THREE PROBLEMS IN OPERATIONS MANAGEMENT

by

Zhongwen Ma

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To my family,
mentors
and friends.

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THREE PROBLEMS IN OPERATIONS MANAGEMENT

by

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DISSERTATION

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Last but not least, support from family has been the very motivation that gave me power to conquer challenges.

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THREE PROBLEMS IN OPERATIONS MANAGEMENT

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The University of Texas at Dallas, 2019

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Three problems in operations management are examined in this dissertation, with methodologies ranging from theoretical modeling and empirical research. The topics focus on quality issues as well as remanufacturing decisions.

In Chapter 2, we investigate how to contract on quality with private information. Supply chains today routinely use third parties for many strategic activities, such as manufacturing, R&D, or software development. These activities often include relationship-specific investment on the part of the vendor, while final outcomes can be uncertain. Therefore, writing complete contracts for such arrangements is often not feasible, but incomplete contracts, especially when relationship-specific investment is required, may leave the supplier vulnerable to a version of the "hold-up problem," which is known to result in sub-optimal levels of investment. We model the phenomenon as a sequential move game with asymmetric information. Absent behavioral considerations, the unique Perfect Bayesian Equilibrium implies zero investment. However, with social preferences, the hold-up problem may be mitigated. We propose a model that incorporates social preferences and random errors, and solve for the equilibrium. In addition, we look at reputation and find it to be effective for increasing investment. We conduct laboratory experiments



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with human subjects and find that a model with social preferences and random errors organizes our data well.

In Chapter 3, we study investigated the problem of process quality improvement between a buyer and a supplier in a supply chain. The key words include supply chain contracts, behavioral economics, game theory, quality improvement. Products a supplier produces might be defective depending on the process' quality, and such products may incur a loss both to the supplier and buyer because of factors such as the warranty, loss of customer goodwill, or the loss of potential market share. We show that when the buyer's share of the loss is sufficiently large, it should be his full responsibility to improve the process quality optimally. In contrast, when the buyer's share of the loss is low, it should be the supplier's full responsibility to improve the process quality to the optimal level. These predictions were tested in the laboratory and systematic deviations from them were found. Specifically, when the buyer's share of the loss is low, he still contributes to process quality improvement, while theory predicts free riding. Moreover, when the buyer's share of the loss is high, the supplier still contributes to process quality improvement, while theory predicts otherwise. Moreover, the centralized supply chain served as the benchmark, and illustrated that negotiation can be used to improve system performance. This new mechanism was tested in the laboratory and found to be superior.

In Chapter 4, we investigate firms' remanufacturing strategies in the case of a Cournot duopoly. Keywords include pricing, remanufacturing, competition, and operations-marketing interface. On the one hand, remanufactured products cannibalize sales of new products of the same firm thereby hurting its profits. On the other hand, they can be part of a profitable marketing strategy that targets different customer preferences by providing a larger number of alternatives to customers. This



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paper studies the tradeoff between these effects and how it is influenced by competition. We develop a model where demand functions for new and remanufactured products of each firm are derived from utility maximization by a representative consumer. This allows us to capture preference and substitution effects between all offered products in the market. We discuss how equilibrium strategies are affected by factors such as competition, substitutability, production cost as well as remanufacturing cost. For example, when competitive intensity (between new and new products, and remanufactured and remanufactured products, is low (respectively, high), both (respectively, neither) firms offer remanufactured products in a symmetric equilibrium.



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# CHAPTER 1

# INTRODUCTION

This dissertation focuses on three problems in supply chain, all related to either quality or remanufacturing. In specific, we investigate hold-up problem in Chapter 2, to answer the question of how to contract on quality. In Chapter 3, we examine quality investment problem, to answer the question of how to invest in quality. In Chapter 4, we talk about remanufacturing problem. Below we introduce background, motivations as well as literature review for each of these three problems.

## 1.1 Hold-up Problem

### 1.1.1 Overview

Today, firms increasingly rely on third party vendors for many strategic activities, including manufacturing. For example, The New York Times reported that "…almost all of the 70 million iPhones, 30 million iPads and 59 million other products Apple sold last year were manufactured overseas" (Duhigg and Bradsher 2012). Reliance on vendors for performing strategic activities, such as the manufacturing of products using proprietary technology, creates a number of pitfalls. One of the major pitfalls, and the focus of our chapter, has to do with a version of the hold-up problem.

### 1.1.2 Literature Review

#### 1.1.2.1 Theoretical and Empirical Background

The hold-up problem (Rogerson 1992) emerges when one firm in a relationship is able to expropriate the returns from an investment made by another firm (for a discussion on the ability of a firm to appropriate value, see MacDonald and Ryall 2004). Specifically, if one firm makes an investment that has a low value outside of the relationship, that firm is vulnerable to being "held



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up" for the value of that relationship-specific investment. The hold-up problem is particularly likely to emerge in settings in which writing complete contracts is not feasible due to some combination of information asymmetry and environmental uncertainty (Rogerson 1992). It has long been argued in the economics literature (see Coase 2006 for an overview) that the presence of a potential hold-up problem results in underinvestment in relationship-specific investments leading to inefficiency, and so the ability to mitigate the hold-up problem has potential value.

Crocker and Reynolds (1993) describe an interesting example from the 1970s dealing with government procurement. The US military made a significant investment in Research & Development (R&D) for production of jet engines for F-15 and F-16 fighter. The military was working with Pratt & Whitney as a sole source supplier on this project. As the sole supplier, Pratt was in a strong position to hold up the US military by demanding excessive concessions to correct quality problems. As a result, in 1979 the Air Force commissioned General Electric to develop a functionally equivalent jet engine for the use in its B-1 bomber. This resolved the hold-up problem and the number of contract disputes decreased, but at the cost of funding a second engine by the US Military. The US Congress has continued to fund the two engines through 2011 (Schone 2011).

Other examples of negative and costly consequences that have the hold-up flavor include expensive and protracted lawsuits, such as one between the U.S. Postal Service and Northrop Grumman Corp., whose contract dispute led to over $500 million in lawsuits (Reilly 2012). Fears of the hold-up problem, on the other hand, result in under-investment by suppliers (Haruvy, Li and Sethi 2012), leading to Original Equipment Manufacturers (OEMs) being unable to fill lucrative contracts. Barnes (2012) describes Boeing's situation of being unable to fill orders worth billions



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of dollars for many years due to its suppliers' inability or unwillingness to invest in required capacity.

**1.1.2.2 Experimental literature on the hold-up problem**

We study incomplete contracts that make one of the players vulnerable to a version of the hold-up problem, using laboratory experiments with human subjects. In the experimental economics literature, the hold-up problem builds on the extensively studied investment game (Berg et al. 1995). In the investment game, the first mover—the seller (the terms seller and buyer are accepted terminology, e.g., Hoppe and Schmitz 2011)—decides whether to invest in production. Investment creates surplus (generally in investment game experiments, the surplus to be divided is three times the investment amount—a parameterization not required for the definition of an investment game). The second mover—the buyer—decides how much of the created surplus to expropriate. There is much room for mutual gain of both parties, but given the sequential nature of the game, it is best response of the buyer to expropriate the entire surplus in a single shot game. By backwards induction, the seller will not invest. In numerous experimental studies (see overview in Camerer 2003), the general pattern is that sellers do invest and buyers share some of the surplus with the sellers.

The setting that we study in this chapter is different from the standard investment game in several aspects. One aspect is that the seller has the last word and can accept or reject the buyer's offer. In Dufwenberg et al. (2013), two variations were studied. In the first, the "Low game," the first mover could reject an unkind surplus division, resulting in a loss to both himself and the second mover. In the second, the "High game," rejection would actually improve the outcome for the buyer, and thus may not be useful as a threat. As expected, none of the sellers who decided to



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initially produce chose to reject an unkind offer that results in a gain to the buyer. Even in this High game version, there is investment (40%) by the seller, which is difficult to justify in an equilibrium sense. The authors also report that the vast majority of buyers (90%) in fact did choose the unkind surplus division, which makes the fact that 40% of the sellers chose to invest particularly surprising.

Ellingsen and Johannesson (2004a) run a hold-up game experiment as well (using the term hold-up), to study the effect of communication. Their interpretation of what constitutes a hold-up game is the same as Dufwenberg et al. The seller (their terminology has seller and buyer) first decides whether to invest 60 or not. Then the buyer proposes a division of 100 tokens, which is the revenue created by the investment. The seller can then accept or reject. This structure is the same as Dufwenberg et al. with somewhat different payoffs. The purpose of the experiment was to compare the basic treatment to communication treatments with promises by the buyers or threats by the seller. They found that communication did in fact mitigate the hold-up problem. An important companion to Ellingsen and Johannesson (2004a) is Ellingsen and Johannesson (2004b). A key difference between these two studies is that bargaining in the latter is not in ultimatum format. In that design, each of the two agents makes a claim. The revenue is equal to 0 if the sum of the claims exceeds 100. If the sum of the claims is 100 or less, each subject gets his claim (i.e., bilateral bargaining according to Nash's demand game, Nash 1953). Other than that, the experimental designs are largely identical. Ellingsen and Johannesson (2004a) find that communication mitigates the hold-up problem. Specifically, unilateral communication—by buyer or seller—facilitates coordination and increases investment.



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Hoppe and Schmitz (2011) study the effect of contracting on the hold-up game. They find that option contracts improve performance. Unlike Dufwenberg, they add a participation decision in which either party can decide to decline participating in the game. After that stage, the game has the same structure as Dufwenberg et al. (2013): The seller makes an investment decision (0 or 8). The buyer then learns the investment decision and makes a take-it-or-leave-it price offer. The seller can then take it or leave it. If he leaves it, he forgoes the cost of the investment—thus the hold-up. Hoppe and Schmitz model all contract decisions as eliminating one of the stages and thus reducing the hold-up problem to an investment problem. In the fixed price contract, the buyer's pricing decision and the seller's final accept/reject decisions go away and the problem becomes equivalent to an investment/trust game with the buyer moving first, choosing to pay the seller or not. If he pays, he has to trust the seller to make the investment and not to expropriate the surplus. In the option contract, the seller invests without the option of accepting or rejecting. They also investigated a contract with renegotiation which is similar in spirit to the communication study of Ellingsen and Johannesson (2004) described above.

Davis and Leider (2013), similar to Hoppe and Schmitz (2011), study the possibility that an option contract mitigates the holdup problem. In the option contract, the retailer and supplier agree ex ante to buy and sell units up to *D* units at a wholesale price of *w* and the retailer pays a lump sum option fee to the supplier. The framework is different in that the first mover makes a capacity investment, demand is random, and bargaining is structured. Bargaining is such that both roles have the ability to make multiple back-and-forth offers while also providing feedback on the offers they receive. They find that the option contract does indeed mitigate the hold-up problem. They further find that the evolution of offers during bargaining suggests "superficial fairness."



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Specifically, wholesale price falls in the middle of the available contracting space, away from the coordinating contract parameter.

There are other studies that model settings that are closer to the theoretical hold-up problem, without invoking the term. In Hackett (1994) experiment, for example, two players decide on respective investments that increase joint surplus but also increase individual cost. They then realize a probabilistic outcome that depends on the investments and then bargain over the joint surplus, with either party having a veto power. Hackett (1994) finds that the surplus division is responsive to the investments. The setting is closer to the theoretical literature in that the unknown realization of the eventual outcome makes the contract incomplete—unlike the settings of Dufwenberg et al. (2013) and Hoppe and Schmitz (2011).

The key innovation in the setting we study, that distinguishes it from the literature we summarized above, is the presence of asymmetric information. Asymmetric information makes designing a "better contract" less plausible because contingent contracts may be impossible to enforce. So the asymmetric information aspect in our study is important for practice, and new in terms of research focus.

**1.1.2.3 Behavioral Contribution**

It has been shown in experimental economics, as well as in the behavioral operations management literature, that people are not motivated exclusively by monetary payoffs—they have social preferences (see Cooper and Kagel 2008, Loch and Wu 2008, Katok and Pavlov 2013). A stream of theoretical works investigates social preferences, such as inequality aversion, in the context of the hold-up problem (Gantner et al. 1998, Oosterbeek et al. 1999, Sonnemans et al. 2001, von Siemens 2009). Dufwenberg et al. (2013) argue that the patterns observed in the hold-



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up problem are explained by reciprocity. We use a behavioral model to analyze the hold-up problem, but our behavioral model uses inequality aversion (Bolton and Ockenfels 2000, Fehr and Schmidt 1999, Cui et al. 2007). We further solve the problem in a dynamic framework whereas Dufwenberg et al. (2013) analyze the one-shot setting. We analyze the dynamics by approximating a dynamic setting in our experiments and refer to this as dynamic approximation.

Thus, our solution concept involves a tradeoff. On the one hand, it is quite broad, which allows us to use it for testing a model that does not rely on reciprocity preferences and generalizing the solution to dynamic environments. On the other hand, our approach involves an approximation that captures how people think about the uncertain future actions of others. We think this approximation is reasonable and is a good first step to understanding behavior in repeated settings. Our second behavioral contribution is a demonstration that reputation information can help solve the hold-up problem. Reputation may serve in lieu of informal agreements (Hart 2013). Board (2011) shows that theoretically, even in the presence of many potential partners, an optimal contract design implies loyalty to existing partners.[1] Bolton, Katok and Ockenfels (2004) show that reputation increases both trust and trustworthiness. They also report that, contrary to standard theory, some cooperation exists even without a formal feedback mechanism. This argument is also consistent with the findings by Özer, Zheng and Chen (2011) that people are more truthful than the standard theory predicts. Özer, Zheng and Ren (2013) refine these findings and extend

[1] The proof hinges on grim-trigger punishment in an infinitely repeated game. Once a partner defects, investment is zero forever after a certain period. The setting is not at all like ours because the principal has multiple partners to choose from, and a rich space of repeated game strategies to employ, but the idea of the game being more than a one-shot is an important component of the present setting, as well as the concept of reputation.



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them to a multi-cultural setting. Our work complements these earlier findings by showing that some cooperation is consistent with the dynamic equilibrium approximation in a repeated setting with a finite number of players. More importantly, we show that even though the dynamic approximation analysis is only an approximation for the actual setting in our experiment, it predicts the outcomes remarkably well.

## 1.2 Quality problem

### 1.2.1 Overview

Quality is increasingly important, as more consumers today expect high product quality. According to J.D. Power's research on the auto industry, quality is a consumer's most important consideration when purchasing a new vehicle (J.D. Power 2016). However, quality control is beyond a firm's control, because often, the final products rely on collaboration among supply chain members. For example, 76% of Ford's quality issues derive from its suppliers (Sherefkin 2002). This research is the first paper to investigate behavioral issues experimentally in process quality improvement in the supply chain.

The study captured the quality issue within a supply chain that includes one supplier and one buyer, where the buyer faces a deterministic demand from the market. There will be costs related to quality in the supply chain whenever a customer is sold a defective product, and the buyer and supplier share that cost. Furthermore, quality is measured as the proportion of defective products, which can be improved through efforts either on the part of the supplier or buyer or both.

The purpose of this research is to investigate whether data from laboratory experiments deviate from theoretical predictions of process quality improvement, and those deviations were documented not only at the aggregate level, but also at the detailed level.



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The theory was tested in the laboratory. Specifically, the experiment investigated 1) whether the supplier's decision to improve quality is independent of the buyer's; 2) whether the supplier (or the buyer) free-rides, and 3) whether the supply chain performance is optimal based on decisions people make.

Furthermore, an innovative mechanism was developed using negotiation to improve the supply chain's performance and the mechanism was tested in the laboratory.

### 1.2.2 Literature Review

The quality improvement literature is vast. Porteus (1986) investigated quality improvement issues, and found that products may be defective with a particular probability that can be reduced by investing in process quality. Similar to this study, Porteus (1986) assumed that the investment cost is a logarithmic function of the probability of defective products. Our study showed that the conclusion still holds under any cost function that is decreasingly convex[2], including a logarithmic cost function.

Chao et al. (2009) discussed several contracts that facilitate collaboration in improving quality in a supply chain. They examined two contractual agreements with which a manufacturer and a supplier can share product recall costs to motivate efforts to improve quality, and proposed a menu of contracts to mitigate information asymmetry. Moreover, they showed that in equilibrium, the menu of contracts actually increases product quality.

Zhu et al.'s (2007) study is related most closely to this one. In the context of a supply chain with one supplier and one buyer, they investigated theoretically the way in which order quantity,

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[2] In fact, as long as the cost function is decreasing and convex (here, $A\ (\overline{\alpha\mu}/\widehat{\alpha\mu})$) was used in the proportion of defective products, and the low-quality product rate is increasing and convex (a linear function was used here) in the proportion of defective products, and the conclusions still hold.



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production batch, as well as quality improvement, interact, and characterized optimal solutions that feature the potential free riding outcome. Specifically, equilibrium is reached when one of the two players takes full responsibility to improve quality, while the other does nothing, but benefits from the product's improved quality.

Experimental studies in economics have gained popularity in recent years. This study's experimental framework is similar to the threshold public goods game, as both have an equilibrium characterized by free riding. Cadsby et al. (1999) investigated a standard threshold public goods game with two players, each of which makes a private contribution to the production of the public good. The threshold public goods game is characterized by the fact that if sufficient contributions are made to reach the stated threshold level, the public good is provided. Otherwise, players lose their investment and no public good is provided. Everyone is better off if the good is provided than if it is not, but those who do not contribute are better off than those who do, regardless of the outcome. Palfrey et al. (2017) conducted another study similar to this one, and used a Bayesian mechanism design approach to investigate the effects of communication in a threshold public goods game.

Fairness is one of the major behavioral regularities. Specifically, people like to help those who help them, and to hurt those who hurt them. Outcomes that reflect this motivation are referred to as fairness equilibria (Rabin 1993). Kagel and Roth (2016) provided a comprehensive overview of recent developments on the topic of fairness. Cappelen et al.'s (2016) study is one of the recent efforts to show evidence of fairness. They found a strong association between a short response time and fair behavior in the dictator game. Using large and heterogeneous candidates from the general population in Denmark, they demonstrated that fairness is intuitive and is a general human



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trait that is robust regardless of decision makers' cognitive ability and swiftness. Moreover, the association between response time and fairness behavior also is consistent across groups in society.

Mental accounting, or psychological accounting, is a framework that attempts to describe the process of making decisions by considering the fact that monetary utility from different sources may be treated differently. Shafir and Thaler (2006) identified the mental accounting factor by documenting typical wine connoisseurs' decision making process. A wine connoisseur often treats the initial purchase of a case of wine as an investment. However, when s/he consumes it later, the wine is treated as if it is free, and therefore, the entire decision making process never experiences the pain of payment.

Katok and Pavlov (2013) tested a supply chain contract between a supplier and retailer experimentally. The supplier has all of the bargaining power, while the retailer either can accept or decline the supplier's offer. The authors designed a sequence of laboratory experiments to separate three possible causes of channel inefficiency, i.e. fairness, bounded rationality, and incomplete information. While all three factors affect human behavior, they found that fairness had the greatest power to explain the retailer's behavior.

Our paper is the very first one to experimentally investigate behavioral issues in process quality improvement in supply chain.

We capture the quality issue within a supply chain including one Supplier and one Buyer, where the Buyer faces deterministic demand from the market. There will be quality related cost to the supply chain whenever there is a nonconforming product sold to a customer. The cost is shared by the Buyer and the Supplier. Furthermore, the quality is measured by the proportion of



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nonconforming products, which can be improved through efforts by either the Supplier or the Buyer, or both of them.

The purpose of this chapter is to investigate whether observations from lab experiments deviate from theoretical predictions on process quality improvement. For those deviations, we try to document not only at aggregated level, but also at detailed level.

We test our theory in the lab. Specifically, we investigate 1) whether the Supplier's decision on quality improvement is independent of the Buyer's; 2) whether the Supplier (or the Buyer) free-rides; 3) whether the supply chain performance is optimal based on decisions made by human subjects

Furthermore, we design an innovative mechanism using negotiation to improve the performance of the supply chain and test the new mechanism in the lab.

**1.3 Remanufacturing problem**

**1.3.1 Overview**

Remanufacturing has been employed in industry as a strategy for numerous reasons (Atasu et al. 2010, Kleindorfer et al. 2005). For example, firms can use remanufacturing to gain market share, to reduce production costs, to follow government rules, or to cater to green consumers. However, remanufactured products can potentially cannibalize the sales of the new products sold by the firm, and thus optimizing on the marketing decisions for remanufactured products is desirable, including whether they should be offered in the first place.

Remanufacturing can be observed in the US automobile market -for example, certified pre-owned cars. The used-car market in the US is comparable to that of the new car market and estimated at over $370 billion annually, but it has traditionally been outside the manufacturer's



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control. Traditionally, used-car owners sold their cars in the secondary market as dealer trade-ins or private sales to individual consumers. The current practice of certified pre-owned (CPO, i.e., remanufactured) cars was introduced by luxury-car manufacturers for maintaining their brand reputation. Unsurprisingly, CPO cars have gained popularity. Manufacturers offer fully inspected, refurbished, high-quality used cars, benefiting from the reputation of their brands, and extended warranties provided to reassure about quality (Sultan 2009). Similarly, Xerox, a printing equipment maker, manages its remanufacturing business successfully (Atasu et al. 2010). According to Atasu et al. (2010), Xerox recovers models and parts from used or leased high-end imaging equipment, and then blends them with new models and parts. It recoups a savings on the manufacturing costs and offers the remanufactured products at a lower price compared to the new products.

### 1.3.2 Literature Review

The Operations Management literature on remanufacturing has examined its various facets and uses. Kleindorfer et al. (2005) provide an extensive review of remanufacturing research of the past two decades. Atasu et al. (2010) discuss remanufacturing practices and the issues raised from these practices. Consumer return, a component of remanufacturing, was studied by Su (2009). Debo et al. (2005) consider the joint pricing and production technology selection problem faced by a firm, which plans to introduce a remanufacturable product into a market of heterogeneous consumers. They assume that production of remanufacturable product is more costly than a single-use product, and investigate the tradeoff between the benefit of capturing lower willingness-to-pay consumers and the additional cost of allowing products to be remanufactured. They further evaluate how the tradeoff changes, based on the profile of consumers and the corresponding



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pricing policy. Chen and Chang (2013) examine price competition between new and remanufactured products of the same firm in a dynamic setting. The dynamic constraint is that past period sales of the product will affect current period availability to remanufacture. In the context of used goods collection, Savaskan et al. (2004) analytically compare different strategies. We consider a static model where the availability constraint for remanufacturing does not play a role.

The above papers assume that the manufacturer is a monopoly and Govindan et al. (2015) in a review of closed-loop supply chains also did not note competition as an issue. A more complete picture necessitates inclusion of competition. Ferguson and Toktay (2006) model remanufacturing under competition, but consider the competition to be between a third-party remanufacturer and the original equipment manufacturer (OEM) of the remanufactured products. This is different from the present paper which models competition between two OEMs both providing new products and remanufactured products.

Atasu et al. (2008) investigate the profitability of the remanufacturing strategy from a demand-related perspective, i.e., in the presence of a green consumer segment, and under the scenario of OEM competition and product life cycle effects. They assume that all consumers prefer one brand over the other. They find threshold points as functions of the green segment size, market growth rate, and consumer valuations, above which a monopoly will profit from remanufacturing. They investigate remanufacturing under competition, and conclude that remanufactured products can be applied for price discrimination.

Örsdemir et al. (2014) is another paper focusing on a remanufacturing problem related to ours. They investigate the competition between an original equipment manufacturer (OEM) and an independent remanufacturer (IR). They characterize how the OEM competes with the IR in



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equilibrium and find that the OEM relies more on quality (quantity, respectively) as a strategic lever when it has a stronger competitive position (weaker position, respectively). They also compare against a benchmark in which the OEM remanufactures, and find that encouraging IRs to remanufacture may not benefit the environment. Our problem is different in the sense that we have two OEMs competing with each other; moreover, both of them have the capability to remanufacture.

Van Den Heuvel et al. (2008) examine a handful of models, one of them is a lot-sizing model with a remanufacturing option. They show the equivalence of this model with a classical model: the lot-sizing model with inventory bounds. Different from their models, our paper examines remanufacturing option in the framework of game theory.

Zhang et al. (2014) investigate the problem of designing contracts in a closed-loop supply chain. Remanufacturing cost is the potential private information. Two different contracts are examined, each under complete information and private information. They derived the manufacture's optimal contracts in each case, and analyze the impact of information on the equilibrium results of supply chain members. In our paper, all the information is public, and the focus is the strategic option of whether remanufacturing or not under competition.

Our paper contributes to the literature by investigating remanufacturing strategy under the competition between new and remanufactured products offered by each firm in a duopoly. To our knowledge, it is the first to investigate firm's remanufacturing policy with quality differentiation and brand competition.



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# CHAPTER 2

# HOLD-UP PROBLEM

The full title of this chapter is as below: Relationship-Specific Investment and Hold-Up Problems in Supply Chains: Theory and Experiments.

This chapter is a published paper co-authored by Suresh P. Sethi, Ernan Haruvy, Elena Katok, and Zhongwen Ma, all from The University of Texas at Dallas

## 2.1 Model

In this section, we describe the basic game setting used in our study. We show that if players are motivated exclusively by monetary payoffs, the hold-up problem is severe. We then proceed to extend the model to include social preferences and random errors, and develop the dynamic equilibrium approximation that can predict that these behavioral considerations may mitigate the hold-up problem.

### 2.1.1 The Game and Standard Model

We begin with the basic setting, which is a sequential game with asymmetric information. The standard analysis assumes that players care exclusively about their monetary payoffs. We then proceed to add social preferences and random errors. Figure 2.1 displays the extensive form of the game we analyze.



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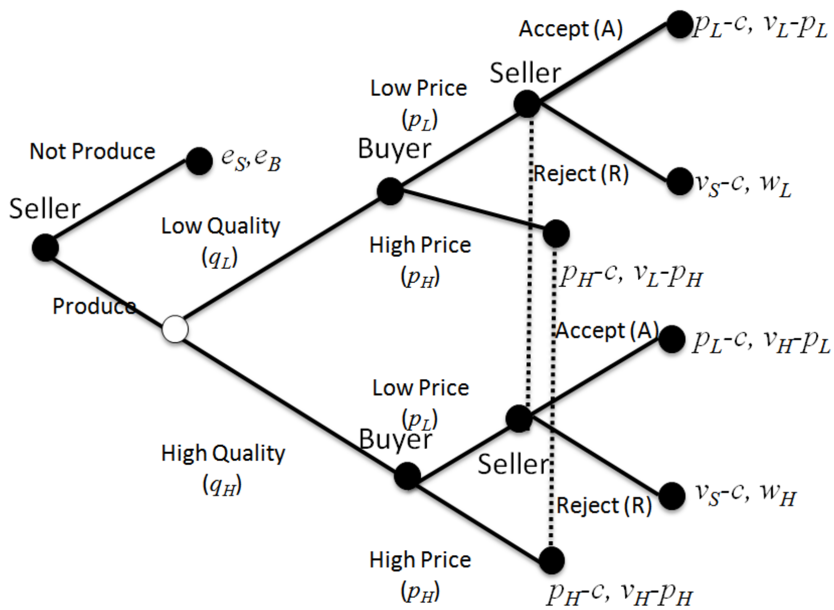


Figure 2.1 Extensive form game.

