scenarios will be noted.

In Figure 4.29, savings as high as 60% are possible with a low $L_S$ value. In these same graphs, similar to the strong buyer's case, we observe some interesting

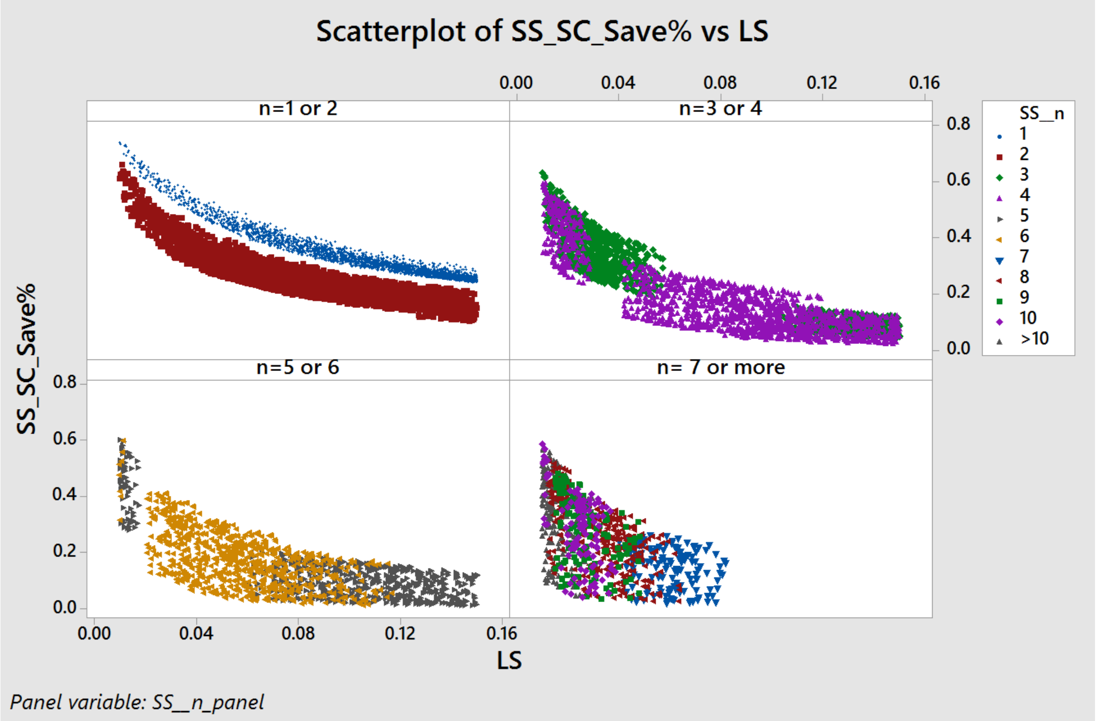

Figure 4.29: Potential Supply Chain Savings against the Supplier's Cost of Commitment ($L_S$), Grouped by SS Choice of $n$

relationships based on the strong supplier's choice of $n$, along with breaks and gaps within some choices of $n$, but not others. To better understand the causes behind these gaps, each of these four panels will also be divided by the $^D/_P$ ratio. These can be seen in Figure 4.30. Note that each of the four panels in Figure 4.29 have now been further broken down by the $^D/_P$ ratios. Quadrants moving from upper left (Q1) to lower right (Q4) have $^D/_P$ ratios of 0.01 to <0.25, 0.25 to <.5, .5 to <.75, and .75 to ~1.00, respectively.

A few things become apparent from these graphs. First, we can better understand the cause of some of the disjointed clusters of $n$ decisions stems as rooted in $L_S$ and the $^D/_P$ ratio. For example, in the lower left quadrant labeled "SS_n_panel = n=5 or 6", the previously disconnected clusters of $n$=5 now has the two groups of data points split between categories of $^D/_P$ ratio. This is repeated, to varying effectiveness,

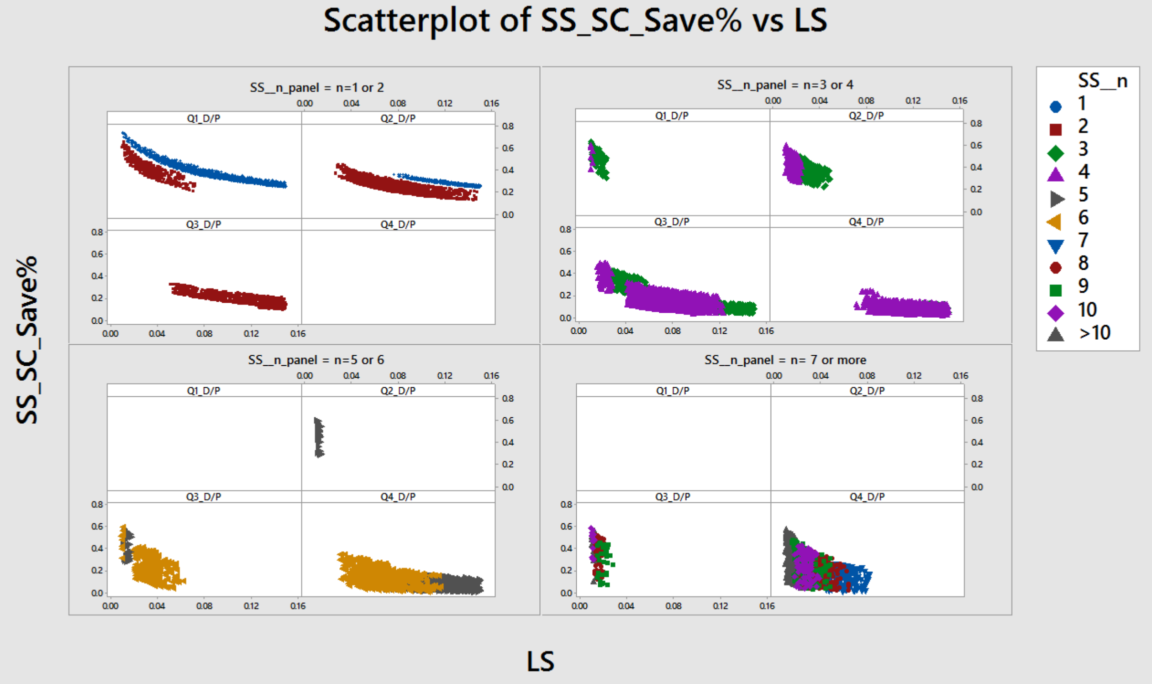

Figure 4.30: Potential Supply Chain Savings against $L_S$, Grouped by SS Choice of $n$, Paneled by $^D/_P$ ratio

for other choices of $n$. Considering only the case of $n$=2, we can see that as either the $^D/_P$ or $L_S$ increase, the savings diminish. The is mirrored by other choices of $n$, which in general informs us that we can expect lower potential savings when $L_S$ and $^D/_P$ are both high and higher potential savings when $L_S$ and $^D/_P$ are both low, regardless of $n$. Similarly, we see the influence of the $^D/_P$ ratio on $n$ by noting that if $^D/_P < 0.25$, we have $n \in (1, 2, 3)$ and if $^D/_P > 0.75$, we have $n \in (4, 5, 6, \ldots)$, regardless of $L_S$. The above conclusions are supported by both parametric or nonparametric tests. The interactions between $^D/_P$, $L_S$, and the supplier's choice of $n$ are shown in Figures 4.31, 4.32, and 4.33. Note that there are no surprising interactions between these three factors. However, in Figure 4.31, we see $^D/_P$ ratios in the third quartile displaying some surprisingly erratic behavior. Also, in Figure 4.33, we can see some interesting

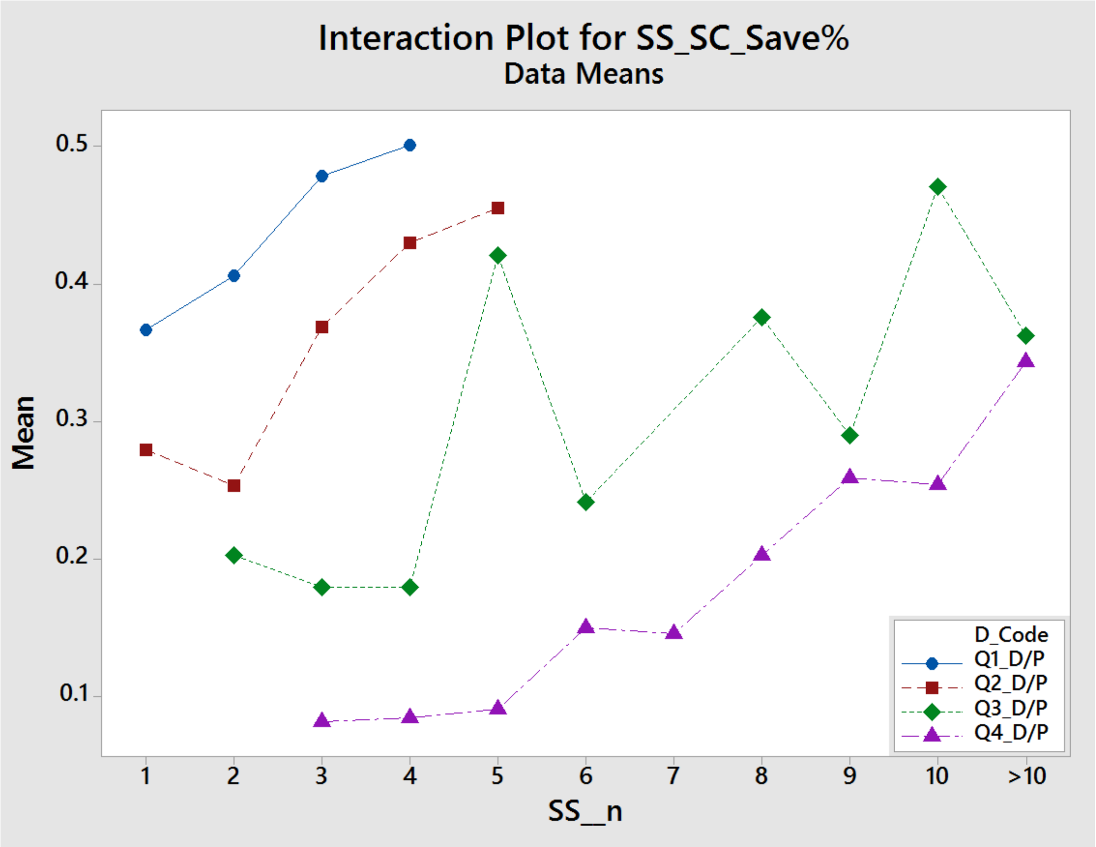

Figure 4.31: Interaction between ${}^{D}/{}_{P}$ Ratio and the Supplier's Choice of $n$ in Scenario 1

curves showing dips in the middle. This shape is due to the large savings at both high and low $n$ values, as can be seen in the earlier discussed Figure 4.30.

