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ESSAYS ON SUPPLY CHAIN COORDINATION

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by

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ABSTRACT

A supply chain, which typically employs decentralized decision-making, is coordinated if in the equilibrium firms make decisions that are system-wide optimal. Such decisions, called the first-best, would be made if the supply chain were centralized so that a single decision-maker could force all firms to take recommended actions. Under decentralized decision-making, in order to implement first-best one needs to impose a proper structure of incentives. Supply chain literature, building upon developments in mechanism design, proposes various coordination schemes in the applied business contexts. However, the empirical evidence, coming both from the real world and laboratory experiments, confronts many theoretical predictions. In particular, theoretically optimal contracts are notably more complex than those used in the real world. More importantly, in laboratory experiments the theoretically optimal contracts not just fail to coordinate but, ironically, perform very close to the Double Marginalization benchmark. Thus, legitimate concerns regarding ability of the proposed schemes to coordinate in applied contexts arise. This dissertation focuses on some of the factors leading to coordination failures and investigates their impact on the performance of a supply chain.

Chapter 1 analyzes a scenario when externalities, created by the third parties, force supply chain partners to use contracts contingent on revealed information. Most of the supply chain literature on coordination deals with perfect information models. The assumption of perfect information is usually justified by instances of information sharing, observed in practice. Researchers conjecture that information sharing ensures perfect information. However, there exists empirical evidence that even under the ultimate form of information sharing, when parties implement "open book accounting", revealed information may not be true. Unfortunately, there is always a possibility to misrepresent information. Notably,

under perfect information sharing supply chain partners are likely to find themselves in a situation when they essentially have no choice other than to use a contract that delivers first-best provided that "open books" contain truth. The model of this chapter analyzes performance of a supplier-buyer supply chain under the assumption that questioning each other's reports is prohibitively costly, while parties are aware of possible misrepresentation. Therefore, no matter who offers a contract, it cannot be a screening contract or anything else except a contingent contract that delivers "first-best", given revealed information. The outcome of the arising Bayesian game is distribution-specific, and can be very different from the conjectured performance of a "coordinating" contract.

Chapter 2 addresses a gap between performance of the contracts suggested by the standard theory, which assumes fully rational profit-maximizing players, and existing data, obtained in the experimental tests of coordinating contracts. Numerous experimental studies find that human decision-makers are neither perfectly rational nor profit-maximizers. While various behavioral factors, such as risk- and loss-aversion, counter-factual payoffs and more general social preferences can greatly affect contracting outcomes, they cannot fully explain the existing data. In the controlled laboratory environment, it is possible to either completely eliminate some of these factors, or, at least, to significantly mitigate and control for them. What is not possible to eliminate, is the players' attitude to contracting outcomes, most commonly called "fairness concerns". The existing models, incorporating fairness concerns into models, assume fairness concerns of players is common knowledge. Realistically, how much a particular person cares about fairness cannot be easily observed or measured and, in fact, is not known to anybody else except that person. In other words, fairness concerns are private information. Therefore, the model presented here takes the next step and treats fairness concerns as private information of players. Given the resulting information asymmetry, it is not surprising that coordination of a dyadic channel with a contract is, in general, no longer possible. At the same time, is possible to coordinate a channel with just a wholesale price contract in case the retailer is sufficiently averse to making higher profit than the supplier. However, we show that when the contract choice is endogenous, the supplier will not choose a wholesale price contract but, instead, a profit-maximizing contract that does not coordinate. The results of the experiment that tests the model's predictions, as well as some underlying assumptions and competing theories, provide strong support for the theory and show that fairness organizes the data very well.

Chapter 3 presents a simple and, in many respects, robust coordination mechanism. Its performance approaches first-best asymptotically in a setting with one supplier and multiple retailers. By introducing horizontal (Bertrand) competition among the retailers the supplier not only induces retailers to make first-best decisions, but also does it by means of the simplest possible linear pricing scheme. Competition does the entire coordinating job, whereas a wholesale price contract suffices to extract all profit of the competing retailers. Although Bertrand competition is not a new concept, little has been known about its actual performance in the contacting context. It turns out that a competition-based mechanism is not only extremely simple, but it is also robust to several relaxations of the standard assumptions, any of which is enough destroy a coordinating contract. First, it survives certain types of information asymmetry. In the extreme example of private information used in this chapter, the mechanism coordinates the channel even if the supplier is not aware of the very fact of private information. Second, Chapter 2 shows how fairness concerns generally make coordination of a dyadic channel impossible. However, for the competition-based mechanism fairness concerns is not an obstacle. Turning to the methodological aspects, we would like to note that the mainstream literature suggests coordinating contracts resulting from models that assume the supplier's ability to make a "take-it-or-leave-it" offer. Credibility of such models has been long debated in the literature. Critics insist that the "take-it-or-leave-it" offer is either not a credible threat in the bilateral monopoly or it is a shortcut, implicitly implying perfect competition on the retailers' side. Allowing for competition explicitly not only avoids this criticism but also brings fuller insights, non-available otherwise.

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Chapter-specific notation is fully introduced in the corresponding chapters. Most of the notation, used throughout the dissertation, follows common conventions:

p	market price
q	order quantity
$E[X]$	expectation of a random variable X
$Var[X]$	variance of a random variable X
$\frac{df}{dx}$	a derivative of function f with respect to x
$\frac{\partial f}{\partial x}$	a partial derivative of function f with respect to x

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PREFACE

The material presented in Chapter "Competition and Contracting in Supply Chains" constitutes a part of the joint project with my advisor, Dr. Elena Katok and Dr. Engelbrecht-Wiggans (University of Illinois at Urbana Champain)

The material presented in Chapter "Fairness and coordination failures in supply chain contracts" constitutes a part of the joint project with my advisor, Dr. Elena Katok.

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DEDICATION

to my family

Chapter 1

Contingent contracts

1.1 Introduction

One of the main results, coming from the literature on contracting under information asymmetry, is ex-post inefficiency of the outcomes. An uninformed party, offering a contract to its privately informed supply chain partner, can neither coordinate the channel nor extract information rents. However, in business environments private information is not absolute. Production cost of a company, as opposed to some inherent characteristic of an individual, can be (rather precisely) inferred from the environment (the existing technology, market prices for labor, raw materials, etc.). Therefore, if costs to process information are low, the uninformed party having all the bargaining power may well require information sharing in order to eliminate information asymmetry. However, this may be not an obvious choice. First, there is no absolute guarantee that information asymmetry will be eliminated. Second, bilateral monopolies rarely (if ever) operate in isolation. They are commonly thought of as building blocks, but most studies are silent about a building these blocks belong to. In the light of some available empirical evidence, the very fact of employing information sharing can make a difference. For various reasons parties may then be forced to use contracts, contingent on the shared information. Intuitively, with information sharing in place, parties are expected to make well-informed, optimal decisions.