The seller moves first and decides whether to produce or not produce. If the seller chooses not to produce, then the buyer and the seller earn their outside option payoffs $e_B$ and $e_S$, respectively. If the seller chooses to produce, product *quality* is $q_L$ with probability $\delta = P(q_L)$ and $q_H$ with probability $1 - \delta = P(q_H) = 1 - P(q_L)$.

Quality is privately known to the buyer.[3] That is, the seller does not know the quality while the buyer does. In the context of the buyer being an end consumer, this is a straightforward assumption. The end consumer knows whether he likes the product and finds it esthetically pleasing, functional, fitting, or satisfying. The seller does his best to satisfy the consumer but if the consumer claims to be dissatisfied the seller cannot verify whether this claim is correct. In a supply chain context, this motivation extends to downstream channel members. The closer a channel

[3] In the experiment the buyer is told realized quality.



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member is to the end consumer, the more knowledge he has regarding end customer satisfaction, customer returns, malfunctions, customer service calls, warranty claims, customer reviews, customer churn, etc. Thus, the buyer possesses information about quality that the seller does not. The value of high quality product to the buyer is $v_H$ and the value of low quality product to the buyer is $v_L$. Upon observing quality, the buyer decides to offer either high price $p_H$ or low price $p_L$. In the last stage of the game, the seller decides whether to accept or reject the buyer's price. If the seller accepts price $p_k$, $k \in \{H, L\}$, then the seller earns $p_k - c$ and the buyer earns $v_H - p_k$ if quality was high or $v_L - p_k$ if quality was low. If the seller rejects $p_L$ (in Figure 2.1 we assume that the seller never rejects the high price), then the seller earns $v_S - c$, where $v_S$ is the value of the product to the seller outside of the relationship, and the buyer earns $w_L$ when $q = q_L$ and $w_H$ when $q = q_H$. Note that the innovation in our game is the presence of incomplete information: the buyer learns the product quality, and the seller does not.

The hold-up problem emerges when two conditions hold:

Condition 2.1. The seller's profit from accepting a low price is higher than from rejecting: $p_L > v_S$.

Condition 2.2. The seller's profit from the outside option is between expected profit from low price and expected profit from high price for high quality: $p_L - c < e_S < (\delta p_L - (1 - \delta)p_H) - c$.

Condition 2.1 ensures that after producing, the seller will not reject the low price. Knowing this implies that in a single-shot game, the buyer has a dominant strategy to offer low price regardless of quality. Condition 2.2 ensures that the seller will not produce under these circumstances.



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Additionally, if the buyer's outside option is higher than the net profit from paying high price for low quality, $e_B > v_L - p_H$, the parties are likely to be unable to contract at high price prior to the production decision because such a contract would not be ex post rational for the buyer. But if the buyer earns higher profit from paying high price for high quality and low price for low quality than from his outside option: $\delta(v_L - p_L) + (1-\delta)(v_H - p_H) > e_B$, then there are positive gains from trade—if the parties could overcome the hold-up problem, they would both potentially be better off. We summarize the analysis of a single-shot game with profit-maximizing players as Proposition 2.1.

**Proposition 2.1** (the hold-up problem): when conditions 2.1 and 2.2 are satisfied, the game is single shot, and players care exclusively about their monetary payoffs, the buyer will never offer a high price and the seller will never produce.

**Proof***:* Sellers will not reject a low price due to condition 2.1. Buyers will not offer a high price in the single-shot game when they are motivated solely by monetary payoffs. Offering a low price in this setting is a dominant strategy. Sellers will not produce due to condition 2.2. ■

### 2.1.2 Social Preferences

We will apply to the game in Figure 2.1 a simplified version of the inequality aversion model by Bolton and Ockenfels (2000) that has been extended to a supply channel setting by Cui et al. (2007).

Consider a linear version of the Bolton and Ockenfels (2000) and Fehr-Schmidt (1999) model in which player $i$ derives negative utility when her profit is below some fair outcome in terms of the relative difference between her and player *j*'s profit. Player *i*'s utility can be written as:



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$$u_i = \pi_i - \alpha\left(\gamma\pi_j - \pi_i\right)^+ - \beta\left(\pi_i - \gamma\pi_j\right)^+, \tag{2.1}$$

where $\alpha$ is player $i$'s degree of *disadvantageous inequality aversion* (negative utility from earning less than some relative fair share $\gamma$), and $\beta$ is $i$'s degree of *advantageous inequality aversion*. Parameter $\gamma$ represents the share of the channel profit that player $j$ earns under profit distribution that is considered to be fair ($\gamma$ may reflect differences in initial investment or other value-added activities; see Cui et al. 2007).

In the rest of the chapter we will set $\gamma = 1$ because it is reasonable for our laboratory setting and will simplify notation. For the same reasons, we will also make the simplifying assumption $\beta = 0$. The assumption of $\gamma = 1$ means that player *i* considers the fair allocation to be at the point where the profits of both players are exactly equal. Cui and Mallucci (2016) experimentally evaluated an environment structured similarly to ours in that there is a two-stage dyadic channel, in which firms decide on investments in the first stage and then on prices in the second stage. Their utility specification is identical to our utility Eq. (2.1), with only a slight notation difference. Specifically, they denote $\tau/(1-\tau)$ for our $\gamma$. They note that $\tau = \frac{1}{2}$ ($\gamma = 1$ in our notation) corresponds to the strict egalitarian ideal.

They also proposed a "sequence-aligned" notion of fairness in their framework which corresponds to the share of the decision maker in their framework under the Stackelberg equilibrium. In their setting, this notion prescribed ⊡ $= \frac{1}{3}$. In our experiment, the equilibrium is for no production to take place, and both players earn equal outside payoffs of 2, resulting in a sequence-aligned prescription of $\tau = \frac{1}{2}$ ($\gamma = 1$ in our notation), identical to the egalitarian notion. Our study thus does not distinguish these fairness notions, as they both prescribe $\gamma = 1$.



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Incidentally, Cui and Mallucci (2016) found that the sequence-aligned notion of fairness fits their data better than the strict egalitarian value, and this is consistent with $\gamma = 1$ in our framework. They also conclude that $\beta = 1$ which we rely on as support for our own $\beta = 0$ assumption.

The simplified seller's utility function then becomes

$$u_S = \pi_S - \alpha(\pi_S - \pi_B)^+,$$

and it will be used in the rest of the chapter.

The main effect of inequality aversion on the seller has to do with the seller's reaction to low price. With inequality aversion, the seller needs to form a belief about the buyer's payoff, meaning that he has to form a belief about quality which he does not observe. Specifically, the seller does not know quality realization but can form a belief about quality conditional on the price he was offered. The critical piece of information that the seller would like to know when he is offered a low price is whether this was due to low quality or not. In other words, the seller would like to know $P(q_L|p_L)$. We assume that the seller knows the unconditional probability of being offered a high price, $P(p_H)$ (for example, based on historical data), and then uses Bayes' rule to calculate conditional probabilities. We further assume that high price for low quality is dominated for the buyer so that $P(p_H|q_L) = 0$). This gives us

$$P(q_L|p_L) = \frac{P(p_L|q_L)P(q_L)}{P(p_L)} = \frac{P(q_L)}{P(p_L)} = \frac{\delta}{1 - P(p_H)}\,. \tag{2.2}$$

We assume that the seller operates in the environment of being subject to disadvantageous inequality only. The seller's expected utilities from accepting and rejecting a low price are



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$$\mathbb{E}[u_S(p_L, A)] = p_L - c$$
$$- \alpha \left[ \left(1 - \frac{\delta}{1 - P(p_H)}\right)(v_H - p_L) + \left(\frac{\delta}{1 - P(p_H)}\right)(v_L - p_L) - (p_L - c) \right]^+,$$
$$\mathbb{E}[u_S(p_L, R)] = v_S - c - \alpha \left[ \left(1 - \frac{\delta}{1 - P(p_H)}\right) w_H + \left(\frac{\delta}{1 - P(p_H)}\right)(w_L - (v_S - c)) \right]^+. \qquad (2.3)$$

Consider the terms in equation (2.3) that multiply $\alpha$. These terms represent potential loss in utility to the seller due to being relatively worse off than the buyer. If $v_S < p_L$ (according to Condition 2.1), which is a reasonable assumption for a setting in which the seller makes a relationship-specific investment, then rejecting a low price makes the seller worse off in absolute terms. If it is also the case that

$$\left[ \left(1 - \frac{\delta}{1 - P(p_H)}\right)(v_H - p_L) + \left(\frac{\delta}{1 - P(p_H)}\right)(v_L - p_L) - (p_L - c) \right]^+ <$$
$$\left[ \left(1 - \frac{\delta}{1 - P(p_H)}\right) w_H + \left(\frac{\delta}{1 - P(p_H)}\right)(w_L - (v_S - c)) \right]^+, \qquad (2.4)$$

then rejecting makes the seller worse off in relative terms as well, and consequently the seller has no reason to reject, and the buyer can offer low prices with impunity. We call equation (2.4) the impunity condition.

**Proposition 2.2** (Reciprocity*)*: If the impunity condition elaborated in equation (2.4) does not hold and the buyer earns higher profit from high price for high quality than from a rejection ($v_H - p_H > w_H$), the buyer motivated exclusively by profit may offer high price for high quality in the single-shot game if the seller has sufficiently high $\alpha$. A seller with sufficiently high $\alpha$ will produce.



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**Proof**: If impunity condition in equation (2.4) does not hold, it means that there exists a high enough $\alpha$ that the seller with this $\alpha$ will have higher utility from rejecting than from accepting a low price. Therefore, this seller may reject a low price. Since $v_H - p_H > w_H$, the buyer will offer high price for high quality. Since $p_H - c > e_S$, the seller will produce. ∎

### 2.1.3 Incorporating Errors

It has been shown that laboratory participants make random errors (Su 2008). It is useful to incorporate these random errors into the analysis in order to obtain better estimates of behavioral parameters. We follow the basic idea of a logistic mapping between expected utilities and action probabilities (e.g., McKelvey and Palfrey 1995). It implies that people are more likely to choose an action that yields higher expected utility.

Our goal here is to construct a parsimonious model that captures the essential aspects of the problem setting. The critical aspects of the problem setting are the ones that result in the hold-up problems: (1) the seller is financially better off to not produce unless there is a *sufficient likelihood* that the buyer will offer high price for high quality, and (2) in the long run, the buyer is much better off if the seller produces, even if he has to induce production by sometimes paying high prices for high quality. So the buyer and the seller face fundamentally different problems.

The seller will only produce if he expects to see a high price with sufficiently high probability. It is reasonable to model a seller as if he is playing a game in which he is using information from past rounds to forecast the probability $P(p_H)$ but is not attempting to affect the future behavior of the buyers. In contrast, the buyer is facing a clear tradeoff each period between the immediate payoff from paying low price for high quality and the loss from lack of production by suppliers in future rounds. Therefore, we approximate buyers' behavior with a model in which



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buyers decide on a *fixed probability of offering high price for high quality* given the sellers' response function and the behavior of other buyers in the market.[4] That is, sellers need to form beliefs given the history of the game, whereas buyers need to develop reputations (individually or as a group) in order to make it desirable for sellers to produce. This framework results in simple theoretical benchmarks that capture most of the regularities of the data in our laboratory experiments.

**2.1.3.1 The Sellers**

We model the seller's probability of producing as a logit function (McKelvey and Palfrey 1995).[5]

$$P(\text{Produce}) = \frac{\exp(\tau \mathbb{E}[u_S(\text{Produce})])}{\exp(\tau e_S) + \exp(\tau \mathbb{E}[u_S(\text{Produce})])} \quad , \qquad (2.5)$$

where $\tau$ is the rationality parameter and

$$\mathbb{E}[u_S(\text{Produce})] = P(p_H)\mathbb{E}[u_S(p_H, A)] +$$
$$+\big(1 - P(p_H)\big)\big[P(p_L, A)\mathbb{E}[u_S(p_L, A)] + P(p_L, R)\mathbb{E}[u_S(p_L, R)]\big] .$$

[4] The model of buyers we propose is parsimonious, and we do not argue that it is "the right model" but merely a very simple one that has a chance of being consistent with the data. For example, Özer, Zheng and Chen (2011) propose a model in which retailers, faced with a problem that has similar features to ours, are averse to lying. Additionally, buyers could make random errors, which would not affect qualitative predictions, but in all likelihood would make the model fit the data even better.

[5] In this section we are analyzing the repeated game equilibrium approximation under the assumption that sellers are ex ante symmetric, and therefore we do not subscript sellers' decisions either by time subscript *t* or seller subscript *j*. In the estimation section, in which we use the panel data from our experiment, we will add subscripts for seller *j* and time period *t* to our notation.



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If the seller's decision to reject is not dominated, then we start with the seller's decision to accept or reject a low price. The seller's expected utility from accepting a low or a high price works out to be

$$\mathbb{E}[u_S(p_L, A)] = p_L - c - \alpha\left(\left(1 - \frac{\delta}{1 - P(p_H)}\right)(v_H - v_L) + v_L - 2p_L + c\right)^+, \qquad (2.6)$$

and

$$\mathbb{E}[u_S(p_H, A)] = p_H - c - \alpha(v_H - 2p_H + c)^+.$$

To keep the problem tractable, we assume $v_L - p_L > p_L - c$ meaning that paying low price is fair to the buyer. Therefore, equation (2.6) is equivalent to

$$\mathbb{E}[u_S(p_L, A)] = p_L - c - \alpha\left(\left(1 - \frac{\delta}{1 - P(p_H)}\right)(v_H - v_L) + v_L - 2p_L + c\right). \qquad (2.6`)$$

Meanwhile, the seller's expected utility from rejecting either a low or a high price is

$$\mathbb{E}[u_S(p_L, R)] = \mathbb{E}[u_S(p_H, R)] = v_S - c - \alpha\big(v_B(q) - (v_S - c)\big)^+.$$

It follows that the probability of accepting price $p_k$ is

$$P(p_k, A) = \frac{\exp(\tau\mathbb{E}[u_S(p_k, A)])}{\exp(\tau\mathbb{E}[u_S(p_k, A)]) + \exp(\tau\mathbb{E}[u_S(p_k, R)])}, k \in \{H, L\}. \qquad (2.7)$$

**2.1.3.2 The Buyers**

Let us assume that there are *n* buyers in the market, randomly matched with *n* sellers, but the number of periods is large relative to *n* so that after some number of periods, sellers assume that $P(p_H)$ in the current period will follow the probability distribution of the past $P(p_H)$. We assume full information, which means that $P(p_H)$ forecasted by sellers, $\delta = P(q_L)$, as well as



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sellers' $\alpha$ and $\tau$, are all known to buyers. This means that buyers know (2.5) and (2.7)—the sellers' probabilities of future production and of rejecting a low price.

Each buyer $i$ maximizes her expected long run average profit by choosing $P_i(p_H|q)$ where $q \in \{q_L, q_H\}$.

$$\max_{P_i(p_H|q)} \mathbb{E}\left[u_B\left(P_i(p_H|q)\right)\right] \tag{2.8}$$

where

$$\mathbb{E}\left[u_B\left(P_i(p_H|q)\right)\right]$$
$$= P(\text{Produce})\left\{\delta\mathbb{E}\left[u_B\left(P_i(p_H|q_L)\right)\right] + (1-\delta)\mathbb{E}\left[u_B\left(P_i(p_H|q_H)\right)\right]\right\}$$
$$+ \left(1 - P(\text{Produce})\right)e_B,$$

and $P(\text{Produce})$ is defined by equation (2.5) and in the long run depends on $P(p_H)$ observed by the seller. Note that $P(p_H)$ is based on the behavior of all $n$ buyers, so each buyer $i$ has an effect on the average $P(p_H)$ that a seller observes.

If the buyer never pays high price for low quality, so $P_i(p_H|q_L) = 0$, then the buyer's expected utility when he observes low quality is

$$\mathbb{E}\left[u_B\left(P_i(p_H|q_L)\right)\right] = P(p_L, A)(v_L - p_L) + P(p_L, R)\left(v_B(q_L)\right).$$

Let us also assume that sellers accept high prices with certainty, so the buyer's expected utility when he observes high quality and offers high price for it with probability $P_i(p_H|q_H)$ is

$$\mathbb{E}\left[u_B\left(P_i(p_H|q_H)\right)\right]$$
$$= P_i(p_H|q_H)(v_H - p_H) + \left(1 - P_i(p_H|q_H)\right)[P(p_L, A)(v_H - p_L) + P(p_L, R)w_H].$$



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The last piece of the model is the link between buyer *i*'s average probability of offering high price for high quality, $P_i(p_H|q_H)$, and the seller's forecasted probability of being offered a high price, $P(p_H)$.

In the dynamic equilibrium approximation, let $P_{-i}(p_H|q_H)$ be the average probability from the other *n*-1 buyers in the market of offering high price for high quality. In this case, let the average probability of high price that sellers observe be

$$P(p_H) = (1-\delta)\big((1-\lambda)P_{-i}(p_H|q_H) + \lambda P_i(p_H|q_H)\big)\,, \tag{2.9}$$

where $\lambda$ is the effect buyer *i* has on the total probability of high price in the population of buyers. So for example, in the impunity treatments, if sellers correctly calculate the historical probability of high price, then $\lambda = \frac{1}{n}$, where *n* is the total number of buyers. In the dynamic equilibrium approximation, sellers use (2.9) in (2.5)-(2.7) when they make their production and acceptance decisions. The buyer solves (2.8) in order to find her average equilibrium probability of offering high price for high quality. Let buyer *i*'s average equilibrium probability of offering high price for high quality when the other *n*-1 buyers use $P_{-i}(p_H|q_H)$ be

$$P^*_{i,-i}(p_H|q_H) = \underset{P_i(p_H|q_H)}{\operatorname{argmax}}\ \mathbb{E}\big[u_B\big(P_i(p_H|q_H)\big)\big]\,. \tag{2.10}$$

**2.1.3.3 Reputation**

Consider a setting in which a seller, rather than observing the history $P(p_H)$ for the entire market, observes instead seller-specific history, $P_i(p_H) = (1-\delta)P_i(p_H|q_H)$, for the seller *i* with whom she is matched in the current period. This implies $\lambda = 1$, and (2.9) becomes

$$P(p_H) = (1-\delta)P_i(p_H|q_H)\ . \tag{2.11}$$



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In other words, $P_i(p_H)$ is buyer *i*'s *reputation*. Intuitively, as $\lambda$ increases, buyer $i$ benefits more from offering a high price for high quality because he captures more of the future benefits.

**Proposition 2.3** (reputation): In the dynamic equilibrium approximation, $P^*_{i,-i}(p_H|q_H)$ increases in $\lambda$.

**Proof**: see Appendix A2.1.

**Corollary 2.1** $P^*_{i,-i}(p_H|q_H)$ is higher when reputation information is available than when it is not available.

**Proof**: Follows from the fact that $\lambda$ is higher when reputation information is available. ■

In summary, $P^*_{i,-i}(p_H|q_H)$ is increasing in $\lambda$. Moreover, reputation information increases its value.

## 2.2. Experimental Design and Hypotheses

### 2.2.1 Experimental Design

We designed a laboratory setting in which the hold-up problem would be present in the single-shot game (consistent with Proposition 2.1). In all experimental treatments, we set parameters at $\delta = 0.2, e_S = e_B = 2, v_H = 14, v_L = 7, c = 4, p_H = 9, v_S = 5$, and $p_L = 5.5$. This means that if the quality is high and the buyer offers a high price, both players earn 5 ($\pi_B = \pi_S = 5$), if the quality is high and the buyer offers a low price that the seller accepts, then $\pi_B = 14 - 5.5 = 8.5$ and $\pi_S = 5.5 - 4 = 1.5$. If the quality is low and the buyer offers a high price that the seller accepts, then $\pi_B = 7 - 9 = -2$ and $\pi_S = 9 - 4 = 5$. If the quality is low and the buyer offers a low price that the seller accepts, then $\pi_B = 7 - 5.5 = 1.5$ and $\pi_S = 5.5 - 4 = 1.5$. If the seller rejects, then $\pi_S = 5 - 4 = 1$ in all treatments.

Our experimental treatments vary in the effects seller rejection have on the profit of the buyer. In the *impunity* condition we set $w_L = 2$ and $w_H = 9$, and in the *reciprocity* condition we



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set $w_L = w_H = 1$. Thus, if the seller rejects, then in the impunity condition $\pi_B = 9$ if the quality is high and $\pi_B = 2$ if the quality is low (making the seller worse off from rejecting in relative terms as well as in absolute terms), while in the reciprocity condition $\pi_B = 1$ regardless of quality (so the seller is worse off in absolute terms, but better off in relative terms). Figure 2.2 provides experimental parameters in the extensive form of the game. See on-line appendix for experimental instructions.

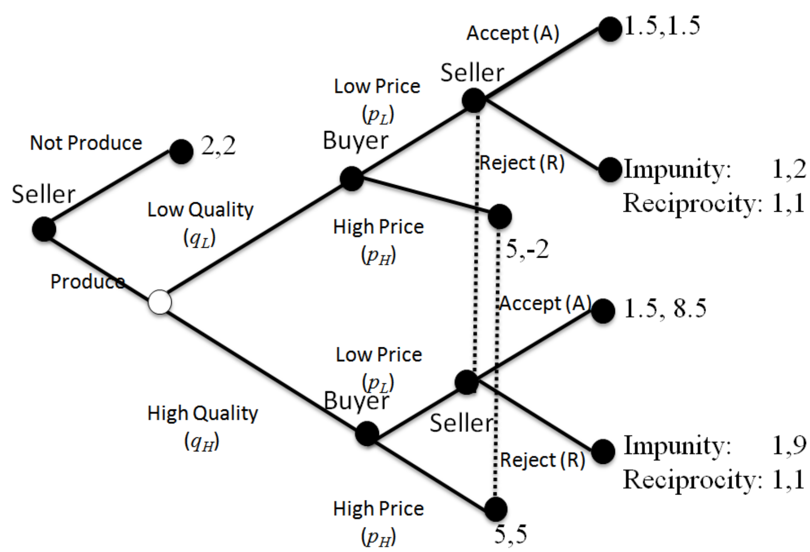


Figure 2.2 Extensive form representation of the game in the laboratory experiment.

### 2.2.2 Experimental Treatments

The experiment includes three treatments. In all treatments, we randomly assign participants to buyer and seller roles when they arrive at the laboratory, and they keep the roles for the duration of the session. Each treatment includes four sessions, and each session includes 4 buyers and 4 sellers. Participants play the game corresponding to one treatment (with payoffs corresponding to Figure 2.2) for 100 rounds. They are randomly re-matched each round. In total, our experiment includes 96 participants. We pay participants a \$5 show-up fee and an additional



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amount proportional to their total profits earned in the experiment. Average earnings were $26.68 for buyers and $18.78 for sellers. We recruited participants using ORSEE recruitment system (Greiner 2004) and offered cash as the only incentive to participate. We designed experimental software using zTree (Fischbacher 2007).

Our design examines the effect of social preferences by comparing *impunity* and *reciprocity* conditions. Additionally, we test an intervention that we call *reputation*, in which we keep track and show to the seller the average number of times the current buyer offered a high price. In summary, our experiment includes the following three treatments:

1. In the *impunity treatment*, participants have access to their own prior history that includes past production decisions, the price offered (if production occurred), and their own realized profits. The buyers have one additional piece of information that sellers do not have — the realized quality for the current and all past periods.
2. In the *reciprocity treatment*, the payoffs are different from the impunity treatment — the only difference being in the buyer's payoff that results from seller's rejection. Participants have access to the same historical information as in the impunity treatment.
3. In the *reputation treatment*, the payoffs are the same as in the impunity condition. Historical information is different. Specifically, sellers see the proportion of the time the buyer with whom the seller is matched during the current period offered a high price; this buyer-specific history is shown to the seller prior to making the production decision.

### 2.2.2 Theoretical Predictions and Hypotheses

In this section, we derive theoretical predictions for the behavior in the three treatments in our experiment.



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#### 2.2.2.1 The Impunity Treatment

In the impunity treatment, a buyer motivated exclusively by monetary payoff derives his average equilibrium probability of offering high price for high quality according to equations (2.8) and (2.9). Figure 2.3 plots the buyer's equilibrium expected profit as a function of the probability of offering high price for high quality for three levels of $\alpha$ ($\alpha = 0, \alpha = 0.25$ and $\alpha = 1$), and $\tau = 2$ in Figure 2.3(a) and lower levels of $\tau$ in Figure 2.3 (b).

It is easy to calculate that a fully rational seller (very high $\tau$) not concerned with inequality aversion ($\alpha = 0$) prefers to produce as long as $P(p_H|q_H) > \frac{2-1.5}{0.8(5-1.5)} = 0.1785$, or equivalently $P(p_H) > 0.1428$. For a seller concerned with inequality aversion, this threshold would be higher. A seller with a low $\tau$, however, would produce even for a lower $P(p_H)$.

Figure 2.3(a) shows that when $\tau = 2$ (this is the approximate level of $\tau$ we measured in our data), buyer's equilibrium $P^*(p_H)$ ranges from 26% when $\alpha = 0$ to 36% when $\alpha = 0.25$ ($P^*(p_H) = 0.32$ for $\alpha = 1$). Figure 2.3(b) varies $\tau$ for each level of $\alpha$ so as to make $P^*(p_H|q_H) = 0.1785$. Here, $\tau$ ranges from 0.93 for $\alpha = 0.25$ to 1.3 for $\alpha = 0$ ($\tau = 1.07$ for $\alpha = 1$). Because those levels of $\tau$ are much lower than the levels observed in our data, our first hypothesis predicts positive levels of production and significant probability of high prices given for high quality in the impunity treatment.



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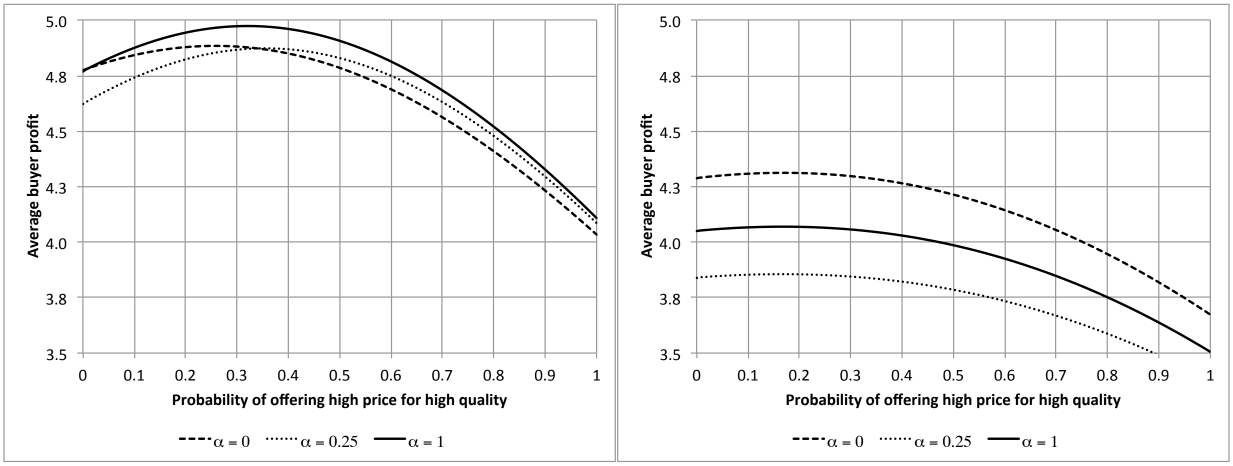


(a) $\tau = 2$.