Further, we can confirm that a choice of $n$=1 is only made for ${}^{D}/{}_{P}$ ratios of less than 0.5. This can also be seen if we look at just $n$ vs $m$ as in Figure 4.34. In this figure, we can observe that if the ${}^{D}/{}_{P}$ ratio is less than 0.5, a SS will always choose $m$=1, as expected and shown by Kelle et al. (2007). Note that this holds even with the introduction of $L_S$ and $OTC_S$. However, we also see that this is no guarantee that $n$=1 or $n$=$m$. This suggests that even though it is advantageous to produce all parts at once (i.e. $m$=1) when the ${}^{D}/{}_{P}$ ratio is less than 0.5, it is better to commit to a longer contract in some cases.

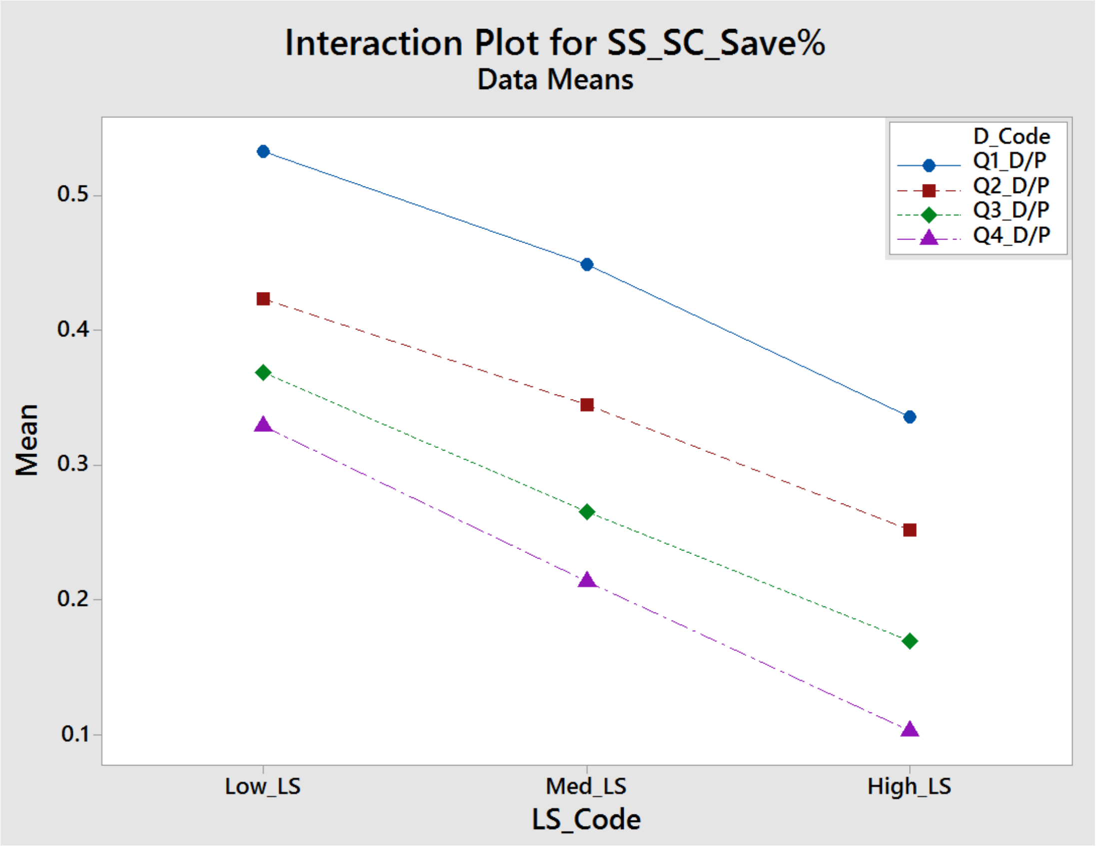

Figure 4.32: Interaction between $L_S$ and the ${}^{D}/{}_{P}$ Ratio in Scenario 1