At the same time, it is widely acknowledged in the business world that it is possible to misrepresent almost any information. We consider the environment where parties are not only using contingent contracts but also have a possibility to misrepresent information they share. Such environments may arise in various contexts. We do not address questions how those environments exactly look like, how they arise or why. Formally, to operationalize the fact that information sharing and information misrepresentation may coexist, we introduce a third party, a higher hierarchy with a pecuniary interest in the supply chain profit. This third party has access to the shared information and mistakenly believes it has superior technology to verify whether the shared information is shared truthfully or not. In fact, as long as both firms act consistently with the shared information, the technology cannot detect if there was any misrepresentation at all. Otherwise, if the parties' decisions are not consistent with the shared information, i.e., they do not seem rational, this third party concludes that misrepresentation takes place, steps in, investigates and severely punishes one of the firms. However, since its verification technology is not perfect, its decision who should be punished is essentially random. This creates incentives for both firms to cover up misrepresentation, no matter whether only one party misrepresents information or both.

This third party, a supervisory authority, should not be understood literally or necessarily identified with a tax-collecting agency, or headquarters of a corporation, or a company's CEO. It is rather some general feature of the environment. In a business community, for example, a refusal to sign a contingent contract or a deviation from it is likely to be considered mistrust and, even if mutual accusations of fraud do not follow, may have detrimental effects on reputation. One can find examples of such environments in various contexts. Analyzing one of them, Ford & Sterman (2003) described it as "Liar's club": "Everyone in the liar's club knew that everyone was concealing rework requirements ...". One can hypothesize that this feature can be a part of an equilibrium of some repeated meta-game. For us, this assumption is just a short way to incorporate a part of empirical evidence that information sharing and misrepresentation may well go together.

The model of this chapter analyzes performance of contracts contingent on shared information. Our analysis covers both cases: when information sharing eliminates incomplete information and when it does not. Although one might expect that coordination may be problematic in this environment, our model identifies the existing issues formally. In particular, it predicts that even under complete information the channel performance will not improve over the Double Marginalization benchmark.

The rest of this Chapter is organized as follows. Section 1.2 presents a review of relevant literature. Section 1.3 develops a model of channel coordination when parties are forced to use contingent contracts. Section 1.4 summarizes the paper, offers directions for future research, and discusses managerial implications of this work.

1.2 Literature review

Although this study is dealing with the issues associated with information sharing, we do not provide a full review of supply chain literature on information sharing. First, because this study builds on a broader set of literature. Second, because there exist excellent reviews of that literature, such as, for example, Chen (2003). Here, we only mention some representative studies that help describe the field and position this study. For the same reason, we do not aim to provide full reviews of economics literature on information asymmetry or implementation. Our review embraces only a very small subset of papers that are directly related and essential for this study.

Historically, supply chain literature on information sharing has been developing in several directions. One stream of research analyzes the value of information by taking a perspective of the central planner. By their nature, system-wide optimal decisions rely on all relevant information. At the same time, firms in a supply chain may have relatively little knowledge of anything that is beyond their scope of responsibility. For example, suppliers typically do not know as much about demand as retailers do. Lacking exact information about demand, suppliers are unlikely to make globally optimal decisions. Thus, from the supply chain (or the central planner) perspective, it is necessary to make this information available to the suppliers. Gavirneni et al. (1999) study how information flow affects a serial supplier-retailer supply chain in the multi-period setting. The retailer is facing stochastic *iid* demand and implements an (s, S) inventory replenishment policy. The supplier can fulfill the retailer's order using only available inventory on hand. Production takes one period and is subject to a capacity constraint. The authors show that when the only information available to the supplier is the retailer's order, the resulting supply chain performance is suboptimal. In this setting, the quality of the supplier's decisions crucially depends on the information available. Even sharing the information only about the demand distribution and parameters of the (s, S) policy greatly improves supply chain performance. In numerical examples, the authors compute the value of information about the parameters of retailer's replenishment policy, demand distribution and sales data, and find improvements up to 90%. However, optimality of the supplier's decisions requires knowing all information available to the retailer, including sales. Lee et al. (2000), analyzing a similar model but with auto-correlated demand, also find that it is not possible for the supplier to make system-wide optimal decisions, unless the retailer provides complete information including realized demand. Aviv (2001) studies a channel under the assumption that firms share a common objective to maximize performance of the supply chain as a whole. Even in this purest setting, when all incentive issues are assumed away, optimal replenishment decisions are only possible if the retailer fully shares the demand forecast with the supplier. The main criticism of these analyses it that they assume that all relevant information is readily available to the central planner, thus ignoring information asymmetries.

Another stream of research focuses on implications of information asymmetry. A version of a screening or a signaling model, vastly studied in the economics literature, is standard here. Speaking of screening contracts, the classic pieces of the economics literature on contracting under information asymmetry (ex. Stiglitz (1975), Baron & Myerson (1982)) suggest two main insights. An uninformed party can neither ensure ex-post efficiency nor extract information rents from the privately informed party. Building on this literature, Ha (2001) derives the optimal screening contract in the Newsvendor setting, which proves to be rather complex,. As a side note, well-performing contracts do not have to be very complex. Corbett et al. (2004) assess the value of contract complexity under information asymmetry and their numerical experiments show that the optimal contracts provide only marginal improvement over much simpler two-part linear ones. One limitation of the screening models is that they assume away a possibility for voluntary information transmission by the informed party. Spence (1973) was the first to show that private information can be credibly communicated by means of a costly signal. Crawford & Sobel (1982) show that strategic information can be credibly transmitted, even if a costly signal is not available. In supply chain literature, Cachon & Lariviere (1999) consider a one-period model with one capacitated supplier and multiple retailers. They obtain a somewhat counterintuitive result: for the supply chain as a whole, truth-telling mechanisms employed by the supplier, may result in lower profits than those that allow order inflation. Next, looking at the signaling problem from another perspective, Cachon & Lariviere (2001) study how a privately informed downstream party can credibly communicate demand forecasts to the upstream party in order to ensure that optimal capacity will be built. They find that many popular contracts, as long as they impose a firm commitment on the informed party, can perfectly serve this purpose. As a general rule, the information asymmetry literature does not consider a possibility of contingent contracts. Hart (1988) argues that unverifiable information cannot be contracted upon. As a rare exception, Gal-Or (1991) studies a model in which contractible variables are contingent on the demand report that the informed retailer sends at the communication stage. She finds that despite information asymmetry, truthful reporting is possible, and parties may achieve ex-post efficient outcomes under retail price maintenance.