(b) $\tau = 1.3$ for $\alpha = 0$; $\tau = 0.93$ for $\alpha = 0.25$ and $\tau = 1.07$ for $\alpha = 1$.

Figure 2.3 Buyer's expected profit as a function of the probability of offering high price for high quality in the impunity treatment.

Hypothesis 2.1: In the impunity treatment, buyers offer high prices for high quality on average at least 17.85% of the time, and sellers sometimes produce. Sellers never reject any price offer.

Whether a seller produces depends on the seller's $\alpha$ and on the $P(p_H)$ the seller anticipates. The utility from not producing is 2, while the expected utility from producing is

$$\mathbb{E}[u_S(\text{Produce})] = 5P(p_H) + \left(1 - P(p_H)\right)\left(1.5 - 7\left(1 - \frac{\delta}{1 - P(p_H)}\right)\alpha\right). \qquad (2.12)$$

Setting $\mathbb{E}[u_S(\text{Produce})]$ in equation (2.12) equal to 2 and solving for $\alpha$ characterizes when a fully rational seller produces, i.e.,

$$\alpha < \frac{5P(p_H) + 1.5(1 - P(p_H)) - 2}{7(1 - P(p_H)) - \delta} \quad . \qquad (2.13)$$

Note that since it is dominated for the buyer to offer a high price for low quality, it follows that $P(p_H) \leq 1 - \delta$. Therefore, the closer $P(p_H)$ is to $1 - \delta$, the closer to certainty it is for the seller to get high price for high quality and the more likely he is to produce regardless of $\alpha$.



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Generally, we see from (2.13) that for a fully rational seller, the likelihood of production decreases in $\alpha$ and increases in $P(p_H)$.

### 2.2.2.2 The Reciprocity Treatment

In the reciprocity treatment, rejection is not a dominated action for a seller because even though the seller foregoes 0.5 in absolute profit, he implements the equal split. The seller's utility from rejecting a low price is 1, and based on equation (2.6), his expected utility from accepting a low price is $\mathbb{E}[u_S(p_L, A)] = 1.5 - 7\alpha\left(1 - \frac{\delta}{1-P(p_H)}\right)$, so a fully rational seller whose $\alpha > \frac{0.5}{7}\left(\frac{1-P(p_H)}{1-P(p_H)-\delta}\right)$ would reject a low price. This gives buyers an additional incentive to offer a high price for high quality in the reciprocity treatment.

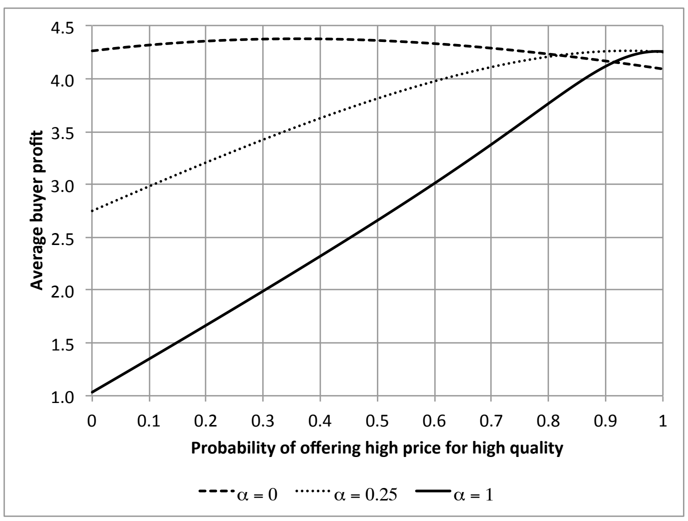


Figure 2.4 Buyer's expected profit as a function of the probability of offering high price for high quality in the reciprocity treatment.

We plot the buyer's expected profit function for three levels of $\alpha$ and $\tau = 2$ in Figure 2.4. We see from the figure that $P^*(p_H)$ is higher in the reciprocity treatment than in the impunity



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treatment for all three levels of $\alpha$, and the differences are especially pronounced for higher values of $\alpha$.

We summarize predictions about the differences between the impunity and reciprocity treatments in the following hypothesis:

Hypothesis 2.2: In the reciprocity treatment, rejections of low prices will be higher than in the impunity treatment, high prices for high quality will be higher than in the impunity treatment, and the production rate will be higher than in the impunity treatment.

**2.2.2.3 The Reputation Treatment**

In the reputation treatment, we keep track of each buyer $i$'s proportion of high prices, denoted $P_i(p_H)$. We use the notation $P(p_H)$ to denote the average proportion of high prices over the buyers in a cohort. In the reputation treatment, the seller observes the buyer specific $P_i(p_H)$ prior to deciding whether or not to produce. Knowing $P_i(p_H)$, the seller can use equation (2.5) to decide whether or not to produce for each specific buyer. In the reputation treatment, each buyer controls his own $P_i(p_H)$, in contrast to the impunity treatment, in which each buyer only affects the average $P(p_H)$ in his group. Therefore, we expect higher proportion of high prices offered for high quality in the reputation treatment than in the impunity treatment, and indeed we can see from comparing Figure 2.5 to Figure 2.3(a) that $P^*(p_H)$ is higher in the reciprocity treatment than in the impunity treatment for all three levels of $\alpha$. A higher $P^*(p_H)$ also implies a higher production rate in the reputation treatment than in the impunity treatment, as we summarize in our last hypothesis.



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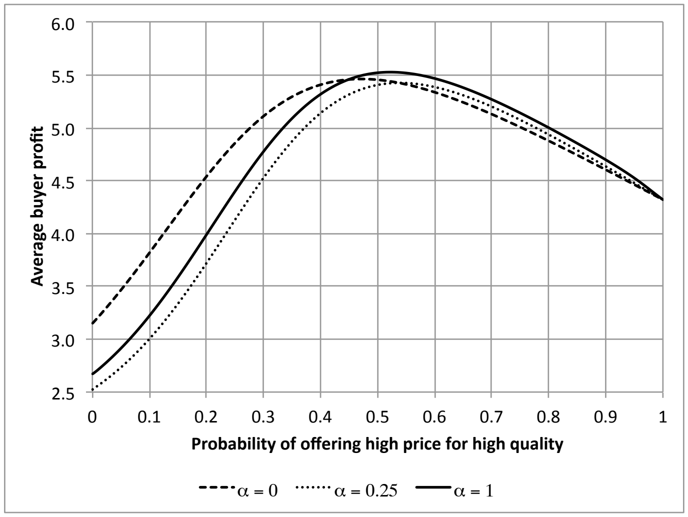


Figure 2.5 Buyer's expected profit as a function of the probability of offering high price for high quality in the reputation treatment.

Hypothesis 2.3: In the reputation treatment, production and high prices for high quality will be higher than in the impunity treatment. Rejections will be similar across the two treatments.

**2.3 Results**

We present summary statistics for production, prices, profits and rejections in the three treatments. We then report estimates for a behavioral model that includes non-monetary preferences and errors.

**2.3.1 Summary Statistics**

Table 2.1 reports average rates for production, high prices for high and low quality, rejections and players' earnings. We report standard errors in parenthesis, and we use the session average as a unit of analysis (recall that each treatment includes 4 sessions).

All p values reported are for a t test with four independent session-level observations. We examine the results as they relate to H1 pertaining to the impunity treatment. As hypothesized, the proportion of high prices given for high quality is significantly above zero in the impunity



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Table 2.1 Summary statistics.

| | Treatment | | |
|---|---|---|---|
| Probability | Impunity | Reciprocity | Reputation |
| High prices for high quality | 0.256 | 0.695 | 0.589 |
| | (0.090) | (0.177) | (0.083) |
| Production | 0.569 | 0.821 | 0.771 |
| | (0.156) | (0.183) | (0.126) |
| Low prices rejected | 0.140 | 0.527 | 0.105 |
| | (0.139) | (0.185) | (0.137) |
| High prices for low quality | 0.075 | 0.003 | 0.103 |
| | (0.027) | (0.007) | (0.136) |
| High prices rejected | 0.000 | 0.000 | 0.003 |
| | (0.000) | (0.000) | (0.004) |
| Seller Earnings | 2.154 | 3.205 | 2.909 |
| | (0.027) | (0.688) | (0.221) |
| Buyer Earnings | 4.523 | 3.848 | 4.401 |
| | (0.469) | (0.344) | (0.335) |

Note: Session is used as a unit of analysis. Each treatment incudes 4 sessions. Standard errors are in parenthesis.



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treatment ($p = 0.010$). In fact, the proportion of high prices for high quality is not significantly different from the hypothesized 0.1785 ($p = 0.168$), indicating that sellers with low $\alpha$ values are nearly indifferent, on average, between producing and not producing. Lastly, as predicted, the proportion of production is significantly above zero ($p = 0.0053$). These aspects of the data are consistent with H1.

However, two aspects of the data are not entirely consistent with the theory. First, the proportion of high prices given for low quality is low, but is significantly above zero ($p = 0.012$). Second, the proportion of rejections is significantly above zero in the impunity treatment ($p = 0.011$). However, both are sufficiently small in absolute terms to be attributed to errors as we will show in the model estimation.

We now turn our attention to H2, concerned with the comparison of the impunity and reciprocity treatments. We find that the data is consistent with H2 in that the proportion of high prices given for high quality is significantly higher in the reciprocity treatment than in the impunity treatment ($p = 0.004$), and the proportion of production is higher in the reciprocity treatment than in the impunity treatment (although only weakly significant; $p = 0.080$).

H3 is concerned with the comparison of the impunity and reputation treatments. We find the patterns in the data to be consistent with H3. Specifically, the proportion of high prices for high quality in the reputation treatment is above the corresponding proportion in the impunity treatment ($p = 0.002$), and the proportion of production in the reputation treatment is higher than the corresponding proportion in the impunity treatment (weakly so; $p = 0.086$).



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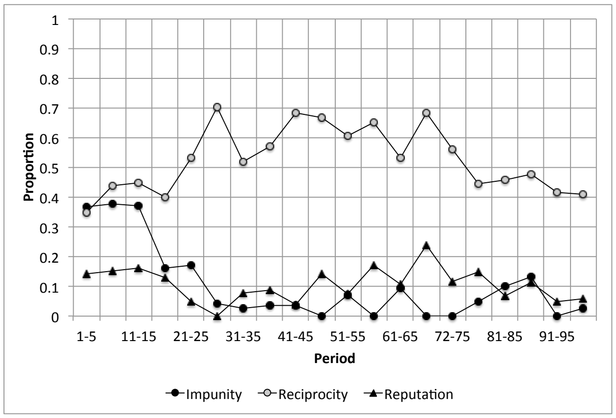
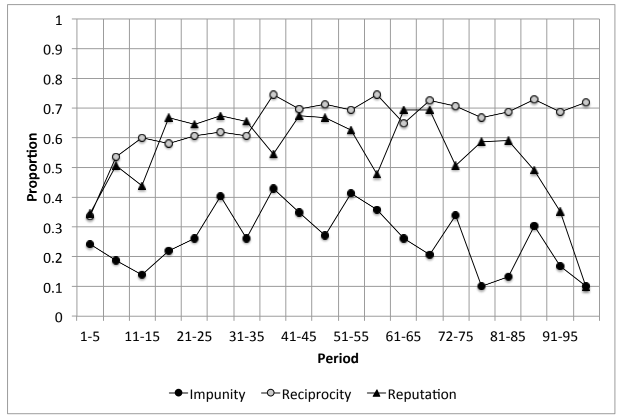
### 2.3.2 Dynamics

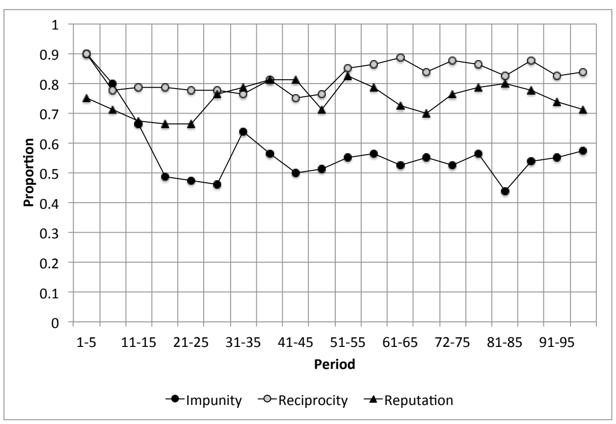
In Figure 2.6, we present rejections, high prices offered for high quality, and production rates, as they evolve over time. To focus on the trend, we aggregate 100 periods of data into 20 five-period blocks. Rejections and production are highly stable after an initial learning that takes about 20 periods. The proportion of high prices for high quality is quite stable in rounds 21-80, but in the reputation treatment, in contrast to the reciprocity treatment, it exhibits end-game effect




(a) Proportion of low prices rejected.




(b) Proportion of high prices offered for high quality.




(c) Average production rate.

Figure 2.6 Average rejections, prices and production over time.



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in the last 20 rounds. This is not surprising; other studies also found end-game effects in reputation treatments (see for example Bolton, Katok and Ockenfels 2005).

In the next section, we report on estimation of a behavioral model using periods 21-100 for the analysis to eliminate the initial periods of steep learning.

**2.3.3 Estimation**

In this section, we jointly estimate behavioral parameters $\alpha$ and $\tau$ for the behavioral model presented in Section 2.1. We estimate behavioral parameters for sellers only. The buyers are assumed to anticipate seller's reactions, and we capture their decisions with a dynamic equilibrium approximation. Sellers make two decisions—production and accept/reject—and these decisions are not independent. The production decision of seller $j$ in period $t$ results in the probability of production $P_{jt}(\text{Produce})$, specified in equation (2.5) (but now indexed by $j$ and $t$ because we are using panel data for estimation). This production decision depends, in turn, on the probabilities of accepting price $p_k$, $k \in \{L, H\}$, $P_{jt}(p_k, A)$ — the seller's second decision is determined by equation (2.7). Because the two decisions are not independent, we estimate them jointly through a joint likelihood function.

Both of the seller's decisions depend on the seller's forecast of the buyer's conditional probability of paying a high price $P_{jit}(p_H|q_H)$, where $i$ denotes the buyer who has been matched with seller $j$ in period $t$. We assume that in the impunity and the reciprocity treatments, these forecasts are simply the average probability that seller $j$ observed high prices in the past, multiplied by the unconditional probability of high quality. Specifically, in the estimation for impunity and reciprocity treatments, $P_{jit}(p_H|q_H) = \frac{1}{t-1}\sum_{s=1}^{t-1}(P_{js} = p_H)$. Note that subscript $i$ does not appear on the right hand side because the seller cannot distinguish among different buyers in the impunity



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and the reciprocity treatments. In the reputation treatment, on the other hand, the seller has historical information specific to buyer *i*: $P_{jit}(p_H|q_H) = \frac{1}{t-1}\sum_{s=1}^{t-1}(P_{jis} = p_H)$.

The joint log-likelihood is defined as

$$LL = \sum_{j=1}^{n}\sum_{t=1}^{T}\left[ln\left(P_{jt}(Produce)\right)Produce_{jt} + ln\left(1 - P_{jt}(Produce)\right)\left(1 - Produce_{jt}\right) + ln\left(P_{jt}(p_{jt}, A)\right)Accept_{jt} + ln\left(1 - P_{jt}(p_{jt}, A)\right)(1 - Accept_{jt})\right],$$

where *n* is the total number of sellers in the session (*n*=4), *T* is the number of periods in a session (*T*=100), $Produce_{jt}$ is 1 if seller *j* decided to produce in period *t* and 0 otherwise, and $Accept_{jt}$ is 1 if seller *j* accepted the price the buyer offered in period *t* and 0 otherwise.

The joint estimation implies that the parameter $\alpha$ is estimated in a way that maximizes the fit not only of the acceptance/rejection decision but also of the production decision. In the impunity and reputation treatments, where it is optimal to always accept, one could expect that the production decision would have the greater influence over the estimate of $\alpha$, whereas in the reciprocity treatment, where acceptance depends largely on inequality aversion, it would be the accept/reject decision that would have the greater impact on the estimate.

We report results of the estimation in Table 2.2.

The main takeaway from the estimation has to do with the comparison between predicted behavior, based on the estimates of $\alpha$ and $\tau$ under the dynamic equilibrium approximation analyzed in section 2.3[6] (see bottom section of Table 2.2), and the actual behavior (see Table 2.1).

[6] Predicted high prices for high quality are based on solving equation (2.9) for the impunity and equation (2.10) for the reciprocity treatment and equation (2.11) for the reputation treatment. Production probability is based on equation (2.5). Rejection rates are based on equation (2.7). The average buyer's and seller's profits are also based on repeated game equilibrium approximation solution given average behavioral parameters $\alpha$ and $\tau$.



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Table 2.2 Estimation results and predictions based on MLE.

| | | Impunity Treatment | Reciprocity Treatment | Reputation Treatment |
|---|---|---|---|---|
| Fit | Log Likelihood | -927.05 | -629.61 | -699.30 |
| | Parameters | 3 | 3 | 3 |
| | $\chi^2$ (restricted $\tau$) | $13.068^{**}$ | $15.38^{**}$ | $4.19^{*}$ |
| Estimated Parameters | $\tau$ Production | $1.562^{**}$ (0.029) | $2.633^{**}$ (0.141) | $1.880^{**}$ (0.131) |
| | $\tau$ Acceptance | $2.342^{**}$ (0.162) | $1.435^{**}$ (0.168) | $1.564^{**}$ (0.079) |
| | $\alpha$ | $0.042^{**}$ (0.009) | $0.102^{**}$ (0.011) | $0.042^{**}$ (0.013) |
| Predictions \| *MLEs* | High Prices for High Quality | 0.260 | 0.763 | 0.510 |
| | Production | 0.569 | 0.996 | 0.894 |
| | Rejection Rate | 0.253 | 0.446 | 0.188 |
| | Seller Profit | 2.285 | 4.115 | 3.191 |
| | Buyer Profit | 4.562 | 4.275 | 5.383 |

Note: * $p < 0.05$; ** $p < 0.01$



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We stress that even though the dynamic equilibrium approximation model in section 2.3 is only a rough approximation for the actual setting, its prediction qualitatively matches virtually all important aspects of the data:

- Proportions of high prices for high quality and production rates are lowest in the impunity treatment, highest in the reciprocity treatment, and in between in the reputation treatment. None of the high price proportions are different from predictions.
- Proportions of low prices rejected are highest in the reciprocity treatment, lowest in the reputation treatment, and in between in the impunity treatment. None of the rejection rates are significantly different from predictions.
- Seller profits are highest in the reciprocity treatment and lowest in the impunity treatment. None of the seller's profits are significantly different from predictions.
- Buyer's profits are lowest in the impunity treatment. Buyer profits in the impunity and reciprocity treatments are not significantly different from predictions,

The only qualitative difference between predictions and the actual data is that buyer's profits are predicted to be higher in the reputation than in the impunity treatment, while there is no statistically significant difference between them in the data ($p = 0.719$). In fact, average buyer profits in the reputation treatment are significantly lower than predicted ($p = 0.031$).

A deviation from predictions is that quantitatively the proportion of high prices offered for high quality and production rates are slightly lower than predicted in the reciprocity and reputation treatments. This may be due to individual heterogeneity—we computed predictions based on



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average values of $\alpha$ and $\tau$. In fact, there is a good deal of heterogeneity in behavior (see Appendix B).

Lastly, inequality aversion appears low (although significant) in all three treatments. The estimates are lower than estimates reported in the literature (for example, DeBruyn and Bolton (2008) report $\alpha = 1.03$ in the linear version of the model—of course they analyze bargaining games that are structurally quite different from ours). In terms of our treatments, estimated $\alpha$'s are not significantly different between the impunity and reputation treatments ($\chi^2 = 0.002, p = 0.989$) but are significantly higher in the reciprocity treatment ($\chi^2 = 15.51$ for the comparison with impunity and $\chi^2 = 10.89$ for the comparison with reputation; $p < 0.001$ for both comparisons). It is possible that inequality aversion is more salient in the reciprocity treatment than in the other two treatments because the seller can implement a fair split by punishing the buyer in that treatment. Saliency of inequality aversion is, however, beyond the scope of this chapter.

**2.4 Conclusion**

With the prevalence of using third party vendors for strategic activities, such as manufacturing, by many major firms, the hold-up problem has to be considered as one of the major pitfalls in supply chain management. For example, contract manufacturers take on increasingly sophisticated tasks and activities requiring relationship-specific investments which leave firms on both sides of the transaction more vulnerable to the hold-up problem than ever before. Additionally, incomplete information is typically present in these arrangements because the OEMs and contract manufacturers are often located on different continents and are subject to different cultural norms.



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We analyze and test in the laboratory a stylized game designed to highlight the possibility of the hold-up problem due to the relationship-specific investment by the supplier. We derive approximate equilibrium predictions that match the data remarkably well. In our impunity setting, the analysis predicts limited cooperation but also a large loss in efficiency due to the hold-up problem—predictions that match the data well. We also find, both analytically and empirically, that a setting in which the supplier has the ability to negatively reciprocate, cooperation increases, as does efficiency. Whether or not negative reciprocity is possible is usually not a decision made by the parties but is rather a function of the environment, so we also consider a setting in which we provide to the supplier basic reputation information about the buyers' past actions. We find that reputation information mitigates the hold-up problem, both analytically and empirically.

The managerial implication of our work is that the hold-up problem can be effectively mitigated in settings in which the relationship is not one-shot. Most supply chain relationships, even the ones that involve short-term contracts, are not one shot, because information about the firm's past actions tends to become available to the community, even if informally. Our findings suggest that a systematic way of making this reputation information available mitigates the hold-up problem a great deal.

A fruitful direction for future research would be to test other, more sophisticated, reputation system designs. For example, systems that track not just average performance, but also provide information about recent versus past actions, may work even better. It may also be worthwhile to analyze informal arrangements, such as hand-shake agreements, in the context of relationship-specific investments, to learn to what extent they may mitigate the hold-up problem.



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# CHAPTER 3

# QUALITY PROBLEM

The full title of this chapter is: Supplier Development—Advancing Quality Improvement along the Supply Chain: An Experimental Investigation.

This chapter is structured as below: section 3.1 introduces theoretical model; section 3.2 outlines hypothesis while section 3.3 elaborates experimental design. Results are described in section 3.4 while section 3.5 concludes.

## 3.1 Model

### 3.1.1 Model Setup

Zhu et al.'s (2007) theoretical framework was used directly. Based on their framework, the optimal solution in a centralized supply chain was derived and tested empirically using laboratory data combined with the insights in their paper.

This research began by elaborating Zhu et al.'s (2007) framework: In a supply chain with one supplier and one buyer, the buyer faces a deterministic demand, $D$. Whenever a customer is sold a defective product, there will be a quality related cost per unit, $s$, to the supply chain. The buyer shares the cost with proportion $\lambda$, and the supplier with proportion (1- $\lambda$). For each product unit, the production cost is $c$, the wholesale price is $w$, and the retail price is $p$. The quality is measured by the proportion of defective products, which can be improved through efforts either on the part of the supplier or buyer or both.

In Zhu et al. (2007), the buyer and the supplier make the quality improvement decisions sequentially. It prevails in practice that the buyer acts first to design the product and the supplier follows to arrange production. Because both the product's design and the production arrangement



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will affect process quality, the practice was modeled herein by having the buyer act first as the Stackelberg game leader who anticipates the supplier's response.

Process quality is measured by $\alpha\mu$, which represents the system quality status, and therefore, the proportion of defective products. In general, the quality process can be improved to reduce the proportion of defective products. Zhu et al. (2007) used $\alpha$ and $\mu$ to denote factors that the buyer and the supplier, respectively, can improve. Specifically, they denoted $1/\mu$ as the average time the process is in control in a production run and claimed that the production technology may determine it, and therefore the supplier can make a more informed decision whether to upgrade her existing technology. In contrast, $\alpha$, "…the percentage of defective units produced in the out-of-control state and delivered to customers, may depend on the training level of the machine operators. Because the buyer is responsible for the design of the product, he has domain knowledge of the product and may be in a better position to train the operators" (Zhu et al. 2007). Table 3.1 summarizes the notations.

To facilitate the experimental design and focus on the quality issue, the 4 simplifications below were performed:

1. Removed the effects of setup cost: $K=k=0$
2. Removed the effects of holding cost: $H=h=0$
3. Removed the effect of production size: $\frac{D*q}{2r} = 1$
4. Simplified the cost improvement coefficients: $b_\alpha = b_\mu = A,\ B_\alpha = B_\mu = B$

With these simplifications, the buyer's profit derived from the cost function in section 3.5.2 in Zhu et al. (2007) now is:



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$$\Pi_B(\hat{x}) = R - (\lambda s(x)^* + B \ln \frac{\bar{x}}{\hat{x}})$$

Meanwhile, the supplier's profit derived from the cost function in section 3.5.1 of Zhu et al. (2007) now is:

$$\Pi_S(x \mid \hat{x}) \quad = R - ((1-\lambda)sx + A \ln \frac{\hat{x}}{x})$$

in which $x \triangleq \alpha\mu$ as $\alpha$ and $\mu$ always show up together in $\alpha\mu$. Now, $x$ represents the percentage of non-conform products.

The buyer, as the first actor, has with the following cost function:

$$B\, ln\, (\bar{x}/\hat{x})$$

in which B is a constant that measures how costly it is for the buyer to improve the system process quality; $\bar{x}$ is the initial proportion of defective products, and $\hat{x}$ is the buyer's target proportion of defective products. Similarly, the supplier has the following cost function:

$$A\, ln\, (\hat{x}/x),$$

in which *A* is the supplier's cost coefficient, while $x$ is the target proportion of defective products. The logarithm function implies that the cost of reducing a particular percentage of remaining defective products is constant for either party. For example, the supplier's cost of choosing $x = 0.8\hat{x}$ is $B\, ln\, (5/4)$, is the same as the buyer's cost of reducing the percentage further $0.8\hat{x}$ to $0.8 * (0.8\, \hat{x})$.