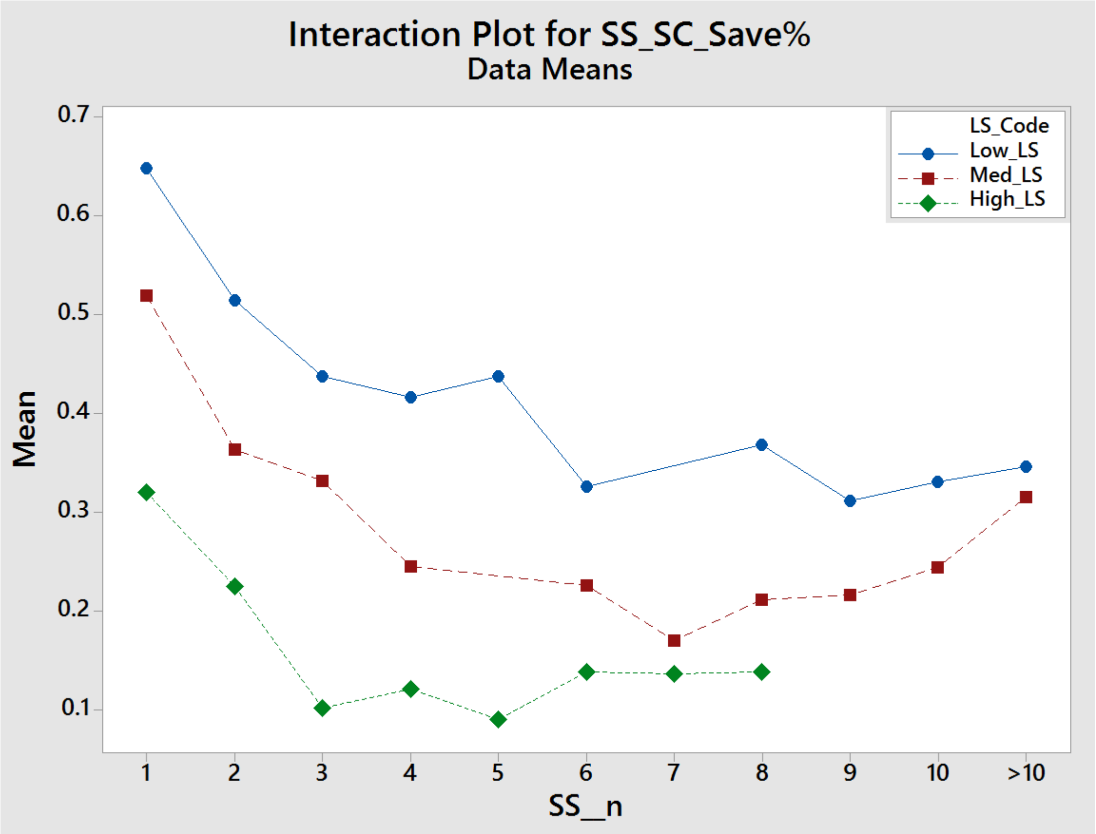

Figure 4.33: Interaction between $L_S$ and Supplier's Choice of $n$

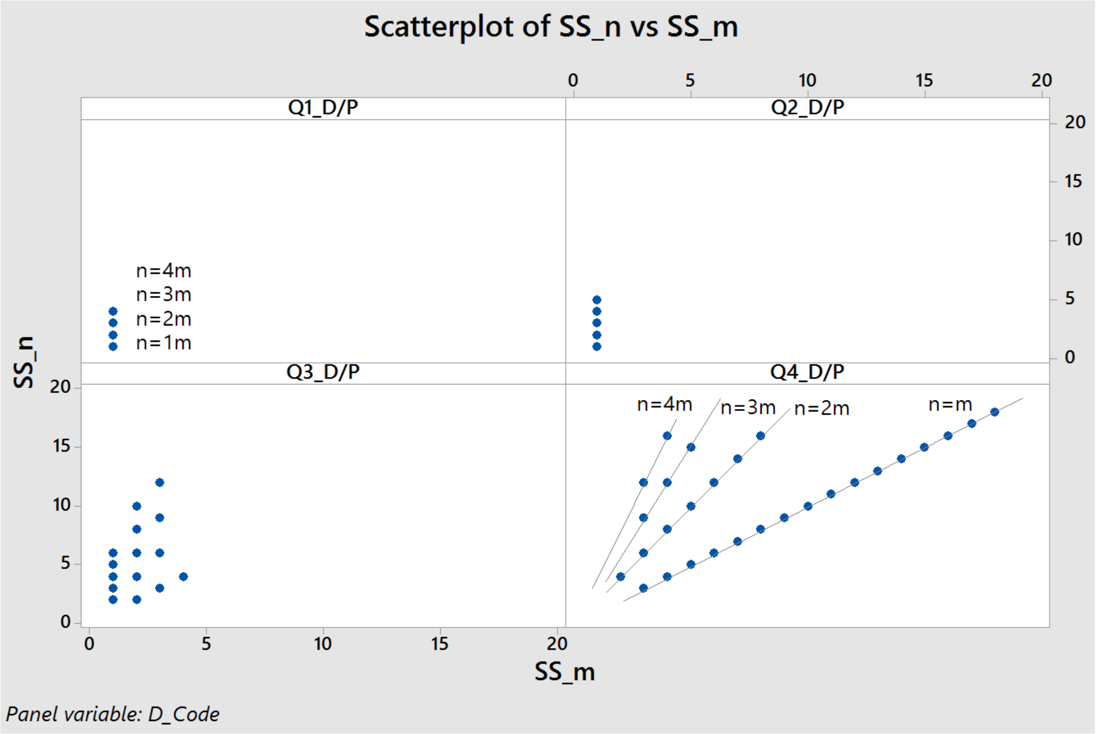

Figure 4.34: SS Choice of $n$ vs $m$, by ${}^{D}/{}_{P}$ Ratio in Scenario 1 or 2

#### 4.5.3.1 Buyer's Response to Strong Supplier

For a strong supplier with $L_{S_i} \neq 0$ for some $i$ and/or $OTC_S \neq 0$, all decision variables ($m$,$n$,$q$) will be decided by the strong supplier. The buyer will only have a “take it or leave it” decision for the proposed contract.

A strong supplier with $\forall i : L_{S_i} = 0$ and $OTC_S = 0$, will not have a preference for $n$, the number of deliveries per contract, and would rationally leave the decision to the buyer. Recall that for reasons emphatically stated in previous sections, this scenario is rather unrealistic. Rather, we will consider suppliers with an *effective* $\forall i : L_{S_i} = 0$ and $OTC_S = 0$ due to factors such as marketing, industry norms, or regulation. This is explored in-depth below in Section 4.6.

### 4.5.4 The Perspective from a Third Party Coordinator (3PC)

Until this point, we have only considered an unquestionably powerful strong buyer or supplier, followed by the weaker party's response. In this section, our goal is to investigate the ability of a third party to predict the potential savings of a supply chain provided limited information. The only information available to the 3PC are the terms known to all parties at the time of the negotiation. These terms are the supplier's preferred $n$ and $q$ ($n_S$, $q_S$), the buyer's preferred $n$ and $q$ ($n_B$, $q_B$), the demand ($D$), and the wholesale price, $C_B$. Of course, the preferred contract commitments ($nq$) for the buyer and supplier are also known by inference. There are two reasons to consider only the 3PC's ability to predict possible savings. First, from a practical viewpoint, a commission-based third party coordinator has an incentive to accurately predict the potential savings from cooperation and jointly optimized policies. Second, it provides us with a lower bound of either the buyer's or supplier's ability to predict the potential savings, an important aspect since we expect one of the parties (likely the weaker party) to recognize situations where there is the most to gain by bringing in outside assistance in coordination.

To conduct this analysis, a simulation experiment is performed in a manner analogous to Scenario 1 and 2. To prevent scaling issues, maintain consistent profit margins, and to ease interpretation, $P$, $C_B$, and $C_S$ are kept constant throughout the simulation while the 10 other parameters are allowed to vary widely. In a fashion similar to the previous section, we systematically simulate sets of parameters throughout virtually all possible ${}^{D}\!/_{P}$ combinations. The parameter ranges used are summarized in Table 4.9. We will use what was learned in the numerical example to aid in interpretation of these results.

We begin by taking a look at the overall summary of the results. Recall that our principal metric is savings as a percent of supply chain cost. The histograms showing

Table 4.9: Scenario Parameters for 3PC Perspective

| Parameter | Scenario 3 |
|---|---|
| Description | “Many Unknowns” |
| $P$ | 40000 |
| $D$ | $\{400, 404, \ldots 4k, \ldots 39996\}$ |
| $Z_B$ | Unif(0,5000) |
| $A_B$ | Unif(0,10000) |
| $C_B$ | 100 |
| $r_B$ | Unif(0.05,0.25) |
| $L_B$ | Unif(0.01,0.15) |
| $Z_S$ | Unif(0,5000) |
| $A_S$ | Unif(0,20000) |
| $C_S$ | 40 |
| $r_S$ | Unif(0.05,0.25) |
| $otc_S$ | Unif(0,100000) |
| $L_S$ | Unif(0.01,0.15) |
| $h_B$ | $= r_B * C_B$ |
| $h_S$ | $= r_S * C_S$ |

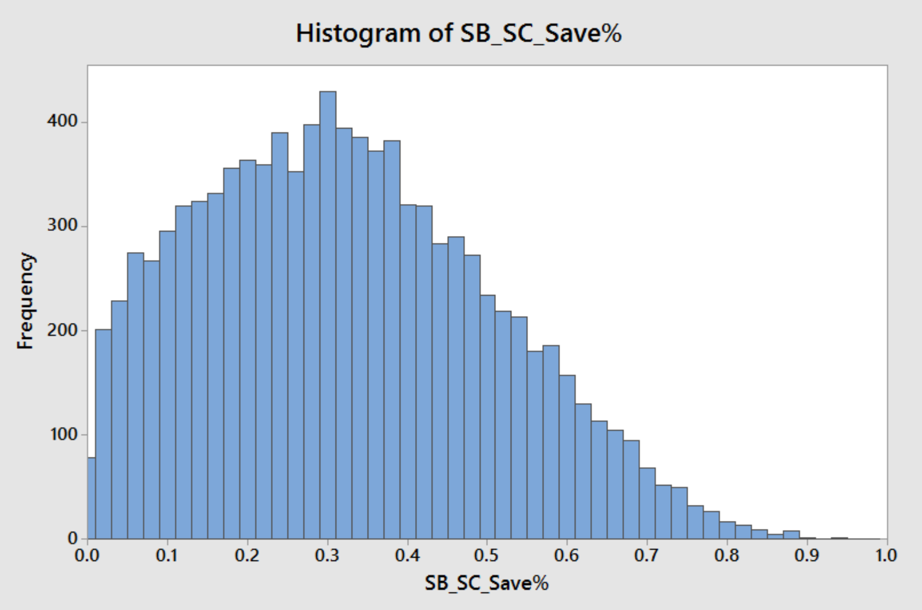

Figure 4.35: Histogram of Supply Chain Savings from Moving a Strong Buyer to a Jointly Optimal Policy

Table 4.10: Summary Statistics for Scenario 3

| Dominant | Mean | Std. Dev. | Min. | Q1 | Median | Q3 | Max. | Skew |
|---|---|---|---|---|---|---|---|---|
| Buyer | 32.3% | 18.3% | 0% | 18.0% | 31.0% | 45.1% | 97.4% | 0.37 |
| Supplier | 24.5% | 14.5% | 0% | 13.2% | 22.4% | 34.4% | 91.2% | 0.57 |

the savings achieved for moving a strong buyer or strong supplier to jointly optimal policies are shown in Figures 4.35 and 4.36, respectively. The summary statistics are shown in Table 4.10.

From the histograms and summary statistics we see that we have similarly shaped, uni-modal distributions with a minor right skew and are slightly platykurtic due to our inherently bounded savings limits. While not normal (see Figure 4.37), they are close enough that most of the analysis can be made with the assumption of normality with minimal loss in accuracy. The departure from normality appears to be caused

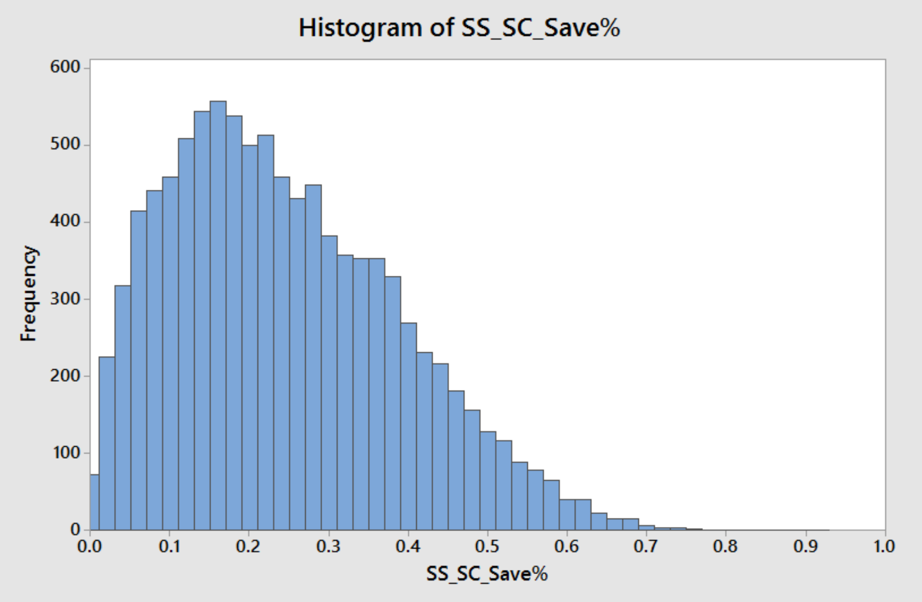

Figure 4.36: Histogram of Supply Chain Savings from Moving a Strong Buyer to a Jointly Optimal Policy