The aforementioned literatures assume that private information cannot be learned by any means unless the informed party truthfully communicates it, or, possibly, reveals it via decisions. However, in the business context private information is not always absolutely private. Thus, in principle, production cost can be inferred (rather precisely) from the technology employed, labor cost, market prices for raw materials, etc. Even if it is not possible (or too costly) to learn it precisely, obtaining an informative signal should not be an impossible task. Cremer & McLean (1985) show that having a signal, however slightly correlated with the other party's private information, may be enough to achieve ex-post efficiency and extract all the other party's surplus. Therefore, the uninformed party, which is typically assumed to have all bargaining power, might want to fully exercise its power and insist on employing some kind of information sharing before offering any specific contract. It is, therefore, not surprising to see that supply chain partners sharing not just information about their inventories, or parameters of the replenishment policies, or point-of-sales data, or even costs, but much more. Hoffjan & Kruse (2006) provide an overview of supply chain practices in "open book accounting". This is the case when supply chain partners provide each other with access to the most sensitive information, the accounting books. Of course, some information, such as a subjective demand forecast for a new product, may still remain private, but as far one is concerned with decisions that require knowing cost or sales, accounting books are the ultimate source to base optimal decisions. And, indeed, Hoffjan and Kruse note (ibid, pp.43, 44): "...In a bilateral dependency, open book accounting is more frequently used to foster optimization". Thus, the existing practice seems to provide support to the paradigm of the central planner having access to all existing information so that all optimal decisions are hard-wired to the information coming from the accounting books. Apart from operational decisions, making payments based on the reported costs is a standard and a multi-billion practice of the US government (see Hofbauer & Sanders (2008)).

At the same time, there also exists empirical evidence about a number of ways to misrepresent payoff- or cost-relevant information even in the accounting books. See, for example, Crocker & Slemrod (2007) and references therein. Such ways vary from legal ones, as in case with Hollywood studios (Weinstein (1998) and references therein), to direct accounting fraud (ex. Enron). PricewaterhouseCoopers (2007) global economic crime survey suggests that such practices may be a rule rather than an exception. Specifically, about 50% of participating companies self-reported internal fraud and the researchers conclude that "the crime of fraud remains intractable". Most surprisingly, perhaps, the companies, being fully aware of fraud, either do not want or cannot get rid of it.

The model we analyze most closely relates to the framework used in Tirole (1986), Laffont & Martimort (1997) and follow-up literature on collusion in hierarchies (see Mookherjee (2006) for a review). However, this literature focuses on the case in which the top level in a hierarchy holds correct although imprecise beliefs. Our model presents a complementary situation, when a higher hierarchy holds precise but incorrect beliefs. We do not allow for a possibility of direct collusion. Nevertheless, in our case some kind of tacit collusion arises in the equilibrium. Regarding the bargaining literature, our problem can be seen as a generalization of the double auction problem studied by Chatterjee & Samuelson (1983).

1.3 The model

1.3.1 Operating environment

We consider a serial supplier-retailer supply chain operating in a Newsvendor environment. A reader, not familiar with it, may find its complete specification in external sources, such as, for example Cachon (2003), but this is not required. All details necessary for our model are given below. The retailer faces a market in which the revenue (or expected sales) function, $U(.)$, is a concave function of the quantity q delivered to the market. The retailer's per unit cost to handle the product is r. There is neither goodwill loss nor salvage opportunity. The supplier delivers (or manufactures) a product at a constant per unit cost s. Although we focus on the Newsvendor environment, this is purely for expositional convenience. The model readily generalizes to encompass more general demand structures including an important case of downward sloping demand. As far as it concerns the supply chain partners, all other assumptions are also standard. Both the supplier and the retailer are perfectly rational expected profit-maximizers; all agreements are enforceable and reservation levels are normalized to zero. In the case when costs are private information, parties know their distributions.

Our model extends this classic bilateral monopoly by adding a third party having a pecuniary interest in the supply chain profit. This third party has almost absolute power with respect to the parties of our bilateral monopoly. It is ignorant of the parties' cost but erroneously assumes they are verifiable. In fact, its verification technology can only detect a discrepancy between the reported costs and the parties' decisions. If this happens, the corporation steps in and one of the firms gets severely punished. Since the technology is unable to establish the truth, the choice of a "guilty" firm is essentially random. Notice, there is nothing naive in what the third does. All its actions are perfectly rational. It is only its wrong belief that leads to *de facto* suboptimal decisions. An immediate implication for the supply chain partners is that this policy of the third party *forces* them to sign contracts *contingent* on the reported costs. Moreover, they are forced to sign contracts that the corporation perceives *first-best*. Otherwise, if the corporation observes that a contract does not deliver "first-best" (given the reported costs), random punishment follows. Therefore, both firms optimally choose to pretend the reported costs are true no matter whether they report truthfully or not.

As we argued there is no absolute guarantee that information sharing will ensure complete information. Therefore, in what follows, we analyze a model of contracting both under complete and incomplete information.

1.3.2 Sequence of events

1. The corporation allows the supply chain to start operating provided that it takes some fraction α of the supply chain profit.

2. Parties employ information sharing that may or may not result in complete information (we consider both cases).

3. The supply chain partners negotiate how to split the *apparent* (see Definition 1) profit of the supply chain, net the fraction α that goes to the corporation. As the result, they agree to split the remaining part according to fractions λ and $(1 - \lambda)$. These fractions can be seen as representing the parties' bargaining powers.

4. Supply chain partners sign a contingent contract (see Definition 2)

5. Supply chain partners learn their costs, s and r.

6. Parties announce costs, s' and r', not necessarily truthfully. The contract is fulfilled and profits accrue.

1.3.3 Notation and technical assumptions

$p > 0$ – competitive market price.

r – retailer's true transaction cost per ordered unit: $r \in [r_0, r_1] : r_0 \geq 0, r_1 = p$. $R(x) \equiv \Pr(r \leq x)$ - distribution of r.

r' – retailer's announced transaction cost per ordered unit, $r' \in [r_0, r_1]$

s – supplier's true production cost per unit: $s \in [s_0, s_1] : s_0 \geq 0, s_1 = p$. $S(x) \equiv \Pr(s \leq x)$ - distribution of s.

s' – supplier's announced production cost per unit, $s' \in [s_0, s_1]$

$r_0 + s_0 < p$

w – supplier's wholesale price.

q – retailer's order quantity.

t – transfer sum between parties.