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Table 3.3 Notations.

| Variable | List of notations |
|---|---|
| $\bar{x} = \bar{\alpha}\bar{\mu}$ | Initial percentage of defective products |
| $\hat{x} = \hat{\alpha}\hat{\mu}$ | Percentage of defective products after the buyer made quality improvement decisions |
| $x = \alpha\mu$ | Percentage of defective products after both the buyer and the supplier made quality improvement decisions |
| $x = \alpha^{*}\mu^{*}$ | Percentage of defective products expected after both the buyer and the supplier made optimal quality improvement decisions |
| $\hat{x}^{*} = \hat{\alpha}^{*}\hat{\mu}^{*}$ | Percentage of defective products expected after the buyer made optimal quality improvement decisions, expecting the supplier will act optimally |
| $s$ | Market cost attributable to each unit of defective product |
| $\lambda$ | The buyer's share of the quality cost attributable to defective products |
| 1- $\lambda$ | The supplier's share of quality cost attributable to defective products |
| $c$ | Production cost per unit |
| $w$ | Wholesale price per unit |
| $p$ | Retail price per unit |
| $D$ | Market demand, a deterministic value |
| $A, B$ | Coefficient related to quality improvement cost |
| $\Pi_B, \Pi_S$ | Profit function for buyer and supplier, respectively |



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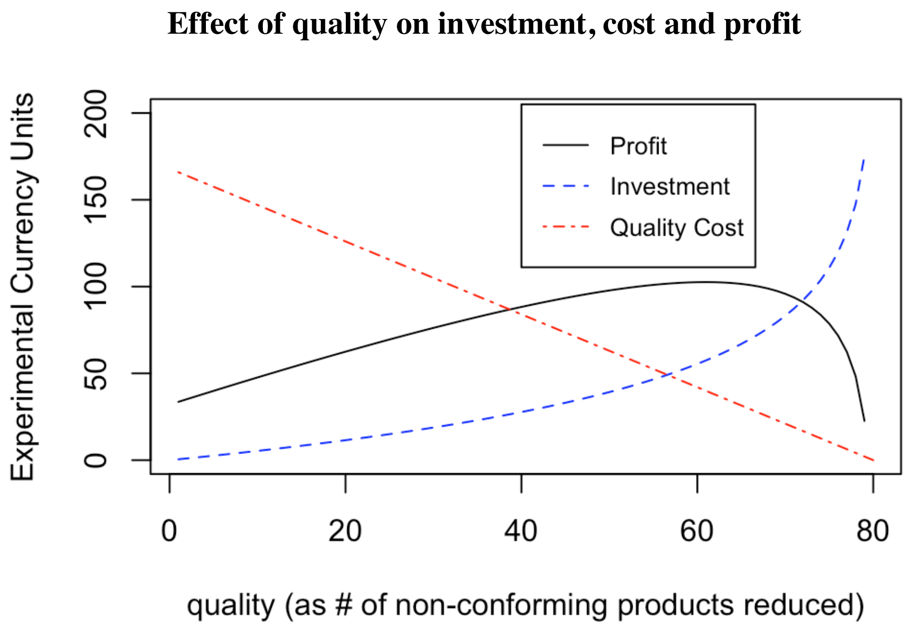


Figure 3.1 Profit, investment and quality cost, each as a function of quality.

### 3.1.2 Decentralized Supply Chain

The sequential game was solved with backward induction. First, the supplier's problem was assessed. The supplier's objective function as the Stackelberg game follower is:

$$\max_{x} \quad D(w-c) - (1-\lambda)sx - A\, ln\, (\frac{\hat{x}}{x})$$

The second order condition, w.r.t $x$ , is $-A(x)^{-2} < 0$.

The first order condition, (FOC), is $-(1-\lambda)s + A(x)^{-1} = 0$, which yields the optimal solution:

$$x^* = \frac{A}{(1-\lambda)s} \quad (3.1)$$

When the supplier's profit is negative at the optimal level, she may still choose to invest if dropping out of the business is not an option because investment will reduce the loss compared to no investment at all.



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Insight 3.1 (derived from section 3.5, Zhu et al. (2007): The supplier's optimal proportion of defective products is $x^* = \frac{A}{(1-\lambda)s}$ , which is independent of the buyer's investment decision.

If the buyer has reduced the proportion of defective products to less than $x^*$, the supplier will not invest any more.

In contrast, if the buyer's target proportion of defective products is greater than $x^*$, the buyer will not invest.

Explanation: This proposition follows from the fact that the optimal proportion of defective products from the supplier's perspective, $x^*$, in Equation (3.1) is independent of the buyer's investment decision.

Particularly, if the buyer has reduced the proportion of defective products to less than $x^*$, i.e., $\hat{x} \leq x^* = \frac{\mathrm{A}}{(1-\lambda)\mathrm{s}}$, the supplier's objective function remains the same. However, as the supplier only will make a proportion of defective products no larger than $\hat{x}$, the supplier will choose $\min\left\{\hat{x}, x^* = \frac{\mathrm{A}}{(1-\lambda)\mathrm{s}}\right\} = \hat{x}$ . Therefore, the supplier will not invest.

By contrast, if the buyer's target proportion of defective products is higher than $(x)^*$, the buyer will not invest, because he predicts that the supplier will always reduce the proportion of defective products to $x^*$.

Insight 3.2 (derived from section 3.5 Zhu et al. 2007): The supplier and the buyer never both invest in process quality.

Explanation: In contrast to both of them investing in process quality, the buyer will be better off not investing because, as the follower, the supplier will target a lower proportion of



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defective products, (i.e., better process quality,) and that target is independent of the buyer's decision.

Second, we evaluate the Buyer's problem.

Following Insight 3.2, when the buyer invests in quality improvement, he anticipates that the supplier will not invest. Therefore, the final proportion of defective products is that of the buyer's target. Hence, the buyer's objective function is:

$$\max_{\hat{x}} \quad D(p-w) - \lambda s x^{*} - B\, ln(\bar{x}/\hat{x})$$

FOC is $-\lambda s - B\,(\hat{x}/\bar{x})(-\bar{x})(\hat{x})^{-2} = 0$, which yields $\hat{x}^{*} = \frac{B}{\lambda s}$. It follows that, if he invests, the buyer's profit is:

$$D(p-w) - \lambda s \frac{B}{\lambda s} - B\, ln \frac{\bar{x}}{\left(\frac{B}{\lambda s}\right)} \tag{3.2}$$

Insight 3.3 (derived from Section 3.5, Zhu et al. 2007): If $\lambda \geq \lambda^{*} = \frac{B}{A+B}$, the supplier free rides while the buyer invests, and the buyer will reduce the proportion of defective products to $\frac{B}{\lambda s}$. By contrast, if $\lambda < \lambda^{*}$, the buyer free rides while the supplier invests, and the supplier will reduce the proportion of defective products to $\frac{A}{(1-\lambda)s}$.

Explanation: The supplier is indifferent to investing and free riding if, and only if, the supplier's target of the defective products is the same as that of the buyer. Note that the supplier's optimal target proportion is:

$$x^{*} = \frac{A}{(1-\lambda)s}$$

while the buyer's optimal target proportion is:



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$$\hat{x}^* = \frac{B}{\lambda s}$$

Therefore, when $x^* = \hat{x}^*$, we have

$$\lambda^* = \frac{B}{A+B} \tag{3.3}$$

$x^*$ is increasing with $\lambda$, while $\hat{x}^*$ is decreasing with $\lambda$. Therefore, $x^* > \hat{x}^*$ when $\lambda \geq \lambda^*$; and $x^* < \hat{x}^*$ when $\lambda \geq \lambda^*$.

### 3.1.3 Centralized Supply Chain

Here, a centralized decision maker's behavior is evaluated. Assume a centralized decision maker will decide the optimal proportion of defective products. Rationally, this decision maker will allocate the task of improvement to the one with the lower cost. Therefore, the centralized decision maker's objective function is to maximize the supplier and the buyer's joint profit function:

$$\max_x \quad D(p-c) - sx - min\{A, B\}\ ln\,(\bar{x}/x)$$

FOC is $-s + min\{A, B\}/q = 0$, which yields $x^* = min\{A, B\}/s$.

Insight 3.4 (derived from Section 3.6, Zhu et al. 2007): The system's optimal proportion of defective products in a decentralized supply chain is lower than that of a centralized supply chain, in that, in a decentralized supply chain, players under-invest.

Explanation: This follows from $x^* = \frac{min\{A,B\}}{s} < min\left\{\frac{A}{(1-\lambda)s}, \frac{B}{\lambda s}\right\}$, where $min\left\{\frac{A}{(1-\lambda)s}, \frac{B}{\lambda s}\right\}$ is the final proportion of the system's defective products in a decentralized supply chain.

### 3.2 Hypotheses

Hypothesis 3.1(a). If $\lambda < \lambda^*$, i.e., in the Suppliers Investment Treatment:

*i.)* The supplier will invest.



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*ii.)* The supplier will reduce the proportion of defective products to $\frac{A}{(1-\lambda)s}$.

*iii.)* The buyer will not invest.

Hypothesis 3.1(b): If $\lambda > \lambda^*$, i.e., in the Buyers Investment Treatment:

*i.)* The buyer will invest.

*ii.)* The buyer will reduce the proportion of defective products to $\frac{B}{\lambda s}$.

*iii.)* The supplier will not invest.

Hypothesis 3.1 follows from Insight 3.3.

Hypothesis 3.2: Statistical Independence. The supplier's target proportion of defective products is statistically independent of that of the buyer.

Hypothesis 3.2 follows from Insight 3.2.

Hypothesis 3.3: Underinvestment. Process quality improvement is underinvested in the decentralized system.

Hypothesis 3.3 follows from Insight 3.4.

Hypothesis 3.4: Negotiation and Centralization. When negotiation is allowed, process quality improvement is as good as in the centralized system.

**3.3 Experimental Design**

This section documents the details and motivation of the experimental design. Specifically, section 3.3.1 describes the experimental settings; section 3.3.2 specifies the parameter values and motivations, as well as the solution from a theoretical model based on the parameter values. Last, section 3.3.3 demonstrates the implementation of experiments in the dedicated experimental software zTree.



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### 3.3.1 Experimental Settings

Overall, there are four treatments, the Buyer Investment Treatment, Supplier Investment Treatment, Centralized Treatment, and Negotiation Treatment, each of which simulated different business scenarios.

The buyer acted first in both the Buyer and the Supplier Investment Treatment. Then the supplier followed after observing the buyer's decision. In contrast, in the Centralized Treatment, a single decision maker determined the quality improvement cost. Finally, the Centralized Treatment served as a benchmark.

In the Negotiation Treatment, both the supplier and matched buyer in each round negotiated the total investment cost spent to improve the quality. The total investment cost was shared in the same way as the cost because the cost of the defective products was shared. Specifically, the buyer shared 30% of the investment cost, as well as 30% of the cost attributable to the defective products. At the same time, the supplier shared the remaining 70% of the investment cost, as well as 70% of the cost attributable to the defective products. As shown in Section 3.3.3, both the supplier and buyer made various offers to each other, until one of them accepted one of the partner's offers. Then, the investment was made, production was implemented, and the profit was realized.

Each of the four treatments above had 4 sessions, with a different number of subjects. Sessions in the Centralized Treatment each had 4 subjects who were centralized decision makers. By contrast, the other sessions in the remaining 3 treatments each included 8 subjects, among which 4 were suppliers and 4 were buyers.



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To simulate the one-shot game repeatedly, all players were matched randomly and re-matched each round. There were 50 rounds for each subject.

Candidate subjects were recruited and maintained through the ORSEE system. Most of the candidates are undergraduate or graduate students in the Dallas area. Candidates in the subject pool were informed of the potential range of US dollars they could earn as incentives. Invitation emails were sent out to the candidates several days before the experiment. Then, subjects were selected on a first-come-first-served basis when they accepted the invitation. Selected students also received reminder emails about the expected payment, time, and location of the experiments.

The experiments were conducted in a computer laboratory in the University that is dedicated to behavioral experiments. Before the experiment began, instructions were distributed, and then the researcher read them to the subjects aloud to ensure that they all received the same information. Questions from the subjects were encouraged and answered.

Thereafter, the experiments began, and the zTree program simulated a real business environment to allow candidates to make decisions. Details of the zTree program are provided in section 3.3.3.

After the experiments concluded, subjects were paid in cash proportional to the experimental currency units (ECU) they earned during the experiments.

### 3.3.2 Parameter values

Equation (3.3) shows that the value of threshold $\lambda^*$ is determined exclusively by $A$, $B$, $s$, and $\bar{x}$. $A$ was set $= B$, and therefore, $\lambda^* = \frac{B}{A+B} = 0.5$.

Moreover, $D$=100, $s$=3, $p$=6, $w$=4, and $c$=2. $A$=$B$=40. $\bar{x} = 80$ were set. Last, $\lambda = 0.7$ for the Buyer Investment Treatment and $\lambda = 0.3$ for the Supplier Investment Treatment. As a matter



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of convenience, the total count of the product is 100 units, so that each 1 unit improvement is equivalent to 1 percent reduction of non-conforming product proportion.

The Buyer Investment Treatment: The buyer should invest in quality improvement, but the supplier should not. In this treatment, $\lambda = 0.7$.

Table 3.4. Summary of the objective functions and optimal target.

| | Objective function | Optimal target |
|---|---|---|
| Buyer | $\max_{\hat{x}} \; D(p-w) - \lambda s x - B \ln \bar{x}/\hat{x}$ | $\hat{x}^* = \frac{B}{\lambda s}$ |
| Supplier | $\max_{x} \; D(w-c) - (1-\lambda) s x - A \ln \left(\frac{\hat{x}}{x}\right)$ | $x^* = \frac{A}{(1-\lambda)s}$ |
| Centralized | $\max_{x} \; D(p-c) - s x - \min\{A, B\} \ln \left(\frac{\bar{x}}{x}\right)$ | $x^* = \frac{\min\{A, B\}}{s}$ |

The Supplier Investment Treatment: The supplier should invest in quality improvement, but the buyer should not. In this treatment, $\lambda = 0.3$.

The target proportion of defective products is each party's decision variable, and is an integer. The buyer chooses a number less than 80, and the supplier chooses a number no larger than that the buyer chose.

Table 3.2 summarizes the theoretical predictions with their parameters, while Table 3.3 shows the theoretical predictions when all the parameters have values assigned to them.



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### 3.3.3 Experiments Implementation

The experiments were implemented in zTree (Fischbacher 2007), and then conducted in the computer laboratory mentioned above.

The work flow, as well as selected screenshots for decision makers during the Buyer Investment Treatment are shown below.

At the very beginning of the experiments, decision makers viewed a welcome screen with the profile information as well as financial data. At the same time, on the right-hand side of the screen, a quiz was provided that asked the candidates to analyze a hypothetical scenario and calculate the outcome of the quality improvement, including each decision maker's investment cost as well as the profit.

Subjects were unable to proceed until they answered all the questions correctly to ensure that they understood the instructions well. Access to a calculator also was provided during the quiz (the calculator icon on the right). This screen is shown in Figure 3.2.

Each round began with the buyer's decision screen. As shown in Figure 3.3, the two blocks on the left show relevant information, while a simulator on the right-hand side calculates the outcome for both matched players based on the buyer's input about both players' hypothetical decisions. The box at the bottom allowed the buyer to enter and submit his/her decision.

After the buyer submitted a decision, the supplier (aka, the Seller in the screenshot) was able to observe the decision, and then make his/her own decision. Figure 3.4 shows the supplier's decision screen, which is very similar to the buyer's. One difference is that the supplier observed one more piece of information about the decision the buyer had made already. The second



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Table 3.5 Theoretical predictions when $\bar{x} = 80$.

| Metrics | | Buyer Investing Treatment | | Supplier Investing Treatment | |
|---|---|---|---|---|---|
| | | Buyer | Supplier | Buyer | Supplier |
| Target of remaining non-conforming products (Units) | Individual | 19.0 | 44.4 | 44.4 | 19.0 |
| | System | 19.0 | | 19.0 | |
| | Centralized supply chain | 13.3 | | 13.3 | |
| Realized Improvement Quantity (Units) | Individual | 61.0 | 0 | 0 | 61.0 |
| | System | 61.0 | | 61.0 | |
| | Centralized supply chain | 66.7 | | 66.7 | |
| Realized Investment Cost (ECU) | Individual | 57 | 0 | 0 | 57 |
| | System | 57 | | 57 | |
| | Centralized supply chain | 72 | | 72 | |
| Revenue | | 200 | 200 | 200 | 200 |
| Loss due to nonconforming products | | 40 | 17 | 17 | 40 |
| Investment cost | | 57 | 0 | 0 | 57 |
| Profit | | 103 | 183 | 183 | 103 |



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difference is that the Calculator on the right simulated only the scenarios based on the buyer's decision.

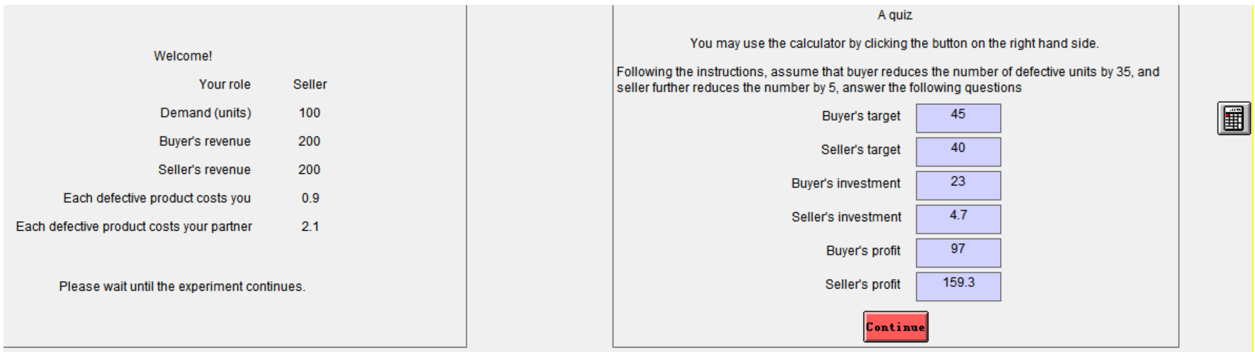


Figure 3.2 Screenshot showing welcome screen and quiz at the beginning of the experiment, in Buyer Investing Treatment.

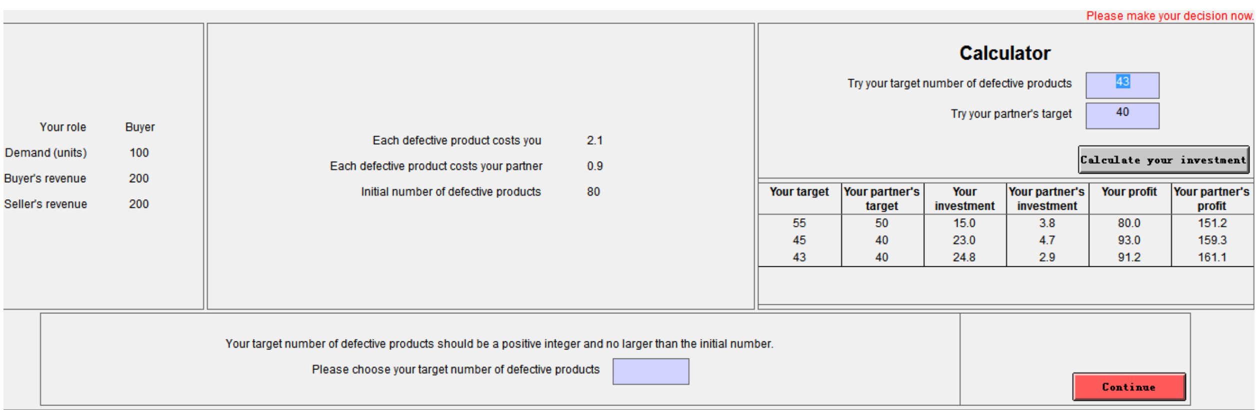


Figure 3.3 Buyer's decision screen, in Buyer Investing Treatment.



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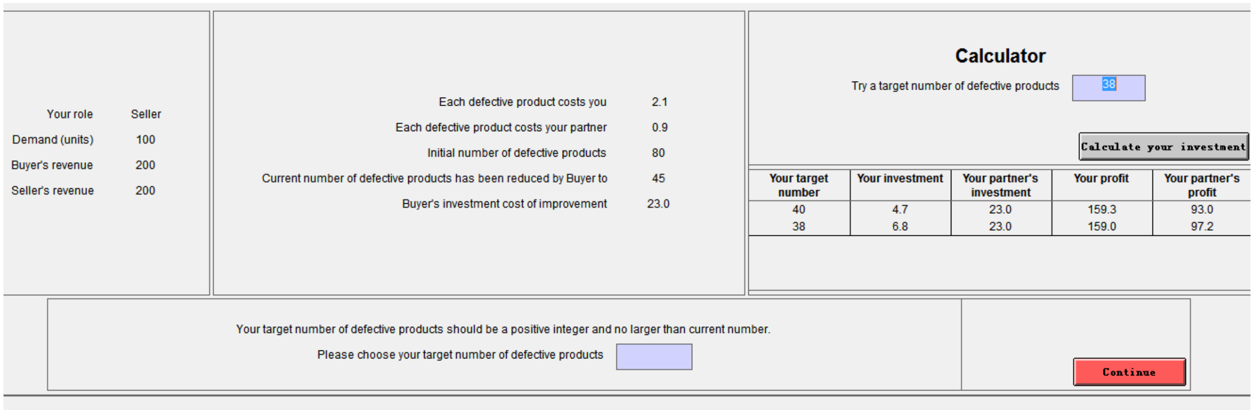


Figure 3.4 Supplier's decision screen, after observing the matched Buyer's decision, in Buyer Investing Treatment.

The Negotiation Treatment employed a different decision process. Figure 3.5 shows the buyer's decision screen, where information is provided on the left, the calculator between, and the offer is proposed on the right. Further, decision makers could review and accept offers from the partner on the right side of the screen. The past performance from previous rounds also was shown at the bottom. The supplier observed a similar screen. At the end of the period, each player observed the output, as shown in Figure 3.6.

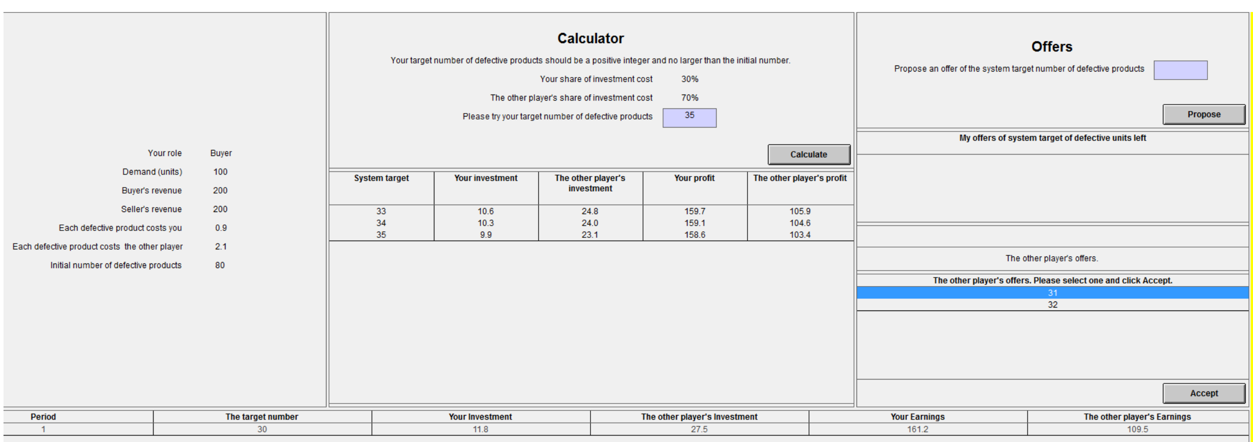


Figure 3.5 Buyer's decision screen, in Negotiation Treatment.
At the end of the period, each player observes the output, as shown in Figure 3.6.



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Figure 3.6 The final screen at the end of each round, for the Supplier, in Negotiation Treatment.

### 3.4 Results

Section 3.4.1 presented an executive summary to illustrate the major findings. Thereafter, section 3.4.2 provided the details from the statistical report. Section 3.4.3 illustrated each subject's decisions over time, while section 3.4.4 presented the heterogeneity among different decision makers.

#### 3.4.1 Summary

The experimental data supported several outcomes from theory: First, the players penalized more heavily did invest (buyers in the Buyer Investment Treatment and suppliers in the Supplier Investment Treatment). Second, the two players' improvements were statistically independent in the Supplier Investment Treatment. Third, process quality improvement was underinvested in the decentralized system. Fourth, negotiation improved the decentralized system to the level of the centralized system.

However, based on the laboratory evidence, some deviations from theory also were found: First, the players penalized more heavily invested less than the optimum. Second, the players penalized less invested, rather than free rode. Third, the two player's improvements were related statistically in the Buyer Investment Treatment.



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Finally, several highlights learned from dynamics and heterogeneity are presented below:

There was evidence of a learning curve during the first several rounds, and decision makers reached equilibrium very quickly.

There was evidence that subjects with the same role may employ different decisions over time or across subjects, indicating a potential mixed equilibrium.

### 3.4.2 Statistics and Hypothesis Testing

Table 3.6 reports each player's improvement in quality, the deviation from optimal improvement, as well as his/her corresponding investment cost and profit. Standard errors are reported in parentheses, and the session mean was used as the unit of analysis. Recall that each treatment included 4 sessions, except the Centralized Treatment, which included 16 independent subjects. Therefore, the Centralized Treatment had 16 independent observations, while all the other treatments each had 4.

Hypothesis 1: Free riding

Hypothesis 1(a). If $\lambda < \lambda^*$, i.e., in the Supplier Investment Treatment:

*i.)* The supplier will invest.

*ii.)* The supplier will reduce the proportion of defective products to $\frac{A}{(1-\lambda)s}$.

*iii.)* The buyer will not invest.

The data from the Supplier Investment Treatment supported i, but both ii and iii in Hypothesis 1(a) were rejected.

First, the supplier's investment was significantly greater than 0, measured in ECU ($t$=27.64, $p$<0.0001). Second, the supplier invested less than the optimal amount. The deviation from the



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supplier's optimal improvement was -4.82, indicating suboptimal investment ($t$=2.53, $p$=0.0231). Third, the buyer's investment also was significantly greater than 0 ($t$=68.04, $p$<0.0001 for the buyer).

As a consequence, it is natural that both the supplier and buyer reduced defective units to a number greater than 0 ($t$=30.78, $p$<0.0001 for the supplier and $t$=57.5, $p$<0.0001 for the buyer).

Hypothesis 3.1(b): If $\lambda > \lambda^*$, i.e. in the Buyer Investment Treatment:

*i.)* The buyer will invest.

*ii.)* The buyer will reduce the proportion of defective products to $\frac{B}{\lambda s}$.

*iii.)* The supplier will not invest.

The data from the Buyer Investment Treatment supported *i*, but rejected both ii and iii in Hypothesis 3.1(b).

First, the supplier's investment was significantly greater than 0, measured in ECU ($t$=37.31, $p$<0.0001). Second, the buyer invested less than the optimal amount. The deviation from the buyer's optimal improvement was -14.92, indicating suboptimal investment ($t$= 2.82, $p$=0.0377). Third, the buyer's investment also was significantly great than 0 ($t$=21.67, $p$<0.0001 for the buyer).

As a consequence, it is natural that both the supplier and buyer reduced the defective units by a number greater than 0 ($t$=43.39, $p$<0.0001 for the supplier, and $t$=21.78, $p$<0.0001 for the buyer).

Hypothesis 3.2: Statistical Independence. The supplier's target proportion of defective products is statistically independent of the buyer's.