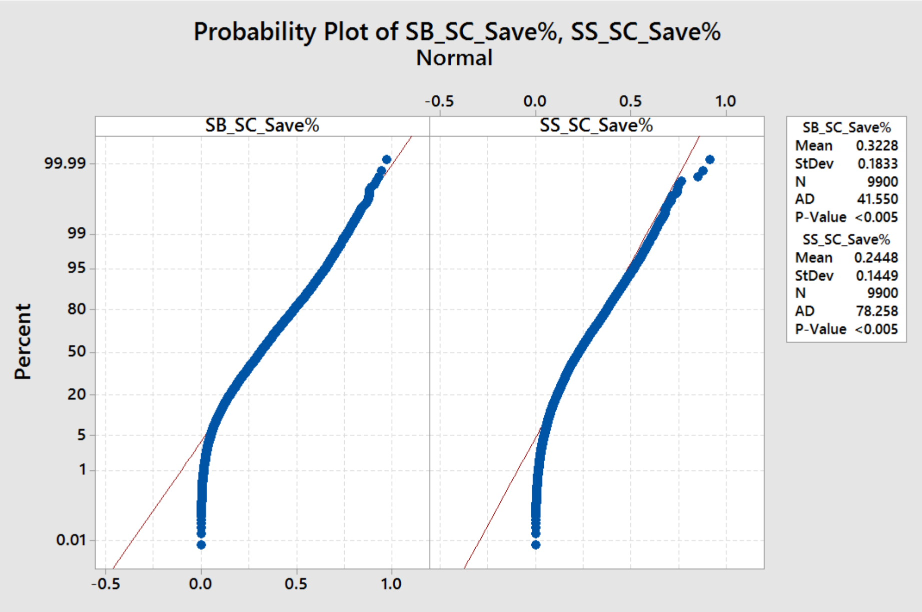

Figure 4.37: Normality of Results for SB and SS

by our lower limit of 0% savings. Analyses were repeated with data transformations. These transformations provided negligible improvement in predictive ability while adding difficulty to interpretation and are therefore omitted from this analysis.

From the above summary statistics, we see that a vast range of savings are possible with the ranges of parameters used. The problem for a third party is finding a reliable method to predict these potential savings so that money and effort are not wasted on ventures with small savings. We turn to stepwise and best subsets multiple regression in an effort to best predict savings based on the values known to all parties. Initial screenings were performed with all reciprocals, squares, and their cross-products, plus various ad-hoc combinations of the known decision variables to find promising candidates with explanatory power. These candidates were further narrowed using best subsets to find the best possible compromise between number of variables and explanatory power. The results of this analysis for a Strong Buyer case are summarized in Table 4.11. From this table, we can note that just three predictors, all forms of $\frac{n_S q_S}{n_B q_B}$, can explain more than 70% of the variation of saving percentages. This ratio of preferred contract quantities is shown to be both a simple and surprisingly powerful predictor. Assuming the 3PC requires a 30% savings to justify participation, we can test the performance of the regression in predicting profits. These results are summarized in Table 4.12 with 500 random samples presented in Figure 4.38.

The process was repeated for a Strong Supplier case with the results shown in Table 4.13. Again, we see a high ability to accurately predict savings. Unfortunately, an explanation of the predictors is not as simple as for the SB case. The ratio of desired contract sizes is still important, but overtaken by the raw values of preferred delivery sizes. Note that due to these being unscaled values, we would expect these to need modification based on the scale involved in the scenario, despite the rather

Table 4.11: Best Subsets Regression for Strong Buyer

| Predictors | $R^2$ | $R^2$ (Pred.) | S | $\frac{n_S q_S}{n_B q_B}$ | $\left(\frac{n_S q_S}{n_B q_B}\right)^2$ | $\left(\frac{n_S q_S}{n_B q_B}\right)^3$ | $\left(\frac{n_S q_S}{n_B q_B}\right)^4$ |
|---|---|---|---|---|---|---|---|
| 1 | 57.5 | 57.3 | 0.12 | x | | | |
| 2 | 68.6 | 68.1 | 0.10 | x | x | | |
| 3 | 73.5 | 73.1 | 0.09 | x | x | x | |
| 4 | 75.2 | 74.9 | 0.09 | x | x | x | x |

Table 4.12: Performance of 3PC's Prediction for SB

| | Average Savings % | Number of Occurrences |
|---|---|---|
| Correctly Accept | 46.0% | 4440 |
| Correctly Reject | 17.6% | 4043 |
| Missed Opportunity | 25.2% | 705 |
| Overestimated Profit | 36.7% | 712 |
| | | |
| Perfect Information | 46.7% | |
| Using Prediction | 45.0% | |

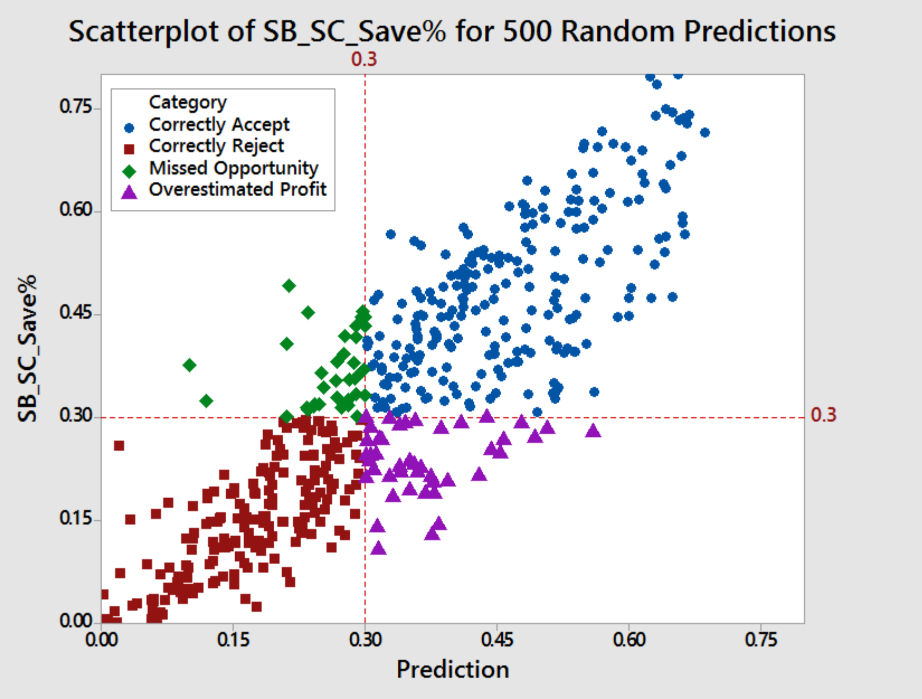

Figure 4.38: Actual Savings Percentages against Predicted Savings for 500 Random Samples

Table 4.13: Best Subsets Regression for Strong Supplier

| Predictors | $R^2$ | $R^2$ (Pred.) | S | $q_B$ | $q_S$ | $\frac{n_S q_S}{n_B q_B}$ | $\frac{D}{n_B q_B}$ | $n_B q_B$ | $\frac{D}{q_S}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23.6 | 23.6 | 0.13 | x | | | | | |
| 2 | 38.6 | 38.6 | 0.11 | x | x | | | | |
| 3 | 52.0 | 52.0 | 0.10 | x | x | x | | | |
| 4 | 58.8 | 58.7 | 0.09 | x | x | x | x | | |
| 5 | 62.1 | 62.0 | 0.09 | x | x | x | x | x | |
| 6 | 64.6 | 64.0 | 0.09 | x | x | x | x | x | x |

Table 4.14: Performance of 3PC's Prediction for SS

| | Average Savings % | Number of Occurrences |
|---|---|---|
| Correctly Accept | 39.3% | 2285 |
| Correctly Reject | 17.5% | 5912 |
| Missed Opportunity | 25.0% | 1000 |
| Overestimated Profit | 34.0% | 703 |
| | | |
| Perfect Information | 41.5% | |
| Using Prediction | 39.0% | |

large range used in the simulation. The fourth largest predictor can be interpreted as the strong buyer's desirable "contracts per year". The fifth and sixth predictors are simply the buyer's requested contract size and deliveries per year, respectively. Again, assuming a third party requires at least 30% savings to justify participation, we test the performance of the regression in predicting profits. These results are summarized in Table 4.39 with 500 random samples displayed in Figure 4.39.