D – random demand realization.

$F(.)$ – cumulative distribution function (cdf) and $f(.)-$ probability density function (pdf) of demand. Following the literature, I assume that the distribution is of the Increasing Generalized Failure Rate (IGFR) type, that is $\frac{d}{dq}\left(\frac{qf(q)}{1-F(q)}\right) > 0$. For example, normal, exponential and uniform. By assumption, $F(.)$ is differentiable.

$\overline{F}(q) = 1 - F(q)$ – tail function.

$U(q)$ – expected sales given order quantity q.

λ – the retailer's share of the total supply chain profit.

π – ex post profit

Π – expected (interim) profit

Subscripts

Single capital letters, such as C, R and S reflect the fact that the corresponding value belongs to the channel, to the retailer or to the supplier, respectively.

Small letters, ex. r or s, serve to denote partial derivatives with respect to r or s, respectively. We assume that all functions are sufficiently smooth, unless otherwise stated. At the end-points of the intervals at least one-sided derivatives exist.

Superscripts

In superscripts, we always use two-letter notations, such as FI, AI, etc. These abbreviations stand for particular environments. For example, $\pi_R^{FI}(.)$ stands for the retailer's ex-post profit under the full (complete) information.

Parties' profits

Given the order quantity, q, the transfer, t, costs r and s, the retailer's profit is

$$\pi_R = pU(q) - qr - t,$$

and the supplier's profit is

$$\pi_S = t - qs.$$

Miscellaneous

For brevity, and only when it should not create any confusion, the supplier is referred to as *he* and the retailer as *she*.

Many expressions that appear in the paper are defined only for those values of parameters and decision variables when trade takes place. Domain specifications are, nevertheless, straightforward and are omitted. For example, evaluating $\Pi_R^{FI}(r)$ at some $r > p$ is inappropriate. The resulting number is meaningless since at $r > p$ there will be no trade in the first place.

LHS and RHS stand for left- and right-hand-side, respectively.

1.3.4 Basic results of the standard theory: bilateral monopoly

Our model builds on the results of the standard theory, and, therefore, we provide some of them below as a short review and also to be used as reference points later on.

First-best

When a single decision-maker runs the whole supply chain there is only one decision to be made, namely the order quantity. If $r + s > p$, the optimal order quantity is zero. In the opposite case, it solves

$$\max_q \pi_C(q) = pU(q) - q(r+s),$$

and, since in the Newsvendor case $U(q) = q - \int_0^q F(x)dx$, the first-best order quantity is defined by the first-order condition:

$$p\overline{F}(q^{FB}) = r + s. \tag{1.1}$$

The second-order condition for such q^* to be a maximizer is also satisfied since $\frac{d^2}{dq^2}\pi_C(q) = -f(q) < 0$, $\forall q$.

Complete information: Double Marginalization

A classic case of Double Marginalization arises if the supplier uses a wholesale price contract. The supplier moves first and proposes a uniform price per unit. The retailer decides on the number of units to buy from the supplier. The subgame-perfect equilibrium of this game can be found by backward induction. The logic of the retailer's best-response is the same as in (1.1), only w replaces s :

$$p\overline{F}(q) = r + w. \tag{1.2}$$

As the result, the supplier's optimal offer induces an order quantity specified by the following condition:

$$p\overline{F}(q^{DM}) - r - s - pq^{DM}f(q^{DM}) = 0. \tag{1.3}$$

This can be rewritten as

$$p\overline{F}(q^{DM})\left[1 - \frac{q^{DM}f(q^{DM})}{\overline{F}(q^{DM})}\right] = r + s. \tag{1.4}$$

Notice that since the LHS of (1.4) decreases faster than the LHS of (1.1), then $q^{DM} < q^{FB}$. That is, the wholesale contract is not efficient.

Complete information: Channel coordination

A complete-information coordinating contract can be constructed in a number of ways. In the simplest possible contract the supplier makes an offer that has only one possible choice of the order quantity: q^{FB}. Any such contract meeting the retailer's reservation level will be efficient. The supply chain literature also proposes many differentiable contracts (see Cachon (2003)). However, they all (with almost no exception) are equivalent to a mechanism that transforms the parties' profits to

$$\begin{aligned} \pi_R = & \quad \lambda\pi_C = & \lambda[pU(q) - (r+s)q], \\ \pi_S = & \quad (1-\lambda)\pi_C = & (1-\lambda)[pU(q) - (r+s)q], \end{aligned} \tag{1.5}$$

where λ is a constant between 0 and 1.

Here, since the retailer's profit equals the channel profit scaled by a constant factor, λ, the optimal order will be first-best.

Incomplete information: a wholesale price contract

For the same reasons we reviewed a wholesale price contract under complete information, it is worthy to analyze it when information is incomplete. Here, again the supplier offers a fixed price per unit, w, and the retailer responds with the order quantity satisfying (1.2). Since, by assumption, the supplier knows only the distribution of the retailer's cost, $R(r)$, with the support $[r_0, r_1]$, he faces the following maximization problem:

$$\max_{w} \int_{r\in[r_0,r_1]:r+w\leq p} q(r,w)(w-s)dR(r), \tag{1.6}$$

where q is given by (1.2).

We postpone the discussion the properties of (1.6) because it turns out to be equivalent to a special case of the contingent contract analyzed below.

Incomplete information: an optimal contract

From a normative perspective, the most appropriate benchmark is an optimal contract. While, by definition, any optimal contract will outperform any other contract (unless, by occasion, the other contract proves optimal itself), the question of practical importance is by how much. However, this is context-dependent. To make comparisons meaningful, we use an optimal contract designed for the same environment that we use to evaluate performance of both the wholesale price and contingent contracts. See section (1.3.6) for more detail.

1.3.5 Contingent contract

In the above example of bilateral monopoly both the wholesale and coordinating contracts are contingent on the information. The supplier designs a contract based on information. If the retailer tried to claim her cost is different from the true cost, the supplier would just ignore it. In our case, reported costs should be treated as true (to some extent) even if they are not. What we call a contingent contract is a contract contingent on announcements.

Definition 1 *The "apparent" profit of the supply chain is*

$$\pi_C^A = pU(q) - (r' + s')q,$$

where r' and s' are reported costs.