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Table 3.6 Summary statistics.

| Items | | Treatment | | | |
|---|---|---|---|---|---|
| | | Supplier Investing | Buyer Investing | Centralized | Negotiation |
| Improvement Quantity | Buyer | 17.93 (sd=4.14) | 36.05 (5.50) | -- | -- |
| | Supplier | 38.25 (4.72) | 10.03 (2.81) | -- | -- |
| | System | 56.18 (2.53) | 46.08 (2.82) | 61.09 (1.98) | 66.02 (0.14) |
| Deviation from Optimal Improvement Quantity * | Buyer | 10.99 (3.00) | -14.92 (2.82) | -- | -- |
| | Supplier | -4.82 (2.53) | -0.44 (0.47) | -- | -- |
| | System | -4.82 (2.53) | -14.92 (2.82) | -5.61 (1.98) | -0.68 (0.14) |
| Investment Cost | Buyer | 11.82 (3.00) | 30.17 (5.46) | -- | 49.26 (0.17) |
| | Supplier | 39.90 (3.69) | 8.58 (1.90) | -- | 21.11 (0.07) |
| | System | 51.72 (2.32) | 38.76 (3.67) | 62.71 (3.09) | 70.38 (0.24) |
| Earnings | Buyer | 166.74 (3.62) | 98.59 (0.65) | -- | 121.37 (0.14) |
| | Supplier | 110.07 (4.45) | 160.89 (4.41) | -- | 166.30 (0.06) |
| | System | 276.81 (5.27) | 259.48 (4.92) | 280.55 (2.94) | 287.67 (0.20) |

Note: Session is used as a unit of analysis. Each treatment incudes 4 sessions, except the Centralized Treatment, which has 16 sessions. Standard errors are in parenthesis.

Note *: the optimal decision of the Buyer is assumed to be based on the expected behavior of the Supplier. We assume such expectation is consistent with the ex post observation.



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Table 3.7 Hypothesis testing.

| Hypothesis | Summary | Treatment | |
|---|---|---|---|
| | | Supplier Investing | Buyer Investing |
| Hypothesis 3.1.i | Heavier penalized player invests | True | True |
| Hypothesis 3.1.ii | Heavier penalized player invests to optimal level | False | False |
| Hypothesis 3.1.iii | Less penalized player free rides | False | False |
| Hypothesis 3.2 | Two players' investments are statistically independent | True | False |
| Hypothesis 3.3 | Decentralized system underinvests | True | True |
| Hypothesis 3.4 | Negotiation improves decentralized system to centralized | True | |

Data from the Supplier Investment Treatment showed that the relation between the supplier's and buyer's improvement was not significant (Pearson Correlation coefficient= -0.84, $p$=0.16).

In contrast, data from the Buyer Investment Treatment showed that there was a strong and significantly negative relation between the supplier's and buyer's improvement (Pearson Correlation coefficient= -0.98, $p$=0.02).

It is interesting to observe these two treatments' different results. Recall that the buyer acts first, while the supplier is the follower. In the Supplier Investment Treatment, the supplier was under greater pressure to improve system quality, and often, s/he improved more than did the buyer



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(refer to Table 3.3 for details). Therefore, concerns for fairness motivated the supplier not merely to make up the remaining investment to achieve an optimal system, but also led him/her to try to be consistent with what the buyer contributed. In contrast, in the Buyer Investment Treatment, the supplier contributed much less than did the buyer (Table 3.3), and thus, had no concerns for fairness to perform consistently with the buyer.

Hypothesis 3.3: Underinvestment. Process quality improvement is underinvested in the decentralized system.

The data supported Hypothesis 3.3. Interestingly, process quality improvement was not only less than the centralized supply chain optimal value, but also was less than the theoretical prediction for the decentralized supply chain ($t$=10.45, $p$<0.0001). The centralized optimal value is 13.3, while the decentralized optimal value is 19.0. This observation may be explained by concerns for fairness.

Hypothesis 3.4: Negotiation and Centralization

The data supported Hypothesis 3.4. In particular, the improvement in the Centralized Treatment did not differ significantly from that in the Negotiation Treatment (Pearson Correlation coefficient=0.31, $p$=0.68).

### 3.4.3 Dynamics

Figures 3.7–3.10 present each player's performance, and show the way each evolved over time. To focus on the trend, 50 periods of data were aggregated into 10 five-period blocks. To facilitate easy comparison, the figures on the left are derived from theory, while those on the right show performance from the data.



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Improvement quantity is measured by the number of units improved, while investment cost is measured by ECU, although both measure system performance. Moreover, investment cost is a monotonic function of improvement quantity. However, because the cost is a log function of the quantity, their relation is non-linear. Therefore, to provide a comprehensive description of performance, performance measured by quantity and cost are illustrated separately. For each treatment, the top two figures are measured as improvement quantity, while the lower two are measured as investment cost.

Figure 3.7 shows the Buyer Investment Treatment dynamics. They were very stable, in that the supplier improved approximately 10 units, and there was almost no learning curve. This pattern is intuitive, because the supplier acts as a follower after observing the buyer's performance.

However, the buyer invested less at the beginning, and then the performance stabilized beginning from block 4 (periods 15-20). Apparently, the buyer had higher expectations of the supplier at the beginning of the game, and lower expectations for him/herself compared with theoretical predictions. Over time, the buyer learned from the interactions with the supplier, and stabilized at approximately 35 units.



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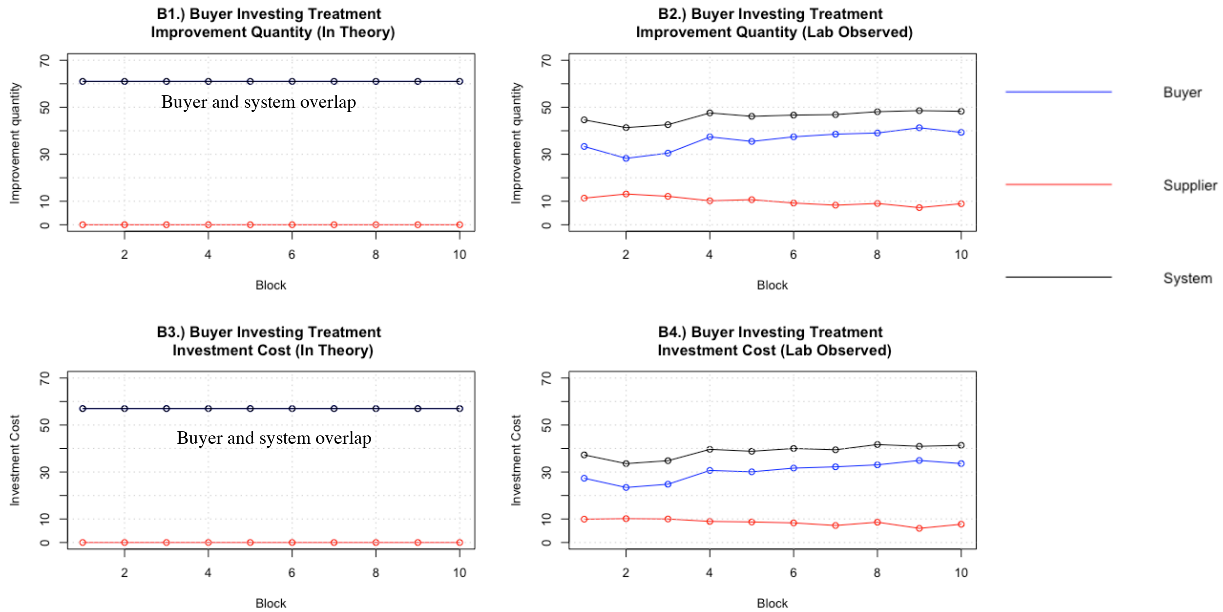


Figure 3.7 Dynamics in Buyer Investing Treatment.

It also is worth noting that there was no significant difference in the patterns when the measures were units or cost.

Figure 3.8 illustrates the performance in the Supplier Investment Treatments. The pattern virtually mirrors that in Figure 3.7 (Buyer Investment Treatment). One major exception is that the system improvement overall was lower in the Buyer Investment Treatment (stabilized at approximately 50 improved units, or 40 ECU of investment cost). By contrast, the system improvement overall was higher in the Supplier Investment Treatment (stabilized at approximately 60 units in improved quantity, or approximately 50 ECU of investment cost).

Figure 3.9 illustrates the performance in the Centralized Treatments. To keep the layout consistent with Figures 3.7 and 3.8, the theoretical prediction is shown on the left and the laboratory observations on the right.



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The performance during the first block (periods 1-5) was lower, indicating that there was a learning curve. However, the learning process was short and the centralized decision maker reached a stable status quickly.

Figure 3.10 shows the dynamics of the Negotiation Treatment. Similar to the Centralized Treatment, the system became stable very rapidly, and unlike the Centralized Treatment, there was no evidence of a learning curve. Further, the system improvement was greater in this Treatment. The observations indicated that group decision making allowed the system to reach a stable status more quickly, and negotiation facilitated the learning process. Moreover, group decision making also promoted system performance compared to the centralized decision maker.

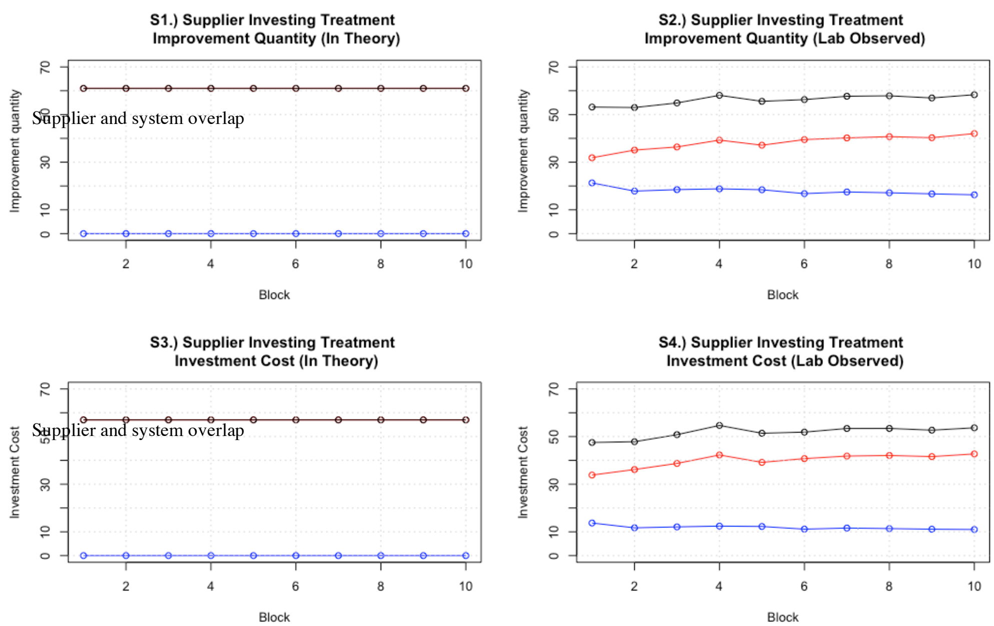


Figure 3.8 Dynamics in Supplier Investing Treatment.



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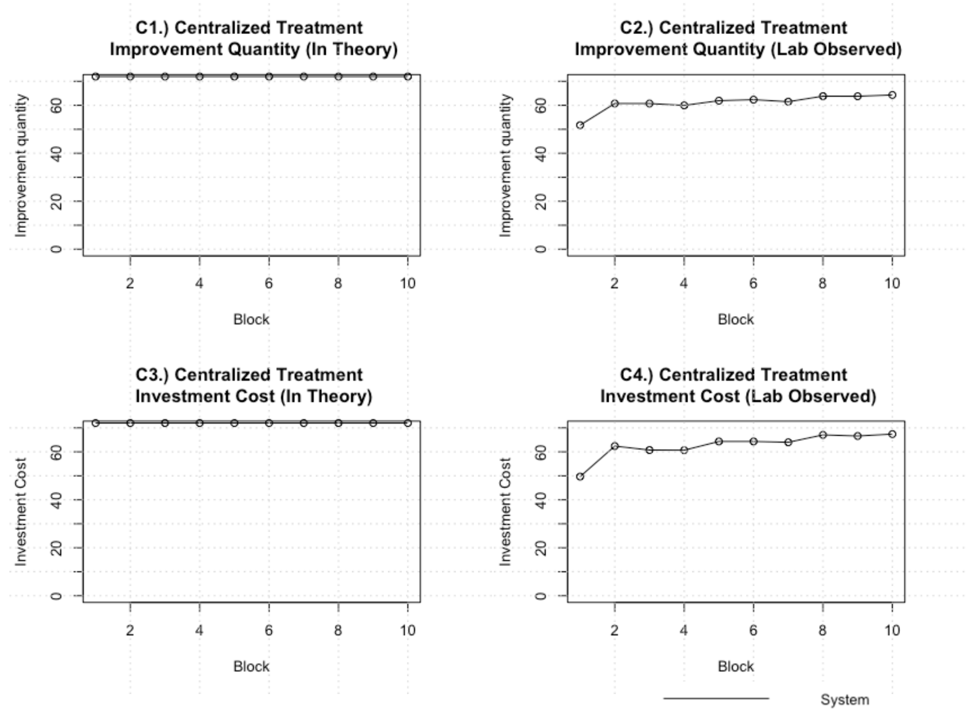


Figure 3.9 Dynamics in Centralized Treatment.

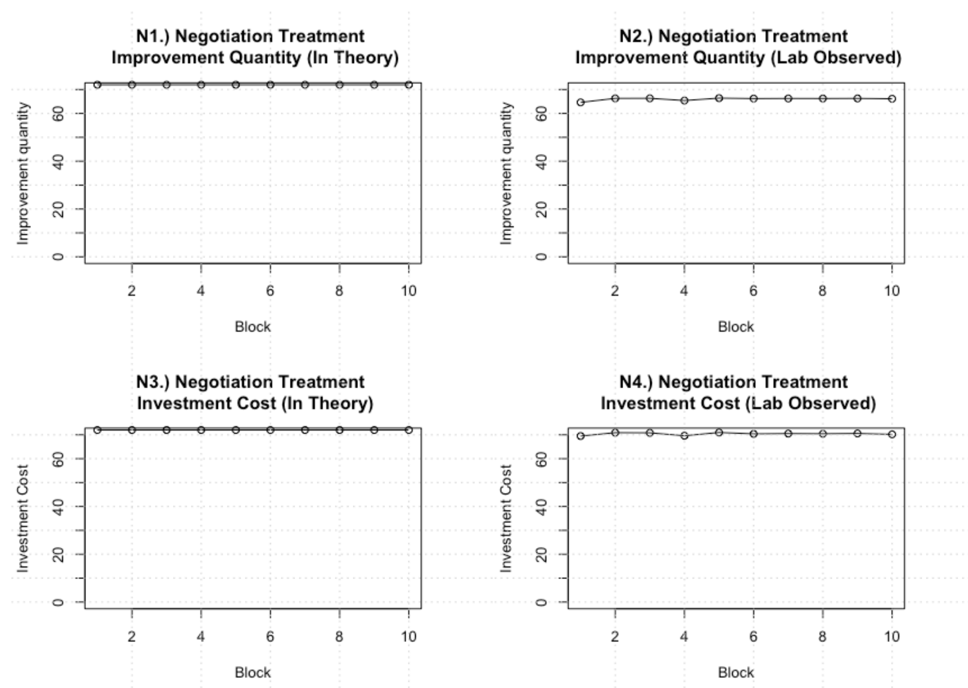


Figure 3.10 Dynamics in Negotiation Treatment.



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### 3.4.4 Heterogeneity

While section 3.4.2 showed the aggregate performance and section 3.4.3 the aggregate dynamics, individual performance has not been examined yet. In what way do individuals interact with each other, and in what way are their performances distributed? These questions are addressed below in a discussion of heterogeneity.

Figure 3.11 illustrates the heterogeneity in the Supplier Investment Treatment. As expected, a large percentage of buyers invested minimally or not at all (on nearly 40% of occasions, they improved fewer than 5 units). This is consistent with the theory, because the buyers act first and are supposed to invest less than the suppliers need. Therefore, the buyer could take advantage of this and free ride.

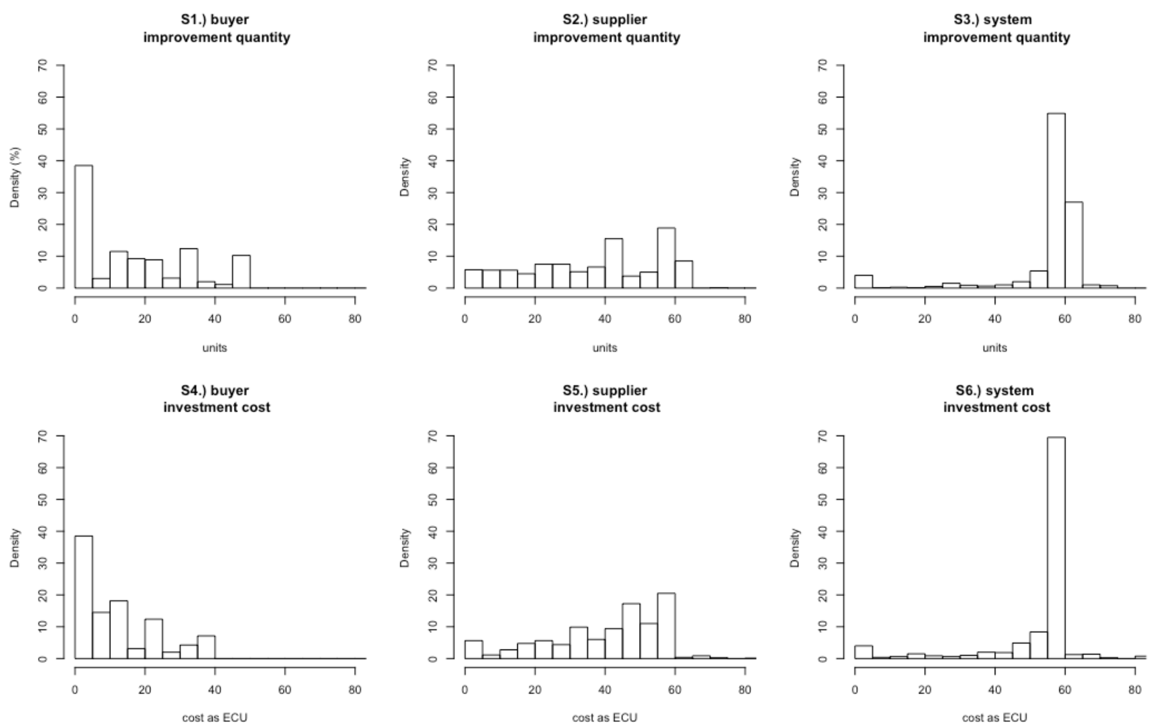


Figure 3.11 Heterogeneity in Supplier Investing Treatment.



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With respect to the supplier's performance, the density function was more nearly a uniform distribution, with slightly more emphasis on heavy investment.

At the system level, although the probability is high that the buyer will invest minimally, it is unlikely that the system will improve little. The results showed that when the buyer invested little, the matched supplier compensated and invested a greater amount.

Figure 3.12 illustrates the heterogeneity in the Buyer Investment Treatment. As expected, a large percentage of suppliers invested minimally, if at all (on more than 60% of occasions, they improved fewer than 5 units). This is consistent with the theory because the buyers act first and are supposed to invest more than the suppliers need. Therefore, the suppliers may free ride. At the same time, a small number of suppliers invested larger amounts.

With respect to the buyer's performance, the density function was more similar to a convex function, as on most occasions, buyers either invested minimally, or approximately optimally (optimal system improvement units = 61, or equivalently to the optimal system investment cost = 57). Therefore, the buyers used mixed strategies.



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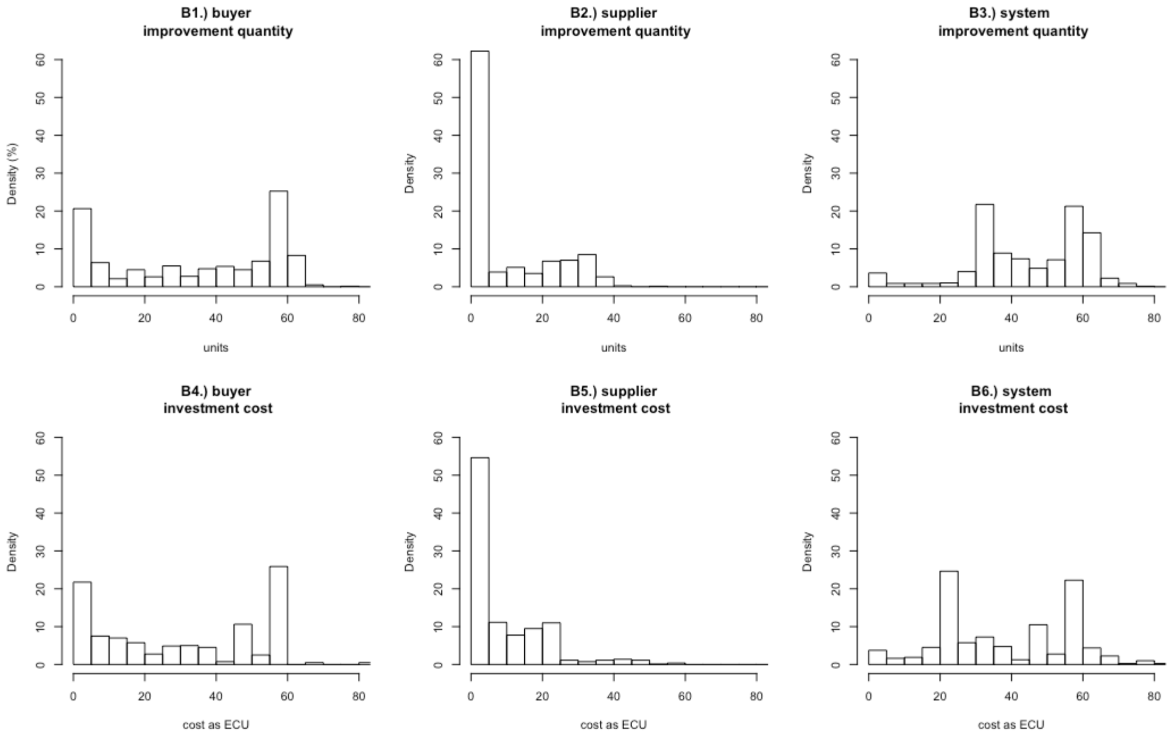


Figure 3.12 Heterogeneity in Buyer Investing Treatment.

At the system level, although the likelihood is high that either the buyer or the supplier will invest minimally, the probability is low that the system will improve little. Apparently, when the buyer invested minimally, the matched supplier compensated and invested a larger amount.

It also is interesting to note that the distribution of the system performance had two peaks, unlike the Supplier Investment Treatment. When measured by system improvement quantity, one peak was located at approximately 35 units, while the other was located at approximately 60 units. As a comparison, Table 3.3 shows that the optimal number of units required for system improvement is 36 for the supplier and 61 for the buyer. Therefore, in a relatively large number of periods, the supplier, as the follower, was rational. If the buyer invested irrationally, and improved



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fewer units than the supplier expected, then the supplier responded rationally, and compensated for the amount up to the level optimal for the supplier.

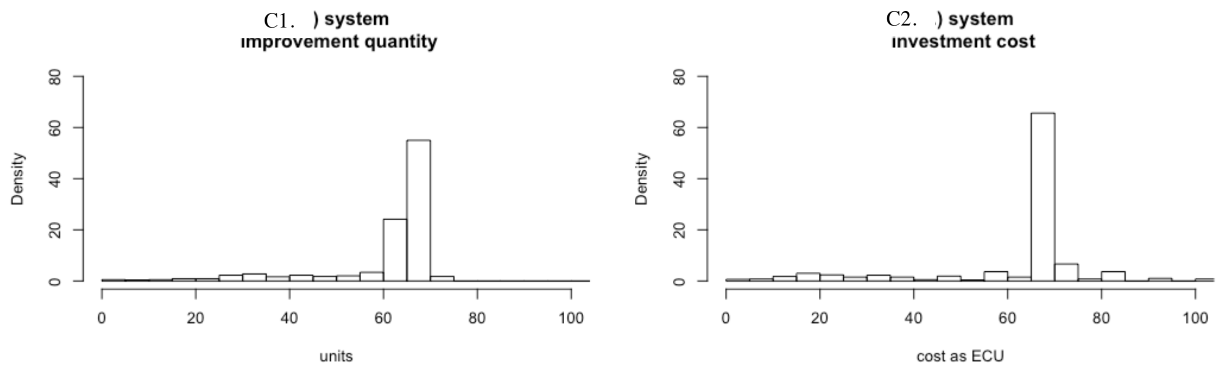


Figure 3.13 Heterogeneity in Centralized Treatment.

Figure 3.13 illustrates the heterogeneity in the Centralized Treatment. Clearly, at the system level, the performance was concentrated highly at a nearly optimum level. Thus, the centralized decision maker was able to make rational decisions.

Figure 3.14 illustrates the heterogeneity in the Negotiation Treatment, in which the system level performance was similar to that in the Centralized Treatment because the investment was concentrated highly. At the same time, it was rare to see investments that were less than optimal, indicating that negotiation facilitated more consistent decisions. Moreover, investments made with negotiation were concentrated even closer to the system optimum, indicating that negotiation facilitated more rational decisions.

**3.5 Conclusion**

This study developed a parsimonious model that captured the essence of Zhu et al.'s (2007) quality improvement model. The theoretical predictions the study was designed to challenge were that one of the two players will take full responsibility to improve the system quality, while the



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other will be a free rider. Specifically, when the buyer's share of the loss is sufficiently large, it should be his full responsibility to improve the process quality optimally. By contrast, when the buyer's share of the loss is low, it should be the supplier's full responsibility to improve the process quality to the optimal level.

These predictions were tested in the laboratory and the results revealed systematic deviations, in which the following behavioral irregularities were observed. First, in contrast to the theoretical predictions, neither the buyer nor supplier was a free rider because of their concerns for fairness. Second, compared to the decentralized system, the centralized system performed better, as the laboratory data verified.

The dynamics were also examined. In general, they demonstrated that it does matter whether the decision maker who is penalized more acts first or not. A comparison of the dynamics between the Negotiation and Centralized Treatment also was interesting. Although both became stable very rapidly, there was no evidence of a learning curve in the Negotiation Treatment. Further, the system improved more in the Negotiation Treatment. In conclusion, group decision making promotes system performance to a greater extent than does the centralized decision maker.

Finally, the heterogeneity was analyzed, and an interesting observation emerged in the Buyer Investment Treatment. With respect to the buyer's performance, the density function was more similar to a convex function, as on most occasions, the investment either was minimal, or approximately optimal. Therefore, the buyers engaged in mixed strategies of investing and nearly not investing. Meanwhile, another observation was that, at the system level, although the likelihood is high that either the buyer or the supplier will invest minimally, the probability is low that the system will improve little. When the buyer invested little, the matched supplier



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compensated and invested a larger amount. With respect to the Centralized Treatment, the investment was concentrated highly, and it was rare to see investments that were much smaller than optimal, indicating that negotiation facilitates more consistent decisions.