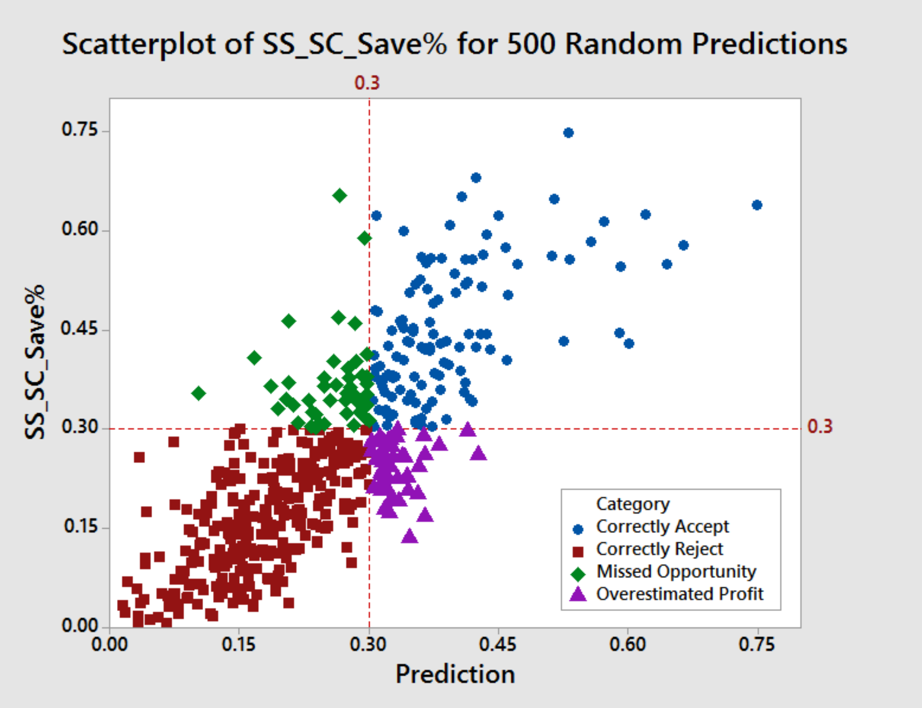

Figure 4.39: Actual Savings Percentages against Predicted Savings for 500 Random Samples

### 4.5.5 Summary of Numerical Analyses and Practitioner Guidelines

A number of important conclusions can be drawn from the numerical analyses. First, we can see that a strong prediction ability for potential savings, for either a Strong Buyer or Strong Supplier scenario, lends reassurance that large savings opportunities are not difficult to notice to the observant practitioner. For example, we simply need to know each party's preferred contract size (and thus, length) to predict the possible savings from coordinating a Strong Buyer case. Next, from the investigation into the relationship of commitment cost rates ($^{L_B}/_{L_S}$), we know that lower savings can be expected for a relatively low $L_B$ or a relatively high $L_S$ (see Figure 4.27). This aligns perfectly with our prediction from the sensitivity analysis of this ratio. The intuition is fairly straightforward since a buyer with a low $L_B$ will prefer longer contracts (better aligning with the supplier), and a supplier with a high $L_S$ will prefer shorter contracts (better aligning with the buyer).

## 4.6 Selected Algebraic Analysis

For a strong supplier, if we relax the integer requirement, disregard the supplier's cost of commitment, and focus on the limited scenario of *m=1*, we can gain some insight for comparing cooperative and non-cooperative costs. The assumption of *m=1* and disregarding the strong supplier's opportunity cost is not unreasonable in the case of a strong supplier with ample capacity. Specifically, we know that if $L_S = 0$ and $\frac{D}{P} < .5$, then $m$=1 (Kelle et al., 2007). Since $m$=1, we can also consolidate $Z_S$ into $A_S$ without loss of generality. For fair comparison, we can similarly limit our scope to where $m_J = 1$. For this scenario, the (relaxed) joint optimals are:

$$\widehat{n_J} = \frac{\sqrt{A_B}\sqrt{h_S D + h_B P}}{\sqrt{P L_B C_B}\sqrt{Z_B + A_S}} \tag{4.11}$$

and

$$\widehat{q_J} = \frac{1}{\widehat{n_J}}\sqrt{\frac{2A_B D}{L_B C_B}} = \frac{\sqrt{2PD}\sqrt{Z_B + A_S}}{\sqrt{h_S D + h_B P}} \tag{4.12}$$

thus the jointly optimal contract size will be

$$\widehat{n_J}\widehat{q_J} = \sqrt{\frac{2A_B D}{L_B C_B}}. \tag{4.13}$$

The minimal total cost to the supply chain in this scenario is therefore:

$$TC_J =$$

$$\sqrt{2L_BC_BA_BD} + \frac{\sqrt{Z_B + A_S}}{\sqrt{2}}\sqrt{h_SD + h_BP}\sqrt{\frac{D}{P}} + \frac{\sqrt{Z_B + A_S}\sqrt{D}}{2\sqrt{h_SD + h_BP}}\left(h_B\sqrt{P} + \frac{h_SD}{\sqrt{P}}\right). \quad (4.14)$$

Note the various forms of $\frac{D}{P}$ observed throughout the equation.

We can compare this cost to the non-cooperative case. The strong supplier (SS) will determine the delivery quantity with its EOQ:

$$\widehat{q_S} = \sqrt{\frac{2A_SP}{h_S}}. \quad (4.15)$$

The buyer will respond by setting the optimal number of deliveries:

$$\widehat{n_B} = \frac{1}{\widehat{q_S}}\sqrt{\frac{2A_BD}{L_BC_B}} = \sqrt{\frac{A_BDh_S}{L_BC_BA_SP}}. \quad (4.16)$$

This yields a minimal total cost to the supply chain in this scenario of:

$$TC_{SS} = \sqrt{2L_BC_BA_BD} + \frac{Z_BD}{\sqrt{2}}\sqrt{\frac{h_S}{PA_S}} + D\sqrt{\frac{2A_Sh_S}{P}} + \frac{h_B}{\sqrt{2}}\sqrt{\frac{A_SP}{h_S}}. \quad (4.17)$$

Note that the first term is the same for both the jointly optimal and strong supplier scenarios. Finally, we can subtract these costs to determine the potential gain from moving a strong supplier to a jointly optimal partnership:

$$TC_{DIFF} = TC_{SS} - TC_J =$$

$$\frac{Dh_SZ_B + 2DA_Sh_S + h_BPA_S}{\sqrt{2PA_Sh_S}} - \sqrt{Z_B + A_S}\sqrt{h_SD + h_BP}\sqrt{\frac{2D}{P}}. \quad (4.18)$$

Note there are no longer $L_B, C_B$, or $A_B$ terms in this equation. Perhaps surprisingly, this tells us that the savings is independent of the buyer's ordering cost. However, with further consideration, we can see that the first three terms, all buyer terms, were used in determining the number of deliveries for both scenarios. We can show that this difference is always positive with just one additional assumption. Differentiating the above equation ($TC_{DIFF}$) with respect to any of the six terms, equating to 0, and solving for that variable can be rearranged to this unity expressing the condition for minimum savings:

$$1 = \frac{P}{D}\frac{h_B}{h_S}\frac{A_S}{Z_B}. \tag{4.19}$$

This is the same result we get from equating the two costs (zero savings). Moving from left to right ratios on the right hand side of the equation, we know that $P > D$ and regularly assume $h_B > h_S$ since parts gain value as they move down the supply chain. This only leaves us with the final term to reconcile. Supplier setup costs are typically large compared to receiving costs of the buyer. Further, recall that $A_S$, the supplier's setup cost, as used here also includes $Z_S$. Therefore, we are almost guaranteed that $A_S > Z_B$. By simply adding this last conservative inequality as an assumption, we can affirmatively state that any deviation from unity will be positive, thus increasing the potential savings by moving to a jointly optimal policy. In other words, we now know that as any or all of these ratios decrease, our savings will increase since there is no possibility of offsetting changes to the parameters.

Since this analysis relies on relaxed variables for $n$ and $q$, we may expect different results when the optimization is applied with integers. To test this expectation, an additional scenario (see Table 4.16) with 10,000 test cases based on values inspired by Kelle et al. (2007) was run. From these results, 5445 cases where $\frac{D}{P} < .5$ or $m$=1 are analyzed for performance.

Table 4.15: Scenario Parameters for Assessing Analytical Performance

| Parameter | Scenario 4 |
|---|---|
| $P$ | Unif(200,1600) |
| $D$ | Unif(.01,.99)$*P$ |
| $Z_B$ | Unif(50,200) |
| $A_B$ | Unif(50,200) |
| $C_B$ | Unif(100,200) |
| $r_B$ | Unif(0.05,0.3) |
| $L_B$ | Unif(0.01,0.05) |
| $Z_S$ | Unif(5,500) |
| $A_S$ | Unif(100,1000) |
| $C_S$ | Unif(40,100) |
| $r_S$ | Unif(0.05,0.25) |
| $otc_S$ | 0 |
| $L_S$ | 0 |
| $h_B$ | $= r_B * C_B$ |
| $h_S$ | $= r_S * C_S$ |

Table 4.16: Performance of Analytical Solution in Scenario 3

| Cases where... | Metric | # Predicted \$ > Realized \$ | # Predicted \$ < Realized \$ | Total |
|---|---|---|---|---|
| *m=1* | Count | 1753 | 1097 | 2850 |
| $\frac{D}{P} < .5$ | Count | 2177 | 2796 | 4973 |
| *m=1* AND $\frac{D}{P} < .5$ | Count | 1305 | 1073 | 2378 |

| Cases where... | Metric | Predicted Savings | Realized Savings | Difference |
|---|---|---|---|---|
| *m=1* | Average | 1899.81 | 1826.52 | -73.3 |
| | Std Deviation | 1390.05 | 1615.82 | 462.7 |
| $\frac{D}{P} < .5$ | Average | 3324.34 | 3482.94 | 158.6 |
| | Std Deviation | 2625.95 | 2970.05 | 534.3 |
| *m=1* AND $\frac{D}{P} < .5$ | Average | 2016.24 | 2025.80 | 9.6 |
| | Std Deviation | 1436.31 | 1642.47 | 442.9 |