Definition 2 *A contingent contract (CC) is one contingent on the announced costs, s' and r', in the following way. The order quantity is*

$$q(r', s') \equiv q^{CC}(r', s') : \begin{cases} p\bar{F}(q^{CC}) = r' + s' & \textit{if} \quad r' + s' \le p \\ q^{CC} = 0 & \textit{otherwise}, \end{cases} \tag{1.7}$$

The transfer is chosen such that

$$\begin{array}{rr} \pi_R^A = & \lambda\pi_C^A \\ \pi_S^A = & (1-\lambda)\pi_C^A \end{array}.$$

Therefore, parties' factual profits are

$$\pi_R(r', s', r) = \lambda[pU(q(r', s')) - (r' + s')q(r', s')] + (r' - r)q(r', s') \tag{1.8}$$

$$\pi_S(r', s', s) = (1-\lambda)[pU(q(r', s')) - (r' + s')q(r', s')] + (s' - s)q(r', s') \tag{1.9}$$

where the last terms in both expressions can be interpreted as information rents.

In words, an outside observer, who believes that r' and s' as true costs, notices that parties act in perfect accord with the standard complete information theory: they use some kind of coordinating contract that induces "first-best", and parties split the channel profit according to λ. In fact, parties split not the actual but the *apparent* profit according to λ, and each party appropriates some information rents.

Information asymmetry

Under incomplete information, each party reports its cost without knowing the cost of the other party but knowing only the distribution. At this stage it is appropriate to work with the parties' interim profits:

$$\begin{array}{c} \Pi_R(r', r) = \int_{s_0}^{s_1} \pi_R(r', s'(s))dS(s) \\ \Pi_S(s', s) = \int_{r_0}^{r_1} \pi_S(r'(r), s')dR(r). \end{array} \tag{1.10}$$

where π_R and π_S are given by (1.8) and (1.9)

The equilibrium Thus, parties are involved in the simultaneous-move game of incomplete information. A Bayesian Nash equilibrium of this game (assuming it exists), is given by

$$r^*(r) = \arg\max_{r'} \int_{s_0}^{s_1} \pi_R(r', s^*(s))dS(s)$$
$$s^*(s) = \arg\max_{s'} \int_{r_0}^{r_1} \pi_S(r^*(r), s')dR(r).$$

Thereafter, $r^*(r)$ and $s^*(s)$ are the equilibrium announced costs for the retailer and the supplier. It is possible to prove several general properties of the equilibrium.

Proposition 1 *In equilibrium, the supplier strictly overstates cost unless* $\lambda = 0$*. In the latter case, truth-telling becomes a unique dominant strategy. A similar statement is true about the retailer, only with* $\lambda = 1$.

Proof. Differentiation of (1.9) w.r.t. s' and using (1.7) gives the suppliers' first-order optimality condition:

$$\int_{r_0}^{r_1} \left(\lambda q(r', s^*) + (s^* - s) q_s(r', s^*)\right) dR(r) = 0. \tag{1.11}$$

Since, from (1.7), $q_s(.)$ is negative, (1.11) cannot be satisfied with $s^* < s$. Truth-telling, i.e., $s^* = s$, only satisfies when $\lambda = 0$, but in this case it satisfies it $\forall r'$. Therefore it is a (unique) dominant strategy. ■

Notice that at this point, we avoid any considerations regarding upper bounds of integration because (1.7) takes care of them automatically. A similar proposition, only with $\lambda = 1$, holds for the retailer. Since the supplier has a dominant strategy only when $\lambda = 0$, whereas the retailer has one only when $\lambda = 1$ it is clear that they cannot have dominant strategies at the same time. For a similar reason, there is no equilibrium in which both parties report truthfully. Thus, we come to the following.

Corollary 3 *The contingent contract is ex-post inefficient.*

The next two propositions (similar propositions hold for the retailer) will alleviate computations of the equilibrium later on.

Proposition 2 *The supplier's best response is unique and strictly increasing in* s.

Proof. First, since $U(q)$ is concave in q then, $\pi_S(s', s)$, given by (1.8), is concave in s' as a superposition of concave functions. Therefore, $s^*(s)$ is single valued.

Second, let $s_1 > s_2$ be two different costs that the supplier may have and let s' and s'' be two optimal (unique) announcements corresponding to those costs. Then

$$\int_{r_0}^{r_1} \left[(1-\lambda)[pU(q(r^*(r),s')) - (r^*(r)+s')q(r^*(r),s')] + (s'-s_1)q(r^*(r),s')\right] dR(r)$$
$$> \int_{r_0}^{r_1} \left[(1-\lambda)[pU(q(r^*(r),s'')) - (r^*(r)+s'')q(r^*(r),s'')] + (s''-s_1)q(r^*(r),s'')\right] dR(r)$$

and

$$\int_{r_0}^{r_1} \left[(1-\lambda)[pU(q(r^*(r),s'')) - (r^*(r)+s'')q(r^*(r),s'')] + (s''-s_2)q(r^*(r),s'')\right] dR(r)$$
$$> \int_{r_0}^{r_1} \left[(1-\lambda)[pU(q(r^*(r),s')) - (r^*(r)+s')q(r^*(r),s')] + (s'-s_2)q(r^*(r),s')\right] dR(r).$$

Adding these two inequalities one obtains

$$\int_{r_0}^{r_1} \left(q(r^*(r),s'')) - q(r^*(r),s')\right) dR(r) > 0.$$

Since q, due to (1.7), is strictly decreasing in s, then by the last inequality, $s'' < s'$. ∎

Now, having established monotonicity of best responses, and using $q_s^* = -\frac{1}{f(q^*)}$, where q^* is the order quantity given by the top line of (1.7), one can re-write the parties' first-order conditions as

$$\int_{s_0}^{s^{*-1}(p-r^*)} \left((1-\lambda)q^* - \frac{r^*-r}{f(q^*)}\right) dS(s) = 0 \tag{1.12}$$

$$\int_{r_0}^{r^{*-1}(p-s^*)} \left(\lambda q^* - \frac{s^*-s}{f(q^*)}\right) dR(r) = 0 \tag{1.13}$$

where $s^{*-1}(.)$ denotes the inverse function of $s^*(s)$.

Notice the change in the upper limit of the integration. Now, as we use q_s^* found from the top line of (1.7), we need to take it into consideration. This change explicitly takes into account that, when announced costs exceed price, no trade takes place.

1.3.6 Comparison with benchmarks

Complete information

Under complete information one can fully characterize the equilibrium in the most general case.