Although this research proposed an experimental framework to test the theory, and observed irregularities in the laboratory data that deviated from theory, there is still room for further exploration. For example, a new behavioral model could be proposed to explain these behavioral regularities. Moreover, such a model could be used to explain the data collected in the laboratory, which confirmed that the traditional fairness model cannot explain the deviations. A viable model could combine the fairness factor with mental accounting to explain the difference. Another direction is to explore the way competition affects the equilibrium. For example, Apple may select at least two vendors to assemble its iPhone, and the competition may affect the quality problem. The third possible future direction could be an analysis of an alternative supply chain in which the supplier acts first to manufacture, and then the buyer acts second to produce the final product using the components the supplier provides.

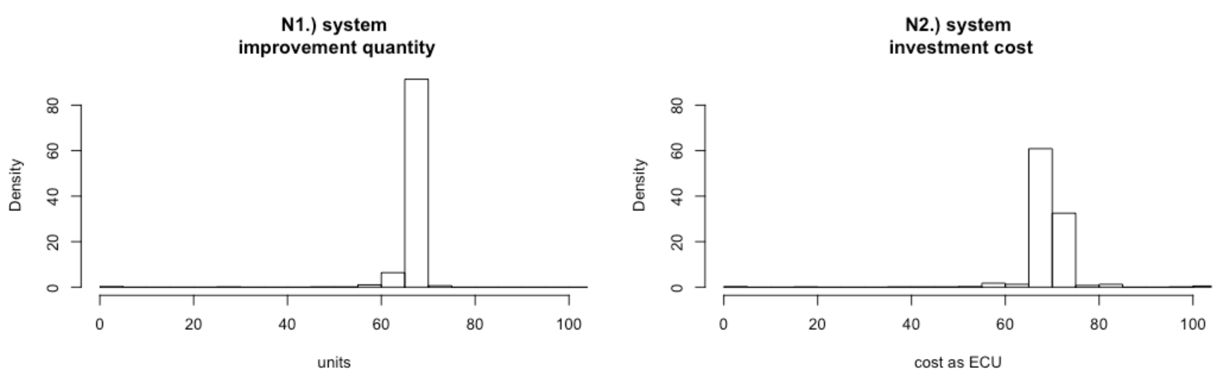


Figure 3.14 Heterogeneity in Negotiation Treatment.



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# CHAPTER 4

# REMANUFACTURING PROBLEM

The full title of this chapter is Strategic Remanufacturing under Competition

This chapter is a working paper co-authored by Zhongwen Ma,[7] Ashutosh Prasad and Suresh P. Sethi. Zhongwen Ma and Suresh P. Sethi are from The University of Texas at Dallas, and Ashutosh Prasad is from University of California, Riverside.

## 4.1 Model

Consider two firms, 1 and 2, competing for sales. For both firms, the production costs of a new product and a remanufactured produce are $c_n$ and $c_r$ respectively, where $c_n > c_r$. Firm $i \in \{1,2\}$ sets the quantity $q_{ni}$ (or alternatively and equivalently, the price $p_{ni}$) of its new product, and $q_{ri}$ of its remanufactured product, if the latter is offered. Note that while both firms of course offer their new product, it is possible for either firm to also offer or not offer a remanufactured product. We denote firm $i$'s optimal profit under a specific remanufacturing strategy as $\pi_i(x, y)$, where $x \in \{n, r\}$ and $y \in \{n, r\}$ denote the strategies of the firm and its rival, where $n$ denotes that a firm is providing only the new product and $r$ denotes that it is providing both new and remanufactured products.

The sequence of events is as follows: Firms invest in their remanufacturing capability. Next, firms move concurrently on pricing decisions for their new products and, if offered, their

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remanufactured products. Thereafter, the prices of the new and remanufactured products for each firm are realized and profits obtained.

Following Singh and Vives (1984), we derive product demand curves from the utility maximization behavior of a representative consumer. Their paper considers two competing firms, each producing one product, whereas we allow for two products, one new and the other remanufactured, produced by each firm. Singh and Vives assume a sector of two firms producing substitutable products, and there is a numeraire good. The representative consumer's direct utility function is separable in the utility of consumption of the goods and the numeraire good. The quasi-linear utility function removes income effects, so that partial equilibrium analysis can be done.

In the Singh and Vives (1984) model, the representative consumer maximizes

$$u(q_1, q_2) - \sum_{i=1}^{2} p_i q_i, \tag{4.1}$$

where $q_i$ and $p_i$ are the quantity and price of the product from firm $i$. The utility function $u(q_1, q_2)$ is quadratic and strictly concave, given by

$$u(q_1, q_2) = \alpha_1 q_1 + \alpha_2 q_2 - \frac{\beta_1 q_1^2 + 2\gamma q_1 q_2 + \beta_2 q_2^2}{2}. \tag{4.2}$$

In our model, the representative consumer maximizes

$$U(q_{n1}, q_{n2}, q_{r1}, q_{r2}) - \sum_{i=1}^{2} p_{ni} q_{ni} - \sum_{i=1}^{2} p_{ri} q_{ri}. \tag{4.3}$$

The utility function $U(q_{n1}, q_{n2}, q_{r1}, q_{r2})$ which we propose is an extension of the Singh-Vives utility function to include four products. That is,



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$$U(q_{n1}, q_{n2}, q_{r1}, q_{r2})$$
$$= \alpha_{n1}q_{n1} + \alpha_{n2}q_{n2} + \alpha_{r1}q_{r1} + \alpha_{r2}q_{r2} - \frac{1}{2}(\beta_{n1}q_{n1}^2 + \beta_{n2}q_{n2}^2 + \beta_{r1}q_{r1}^2$$
$$+ \beta_{r2}q_{r2}^2 + 2\gamma_{n12}q_{n1}q_{n2} + 2\gamma_{r12}q_{r1}q_{r2} + 2\gamma_{n1r1}q_{n1}q_{r1} + 2\gamma_{n1r2}q_{n1}q_{r2}$$
$$+ 2\gamma_{n2r1}q_{n2}q_{r1} + 2\gamma_{n2r2}q_{n2}q_{r2}).$$

However, this function has a large number of parameters to deal with, resulting in lengthy expressions which obscure the main insights. Thus, we will make some simplifying assumptions to focus on the key aspects of the study. We will begin by assuming that the two players are symmetric. An example of this kind of symmetric duopoly is the competition between Verizon and AT&T, where their products, market share, as well as service are very similar. Therefore we have:

$$\alpha_{n1} = \alpha_{n2} \triangleq \alpha_{n0},$$
$$\alpha_{r1} = \alpha_{r2} \triangleq \alpha_{r0},$$
$$\beta_{n1} = \beta_{n2} \triangleq \beta_n,$$
$$\beta_{r1} = \beta_{r2} \triangleq \beta_r,$$
$$\gamma_{n1r1} = \gamma_{n2r2} \triangleq \gamma_0.$$

Because the two players are symmetric, the substitutability between new and remanufactured products are symmetric, to the extent that the impact of the remanufactured product has identical impact to the consumer's utility regardless of which remanufacturer it comes from. An illustrative example would be remanufactured iPhone that is either sold through Verizon or AT&T.

$$\gamma_{n1r1} = \gamma_{n1r2} \triangleq \gamma_0,$$
$$\gamma_{n2r1} = \gamma_{n2r2} \triangleq \gamma_0.$$



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With these simplifications, we get the utility function:

$$U(q_{n1}, q_{n2}, q_{r1}, q_{r2})$$

$$= \alpha_{n0}(q_{n1} + q_{n2}) + \alpha_{r0}(q_{r1} + q_{r2})$$

$$- \frac{1}{2}(\beta_n q_{n1}^2 + \beta_n q_{n2}^2 + \beta_r q_{r1}^2 + \beta_r q_{r2}^2 + 2\gamma_{n12} q_{n1} q_{n2} + 2\tilde{a}_{r12} q_{r1} q_{r2}$$

$$+ 2\gamma_0 q_{n1} q_{r1} + 2\gamma_0 q_{n1} q_{r2} + 2\gamma_0 q_{n2} q_{r1} + 2\gamma_0 q_{n2} q_{r2}).$$

Upon maximization by the representative consumer, the first order conditions will produce the following four price functions (or inverse demand functions):

$$p_{n1} = \alpha_{n0} - \beta_n q_{n1} - \gamma_{n12} q_{n2} - \gamma_0(q_{r1} + q_{r2}),$$

$$p_{r1} = \alpha_{r0} - \beta_r q_{r1} - \gamma_{r12} q_{r2} - \gamma_0(q_{n1} + q_{n2}),$$

$$p_{n2} = \alpha_{n0} - \beta_n q_{n2} - \gamma_{n12} q_{n1} - \gamma_0(q_{r1} + q_{r2}),$$

$$p_{r2} = \alpha_{r0} - \beta_r q_{r2} - \gamma_{r12} q_{r1} - \gamma_0(q_{n1} + q_{n2}).$$

In subsequent analysis, we will focus on a particular case where the following two additional conditions are met:

Condition 4.1) The price functions have the same slope with respect to the underlying product, i.e.,

$$\beta_r = \beta_n \triangleq \beta_0,$$

Condition 4.2) The price functions have the same slope with respect to the competing product from same category. By product category, it is either new or remanufactured, i.e.,

$$\gamma_{n12} = \gamma_{r12} \triangleq \gamma_{12};$$

The motivation is that when the linear demand functions are describing products close to each other, their demand will also be alike.

Now the utility function is:



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$$U(q_{n1}, q_{n2}, q_{r1}, q_{r2})$$
$$= \alpha_{n0}(q_{n1} + q_{n2}) + \alpha_{r0}(q_{r1} + q_{r2}) - \frac{\beta_0}{2}(q_{n1}^2 + q_{n2}^2 + q_{r1}^2 + q_{r2}^2)$$
$$+ \gamma_{12}(q_{n1}q_{n2} + q_{r1}q_{r2}) + \gamma_0(q_{n1}q_{r1} + q_{n1}q_{r2} + q_{n2}q_{r1} + q_{n2}q_{r2}).$$

There are two sets of interaction terms in this utility function. The coefficient $\gamma_{12}$ measures the competitive intensity or substitutability within the same category of products (product category is either new or both remanufacture). In contrast, $\gamma_0$ measures competitive intensity or substitutability across different product category. Finally, it should be the case that $\alpha_{n0} > \alpha_{r0}$, i.e., a brand new product will give more utility *ceteris paribus* than a remanufactured product. This is clear from the lower market prices charged for used, refurbished, certified pre-owned and other forms of remanufactured products compared to new products.

To focus on the effects of substitutability from competing products, we normalize the utility function with respect to $\beta_0$, and have:

$$U(q_{n1}, q_{n2}, q_{r1}, q_{r2}) = \alpha_n(q_{n1} + q_{n2}) + \alpha_r(q_{r1} + q_{r2}) - \frac{1}{2}(q_{n1}^2 + q_{n2}^2 + q_{r1}^2 + q_{r2}^2)$$
$$-\beta(q_{n1}q_{n2} + q_{r1}q_{r2}) - \gamma(q_{n1}q_{r1} + q_{n1}q_{r2} + q_{n2}q_{r1} + q_{n2}q_{r2}). \quad (4.4)$$

where we define:

$$\beta \triangleq \gamma_{12}/\beta_0$$
$$\gamma \triangleq \gamma_0/\beta_0$$
$$\alpha_n \triangleq \alpha_{n0}/\beta_0$$
$$\alpha_r \triangleq \alpha_{r0}/\beta_0$$

Let us consider what these coefficients represent. The coefficient $\beta$ measures competitive intensity or substitutability within the same category of products (product category is either new



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or both remanufacture). Therefore $\beta$ is same-category-products-substitutability-parameter. In contrast, $\gamma$ measures competitive intensity or substitutability across different product category. Therefore $\gamma$ is different-category-products-substitutability-parameter. Finally, $\alpha_n > \alpha_r$, since as mentioned a new product gives more utility *ceteris paribus* than a remanufactured product.

Next, to determine the conditions for the utility function to be concave with respect to $q_{n1}, q_{r1}, q_{n2}, q_{r2}$, we check whether its Hessian matrix is negative definite. It is straightforward to confirm that all of principal minors of the Hessian meet the requirements for the Hessian matrix to be negative definite if the following conditions hold:

$$1 - \beta > 0,\ 1 + \beta > 2\gamma^2,\ 1 + \beta > 2\gamma.$$

Furthermore, these conditions for the utility function to be concave are all satisfied if,

$$1 > \beta > \gamma > 0,$$

which we will assume henceforth. The requirement that $\beta > \gamma$ is reasonable because substitution effects from the same category of the products should always be larger than the competition from different product category. Because $\beta \triangleq \gamma_{12}/\beta_0$ and $\gamma \triangleq \gamma_0/\beta_0$, therefore $1 > \beta$ and $1 > \gamma$ indicate that the slope of a product price is higher to the underlying product quantity, compared with completion product. Moreover, $\beta > 0$ and $\gamma > 0$ indicate that the slope of price is negative: the more the quantity, the less the price.

Upon taking the first-order condition of the representative consumer's utility maximization problem with respect to quantity choices, we obtain a linear demand structure which can be arranged into the following price (or inverse demand) functions:



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$$\begin{pmatrix} p_{n1} \\ p_{r1} \\ p_{n2} \\ p_{r2} \end{pmatrix} = \begin{pmatrix} \alpha_n \\ \alpha_r \\ \alpha_n \\ \alpha_r \end{pmatrix} - \begin{pmatrix} q_{n1} \\ q_{r1} \\ q_{n2} \\ q_{r2} \end{pmatrix} - \beta \begin{pmatrix} q_{n2} \\ q_{r2} \\ q_{n1} \\ q_{r1} \end{pmatrix} - \gamma \begin{pmatrix} q_{r1} + q_{r2} \\ q_{n1} + q_{n2} \\ q_{r1} + q_{r2} \\ q_{n1} + q_{n2} \end{pmatrix}. \tag{4.5}$$

Since the margins for the products $p_n - c_n$ and $p_r - c_r$ should be positive, we require that $\alpha_n > c_n$ and $\alpha_r > c_r$. We next invert the inverse demand equations to obtain the demand functions:

$$((1+\beta)^2 - 4\gamma^2)\begin{pmatrix} q_{n1} \\ q_{r1} \\ q_{n2} \\ q_{r2} \end{pmatrix} = (1+\beta)\begin{pmatrix} \alpha_n \\ \alpha_r \\ \alpha_n \\ \alpha_r \end{pmatrix} - 2\gamma \begin{pmatrix} \alpha_r \\ \alpha_n \\ \alpha_r \\ \alpha_n \end{pmatrix} +$$

$$\begin{pmatrix} \frac{-(1+\beta-2\gamma^2)}{1-\beta} & \gamma & \frac{\beta+\beta^2-2\gamma^2}{1-\beta} & \gamma \\ \gamma & \frac{-(1+\beta-2\gamma^2)}{1-\beta} & \gamma & \frac{\beta+\beta^2-2\gamma^2}{1-\beta} \\ \frac{\beta+\beta^2-2\gamma^2}{1-\beta} & \gamma & \frac{-(1+\beta-2\gamma^2)}{1-\beta} & \gamma \\ \gamma & \frac{\beta+\beta^2-2\gamma^2}{1-\beta} & \gamma & \frac{-(1+\beta-2\gamma^2)}{1-\beta} \end{pmatrix} \begin{pmatrix} p_{n1} \\ p_{r1} \\ p_{n2} \\ p_{r2} \end{pmatrix}. \tag{4.6}$$

Finally, we impose conditions to ensure that the demand functions behave in a typical manner to price changes, i.e., that they are downwards sloping with respect to own price and increasing in the prices of competing products. This condition is given in Lemma 1 and thus we assume that the required condition $(1+\beta)\alpha_r > 2\gamma\alpha_n$ holds henceforth.

**Lemma 4.1** If and only if $(1+\beta)\alpha_r > 2\gamma\alpha_n$, then positive demand is possible for each product and the demand functions will behave typically to price changes. (Proofs: See appendix.)



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### 4.2 Analysis

In the previous section, we developed the demand functions which are functions of the prices of new and refurbished products on the market. We stated assumptions needed to ensure that the utility, demand and profit functions have reasonable properties. We may now proceed with the analysis of firms' behavior. We first analyze a centralized market where a monopoly controls both firms and thus all four products. Thereafter we will analyze the duopoly equilibrium behavior when the two firms are independent.

#### 4.2.1 Monopoly

As a benchmark, we consider a monopoly and begin by deriving the results when remanufactured products are not provided. This is the Singh-Vives model of two products, but with a single firm selling both products. The firm's profit function is,

$$\pi(n,n) = \max_{q_{n1},q_{n2}} (p_{n1} - c_n)q_{n1} + (p_{n2} - c_n)q_{n2},$$

i.e., the sum of the profits from the two new products. The firm maximizes its objective with respect to quantities because prices are inverse demand functions that depend on quantities as discussed in the previous section. The prices can be obtained by modifying equation (4.5) so that the quantities of the remanufactured products sold are zero. In other words, the inverse demand functions are:

$$p_{n1} = \alpha_n - q_{n1} - \beta q_{n2} \text{ and } p_{n2} = \alpha_n - q_{n2} - \beta q_{n1}.$$

Substituting these into the objective function and performing the optimization, we find that the optimal quantities are $q_{n1} = q_{n2} = (\alpha_n - c_n)/2(1+\beta)$. Inserting back into the profit expression yields,



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$$\pi(n,n) = \frac{(\alpha_n - c_n)^2}{2(1+\beta)} = \frac{m_n^2}{2(1+\beta)} \tag{4.7}$$

as the optimal profit where we defined,

$$m_n \equiv \alpha_n - c_n.$$

This $m$ notation is useful and occurs often. It is related to the profit margin of a product, as it is the highest feasible price minus the marginal cost of the product.

Next, we proceed to solve the monopolist's profit maximization problem when remanufactured products are also provided. In this case, the objective of the firm is given by,

$$\pi(r,r) = \max_{q_{n1}, q_{n2}, q_{r1}, q_{r2}} (p_{n1} - c_n)q_{n1} + (p_{n2} - c_n)q_{n2} + (p_{r1} - c_r)q_{r1} + (p_{r2} - c_r)q_{r2} - F,$$

where $F$ is the investment in remanufacturing capability. The inverse demand functions derived earlier in equation (4.5) are substituted into this objective function and it is maximized with respect to the quantity decisions. The optimal quantities are obtained and inserted back into the objective function to yield the firm's optimal profit, which is obtained to be

$$\pi(r,r) = \frac{(1+\beta)({m_n}^2 + {m_r}^2) - 4\gamma m_n m_r}{2(1+\beta)^2 - 8\gamma^2}. \tag{4.8}$$

where $m_n = \alpha_n - c_n$, and $m_r = \alpha_r - c_r$.

It is now possible to compare the optimal monopoly profits from providing remanufactured product or not from equations (4.7) and (4.8). The difference is given by,

$$\pi(r,r) - \pi(n,n) = \frac{(2\gamma m_n - (1+\beta)m_r)^2}{2(1+\beta)^3 - 8(1+\beta)\gamma^2} - F. \tag{4.9}$$

**Theorem 4.1** Under a monopoly, when F=0, the manufacturer prefers remanufacturing to no remanufacturing. This preference is strict if $2\gamma m_n - (1+\beta)m_r \neq 0$.



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The insights of Theorem 4.1 are reasonable given that in a single decision-maker scenario, offering an additional option (of remanufactured products) will at least dominate not having that option, because the quantity of remanufactured products can be set to zero. In that case, the firm will achieve the same profit as the case without remanufactured goods, and possibly it can achieve more. Indeed, when $2\gamma m_n - (1+\beta)m_r \neq 0$, the firm is strictly better off from providing remanufactured products due to capturing more market share which outweighs the disadvantage of cannibalization of new product sales.

### 4.2.2 Competition without remanufacturing

We now consider the case of competing independent manufacturers. For comparison purposes, we begin again with the scenario where the firms do not provide remanufactured products. Each firm $i \in \{1,2\}$ maximizes its objective function, which is $(p_{ni} - c_n)q_{ni}$. The inverse demand functions when only the two new products compete have already been mentioned in equation (4.5). We substitute these into the objective functions and then differentiate with respect to the quantity decision to get the reaction function for each firm. Due to symmetry, the equilibrium values are

$$q_{n1} = q_{n2} = \frac{m_n}{2+\beta}. \quad (4.10)$$

The equilibrium profit for each firm is denoted as $\pi(n,n)$ (because of symmetry, the subscript $i$ is dropped) given by,

$$\pi(n,n) = \frac{m_n^2}{(2+\beta)^2}. \quad (4.11)$$

**Remark 4.1** The equilibrium profit function is decreasing and convex in the products-substitutability-parameter β.



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The basic intuition for Remark 4.1 is that more substitutable products have a greater downward effect on profit of competing products. Each individual firm's profits and the sum of their profits are less than that of the monopolist in the corresponding scenario.

### 4.2.3 Competition with remanufacturing

When both firms provide remanufactured products, the inverse demand functions are given by equation (4.5). Each firm maximizes its profit function, which for firm $i$ is given by the expression

$$\pi_i(r,r) = \max_{q_{ni},q_{ri}} (p_{ni} - c_n)q_{ni} + (p_{ri} - c_r)q_{ri} - F.$$

After making the appropriate substitutions, the necessary conditions for maxima yield the optimal demand decisions

$$q_{n1} = q_{n2} = \frac{m_n(2+\beta)-3m_r\gamma}{(2+\beta)^2-9\gamma^2},\ q_{r1} = q_{r2} = \frac{m_r(2+\beta)-3m_n\gamma}{(2+\beta)^2-9\gamma^2}. \quad (4.12)$$

The following conditions are required. Assumptions (4.A)~(4.C) we have discussed earlier.

Assumption 4.A: $(1+\beta)\alpha_r > 2\gamma\alpha_n$, together with,

Assumption 4.B: $\alpha_n > \alpha_r$, implies:

$$\frac{\alpha_n+\alpha_n\beta-2\alpha_r\gamma}{(1+\beta)^2-4\gamma^2} > 0 \text{ and } \frac{\alpha_r+\alpha_r\beta-2\alpha_n\gamma}{(1+\beta)^2-4\gamma^2} > 0.$$

Assumption 4.C: $1 > \beta > \gamma > 1$.

Assumption 4.D: $m_n(2+\beta) - 3m_r\gamma > 0$; $m_r(2+\beta) - 3m_n\gamma > 0$. This assumption ensures that demand for the corresponding product is nonnegative. Given that the profit function is concave, the optimal demand will be zero rather than negative, which is equivalent to not offering that product at all.



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The optimal profits when both firms choose remanufacturing are denoted as $\pi(r,r)$ for each firm due to symmetry. This is given by

$$\pi(r,r) = \frac{(2+\beta)^2-3(1+2\beta)\gamma^2}{((2+\beta)^2-9\gamma^2)^2}({m_n}^2+{m_r}^2) + \frac{2(\beta-4)(2+\beta)\gamma+18\gamma^3}{((2+\beta)^2-9\gamma^2)^2}(m_n m_r) - F.$$

Rearranging terms, we have:

$$\pi(r,r) = -F + \frac{(m_n^2+2\gamma m_n m_r+m_r^2)[(2+\beta)-3\gamma]^2+6(2+\beta)\gamma(1-\gamma)(m_n-m_r)^2}{((2+\beta)^2-9\gamma^2)^2}.$$

which is positive when $F = 0$ since $0 \leq \gamma \leq 1$.

### 4.2.4 Equilibrium in the Supergame

So far we have considered scenarios where the available remanufacturing strategies of the firms, specifically whether remanufacturing is allowed or not, is exogenous. In this section, we consider the equilibrium in the super-game when the firms make the decision of whether or not to offer a remanufactured product.

Assume that firm 1 decides to invest in the capability to remanufacture while firm 2 does not. (The case that firm 1 decides not to have the capability to remanufacture while firm 2 does will have the same conclusion with an appropriate change of notation.) We have the linear inverse demand functions from a modification of equation (5):

$$p_{n1} = a_n - q_{n1} - \beta q_{n2} - \gamma q_{r1},$$

$$p_{n2} = a_n - \beta q_{n1} - q_{n2} - \gamma q_{r1},$$

$$p_{r1} = a_r - q_{r1} - \gamma(q_{n1} + q_{n2}).$$

Denote the profit of the firm which does not provide a remanufactured product, given that its rival does provide it, as $\pi(n,r)$, and the profit of the firm which provides a remanufactured



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product, given the rival does not provide it, as $\pi(r,n)$. Therefore, the profit functions of firm 1 and firm 2 subject to the above inverse demand functions are, respectively,

$$\pi(r,n) = \max_{q_{n1},q_{r1}} (p_{n1} - c_n)q_{n1} + (p_{r1} - c_r)q_{r1}, \text{ and}$$

$$\pi(n,r) = \max_{q_{n2}} \ (p_{n2} - c_n)q_{n2}.$$

Thus, $\pi_i(x,y)$ where $i \in \{1,2\}$ and $x,y \in \{n,r\}$ is player $i$'s maximum profit given its remanufacturing strategy $x$ and the rival's strategy $y$. After inserting the inverse demand functions, the first-order conditions for a maximum of the firms' problems yield the following equilibrium demand functions:

$$\begin{pmatrix} q_{n1} \\ q_{r1} \\ q_{n2} \end{pmatrix} = \frac{1}{8-2\beta^2-10\gamma^2+4\beta\gamma^2} \begin{pmatrix} \gamma^2 + 4 - 2\beta & \gamma(\beta - 4) \\ -3\gamma(2-\beta) & 4 - \beta^2 \\ 4 - 2\beta - 2\gamma^2 & -2\gamma(1-\beta) \end{pmatrix} \begin{pmatrix} m_n \\ m_r \end{pmatrix}.$$

Substituting these into the profit functions of each firm, we get the optimal profit for each firm. Then Table 4.1 provides the profit for each subgame.

***Remark 4.2*** From Table 4.1, if $\forall i, \pi_i(n,n) > \pi_i(r,n)$, then both firms not remanufacturing is a pure strategy Nash Equilibrium. If $\forall i, \pi_i(r,r) > \pi_i(n,r)$, then both firms remanufacturing is a pure strategy Nash Equilibrium.

To assess whether $(n,n)$ is an equilibrium, we examine the incentive of each firm to deviate from this strategy. If $\pi_1(r,n) - \pi_1(n,n)$ (and by symmetry $\pi_2(r,n) - \pi_2(n,n)$) is negative, then $(n,n)$ is a pure strategy Nash Equilibrium. To assess whether $(r,r)$ is an equilibrium, we examine the incentive of each firm to deviate from this strategy. If $\pi_1(n,r) -$



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$\pi_1(r,r)$ (and by symmetry $\pi_2(n,r) - \pi_2(r,r)$) is negative, then $(r,r)$ is a pure strategy Nash Equilibrium.

### 4.2.5 Numerical Analysis

Because of the complexity of the profit expressions, it is difficult to give an explicit solution of the super-game. Therefore, we resort to numerical analysis to shed some light on the characteristics of the equilibrium. Consider $c_n = 0.1$, $c_r = 0.05$, $\alpha_n = 1$, $\alpha_r = 0.7$, and $F = 0$.