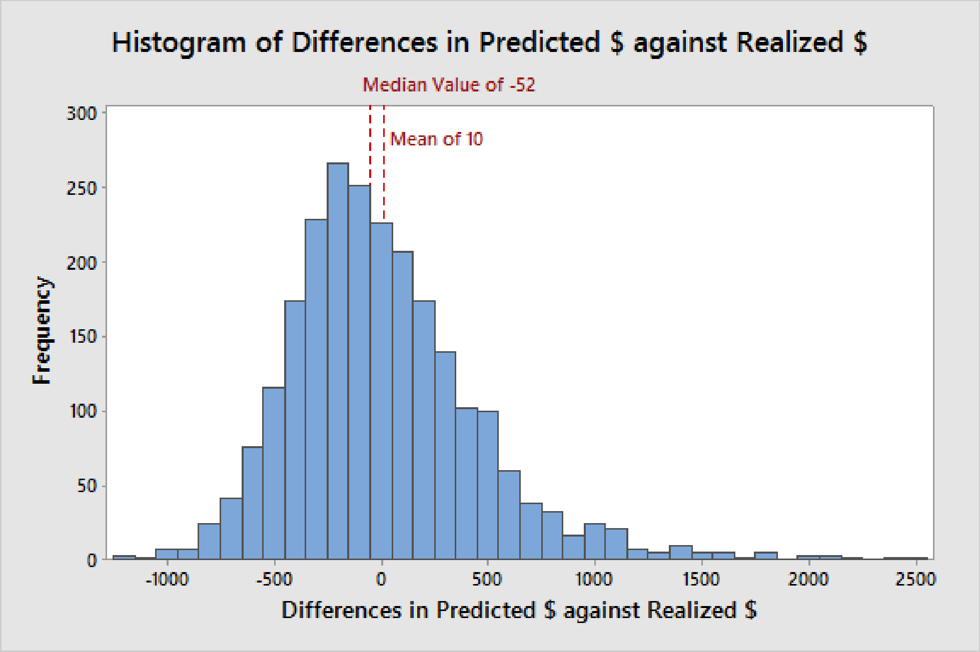

Figure 4.40: Histogram of Differences from Predicted Savings to Realized Savings

From Table 4.16, we see that the relaxed predicted savings, on average, is within 5% of the realized savings. Further, if we examine the difference between the number of times where we overpredicted savings where *"m=1"* against the more conservative *"m=1* AND $\frac{D}{P} < .5$*"*, we can calculate that cases where a strong supplier, with *m=1* and $.5 < \frac{D}{P} < 1$, will overpredict the potential savings by a ratio of more than 18:1. Conversely, when we drop the *m=1* requirement, we see the opposite effect, and underpredict the savings by a ratio of 2:1. Unfortunately, when we consider the relatively large standard deviations, we see that there are quite a few times when the prediction fails us, either high or low. To better examine this effect, the histogram of the case when *"m=1* and $.5 < \frac{D}{P} < 1$*"* is presented in Figure 4.40.

We can see a rather slight right skew of 1.05 in this histogram of the differences (Realized \$ - Predicted \$). The difference is roughly centered over 0, reassuring us that the prediction is quite accurate on average. However, the variance in the results warns us that we should only use the analysis based on relaxed figures only for a rough estimate of the potential savings.

# Chapter 5: Conclusion

There are certainly many examples of an extremely strong party, known to us by both common experience and the literature (examples of which were discussed in Chapter 2). It is not the assertion of this thesis that this is more or less common than having an only *slightly* stronger party, one that would not be able to fully and unquestionably dictate all decisions as was considered in much of this research. However, we know that stronger parties will commonly use any available strength to negotiate more favorable contract terms at the expense of the larger supply chain, making this an important research area. Numerous coordination mechanisms have been offered in an attempt to minimize this inefficiency. However, from research and experience we know there are many limits to this approach. Even if implemented to some degree, perhaps with a quantity discount, it lacks the close collaboration associated with a cooperative solution, something we know many practitioners would prefer. Indeed, it is innately *non-cooperative* to use a coordination mechanism since some level of coercion is inherent to the process of implementing a mechanism. On the other hand, the literature exploring cooperative solutions, such as JELS, rarely offer practical advice on how to proceed or overcome the many reservations preventing closer collaboration. The goal of this research is to offer motivation, method, and some guidance to a practical cooperative solution that includes joint cost minimization as a benefit rather than a singular goal.

The solution to the above problem proposed by this thesis was through the novel introduction and use of an expert third party. This third party is in a unique position to offer many benefits, some financial with others less quantifiable. The most obvious financial benefit is the guarantee of the jointly optimal policy being available. Other significant benefits are possible as well. Supply chain partners, often wary of truly close collaboration for a host of reasons, have many reasons to embrace the concept of a “buffer” party. This third party is in a position to not only help facilitate smooth negotiations and avoid bitter feelings from the onset of the relationship, but can also help resolve conflicts and assist in establishing a robust collaboration. This can be done while keeping sensitive internal cost structures confidential from the trading partner. However, to help realize this solution process, two things are required.

First, we need inclusive cost models that account for previously neglected subjects, such as commitment costs and risk costs. This was done in Chapter 3 through the introduction of buyer risk costs $\sum\limits_i L_{B_i} V_{B_i}(n,q)$ and supplier risk costs $\sum\limits_i L_{S_i} V_{S_i}(m,n,q)$. The use of these cost components, while rather broad due to their nature, expand upon previous research to address an often unspoken part of contract negotiations, i.e. risk considerations in contracts. To aid in the application of these cost factors, an example delineation of the buyer's risk cost (i.e. $L_B C_B \frac{nq}{2}$) was demonstrated to have a cost rate, $L_B$ , equivalent to the probability of an abrupt end of demand, easing interpretation for practitioners.

Second, a willing and able third party is the vehicle of execution to provide many of the desired benefits of collaboration. Although numerous benefits are possible, the limits and consequences of a self-interested third party were considered. Of significant concern is the possibility of a conflict-of-interest stemming from manipulation of the optimal policy. This is relieved through the recommendation of a basic incentive system, basing remuneration for the third party on a proportion of the achieved savings. Facing this recommendation, an interested third party will want to accurately predict the potential savings in a supply chain contract negotiation. A large numerical analysis was conducted to investigate the ability of the 3PC to predict possible savings, and thus compensation. The findings provide evidence that it may well be possible to provide a relatively good estimate of savings based only on the commonly known terms at the time of negotiation.

Comparing a third party solution to a traditional coordination mechanism approach might at first seem unfair. After all, we are guaranteed equal or better results with every coordination effort when using a third party. However, there is a cost to close collaboration. For simple contracts with common or low-value items, we concede it could be hard to justify the extra expense and complication of involving a third party. But, for unique or high-value items, where significant differences in desired policies exist, we have shown that there are significant savings available to those that are willing to invest the time and effort required to cooperate.

## 5.1 Extensions and Future Areas of Research

The results of this research encourage further investigations of the overlooked area of the buyer's and supplier's risk and opportunity costs. The current research considered the possibility of an abrupt end-of-demand event during the execution of the contract. An alternative scenario worth considering is a potential demand shift, rather than an end, throughout the contract period.

Obviously, countless delineations of $\sum_i L_{B_i} V_{B_i}(n, q)$ and $\sum_i L_{S_i} V_{S_i}(m, n, q)$ are possible. Industry-specific values and guidance could prove beneficial to practitioners.

Dropping the integer ratio requirement for number of shipments per production run and number of shipments would allow for better joint performance. This could be accomplished in two ways. First, we could allow the supplier to carry stock between production runs, allowing for a surplus to cover a partial batch at the end. This adds considerable complications to the model as the average supplier inventory calculation becomes more involved. Second, we could allow for the last run to be shorter than the rest. Of course, this would also complicate the model in a similar way.

Allowing for multiple products in the optimal policy could provide synergistic benefits, but with added complications such as accounting for synchronized deliveries. Similarly, including stochastic parameters, like demand, would add significant realism for many applications.

# Bibliography

Altman, E.I., 1968. Financial ratios, discriminant analysis and the prediction of corporate bankruptcy. *The Journal of Finance*, 23(4):589–609.

Arshinder, K., Kanda, A., and Deshmukh, S., 2011. A review on supply chain coordination: coordination mechanisms, managing uncertainty and research directions. In *Supply Chain Coordination under Uncertainty*, pages 39–82. Springer.

Ballou, R.H., Gilbert, S.M., and Mukherjee, A., 2000. New managerial challenges from supply chain opportunities. *Industrial Marketing Management*, 29(1):7–18.

Banerjee, A., 1986a. A joint economic-lot-size model for purchaser and vendor. *Decision Sciences*, 17(3):292–292.

Banerjee, A., 1986b. Note-on "a quantity discount pricing model to increase vendor profits". *Management Science*, 32(11):1513–1517.

Banerjee, A. and Kim, S., 1995. An integrated jit inventory model. *International Journal of Operations & Production Management*, 15(9):237–244.

Barney, J.B. and Hansen, M.H., 1994. Trustworthiness as a source of competitive advantage. *Strategic Management Journal*, 15(S1):175–190.

Barratt, M., 2004. Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal*, 9(1):30–42.

Barratt, M. and Green, M., 2001. The cultural shift: the need for a collaborative culture. In *Conference Proceedings of Supply Chain Knowledge*, volume 2001. Cranfield School of Management.

Benton, W. and Park, S., 1996. A classification of literature on determining the lot size under quantity discounts. *European Journal of Operational Research*, 92(2):219–238.

Bititci, U., Turner, T., Mackay, D., Kearney, D., Parung, J., and Walters, D., 2007. Managing synergy in collaborative enterprises. *Production Planning and Control*, 18(6):454–465.

Bitran, G.R., Gurumurthi, S., and Sam, S.L., 2007. The need for third-party coordination in supply chain governance. *MIT Sloan Management Review*, 48(3):30–+.