Proposition 3 *In equilibrium, parties announce*

$$\begin{aligned} r^* = &\quad r + (1-\lambda)pf(q^*)q^* \\ s^* = &\quad s + \lambda pf(q^*)q^* \end{aligned} \tag{1.14}$$

where $q^* = q^{CC}(r^*, s^*)$*, so that the equilibrium order quantity is given by (1.4).*

Proof. Differentiating (1.7) one finds

$$\frac{\partial q(r', s')}{\partial s'} = -\frac{1}{pf(q(r', s'))}. \tag{1.15}$$

Differentiating (1.8) and using (1.7) & (1.15) one obtains its first derivative

$$\frac{\partial}{\partial s'}\pi_S(s', s) = \lambda q - \frac{s' - s}{pf(q(r', s'))}.$$

Since, $\forall r'$ this expression is positive when $s' < s + \lambda pf(q(r', s'))q(r', s')$ and negative otherwise it follows that (1.9) is quasi-concave and

$$s^* = s + \lambda pf(q(r', s'))q(r', s')$$

is the unique maximizer.

Similarly, one finds that (1.8) is quasi-concave and

$$r^* = r + (1-\lambda)pf(q(r', s'))q(r', s')$$

is its unique maximizer.

Therefore, (1.14) is the unique equilibrium. Finally, adding r^* and s^* and substituting the result into (1.7) gives (1.4). ■

Note that although the equilibrium reports depend on λ, it does not affect efficiency. Second, the contingent contract turns out to be only as efficient as the wholesale contract in bilateral monopoly. The parallel here becomes most clear when $\lambda = 1$. In this case, according to (1.14), the retailer reports truthfully. It is not surprising because the retailer, apart from her information rents, also takes all *apparent* profit of the channel. The supplier has no share in the apparent profit and, therefore, he, basically, uses s' as a wholesale price. However, it would be incorrect to say that parties' would do equally well using a wholesale price contract. In this environment, under supervision of a superpower, a wholesale price contract cannot be a rational choice of the supply chain parties.

Incomplete information

General case First, it turns out that the wholesale price contract obtains as a special case of a contingent contract.

Proposition 4 *The wholesale price contract is equivalent to the contingent contract when* $\lambda = 1$.

Proof. The supplier's problem under a contingent contract with $\lambda = 1$ is

$$\max_{s'} \int_{r \in [r_0, r_1]: r + s' \leq p} q(r, s')(s' - s) dR(r)$$

where q is given by (1.7).

Since, by Proposition 1, when $\lambda = 1$, the retailer reports truthfully then (1.2) is the same as (1.7). It is immediate that in both cases the supplier solves the same problem. The only difference is notational, with s' playing the role of w. ■

The intuition behind this equivalence is exactly the same as the one suggested after Proposition 3. However, unlike the complete information case, the next section shows that this equivalence breaks down when $\lambda \neq 1$.

Uniform costs and demand In order to shed more light on this problem, let us assume specific distributions of demand and costs. The model will retain all substantive features of the problem but allow obtaining closed-form results for a deeper analysis. That is, assume $D \sim U(0,1)$, $r \sim U(r_0,1), s \sim U(s_0,1)$ and, for notational convenience, normalize the market price, to $p = 1$. Then (1.7) takes on a simple form

$$q = \begin{cases} 1 - r' - s', & if \quad r' + s' \leq 1 \\ 0, & \text{otherwise.} \end{cases} \tag{1.16}$$

The equilibrium first-order conditions, (1.12) and (1.13) simplify to

$$\begin{array}{c} \int_{s_0}^{s^{*-1}(1-r^*)} ((1-\lambda)q^* - r^* + r)ds = 0 \\ \int_{r_0}^{r^{*-1}(1-s^*)} (\lambda q^* - s^* + s)dr = 0. \end{array} \tag{1.17}$$

We find the solution to this of set of equations by construction, relying on uniqueness and monotonicity of the best-responses.

Proposition 5 *The equilibrium is characterized by the following strategies:*

$$\begin{array}{l} r^*(r) = \frac{(1-\lambda)(3-3s_0-\lambda(1-r_0-s_0))}{3(2+(1-\lambda))} + \frac{2r}{2+(1-\lambda)} \\ s^*(s) = \frac{\lambda(3-3r_0-(1-\lambda)(1-r_0-s_0))}{3(2+\lambda)} + \frac{2s}{2+\lambda}. \end{array}$$

The equilibrium order quantity is given by:

$$q(r^*, s^*) = \left(\begin{array}{c} 1 - \frac{(1-\lambda)(3-3s_0-\lambda(1-r_0-s_0))}{3(3-\lambda)} - \frac{2}{2+(1-\lambda)}r \\ -\frac{\lambda(2-2r_0+s_0+\lambda(1-r_0-s_0))}{3(\lambda+2)} - \frac{2}{\lambda+2}s \end{array} \right). \tag{1.18}$$

The parties' expected profits in equilibrium are:

$$\begin{array}{l} \Pi_R(r) = \frac{2+\lambda}{3(2+(1-\lambda))^2(1-s_0)} \left(1 - r - s_0 - \frac{\lambda}{3}(1 - r_0 - s_0)\right)^3 \\ \Pi_S(s) = \frac{2+(1-\lambda)}{3(2+\lambda)^2(1-r_0)} \left(1 - r_0 - s - \frac{(1-\lambda)}{3}(1 - r_0 - s_0)\right)^3. \end{array} \tag{1.19}$$

Proof. By Proposition (2), best-responses are unique and monotone and the simplest possible solution is when best-responses are linear in costs:

$$r^* = a_1 + b_1 r \quad \Rightarrow \quad r^{*-1} = \tfrac{r^* - a_1}{b_1}$$
$$s^* = a_2 + b_2 s \quad \Rightarrow \quad s^{*-1} = \tfrac{s^* - a_2}{b_2}.$$

Using these functions and (1.16), start solving (1.17):

$$\tfrac{1}{1-s_0}\int_{s_0}^{\frac{1-r^*-a_2}{b_2}} ((1-\lambda)(1-r^*-s^*(s)) - r^* + r)ds = 0$$
$$\tfrac{1}{1-r_0}\int_{r_0}^{\frac{1-s^*-a_1}{b_1}} (\lambda(1-r^*(r)-s^*) - s^* + s)dr = 0.$$

Integrating and cancelling irrelevant factors, one obtains

$$2r - \lambda - a_2 - 3r^* + \lambda a_2 + \lambda r^* - b_2 s_0 + \lambda b_2 s_0 + 1 = 0$$
$$2s^* - \lambda - 2s + \lambda a_1 + \lambda s^* + \lambda b_1 r_0 = 0.$$

Now, insert $r^*$and s^*everywhere, obtaining

$$2r - \lambda - 3a_1 - a_2 - 3rb_1 + \lambda a_1 + \lambda a_2 - b_2 s_0 + r\lambda b_1 + \lambda b_2 s_0 + 1 = 0$$
$$2a_2 - \lambda - 2s + 2sb_2 + \lambda a_1 + \lambda a_2 + s\lambda b_2 + \lambda b_1 r_0 = 0.$$