Table 4.1 Matrix of subgame equilibrium payoffs

| | Firm 2 does not remanufacture (*n*) | Firm 2 remanufactures (*r*) |
|---|---|---|
| Firm 1 does not remanufacture (*n*) | $\pi_i(n,n) = \frac{m_n{}^2}{(2+\beta)^2}, \forall i \in \{1,2\}.$ | $\pi_1(n,r) = \frac{(m_n(2-\beta-\gamma^2)-(1-\beta)m_r\gamma)^2}{(4-\beta^2-5\gamma^2+2\beta\gamma^2)^2},$<br>$\pi_2(r,n) = -F + \frac{1}{4(4-\beta^2-5\gamma^2+2\beta\gamma^2)^2} \times$<br>$\{((6\beta-11)\gamma^4+4(\beta-2)^2-\gamma^2(\beta-2)(3\beta-2))m_n{}^2$<br>$+((\beta^2-4)^2+\gamma^2(16+\beta^2(2\beta-9)))m_r{}^2$<br>$+(48+\beta(4\beta-34))\gamma^3-2(24-16\beta+\beta^3)\gamma)m_n m_r\}.$ |
| Firm 1 remanufactures (*r*) | $\pi_1(r,n) = -F + \frac{1}{4(4-\beta^2-5\gamma^2+2\beta\gamma^2)^2} \times$<br>$\{((6\beta-11)\gamma^4+4(\beta-2)^2-\gamma^2(\beta-2)(3\beta-2))m_n{}^2$<br>$+((\beta^2-4)^2+\gamma^2(16+\beta^2(2\beta-9)))m_r{}^2$<br>$+(48+\beta(4\beta-34))\gamma^3-2(24-16\beta+\beta^3)\gamma)m_n m_r\}.$<br>$\pi_2(n,r) = \frac{(m_n(2-\beta-\gamma^2)-(1-\beta)m_r\gamma)^2}{(4-\beta^2-5\gamma^2+2\beta\gamma^2)^2}.$ | $\pi_i(r,r) = \frac{(m_n^2+2\gamma m_n m_r+m_r^2)[(2+\beta)-3\gamma]^2}{((2+\beta)^2-9\gamma^2)^2}$<br>$+\frac{6(2+\beta)\gamma(1-\gamma)(m_n-m_r)^2}{((2+\beta)^2-9\gamma^2)^2},$<br>$\forall i \in \{1,2\}.$ |



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Figure 4.1 is a phase diagram that shows the parameter values for which different equilibria occur. (The white areas in Figure 4.1 are ruled out due to Assumption 4.A~4.D. The remaining areas meet those assumptions.)

From Figure 4.1, we observe that when $\beta$ is small, firms reduce their profits by unilaterally deviating from $(n, n)$ where neither is remanufacturing.[8] This indicates that both firms remanufacturing will be an equilibrium for small $\beta$. From Figure 4.1, we also observe that both firms doing remanufacturing can be an equilibrium.

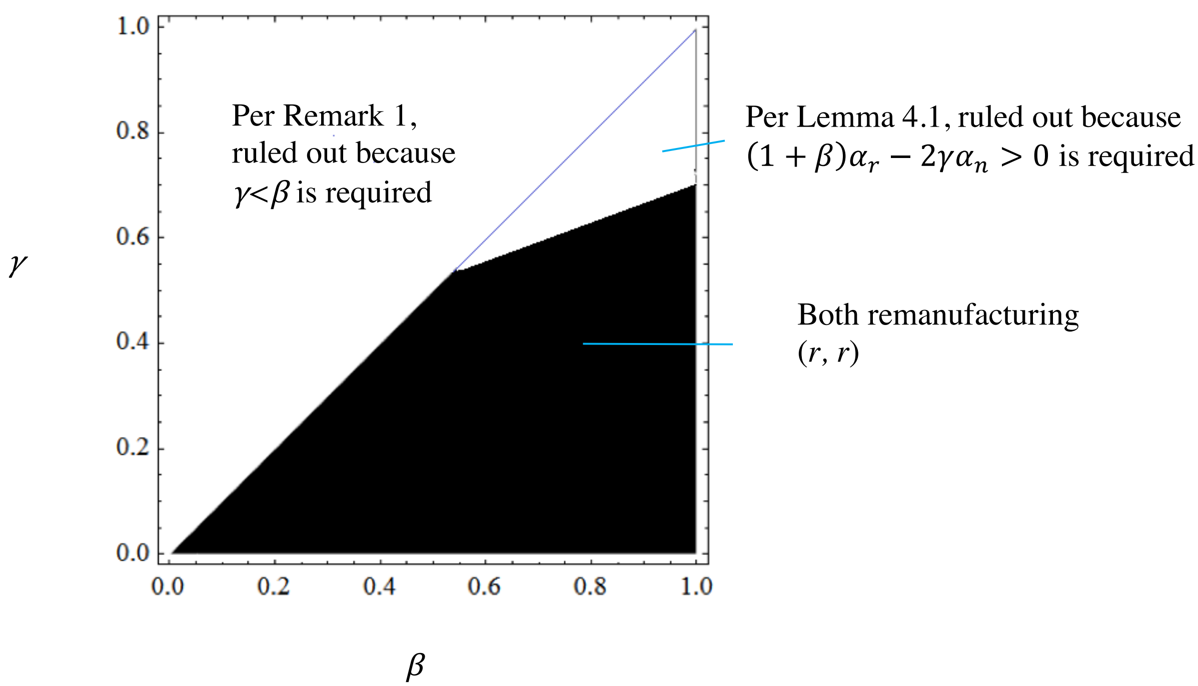


Figure 4.1 Phase Diagram for Equilibrium Strategies

Figure 4.2 compares the firms' profits when both firms remanufacture versus when neither remanufacture.

[8] We also verified Fig 4.1 using a grid of $\beta$ and $\gamma$ values and the game theory software "Gambit" to ensure that all possible equilibria, including mixed strategy equilibria were numerically obtained.



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From Figures 4.1 and 4.2, we observe that when $\gamma$ is large, although in equilibrium both firms remanufacture, they can be worse off compared with the scenario that neither of them remanufacture. This *prisoner's dilemma* arises because of competition. It is shown in the region of Fig. 4.2 where $\pi(n,n) > \pi(r,r)$.

In the next section, we add further theoretical analysis of the problem to shed light on the observations from the numerical analysis.

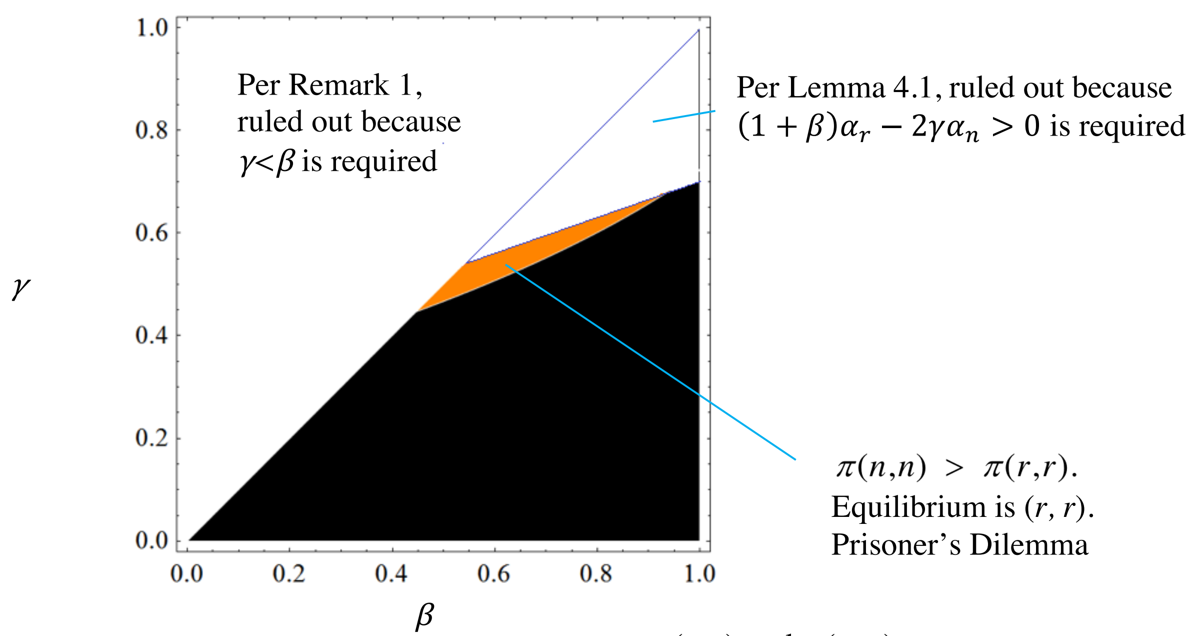


Figure 4.2 Comparison between $\pi(r,r)$ and $\pi(n,n)$.

**4.3 Analysis when competition is present**

We showed numerically that both firms remanufacturing is an equilibrium for small $\beta$ while neither firm remanufacturing is an equilibrium for large $\beta$. Furthermore, it is possible for some values of $\beta$ that remanufacturing occurs because of the Prisoner's dilemma argument. It is



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worthwhile to compare the profits under each scenario to get better bounds on the $\beta$'s that delineate these outcomes. We look at the profit difference $\pi(r,r) - \pi(n,n)$ and attempt to sign it.

**Theorem 4.2** Compared with not remanufacturing, remanufacturing may benefit or hurt firms according to the following rule. If $m_n < m_r \; or \; \gamma m_n > m_r$ for $\beta < \beta_1 \triangleq \frac{3\gamma m_n}{m_r} - 2$ but $\beta$ not too small, firms will be better off, while for $\beta > \beta_1$ but $\beta$ not too large, firms will be worse off. By contrast, if $\gamma m_n < m_r < m_n \; for \; \beta < \beta_1$, but $\beta$ not too small, firms will be worse off, while for $\beta > \beta_1$ but $\beta$ not too large, firms will be better off.

The parameters $m_n = a_n - c_n$ or $m_r = a_r - c_r$ measures the profitability margin of a product. Compared with new products, remanufactured products that have intermediate profitability (but less than that of new products) will hurt firms in fierce competition, but may benefit firms in moderate competition. The reason is that with comparable but less profitability compared with new products, remanufactured products will intensify competition. Therefore, when there is more competition, the disadvantage of competition increases, which more than offsets the benefit of product differentiation.

By contrast, if the profitability of remanufactured product is small or large, the conclusion is reversed. The reason is that significant difference of profitability will hurt the new products with less competition, because fierce competition in remanufactured product will enhance cannibalization effects. However, when competition between new products is strong, cannibalization effects will be alleviated.



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## 4.4 Comparison between monopoly and duopoly

Under duopoly, when prisoner's dilemma is present, decision makers will have one of following two cases in equilibrium:

- both firms choose not to offering remanufactured products, but could have been better off by offering remanufactured products.
- both firms choose to offer remanufactured products, but could have been better off by not offering remanufactured products.

Either of the above two cases, the total optimal profits are no better than the scenario of no remanufacturing in equilibrium.

Note that under duopoly, the total optimal profits of the two players without remanufacturing are $\frac{2m_n^2}{(2+\beta)^2}$, while the optimal profit for the monopoly is $\frac{m_n^2}{2(1+\beta)}$. The former is smaller than the later given the fact that $0 < \beta < 1$. We thus have the following theorem.

**Theorem 4.3** Under prisoner's dilemma, monopoly's profit is greater than the sum of the duopoly profits.

Thus, in terms of total profits, monopoly will be better than monopoly without remanufacturing, which is in turn better than duopoly without remanufacturing, which is in turn no worse than any case when prisoner's dilemma occurs.

## 4.4 Conclusions

In this paper, we have studied the impact of remanufacturing on the sales of new product under competition. On one hand, the cannibalization effect from remanufactured products hurt the firm. On the other, remanufacturing can provide advantages and be an effective marketing strategy



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to offer products that satisfy different preferences and gain competitive advantage. In this paper, we analyzed the tradeoff with a utility based model. We derived the demand functions from maximization of a direct utility function of a representative consumer to capture preferences on new products and remanufactured products. We provided an extensive evaluation from the perspective of competing firms as to how the strategy of remanufacturing will be affected by different exogenous factors, such as market parameters, competition, substitutability, production cost as well as remanufacturing cost.

In summary, we have following managerial insights:

- Remanufacturing option does not hurt but helps a monopoly manufacturer as long as the costs of providing the remanufactured version are sufficiently low.
- Two competing manufacturers may be worse off by adopting remanufacturing options.
- Due to competition, the equilibrium can be for both firms to offer remanufactured versions even though the situation where neither are remanufacturing is more profitable.

One path for future research direction is to consider asymmetric firms. Other possible directions that are worth exploring include models considering uncertain demand, capacity constraints, as well as the impact of a decentralized supply chain.



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# APPENDIX

## Appendix for Chapter 2: Hold-up problem

### A2.1 Proof of Proposition 2.3

To find $P^*_{i,-i}(p_H|q_H)$, buyer $i$ solves the optimization problem:

$$\max_{P_i(p_H|q_H)} \mathbb{E}\left[u_B\left(P_i(p_H|q_H)\right)\right]$$

We assume that seller does not reject offers when it is dominated to do so in the dynamic setting. Therefore, rejections do not depend on $\lambda$ or on $P_i(p_H|q_H)$). Rewriting the objective function for the optimization problem above and setting its decision variable $P_i(p_H|q_H) = x$ gives

$$\left\{\frac{e^{[Y+Z((1-\lambda)P_{-i}(p_H|q_H)+x\lambda)]\tau}}{e^{e_S\tau}+e^{[Y+Z((1-\lambda)P_{-i}(p_H|q_H)+x\lambda)]\tau}}\right\}[(v_H-p_H)x+(v_H-p_L)(1-x)(1-\delta)+C\delta$$

$$-(v_H-p_H)x\delta-e_B]+1, \qquad \text{(A1)}$$

where $C$, $Y$ and $Z$ are constants that we define to simplify the expressions:

$$Y = p_L - c - \alpha\big((1-\delta)(v_H-v_L)+(v_L-2p_L+c)\big),$$

$$Z = p_H - p_L - \alpha(v_H-2p_H+c)^+ + \alpha(v_H-2p_L+c),$$

and $C = P(p_L, A)(v_L-p_L) + P(p_L, R)(w_L) = (v_L-p_L)$.

The first order condition (FOC) of expression (A1) with respect to decision variable $x$ is

$$\frac{\left\{\begin{matrix}\big((v_H-p_H)-(v_H-p_L)\big)e^{[Y+Z((1-\lambda)P_{-i}(p_H|q_H)+x\lambda)]\tau}(1-\delta)\\ +e^{e_S\tau}[\lambda Z(C\delta-e_B)\tau-(v_H-p_L)(1-\delta)(1-Z(1-x)\tau\lambda)+(v_H-p_H)(1-\delta)(1+Zx\tau\lambda)]\end{matrix}\right\}}{e^{-[Y+Z((1-\lambda)P_{-i}(p_H|q_H)+x\lambda)]\tau}\left(e^{\tau e_S}+e^{(Y+Z((1-\lambda)P_{-i}(p_H|q_H)+x\lambda))\tau}\right)^2}$$

$$=0.$$

Because the denominator is strictly positive, we restrict attention to the numerator denoted as $F(\cdot)$.



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According to the implicit function theorem, $x$ is increasing in λ, iff $\frac{\partial x}{\partial \lambda} = -\frac{F_\lambda}{F_x} > 0$.

We show that $F_x$ is negative while $F_\lambda$ is positive for $x \leq P_{-i}(p_H|q_H)$, where

$$F_x = \left(e^{\tau e_s} + e^{\tau\left(Y+Z\left(x\lambda+P_{-i}(p_H|q_H)-\lambda P_{-i}(p_H|q_H)\right)\right)}\right) Z(1-\delta)\lambda\tau(p_L - p_H) \qquad ,$$

$$F_\lambda = Z\tau e^{\tau\left(Y+Z\left(x\lambda+P_{-i}(p_H|q_H)-\lambda P_{-i}(p_H|q_H)\right)\right)} \left((p_L - p_H)(1-\delta)\left(x - P_{-i}(p_H|q_H)\right)\right)$$

$$+ Z\tau e^{e_s\tau}\{\delta C + x(1-\delta)(v_H - p_H) + (1-x)(1-\delta)(v_H - p_L) - e_b\}.$$

$F_x$ is negative because $Z > 0, p_L < p_H$ and $(1-\delta) > 0$.

Since $p_L - p_H < 0$ for $x \leq P_{-i}(p_H|q_H)$, the $F_p$ is positive if $\delta C + x(1-\delta)(v_H - p_H) + (1-x)(1-\delta)(v_H - p_L) - e_B > 0$. Because $-(1-x)(1-\delta) < 0$, therefore

$$-\delta C + x(-1+\delta)(v_H - p_H) + (-1+x+\delta-x\delta)(v_H - p_L) + e_B$$

$$< -\delta C + x(-1+\delta)(v_H - p_H) + (-1+x+\delta-x\delta)(v_H - p_H) + e_B$$

$$= -\delta C + (-1+\delta)(v_H - p_H) + e_B$$

$$= -\delta(v_L - p_L) + (-1+\delta)(v_H - p_H) + e_B$$

The above expression is negative, which follows from the assumption that $\delta(v_L - p_L) + (1-\delta)(v_H - p_H) > e_B$ in Section 2.1. We also checked the second order condition of (A1) to verify that the solution of the optimization problem is a maximum by showing that implicit function theorem when $x \leq P_{-i}(p_H|q_H)$ is sufficient for the global maximum.

■



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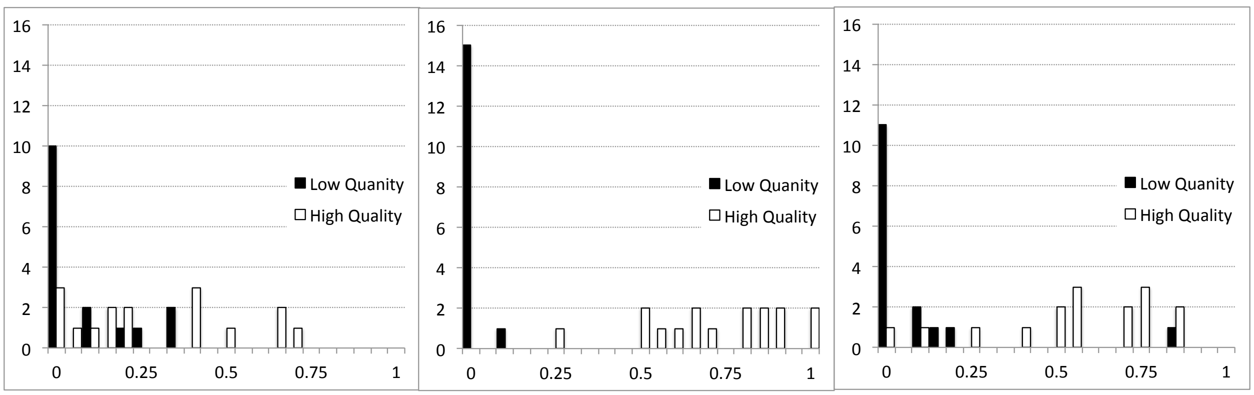
## A2.2 Individual Heterogeneity

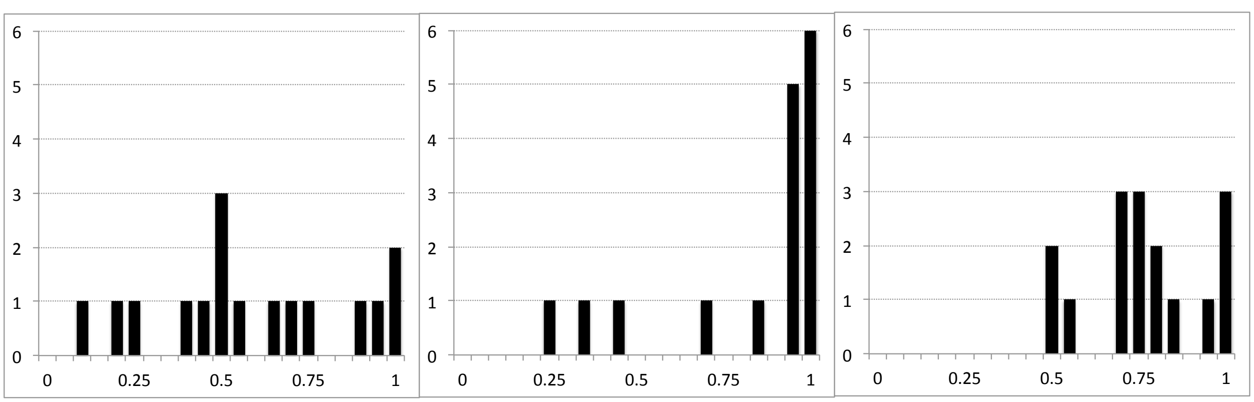
We calculated average $P(p_H|q_H)$ and $P(p_H|q_L)$ for the buyers, as well as average production and rejection rates for the sellers. Figure A1 shows the distributions of average $P(p_H|q_H)$ and $P(p_H|q_L)$ for individual buyers.




(a) Impunity Treatment (b) Reciprocity Treatment (c) Reputation Treatment

Figure A1 Distributions of average $P(p_H|q_H)$ and $P(p_H|q_L)$.

Figure A2 shows the distribution of average production rates for individual sellers.



(a) Impunity Treatment (b) Reciprocity Treatment (c) Reputation Treatment

Figure A2 Distributions of average production rates.



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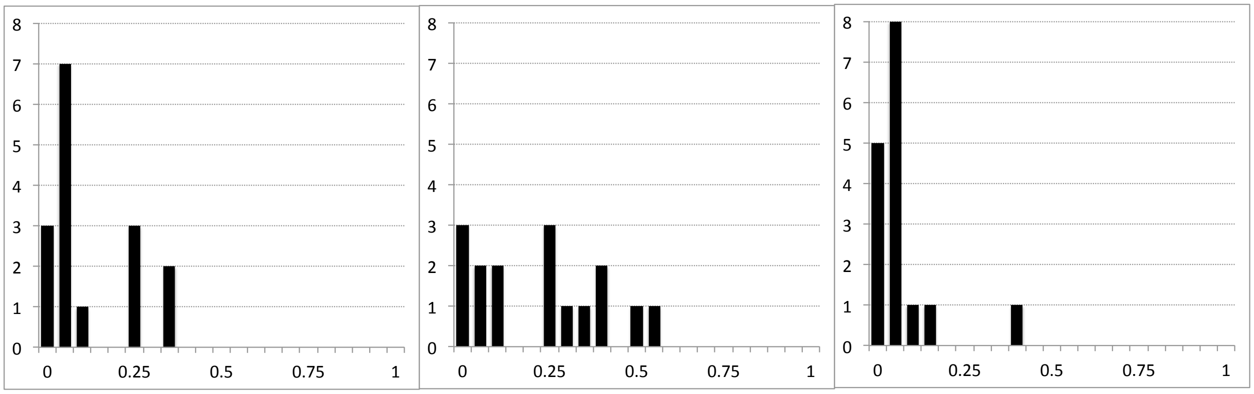
Figure A3 shows the distribution of average rejection rates for individual sellers.




(a) Impunity Treatment (b) Reciprocity Treatment (c)Reputation Treatment

Figure A3 Distributions of average rejection rates.

**A2.3 On-line Appendix, Experimental Instructions (reputation treatment)**

This is an experiment in strategic decision making. If you read these instructions carefully and make good decisions, you may earn a considerable amount of money. The amount of money you make will depend on your decisions as well as the decisions of other participants.

How your role will be determined

At the beginning of the session you will be randomly assigned to one of two roles: Seller or Buyer. Your role will remain the same for the duration of the session.

How you will be matched with other participants

At the beginning of each round you will be randomly matched with another participant in the room with a different role. You will be matched with a different person in each round. The session will last 100 rounds.



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How you earn money

All earnings will be measured in units of experimental currency (ECU), which will be converted to US dollars at the end of the session.

This experiment involves the potential production and transfer of a virtual product. In each round, the Seller has to decide whether or not to produce the product. If the Seller chooses Not Produce, the round ends with both players earning 2 ECU.

Reputation

Before making production decision, the Seller will know the current Buyer's reputation. This is the proportion of time that the Buyer offered a high price in the past.

Production

If the Seller chooses Produce, the Buyer determines whether the quality of the product is high or low. There is an 80% chance of high quality and 20% chance of low quality. A high quality product is worth more to the Buyer than does the low quality. Note that only the Buyer knows the product quality; the Seller does not.

After observing the product quality, the Buyer decides whether to offer the Seller a high price or a low price.



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After observing the Buyer's price but not the product quality, the Seller decides whether to accept or reject the offer. If the Seller accepts the offer, the earnings depend on the price the Buyer offered and the quality of the product:

If the price is high and the quality is high, both players earn 5 ECU.

If the price is high and quality is low, Buyer earns -2 ECU and Seller earns 5 ECU.

If the price is low and the quality is high, Buyer earns 8.5 ECU and Seller earns 1.5 ECU.

If the price is low and the quality is low, both players earn 1.5 ECU.

If the Seller rejects the offer, the earnings depend on the quality of the product:

If the quality is high, Buyer earns 9 ECU and Seller earns 1 ECU

If the quality is low, Buyer earns 2 ECU and Seller earns 1 ECU.

Information you will see at the end of each round

At the end of each round the Buyer and Seller will see:

Current Period

Buyer's proportion of high price in the past

Seller's production decision (Produce or Not Produce)

Product quality (Only observed by Buyer)

Buyer's payment decision (High or Low price)

Seller's accept/reject decision

Earning's of this period



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It is important to note that the Buyer will see product quality (High or Low). The Seller will not see the product quality. However, the Seller will see the Buyer's reputation, which is the proportion of time that the Buyer offered a high price in the past.

How you will be paid

At the end of the session the actual earnings from the game will be converted to US dollars at the rate of 20 ECU for $1 US dollar. These profits will be added to your $5 show-up fee, displayed on your screen, and paid to you in cash at the end of the session.

**Appendix for Chapter 3: Quality problem**

Instructions for Supplier Investing Treatment

Instructions

This is an experiment in economic decision making. If you read these instructions carefully and make good decisions, you may earn a considerable amount of money. The amount of money you earn will depend on your decisions as well as the decisions of other participants.

How your role will be determined

At the beginning of the session you will be randomly assigned one of two roles: The Supplier or the Buyer. Your role will remain the same for the duration of the session.

How you will be matched with other participants



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At the beginning of each round you will be randomly matched with another participant in the room with a different role. You will be matched with a different person in each round. The session will last 50 rounds.

How you earn money

All earnings will be measured in experimental currency units (ECU), which will be converted to US dollars at the end of the session. This experiment involves investment on system quality to reduce the number of defective units.

Production

In each period, the Buyer order 100 units from the Supplier at a unit price of 4 ECU. The Buyer will sell the product at the unit retail price 6 ECU. The Supplier's production cost for each unit is 2 ECU.

Some of those products are defective. Of the 100 units, the initial number of defective units is 80. Each defective unit costs the Supplier 2.1 ECU and the Buyer 0.9 ECU.

Both the Supplier and the Buyer can reduce the number of defective units by making an investment.