Blair, R.D. and DePasquale, C., 2014. "antitrust's least glorious hour": The robinson-patman act. *Journal of Law and Economics*, 57(S3):S201–S216.

Brausch, J.M. and Taylor, T.C., 1997. Who is accounting for the cost of capacity? *Strategic Finance*, 78(8):44.

Cachon, G.P., 2003. Supply chain coordination with contracts. *Handbooks in Operations Research and Management Science*, 11:227–339.

Cao, M. and Zhang, Q., 2010. Supply chain collaborative advantage: A firm's perspective. *International Journal of Production Economics*, 128(1):358–367.

Chopra, S. and Sodhi, M., 2004. Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review (Fall 2004)*.

Colicchia, C. and Strozzi, F., 2012. Supply chain risk management: a new methodology for a systematic literature review. *Supply Chain Management: An International Journal*, 17(4):403–418.

Das, T.K. and Teng, B.S., 2000. Instabilities of strategic alliances: An internal tensions perspective. *Organization Science*, 11(1):77–101.

Daugherty, P.J., Richey, R.G., Roath, A.S., Min, S., Chen, H., Arndt, A.D., and Genchev, S.E., 2006. Is collaboration paying off for firms? *Business Horizons*, 49(1):61–70.

Doll, A., Germany, C.C.B., Friebel, D., Berger, R., Rückriegel, M., and Schwarzmüller, C., 2014. Global logistics markets.

Fabbe-Costes, N. and Roussat, C., 2011. Supply chain integration: Views from a logistics service provider. In *Supply Chain Forum: an International Journal*, volume 12, pages 20–30. BEM-Bordeaux Management School.

Fawcett, S.E., Fawcett, A.M., Watson, B.J., and Magnan, G.M., 2012. Peeking inside the black box: toward an understanding of supply chain collaboration dynamics. *Journal of Supply Chain Management*, 48(1):44–72.

Fawcett, S.E. and Magnan, G.M., 2002. The rhetoric and reality of supply chain integration. *International Journal of Physical Distribution & Logistics Management*, 32(5):339–361.

Fisher, M.L., Raman, A., and McClelland, A.S., 2000. Rocket science retailing is almost here-are you ready? *Harvard Business Review*, 78(4):115–124.

Frankel, R., Goldsby, T.J., and Whipple, J.M., 2002. Grocery industry collaboration in the wake of ecr. *International Journal of Logistics Management, The*, 13(1):57–72.

Fulconis, F., Saglietto, L., and Paché, G., 2006. Exploring new competences in the logistics industry: The intermediation role of 4pl. In *Supply Chain Forum: International Journal*, volume 7.

Gerwin, D., 2004. Coordinating new product development in strategic alliances. *Academy of Management Review*, 29(2):241–257.

Golhar, D. and Sarker, B., 1992. Economic manufacturing quantity in a just-in-time delivery system. *International Journal of Production Research*, 30(5):961–972.

Goyal, S., 1977. An integrated inventory model for a single supplier-single customer problem. *The International Journal of Production Research*, 15(1):107–111.

Goyal, S.K., 1988. "a joint economic-lot-size model for purchaser and vendor": A comment*. *Decision Sciences*, 19(1):236–241.

Goyal, S.K. and Gupta, Y.P., 1989. Integrated inventory models: the buyer-vendor coordination. *European Journal of Operational Research*, 41(3):261–269.

Hassanzadeh, A., Jafarian, A., and Amiri, M., 2014. Modeling and analysis of the causes of bullwhip effect in centralized and decentralized supply chain using response surface method. *Applied Mathematical Modelling*, 38(9):2353–2365.

Hill, J.A., Eckerd, S., Wilson, D., and Greer, B., 2009. The effect of unethical behavior on trust in a buyer–supplier relationship: The mediating role of psychological contract violation. *Journal of Operations Management*, 27(4):281–293.

Hill, R.M., 1997. The single-vendor single-buyer integrated production-inventory model with a generalised policy. *European Journal of Operational Research*, 97(3):493–499.

Hill, R.M., 1999. The optimal production and shipment policy for the single-vendor singlebuyer integrated production-inventory problem. *International Journal of Production Research*, 37(11):2463–2475.

Holweg, M., Disney, S., Holmström, J., and Småros, J., 2005. Supply chain collaboration:: Making sense of the strategy continuum. *European Management Journal*, 23(2):170–181.

Horvath, L., 2001. Collaboration: the key to value creation in supply chain management. *Supply Chain Management: An International Journal*, 6(5):205–207.

Hoyt, J. and Huq, F., 2000. From arms-length to collaborative relationships in the supply chain: An evolutionary process. *International Journal of Physical Distribution & Logistics Management*, 30(9):750–764.

Huang, C.K., 2004. An optimal policy for a single-vendor single-buyer integrated production inventory problem with process unreliability consideration. *International Journal of Production Economics*, 91(1):91 – 98. ISSN 0925-5273. doi: 10.1016/S0925-5273(03)00220-2.

Ireland, R. and Bruce, R., 2000. Cpfr: only the beginning of collaboration. *Supply Chain Management Review*, 4(4):80–88.

Jeuland, A.P. and Shugan, S.M., 1983. Managing channel profits. *Marketing Science*, 2(3):239–272.

Joglekar, P.N., 1988. Note-comments on "a quantity discount pricing model to increase vendor profits". *Management Science*, 34(11):1391–1398.

Jüttner, U., Peck, H., and Christopher, M., 2003. Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: Research and Applications*, 6(4):197–210.

Kanda, A., Deshmukh, S. et al., 2008. Supply chain coordination: perspectives, empirical studies and research directions. *International Journal of Production Economics*, 115(2):316–335.

Kelle, P. and Akbulut, A., 2005. The role of erp tools in supply chain information sharing, cooperation, and cost optimization. *International Journal of Production Economics*, 93:41–52.

Kelle, P., Al-khateeb, F., and Anders Miller, P., 2003. Partnership and negotiation support by joint optimal ordering/setup policies for jit. *International Journal of Production Economics*, 81:431–441.

Kelle, P., Miller, P.A., and Akbulut, A.Y., 2007. Coordinating ordering/shipment policy for buyer and supplier: Numerical and empirical analysis of influencing factors. *International Journal of Production Economics*, 108(1-2):100 – 110. ISSN 0925-5273. doi:DOI:10.1016/j.ijpe.2006.12.005.

Kelle, P., Transchel, S., and Minner, S., 2009. Buyer–supplier cooperation and negotiation support with random yield consideration. *International Journal of Production Economics*, 118(1):152–159.

Khanna, T., Gulati, R., and Nohria, N., 1998. The dynamics of learning alliances: Competition, cooperation, and relative scope. *Strategic Management Journal*, 19(3):193–210.

Kim, S. and Ha, D., 2003. A jit lot-splitting model for supply chain management: Enhancing buyer-supplier linkage. *International Journal of Production Economics*, 86(1):1–10.

Kintner, E., 1970. A robinson-patman primer. *New York*.

Lambert, D.M. and Burduroglu, R., 2000. Measuring and selling the value of logistics. *International Journal of Logistics Management, The*, 11(1):1–18.

Lambert, D.M. and Cooper, M.C., 2000. Issues in supply chain management. *Industrial Marketing Management*, 29(1):65–83.

Lee, H.L. and Billington, C., 1992. Managing supply chain inventory: pitfalls and opportunities. *Sloan Management Review*, 33(3):65–73.

Lee, H.L., Padmanabhan, V., and Whang, S., 1997. Information distortion in a supply chain: The bullwhip effect. *Management Science*, 43(4):546–558.

Lee, H.L. and Whang, S., 2000. Information sharing in a supply chain. *International Journal of Manufacturing Technology and Management*, 1(1):79–93.

Lehoux, N., D'Amours, S., Frein, Y., Langevin, A., and Penz, B., 2011. Collaboration for a two-echelon supply chain in the pulp and paper industry: the use of incentives to increase profit. *Journal of the Operational Research Society*, 62(4):581–592.

Lieb, R.C., 1999. Use of third-party logistics services by large us manufacturers in 1997 and comparisons with previous years. *Transport Reviews*, 19(2):103–115.

Lieb, R.C. and Lieb, K.J., 2016. 3pl ceo perspectives on the current status and future prospects of the third-party logistics industry in north america: The 2014 survey. *Transportation Journal*, 55(1):78–92.

Lu, L., 1995. A one-vendor multi-buyer integrated inventory model. *European Journal of Operational Research*, 81(2):312–323.

Maloni, M.J. and Benton, W., 1997. Supply chain partnerships: opportunities for operations research. *European Journal of Operational Research*, 101(3):419–429.

Masten, K.A. and Banerjee, A., 2014. Demand disruption risks as opportunity costs in jit supply chain coordination. In *Proceedings of the Seventh International Conference on Management Science and Engineering Management*, pages 915–925. Springer.

Masten, K.A. and Kim, S.L., 2015. So many mechanisms, so little action: The case for 3rd party supply chain coordination. *International Journal of Production Economics*, 168:13–20.

Metters, R., 1997. Quantifying the bullwhip effect in supply chains. *Journal of Operations Management*, 15(2):89–100.

Min, S., Roath, A.S., Daugherty, P.J., Genchev, S.E., Chen, H., Arndt, A.D., and Richey, R.G., 2005. Supply chain collaboration: what's happening? *International Journal of Logistics Management, The*, 16(2):237–256.

Monahan, J.P., 1984. A quantity discount pricing model to increase vendor profits. *Management Science*, 30(6):720–726.