Next, terms can be conveniently rearranged as

$$(\lambda - 3)(a_1 + rb_1) = \lambda + a_2 - \lambda a_2 + b_2 s_0 - \lambda b_2 s_0 - 1 - 2r$$
$$(\lambda + 2)(a_2 + sb_2) = \lambda - \lambda a_1 - \lambda b_1 r_0 + 2s.$$

Further, dividing through by non-zero multipliers of LHS yields

$$a_1 + rb_1 = \tfrac{\lambda + a_2 - \lambda a_2 + b_2 s_0 - \lambda b_2 s_0 - 1}{\lambda - 3} + \tfrac{2r}{3-\lambda},$$
$$a_2 + sb_2 = \tfrac{\lambda - \lambda a_1 - \lambda b_1 r_0}{\lambda + 2} + \tfrac{2s}{\lambda + 2}.$$

It is now immediate that

$$b_1 = \tfrac{2}{2+(1-\lambda)}$$
$$b_2 = \tfrac{2}{2+\lambda}.$$

It only remains to solve for a_1 and a_2 :

$$a_1 = (1-\lambda)\,\frac{(3(1-s_0)-\lambda(1-r_0-s_0))}{3(2+(1-\lambda))},$$
$$a_2 = \lambda\frac{(3(1-r_0)-(1-\lambda)(1-r_0-s_0))}{3(2+\lambda)}.$$

Finally, parties' profits that obtain in the equilibrium (for notational brevity, suppress arguments of $r^*$and s^*):

$$\Pi_R(r) =$$
$$= \int_{s_0}^{s_1} \left[\lambda[U(q(r^*,s^*)-(r^*+s^*)q(r^*,s^*)] + (r^*-r)q(r^*,s^*)\right] dS(s)$$
$$= \frac{1}{1-s_0}\int_{s_0}^{\frac{\lambda-6r+3s_0-3r\lambda-\lambda^2+2\lambda r_0-4\lambda s_0+\lambda^2 r_0+\lambda^2 s_0+6}{3(3-\lambda)}} \left(\lambda\left(q-\frac{q^2}{2}-(r^*+s^*)q\right)+(r^*-r)q\right) ds$$
$$= \frac{1}{3}\frac{2+\lambda}{(2+(1-\lambda))^2(1-s_0)}\left(1-r-s_0-\frac{\lambda}{3}(1-r_0-s_0)\right)^3$$

$$\Pi_S(s) =$$
$$= \frac{1}{1-r_0}\int_{r_0}^{r^{*-1}(1-s^*)} \left[(1-\lambda)[U(q(r^*,s^*)-(r^*+s^*)q(r^*,s^*)] + (s^*-s)q(r^*,s^*)\right] dr$$
$$= \frac{1}{1-r_0}\int_{r_0}^{\frac{\lambda-9s+3s_0+3s\lambda-\lambda^2+2\lambda r_0-4\lambda s_0+\lambda^2 r_0+\lambda^2 s_0+6}{3(\lambda+2)}} \left((1-\lambda)\left(q-\frac{q^2}{2}-(r^*+s^*)q\right)+(s^*-s)q\right) dr$$
$$= \frac{2+(1-\lambda)}{3(\lambda+2)^2(1-r_0)}\left(1-r_0-s-\frac{(1-\lambda)}{3}(1-r_0-s_0)\right)^3.$$

■

Figure 1.1 gives some insight regarding how the supplier's profit depends on λ. It shows the supplier's profit corresponding to $\lambda = 0, \frac{1}{2}, 1$ when $r_0 = s_0 = 0$.

Interestingly, the supplier does uniformly better with $\lambda = 1$ than with $\lambda = 0$. One might expect that $\lambda = 0$ should be better for the supplier but it turns out that "generosity" ($\lambda = 1$) pays better (this holds $\forall r_0, s_0$). The next observation is that the thin curve, which depicts the supplier's profit at $\lambda = \frac{1}{2}$, goes above the curve $\lambda = 0$ everywhere (this holds $\forall \lambda, r_0, s_0$) and above the curve $\lambda = 1$ in the narrow region of low costs. It turns out (see below), that this region allows a simple characterization.

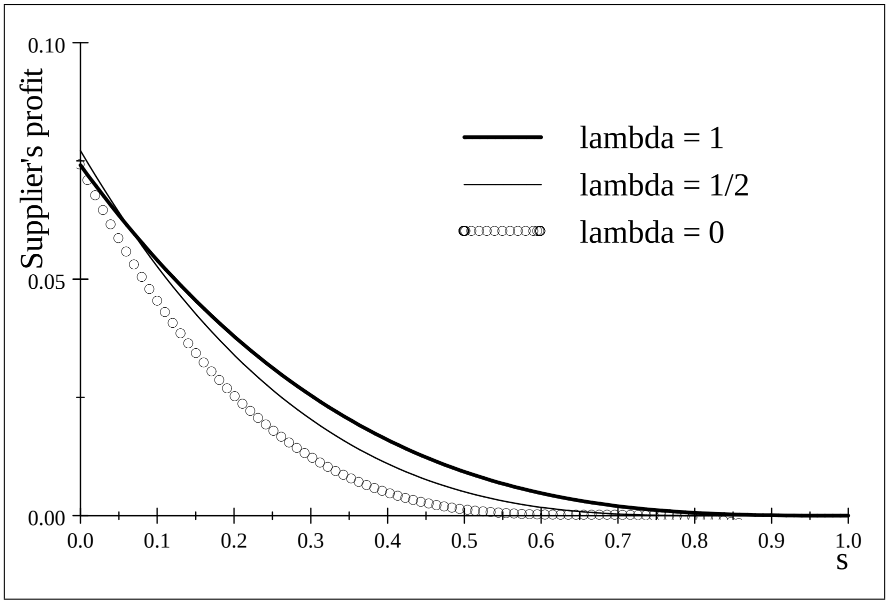

Figure 1.1: Supplier's expected profit as a function of his cost for different $\lambda's$.