The investment cost of reducing the number of defective units

The lower the number of defective units, the more expensive it is to decrease the number of defective units further. The Buyer decides the target number of defective units first. The Supplier will observe the Buyer's selected target, and then decides whether to reduce the defects further. At



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the end of these instructions, we provided tables that calculate the investment cost of improvement for various target numbers, for both the Buyer and the Supplier. A calculator that calculates your exact investment cost of improvement is also provided on your computer screen.

Decision sequence

The Buyer moves first and decides his target number of defective units. Then, observing the Buyer's decision, the Supplier decides the target number of defective units of the system.

Lastly, the number of defective units is realized according to the level the Supplier chose and both players see their earnings from the period. The profit for each player is:

Profit = Revenue – Cost due to defective products

- Investment cost of reducing the number of defective units

Example

For example, if the Buyer reduced the number of defective units from 80 to 44, the cost to the Buyer is 59.8 ECU. If the Supplier further reduces the number of defective units from 44 to 33, the cost to the Supplier 28.8 ECU.

Buyer Profit = 200-33*0.9-18.8=70.9

Supplier Profit = 200-33*2.1-21.8=141.5



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How you will be paid

At the end of the session the actual earnings from the game will be converted to US dollars at the rate of 400 ECU for $1 US dollar. These profits will be added to your $5 show-up fee, displayed on your screen, and paid to you in cash at the end of the session.

Table A1 Buyer's investment cost of improvement

| Buyer's target | 80 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Buyer's cost | 0.0 | 2.6 | 5.3 | 8.3 | 11.5 | 15.0 | 18.8 | 23.0 | 27.7 | 33.1 | 39.2 | 46.5 | 55.5 | 67.0 | 83.2 | 110.9 |

Table A2 Supplier's investment cost of improvement

| | | Supplier's target | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 80 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 |
| Buyer's target | 80 | 0.0 | 2.6 | 5.3 | 8.3 | 11.5 | 15.0 | 18.8 | 23.0 | 27.7 | 33.1 | 39.2 | 46.5 | 55.5 | 67.0 | 83.2 | 110.9 |
| | 75 | --- | 0.0 | 2.8 | 5.7 | 8.9 | 12.4 | 16.2 | 20.4 | 25.1 | 30.5 | 36.7 | 43.9 | 52.9 | 64.4 | 80.6 | 108.3 |
| | 70 | --- | --- | 0.0 | 3.0 | 6.2 | 9.6 | 13.5 | 17.7 | 22.4 | 27.7 | 33.9 | 41.2 | 50.1 | 61.6 | 77.8 | 105.6 |
| | 65 | --- | --- | --- | 0.0 | 3.2 | 6.7 | 10.5 | 14.7 | 19.4 | 24.8 | 30.9 | 38.2 | 47.1 | 58.7 | 74.9 | 102.6 |
| | 60 | --- | --- | --- | --- | 0.0 | 3.5 | 7.3 | 11.5 | 16.2 | 21.6 | 27.7 | 35.0 | 43.9 | 55.5 | 71.7 | 99.4 |
| | 55 | --- | --- | --- | --- | --- | 0.0 | 3.8 | 8.0 | 12.7 | 18.1 | 24.2 | 31.5 | 40.5 | 52.0 | 68.2 | 95.9 |
| | 50 | --- | --- | --- | --- | --- | --- | 0.0 | 4.2 | 8.9 | 14.3 | 20.4 | 27.7 | 36.7 | 48.2 | 64.4 | 92.1 |
| | 45 | --- | --- | --- | --- | --- | --- | --- | 0.0 | 4.7 | 10.1 | 16.2 | 23.5 | 32.4 | 43.9 | 60.2 | 87.9 |
| | 40 | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 | 5.3 | 11.5 | 18.8 | 27.7 | 39.2 | 55.5 | 83.2 |
| | 35 | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 | 6.2 | 13.5 | 22.4 | 33.9 | 50.1 | 77.8 |
| | 30 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 | 7.3 | 16.2 | 27.7 | 43.9 | 71.7 |
| | 25 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 | 8.9 | 20.4 | 36.7 | 64.4 |
| | 20 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 | 11.5 | 27.7 | 55.5 |
| | 15 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 | 16.2 | 43.9 |
| | 10 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 | 27.7 |
| | 5 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0.0 |



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## Appendix for Chapter 4: Remanufacturing problem

### Proof of Lemma 4.1

Examining each of the demand functions, the first term in each demand function when the prices are all zero (i.e., market potentials) are positive if and only if,

$$\frac{\alpha_n+\alpha_n\beta-2\alpha_r\gamma}{(1+\beta)^2-4\gamma^2}>0 \text{ and } \frac{\alpha_r+\alpha_r\beta-2\alpha_n\gamma}{(1+\beta)^2-4\gamma^2}>0.$$

This occurs if and only if $\alpha_r(1+\beta)>2\alpha_n\gamma$. This gives the condition in Lemma 1 because the other conditions are implied.

The demands are decreasing in own price, and increasing in the rival product price if and only if,

$$\frac{(1+\beta-2\gamma^2)}{(1-\beta)((1+\beta)^2-4\gamma^2)}>0, \frac{(\beta+\beta^2-2\gamma^2)}{(1-\beta)((1+\beta)^2-4\gamma^2)}>0, \text{and } \frac{\gamma}{(1+\beta)^2-4\gamma^2}>0.$$

Simplifying these, we have the requirements

$$\beta+\beta^2-2\gamma^2>0, \alpha_n(1+\beta)-2\alpha_r\gamma>0, \text{and } 1+\beta-2\gamma>0.$$

The last inequality is always satisfied since $1>\beta>\gamma$. The first inequality is implied from the third. Finally, the middle inequality holds because $\alpha_n>\alpha_r$.

■

### Proof of Theorem 4.1

Because $1>\beta>\gamma$, we can show that $2(1+\beta)^3-8(1+\beta)\gamma^2\geq 0$. Furthermore, in $\pi(r,r)-\pi(n,n)=\frac{(2\gamma(\alpha_n-c_n)-(1+\beta)(\alpha_r-c_r))^2}{2(1+\beta)^3-8(1+\beta)\gamma^2}$, the numerator is a square and hence nonnegative. Thus, the entire expression is nonnegative. Moreover, $\pi(r,r)=\pi(n,n)$ if the numerator is zero, i.e., if $2\gamma(\alpha_n-c_n)=(1+\beta)(\alpha_r-c_r)$.

■



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**Proof of Theorem 4.2**

Firms are indifferent between adopting remanufacturing strategy and not adopting it iff $\pi(r,r)(\beta) - \pi(n,n)(\beta) = 0$. Therefore, we have,

$$0 = \left(\beta - \frac{-2c_r + 2\alpha_r + 3c_n\gamma - 3\alpha_n\gamma}{c_r - \alpha_r}\right)\frac{\alpha_r - c_r}{((2+\beta)^3 - 9(2+\beta)\gamma^2)^2}$$
$$\times \begin{bmatrix} (2+\beta)^2(2\beta - 5)\gamma(\alpha_n - c_n) + (2+\beta)^3(\alpha_r - c_r) \\ -3(2+\beta)(1+2\beta)\gamma^2(\alpha_r - c_r) + 27\gamma^3(\alpha_n - c_n) \end{bmatrix}.$$

The first term yields the root $\beta_1 = \frac{-2c_r+2\alpha_r+3c_n\gamma-3\alpha_n\gamma}{c_r-\alpha_r}$. The second term $\frac{\alpha_r-c_r}{((2+\beta)^3-9(2+\beta)\gamma^2)^2}$ is always positive. The third term yields all the other possible roots of $\beta$. Substituting root $\beta_1$ into the third term, we have,

$$\frac{54\gamma^3(\alpha_n-c_n)(\alpha_n-c_n+\alpha_r-c_r)}{(\alpha_r-c_r)^3}((\alpha_n - c_n) - (\alpha_r - c_r))(\gamma(\alpha_n - c_n) - (\alpha_r - c_r)).$$

The above term is positive if $\alpha_n - c_n < \alpha_r - c_r$ or $\gamma(\alpha_n - c_n) > \alpha_r - c_r$. Therefore, for $\beta < \beta_1$, firms will be better off, while for $\beta > \beta_1$ and $\beta$ not too large, firms will be worse off. By contrast, if we have $\gamma(\alpha_n - c_n) < \alpha_r - c_r < \alpha_n - c_n$ then for $\beta < \beta_1$, firms will be worse off, while for $\beta > \beta_1$ with $\beta$ not too large, firms will be better off.

■



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## REFERENCES

### References for Chapter 2: Hold-up problem


Barnes, A, 2012 Boeing: Faster, faster, faster: The planemaker struggles to fulfill a rush of orders. *The Economist* January 28, http://www.economist.com/node/21543555. Accessed 07/26/2013.

Berg, Joyce, John Dickhaut, and Kevin McCabe. 1995. Trust, Reciprocity and Social History. *Games and Economic Behavior* 10: 122–142.

Board, Simon. 2011. Relational Contracts and the Value of Loyalty. *American Economic Review* 101 ((December 2011)): 3349–3367.

Bolton, G.E., and A. Ockenfels. 2000. A theory of equity, reciprocity, and competition. *American Economics Review* 90 (1): 166–193.

Bolton, G.E., E. Katok, and A. Ockenfels. 2004. How effective are online reputation mechanisms? An experimental study. *Management Science* 50 (11): 1587–1602.

Bolton, G.E., E. Katok, and A. Ockenfels. 2005. Cooperation among strangers with limited information about reputation. *Journal of Public Economics* 89 (8): 1457–1468.

Camerer, Colin. 2003. *Behavioral Game Theory: Experiments in Strategic Interaction*. Princeton: Princeton University Press.

Coase, R. 2006. The Conduct of Economics: The Example of Fisher Body and General Motors. *Journal of Economics & Management Strategy* 15 (2): 255–278.

Cooper, D., and J. Kagel. 2015. Other Regarding Preferences: A Selective Survey of Experimental Results. Forthcoming. In *The Handbook of Experimental Economics 2*, eds. Kagel, J., and A. Roth. Princeton, NJ: Princeton University Press.

Crocker, K.J., and K.J. Reynolds. 1993. The Efficiency of Incomplete Contracts: An Empirical Analysis of Air Force Engine Procurement. *The RAND Journal of Economics* 24 (1): 126–146.

Cui, T.H., J.S. Raju, and Z.J. Zhang. 2007. Fairness and channel coordination. *Management Science* 53 (8): 1303–1314.

Cui, Tony Haitao, and Paola Mallucci. 2016. Fairness Ideals in Distribution Channels. *Journal of Marketing Research* 53 (6): 969–987.




المنارة للاستشارات
www.manaraa.com

Davis, Andrew and Stephen Leider (2013), Capacity Investment in Supply Chains Contracts and the Hold-up Problem, working paper.

De Bruyn, A., and G.E. Bolton. 2008. Estimating the influence of fairness on bargaining behavior. *Management Science* 54 (10): 1774–1791.

Dufwenberg, M., A. Smith, and M. Van Essen. 2013. Hold-up: with a Vengeance. *Economic Inquiry* 51: 896–908.

Duhigg C, Bradsher K (2012) How the U.S. Lost Out on iPhone Work. *The New York Times*, 1/21/2012. http://www.nytimes.com/2012/01/22/business/apple-america-and-a-squeezed-middle-class.html?pagewanted=all&_r=0. Accessed 06/09/2013.

Ellingsen, T., and M. Johannesson. 2004a. Promises, Threats and Fairness. *Economic Journal* 114: 397–420.

Ellingsen, Tore, and Magnus Johannesson. 2004b. Is There a Hold-up Problem? *Scandinavian Journal of Economics* 106 (3): 475–494.

Fehr, E., and K.M. Schmidt. 1999. A Theory of Fairness, Competition and Cooperation. *Quarterly Journal of Economics* 114 (3): 817–868.

Fischbacher, U. 2007. z-Tree: Zurich Toolbox for Ready-made Economic experiments. *Experimental Economics* 10 (2): 171–178.

Gantner A, W Güth, M Königstein. 1998. *Equity Anchoring in Simple Bargaining Games with Production*, Discussion paper 128, Department of Economics, Humboldt University

Greiner, B. 2004. An online recruitment system for economic experiments. In *Forschung und Wissenschaftliches Rechnen. GWDG Bericht 63,* ed. K. Kremer, V. Macho Göttingen: Gesellschaft für Wissenschaftliche Datenverarbeitung, 79-93.

Hackett, S.C. 1994. Is Relational Exchange Possible in the Absence of Reputations and Repeated Contact? *Journal of Law Economics and Organization* 10 (4): 360–389.

Hart O, E Fehr, C Zehnder 2013. Working paper. How Do Informal Agreements and Renegotiation Shape Contractual Reference Points?.

Haruvy, E., T. Li, and S. Sethi. 2012. Two-Stage Pricing for Custom-Made Products. *European Journal of Operational Research* 219 (2): 405–414.

Hoppe, E.I., and P.W. Schmitz. 2011. Can contracts solve the hold-up problem? Experimental evidence. *Games and Economic Behavior* 73 (1): 186–199.



المنارة للاستشارات
www.manaraa.com

Katok, E., and V. Pavlov. 2013. Fairness in supply chain contracts. *Journal of Operations Management* 31: 129–137.

Loch, C.H., and Y. Wu. 2008. Social preferences and supply chain performance: An experimental study. *Management Science* 54 (11): 1835–1849.

MacDonald, G., and M.D. Ryall. 2004. How do value creation and competition determine whether a firm appropriates value? *Management Science* 50 (10): 1319–1333.

McKelvey, R.D., and T.R. Palfrey. 1995. Quantal Response Equilibrium for Normal Form Games. *Games and Economic Behavior* 10: 6–38.

Nash, J. 1953. Two-person Cooperative Games. *Econometrica* 21: 128–140.

Oosterbeek, H., J. Sonnemans, and S. van Velzen. 1999. *Bargaining with Endogenous Pie Size and Disagreement Points: A Holdup Experiment*. Mimeo: University of Amsterdam.

Özer, O., K. Zheng, and K. Chen. 2011. Trust in Forecast Information Sharing. *Management Science* 57 (6): 1111–1137.

Özer O, K Zheng, Y Ren. 2013. Forecast Information Sharing in China and the U.S.: Country Effects in Trust and Trustworthiness, *Management Science* forthcoming.

Reilly S. 2012. Northrop Grumman sues USPS in bitter contract dispute. *Federal Times*, May 8. http://www.federaltimes.com/article/20120508/DEPARTMENTS02/205080307/Northrop-Grumman-sues-USPS-bitter-contract-dispute. Accessed 07/26/13.

Rogerson, W. 1992. Contractual Solutions to the Hold-Up Problem. *Review of Economic Studies* 59 (4): 774–794.

Schone, M. 2011. After Work Stopped on Jet Engine, GE Blasts Competitor Pratt Whitney, ABC News, 3/25. http://abcnews.go.com/Blotter/work-stopped-jet-engine-ge-blasts-competitor-pratt/story?id=13219559. Accessed 07/026/13.

Sonnemans, J., R. Sloof, and H. Oosterbeek. 2001. On the Relation between Asset Ownership and Specific Investments. *Economic Journal* 111 (474): 791–820.

Su, X. 2008. Bounded rationality in newsvendor models. *Manufacturing & Service Operations Management* 10 (4): 566–589.

von Siemens, F.A. 2009. Bargaining under incomplete information, fairness, and the hold-up problem. *Journal of Economic Behavior & Organization* 71 (2): 486–494.



المنارة للاستشارات
www.manaraa.com

## References for Chapter 3: Quality problem


Bendoly, Elliot, Karen Donohue, and Kenneth L. Schultz. "Behavior in operations management: Assessing recent findings and revisiting old assumptions." Journal of operations management 24, no. 6 (2006): 737-752.

Cadsby, Charles Bram, and Elizabeth Maynes. "Voluntary provision of threshold public goods with continuous contributions: experimental evidence." Journal of Public Economics 71, no. 1 (1999): 53-73.

Cappelen, Alexander W., Ulrik H. Nielsen, Bertil Tungodden, Jean-Robert Tyran, and Erik Wengström. "Fairness is intuitive." Experimental Economics 19, no. 4 (2016): 727-740.

Chen, Li, A. Gürhan Kök, and Jordan D. Tong. "The effect of payment schemes on inventory decisions: The role of mental accounting." Management Science 59, no. 2 (2013): 436-451.

Feiler, Daniel C., Jordan D. Tong, and Richard P. Larrick. "Biased judgment in censored environments." Management Science 59, no. 3 (2013): 573-591.

Bolton, Gary E., and Elena Katok. "Learning by doing in the newsvendor problem: A laboratory investigation of the role of experience and feedback." Manufacturing & Service Operations Management 10, no. 3 (2008): 519-538.

Chao, Gary H., Seyed MR Iravani, and R. Canan Savaskan. "Quality improvement incentives and product recall cost sharing contracts." Management Science 55, no. 7 (2009): 1122-1138.

Fischbacher, Urs. "z-Tree: Zurich toolbox for ready-made economic experiments." Experimental economics 10, no. 2 (2007): 171-178.

JD Power and Associates, “U.S. Initial Quality Study”, (2016), http://www.jdpower.com/cars/articles/jd-power-studies/2016-us-initial-quality-study-results

Huang, Lu, Jing-Sheng Song, and Jordan Tong. "Supply chain planning for random demand surges: Reactive capacity and safety stock." Manufacturing & Service Operations Management 18, no. 4 (2016): 509-524.

Tversky, Amos, and Daniel Kahneman. "The framing of decisions and the psychology of choice." Science 211, no. 4481 (1981): 453-458.

Kagel, John H., and Alvin E. Roth. "The Handbook of Experimental Economics, Volume 2." Economics Books 2 (2016).

Katok, Elena, and Valery Pavlov. "Fairness in supply chain contracts: A laboratory study." Journal of Operations Management 31, no. 3 (2013): 129-137.




المنارة للاستشارات
www.manaraa.com

Katok, Elena, and Diana Yan Wu. "Contracting in supply chains: A laboratory investigation." Management Science 55, no. 12 (2009): 1953-1968.

Liu, Fang, Jing-Sheng Song, and Jordan D. Tong. "Building supply chain resilience through virtual stockpile pooling." Production and Operations management 25, no. 10 (2016): 1745-1762.

McGinty, Matthew, and Garrett Milam. "Public goods provision by asymmetric agents: experimental evidence." Social Choice and Welfare 40, no. 4 (2013): 1159-1177.

Marks, Melanie, and Rachel Croson. "Alternative rebate rules in the provision of a threshold public good: An experimental investigation." Journal of public Economics 67, no. 2 (1998): 195-220.

Palfrey, Thomas, Howard Rosenthal, and Nilanjan Roy. "How cheap talk enhances efficiency in threshold public goods games." Games and Economic Behavior 101 (2017): 234-259.

Porteus, Evan L. "Investing in reduced setups in the EOQ model." Management Science 31, no. 8 (1985): 998-1010.

Porteus, Evan L. "Optimal lot sizing, process quality improvement and setup cost reduction." Operations research34, no. 1 (1986): 137-144.

Porteus, Evan L. "Note—The Impact of Inspection Delay on Process and Inspection Lot Sizing." Management Science 36, no. 8 (1990): 999-1007.

Rabin, Matthew. "Incorporating fairness into game theory and economics." The American economic review (1993): 1281-1302.

Sherefkin, Robert. "Ford's recall challenge." Automotive News62, no. 5985 (2002): 8-9.

Thaler, Richard. "Mental accounting and consumer choice." Marketing science 4, no. 3 (1985): 199-214.

Thaler, Richard H. "Mental accounting matters." Journal of Behavioral decision making 12, no. 3 (1999): 183-206.

Thaler, Richard H. "Mental accounting and consumer choice." Marketing Science 27, no. 1 (2008): 15-25.

Tong, Jordan, Daniel Feiler, and Anastasia Ivantsova. "Good choice, bad judgment: How choice under uncertainty generates overoptimism." Psychological science 29, no. 2 (2018): 254-265.

Tong, Jordan, and Daniel Feiler. "A behavioral model of forecasting: Naïve statistics on mental samples." Management Science 63, no. 11 (2016): 3609-3627.



المنارة للاستشارات
www.manaraa.com

Zhu, Kaijie, Rachel Q. Zhang, and Fugee Tsung. "Pushing quality improvement along supply chains." Management science 53, no. 3 (2007): 421-436.



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www.manaraa.com

## References for Chapter 4: Remanufacturing problem


Atasu, Atalay, Daniel Guide, and Luk N. Van Wassenhove. 2010. “So what if Remanufacturing Cannibalizes my New Product Sales?” *California Management Review* 52(2): 56–76.

Atasu, Atalay, Miklos Sarvary, and Luk N. Van Wassenhove. 2008. “Remanufacturing as a Marketing Strategy.” *Management Science* 54(10): 1731–1746.

Chen, Jen-Ming, and Chia-I Chang. 2013. “Dynamic Pricing for New and Remanufactured Products in a Closed-Loop Supply Chain.” International Journal of Production Economics 146: 153–160.

Debo, Laurens G., L. Beril Toktay, and Luk N. Van Wassenhove. 2005. “Market Segmentation and Product Technology Selection for Remanufacturable Products.” Management Science 51(8): 1193–1205.

Govindan, Kannan, Hamed Soleimani, and Devika Kannan. 2015. “Reverse Logistics and Closed-Loop Supply Chain: A Comprehensive Review to Explore the Future.” European Journal of Operations Research 240: 603–626.

Ferguson, Mark E., and L. Beril Toktay. 2006. “The Effect of Competition on Recovery Strategies.” Production and Operations Management 15(3): 351–368.

Kleindorfer, Paul R., Kalyan Singhal, and Luk N. Van Wassenhove. 2005. “Sustainable Operations Management.” Production and Operations Management 14(4): 482–492.

Örsdemir, Adem, Eda Kemahlıoğlu- Ziya, and Ali K. Parlaktürk. 2014. “Competitive Quality Choice and Remanufacturing.” Production and Operations Management 23(1): 48–64.

Savaskan, R. Canan, Shantanu Bhattacharya, and Luk N. Van Wassenhove. 2004. “Closed-Loop Supply Chain Models with Product Remanufacturing.” Management Science 50(2):239–252.

Singh, Nirvikar, and Xavier Vives. 1984. “Price and Quantity Competition in a Differentiated Duopoly.” RAND Journal of Economics 15(4): 546–554.

Su, Xuanming. 2009. “Consumer Returns Policies and Supply Chain Performance.” Manufacturing & Service Operations Management 11(4): 595–612.

Sultan, Arif. 2010. “Lemons and Certified Pre-owned Cars in the Used Car Market.” Applied Economics Letters 17(1): 45–50.

van den Heuvel, Wilco, and Albert P.M. Wagelmans. 2008. “Four Equivalent Lot-Sizing Models.” Operations Research Letters 36(4): 465–470.




المنارة للاستشارات
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Zhang, Pan, Yu Xiong, Zhongkai Xiong, and Wei Yan. 2014. "Designing Contracts for a Closed-Loop Supply Chain under Information Asymmetry." Operations Research Letters 42(2): 150–155.



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## BIOGRAPHICAL SKETCH

Zhongwen Ma, also known as Owen, with an ambition on applying behavioral economics to real estate innovation and hedge fund innovation, graduated from UT Dallas in 2019, with a PhD in Management Science and a concentration in Operations Management.

He has an educational background in multiple domains, including mechanical engineering, industrial engineering, supply chain management, statistics, as well as computer science. While each of the domains is different by nature, his interdisciplinary educational background is the cornerstone to his successful practice in real estate innovation, as well as his career.

He is currently a data scientist at Verizon Wireless, has contributed to highly visible projects, and has received recognitions multiple times.



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**CURRICULUM VITAE**

# Owen (Zhongwen) Ma

## Summary

- A Data Scientist at Verizon with a focus on Supply Chain Management
- Having been utilizing skills in statistics and econometrics, predictive modeling, decision and optimization (prescriptive) modeling, and data management in depth for 5 years, plus another 5-year engineering background

## Education

**Ph.D. in Management Science, Operations Management Concentration** **May 2019**
**M.S. in Statistics** **Straight-A's in 11 courses; December 2015**
**M.S. in Supply Chain Management** **August 2014**
University of Texas at Dallas, Richardson, TX

- Sponsored by Research Assistantship and Teaching Assistantship

**M.S. in Computer Science, Machine Learning Concentration** **December 2019, expected**
Georgia Institute of Technology, Atlanta, GA
**B.S. in Mechanical Engineering** **July 2007**
Shanghai Jiao Tong University, Shanghai, China

- Honored *Excellent Graduate* by Shanghai Municipal Government; ranked No. 1 in the Overall Evaluation

## Working Experience

**Data Scientist at Verizon** **Oct. 2016-Present**

- Led various projects that optimize operations with revenue $1 billion or more, including sentimental analysis on consumer remarks, reverse supply chain revenue prediction, and prescriptive analysis on FiOS customer support dispatch, using statistical models and machine learning algorithms in various statistical programming environments (e.g. R, Python, Java)
- Investigated extensively data pre-processing methodologies and designed effective and efficient pre-processing strategies with multiple algorithms combined
- Implemented, evaluated and improved predictive analysis with statistical models and machine learning algorithms such as random forest, deep learning, support vector machine, decision tree, as well as generalized linear regression
- Communicated with upper-level managers and executives to present model results, illustrate hidden insights, and suggest innovative new directions

**Business Analyst at HealthSmart** **June 2015-Oct. 2016**

- Conducted data and analytically intensive tasks necessary to generate campaign findings, analytic insights and recommendations to improve the performance of marketing campaigns and sales strategies
- Developed analytic insights and recommendations utilizing data manipulation and data analysis techniques such as time series modeling and VBA programming
- Programed sophisticated and error-proof SQL queries on large data tables to produce daily actionable reports, build SQL library and facilitate database consolidation
- Collaborated closely with colleagues and communicated effectively with upper-level managers across departments to facilitate cross-department coordination, new campaign support and new product analytics

**Researcher at the University of Texas at Dallas** **September 2009- August 2014**

- Focused primarily on fraud detection, risk management, efficiency optimization and mechanism design, with an emphasis on mathematical optimization and statistical modeling, plus business model innovation and illustration
- Defined research questions to evaluate and coordinate irrational but predictable human behavior under various business settings, including investment, manufacturing as well as service
- Conducted comprehensive research including optimization modeling, experimental design, data collecting



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as well as statistical modeling using SAS

- Improved systematical performance by an amount ranging from 3.64% to 5.63% with innovative contracts that reduce chances of fraud; developed an innovative and effective forecasting model based on nested logistic model, to better capture behavioral regularities
- Presented research achievements in multiple international conferences in America or abroad

## Skills and Leadership

**Computer Skills**

**Office**: MS Word/ Excel/ Access/ PowerPoint
**Languages**: Python/ SQL
**Statistics**: R/ SAS/ GAUSS
**Mathematics**: Matlab/ Mathematica/ CPLEX

**Certificates**

- SAS Certificated Programmer for SAS 9 (January, 2016)

**Management and Communication** **October 2011-August 2014**

- Lab Manager of Laboratory for Behavioral Operations and Economics at UT Dallas, with 21 people affiliated
- Instructed one MBA course, and assisted various statistics and management courses



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