Munson, C.L. and Rosenblatt, M.J., 1998. Theories and realities of quantity discounts: An exploratory study. *Production and Operations Management*, 7(4):352–369.

Nakamoto, M., 1997. Fire hits parts supply network at toyota. *Financial Times*, 4:34.

Norrman, A. and Jansson, U., 2004. Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution & Logistics Management*, 34(5):434–456.

Park, Y., 2005. An integrated approach for production and distribution planning in supply chain management. *International Journal of Production Research*, 43(6):1205–1224.

Popesko, B., 2009. How to calculate the costs of idle capacity in the manufacturing industry. *Global Business and Management Research: An International Journal*, 1(2):19.

Prajogo, D. and Olhager, J., 2012. Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration. *International Journal of Production Economics*, 135(1):514–522.

Qi, X., Bard, J.F., and Yu, G., 2004. Supply chain coordination with demand disruptions. *Omega*, 32(4):301 – 312. ISSN 0305-0483. doi:10.1016/j.omega.2003.12.002.

Rice, J.B. and Hoppe, R.M., 2001. Supply chain vs. supply chain: The hype and the reality. *Supply Chain Management Review, V. 5, No. 5 (Sept./Oct. 2001), P. 46-54: ILL.*

Ryall, M.D. and Sampson, R.C., 2006. Do prior alliances influence alliance contract structure. *Strategic Alliances: Governance and Contracts. IESE Business School.*

Sabath, R.E. and Fontanella, J., 2002. The unfulfilled promise of supply chain collaboration. *Supply Chain Management Review*, 6(4):24–29.

Salameh, M. and Jaber, M., 2000. Economic production quantity model for items with imperfect quality. *International Journal of Production Economics*, 64(1-3):59 – 64. ISSN 0925-5273. doi:DOI:10.1016/S0925-5273(99)00044-4.

Sarmah, S., Acharya, D., and Goyal, S., 2006. Buyer vendor coordination models in supply chain management. *European Journal of Operational Research*, 175(1):1–15.

(SCMR), S.C.M.R. and (CSC), C.S.C., 2004. The second annual global survey of supply chain progress.

Simatupang, T.M. and Sridharan, R., 2002. The collaborative supply chain. *International Journal of Logistics Management, The*, 13(1):15–30.

Simchi-Levi, D., Schmidt, W., and Wei, Y., 2014. From superstorms to factory fires managing unpredictable supply-chain disruptions. *Harvard Business Review*, 92(1-2):96–+.

Spengler, J.J., 1950. Vertical integration and antitrust policy. *The Journal of Political Economy*, pages 347–352.

Storey, J., Emberson, C., Godsell, J., and Harrison, A., 2006. Supply chain management: theory, practice and future challenges. *International Journal of Operations & Production Management*, 26(7):754–774.

Svensson, G., 2002. A conceptual framework of vulnerability in firms' inbound and outbound logistics flows. *International Journal of Physical Distribution & Logistics Management*, 32(2):110–134.

Tang, C. and Tomlin, B., 2008. The power of flexibility for mitigating supply chain risks. *International Journal of Production Economics*, 116(1):12–27.

Tang, C.S., 2006. Perspectives in supply chain risk management. *International Journal of Production Economics*, 103(2):451–488.

Thomas, D.J. and Griffin, P.M., 1996. Coordinated supply chain management. *European Journal of Operational Research*, 94(1):1–15.

Ton Hien Duc, T., Luong, H.T., and Kim, Y.D., 2010. Effect of the third-party warehouse on bullwhip effect and inventory cost in supply chains. *International Journal of Production Economics*, 124(2):395–407.

Van der Vaart, T. and van Donk, D.P., 2008. A critical review of survey-based research in supply chain integration. *International Journal of Production Economics*, 111(1):42–55.

Vereecke, A. and Muylle, S., 2006. Performance improvement through supply chain collaboration in europe. *International Journal of Operations & Production Management*, 26(11):1176–1198.

Verespej, M., 2002. Supply chain collaboration. *Frontline Solutions*, 3(9):20. ISSN 15286363.

Weng, Z.K., 1995. Channel coordination and quantity discounts. *Management Science*, 41(9):1509–1522.

Wognum, P. and Faber, E.C., 2002. Infrastructures for collaboration in virtual organisations. *International Journal of Networking and Virtual Organisations*, 1(1):32–54.

Wuyts, S. and Geyskens, I., 2005. The formation of buyer-supplier relationships: detailed contract drafting and close partner selection. *Journal of Marketing*, 69(4):103–117.

Zacharia, Z.G., Sanders, N.R., and Nix, N.W., 2011. The emerging role of the third-party logistics provider (3pl) as an orchestrator. *Journal of Business Logistics*, 32(1):40–54.

Zand, D.E. and Sorensen, R.E., 1975. Theory of change and the effective use of management science. *Administrative Science Quarterly*, pages 532–545.

Zhao, W. and Wang, Y., 2002. Coordination of joint pricing-production decisions in a supply chain. *IIE transactions*, 34(8):701–715.

# Appendix A: List of Notation

Note on use of notation in this thesis: All formulas and models created by other authors are presented, when possible, with notation consistent with the rest of this thesis without explanation or exposition. Unique terminology is described at the time it is used.

Table A.1: Summary of Buyer's Model Parameters

| Parameter | Description | Example Value(s) |
|---|---|---|
| $Z_B$ | The cost to buyer to receive a shipment from the supplier. Includes inspection and buyer handling costs. | \$1/shipment |
| $D$ | The constant demand rate predicted by the buyer throughout the planning horizon. | 1000 units/time unit |
| $A_B$ | The buyer's one-time fixed ordering cost per contract. | \$225/order |
| $C_B$ | The buyer's unit purchase cost, committed to at the time of contract. | \$20/unit |
| $\widehat{C_B}$ | The updated but not chargeable buyer's unit cost experienced during fixed-price contract execution. | \$20/unit |
| $\overline{C_B}$ | The unsalvageable value for committed but unusable units remaining on contract presented as a cost to buyer. | \$20/unit |
| $r_B$ | The buyer's inventory holding cost rate per time unit. | 0.2/time unit |
| $h_B$ | The buyer's per-unit inventory holding cost per time unit where $h_B = C_B r_B$. | \$4/time unit/unit |
| $L_{B_i}$ | The buyer's $i^{th}$ commitment rate per time unit where $i \in \mathbb{Z}^+$. | .05/time unit |

Table A.2: Summary of Supplier's Model Parameters

| Parameter | Description | Example Value(s) |
|---|---|---|
| $Z_S$ | The fixed cost to the supplier to send a shipment to the buyer. Includes shipping and supplier handling costs. | \$4.5/shipment |
| $P$ | The constant production rate predicted by the supplier throughout the planning horizon. | 2500 units/time unit |
| $A_S$ | The supplier's fixed setup cost per production run. | \$1000/batch |
| $C_S$ | The supplier's unit cost. | \$10/unit |
| $r_S$ | The supplier's inventory holding rate per time unit. | 0.2/time unit |
| $h_S$ | The supplier's per-unit inventory holding cost per time unit where $h_S = C_S r_S$. | \$2/time unit/unit |
| $L_{S_i}$ | The supplier's $i^{th}$ commitment rate per time unit where $i \in \mathbb{Z}^+$. | .05/time unit |
| $OTC_S$ | All one-time costs per contract to supplier (e.g. negotiation or tooling). Comparable to $A_B$. | \$1000/contract |

Table A.3: Summary of Supply Chain Decision Variables

| Decision Variable | Description | Example Value(s) |
|---|---|---|
| $q$ | The shipment size throughout the entire contract | 100 units |
| $n$ | The total number of shipments in the contract. | 15 shipments |
| $m$ | The number of shipments per production run | 5 shipments |
| $n_B$, $q_B$ | The buyer's optimal $n$ and $q$, respectively | - |
| $m_S$, $n_S$, $q_S$ | The supplier's optimal $m$, $n$, and $q$, respectively | - |
| $m_J$, $n_J$, $q_J$ | The jointly optimal $m$, $n$, and $q$, respectively | - |
| $\widehat{m_S}$ | Optimal $m$ with integer requirement relaxed | 4.13 shipments |

Table A.4: Summary of Functions of Decision Variables

| Decision Variable | Description | Example Value(s) |
|---|---|---|
| $nq$ | The total contract quantity | 1500 units |
| $mq$ | The supplier's production run quantity. | 500 units |
| $V_k(m,n,q)$ | The ad-hoc occurrence cost or value of event $k$, as a function of decision variables $m$, $n$, and $q$ | \$1000/event |
| $\sum_i V_{B_i}(n,q)$ | Summation of all buyer's commitment cost values denoted by $B_i$ and indexed by $i$, as a function of decision variables $n$, and $q$ | $C_B \frac{nq}{2}$ |
| $\sum_i V_{S_i}(m,n,q)$ | Summation of all supplier's commitment cost values denoted by $S_i$ and indexed by $i$, as a function of decision variables $m$, $n$, and $q$ | $C_S \frac{nq}{2}$ |

# Vita

Kurt Alden Masten was born in West Chester, Pennsylvania in April 1977. He completed a Bachelor of Science in Industrial Engineering at the Pennsylvania State University in 1999 and a Ph.D. in Business Administration with a concentration in Decision Sciences in 2016 from Drexel University in Philadelphia, Pennsylvania. His work experience includes 10 years as a manufacturing engineer and 3 years as a college instructor. He has published in the *International Journal of Production Economics* and conference proceedings.

Kurt A. Masten is currently an Assistant Professor of Supply Chain Management at Fairleigh Dickinson University in Florham Park, New Jersey.