Wholesale price contract VS. contingent contract Recall, that parties negotiate λ ex-ante. As the discussion of Figure 1.1 suggests, both parties may have reasons to be as "generous" as possible. To make this observation more precise, consider the supplier's interim profit:

$$\Pi_S^{CC} = \frac{2+(1-\lambda)}{3\,(\lambda+2)^2\,(1-r_0)}\left(1-r_0-s-\frac{(1-\lambda)}{3}(1-r_0-s_0)\right)^3 \tag{1.20}$$

Maximizing this expression w.r.t. λ one can show most of the time the supplier's optimal value of λ equals unity (i.e. $\lambda^* = 1$). It is only when

$$s_0 < s < \frac{1}{7}(1-r_0+6s_0) \tag{1.21}$$

there exist $\lambda < 1$ that allows the supplier make higher profit than $\lambda = 1$ does. Probability that condition (1.21) happen to be true is

$$\frac{1}{7}(1-s_0-r_0) \leq \frac{1}{7},$$

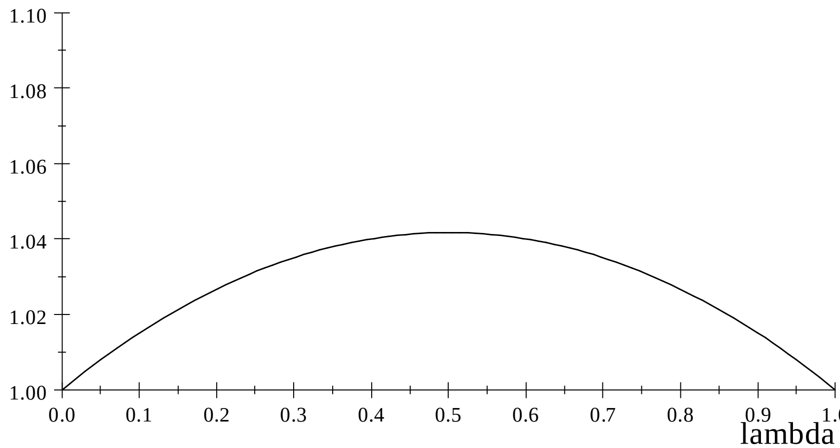

Figure 1.2: Ratio (Upper bound on profit with CC) / (profit with WC)

which is relatively small, and potential gains are rather moderate. To estimate gains in the most straightforward way, one can compute an upper bound on the supplier's interim profit. To this end, re-write (1.20) as

$$\Pi_S^{CC} = \frac{2+(1-\lambda)}{3(\lambda+2)^2(1-r_0)}\left(\frac{2+\lambda}{3}(1-r_0-s)-\frac{(1-\lambda)}{3}(s-s_0)\right)^3,$$

and obtain an upper bound on Π_S^{CC} by omitting the negative term containing $(s-s_0)$:

$$\Pi_S^{CC\_UB} = \frac{(\lambda+2)(3-\lambda)}{81}\frac{(1-r_0-s)^3}{1-r_0}. \tag{1.22}$$

Figure 1.2. shows the ratio $\Pi_S^{CC\_UB}/\Pi_S^{WC}$ as a function of λ (the only parameter it depends on).

That is, the supplier can gain no more than about 4% by offering a CC. The actual gain will, of course, be smaller. For example, when $r_0 = s_0 = 0$, the ratio of the actual profit of the CC with the optimal λ to the profit under WC is shown in Figure 1.3.

In the half region, above 0.07, the gain is less than 1% and may well be considered negligible. Yet, if s is (or is close to) zero, then CC might secure tangible benefits for the supplier.

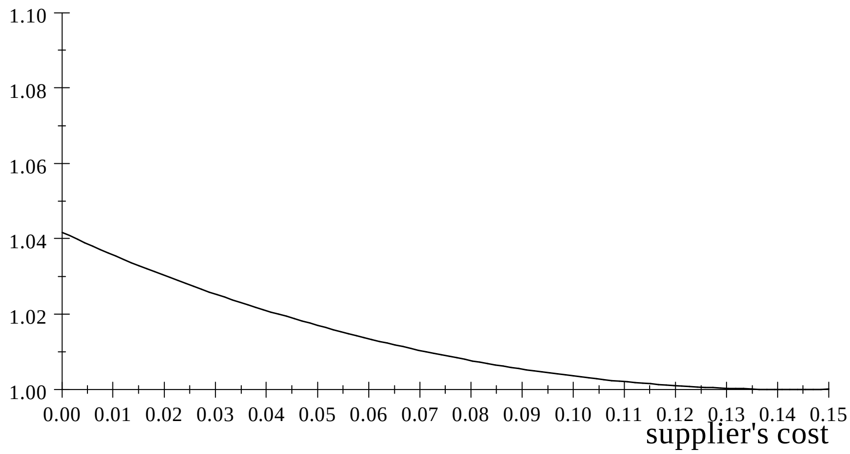

Figure 1.3: Ratio (Profit with the best CC) / (profit with WC)

As a final argument, we compute the supplier's ex-ante profit as a function of λ :

$$E\left[\Pi_S^{CC}\right] =$$
$$= \int_{s_0}^{1-r_0-\frac{1}{3}(1-\lambda)(1-r_0-s_0)} \frac{2+(1-\lambda)}{3(\lambda+2)^2(1-r_0)}\left(1-r_0-s-\frac{(1-\lambda)}{3}(1-r_0-s_0)\right)^3 ds$$
$$= (\lambda+2)^2(3-\lambda)\frac{(1-r_0-s_0)^4}{972(1-r_0)}$$

When $\lambda \in [0,1]$ this expression is monotone increasing in λ so that

$$\frac{E\left[\Pi_S^{CC}\right]\big|_{\lambda=1}}{E\left[\Pi_S^{CC}\right]\big|_{\lambda=0}} = \frac{3}{2}.$$

Therefore, in case the supplier has all the bargaining power, he chooses a contract that gives the retailer all (!) *apparent* profit of the channel. For the rest of the world, it will look just the opposite, as though the retailer is squeezing out everything from the supplier.

The optimal contract VS. contingent contract To better understand performance of a contingent contract under information asymmetry we need to compare it with a proper benchmark, which is an optimal screening contract. To derive it, we use a standard approach. The supplier has all bargaining power and moves first but he is uncertain about the retailer's cost. Parties' true profits are

$$\pi_R = U(q) - rq - t,$$
$$\pi_S = t - sq,$$

where $q-$ order quantity, $t-$ transfer from the retailer to the supplier, $r-$ retailer's cost and $s-$ supplier's cost.

The supplier uses a direct truth-telling mechanism. For it was truth-telling it must be incentive-compatible:

$$\begin{aligned}
\left[\frac{d}{dr'}\left(U(q(r') - rq(r') - t(r')\right)\right]_{r'=r} &= 0 \Rightarrow \\
(U' - r)q_r - t_r &= 0 \Rightarrow \\
t(\bar{r}) - t(r) &= \int_r^{\bar{r}} (U'(q) - x)q_r(x)dx
\end{aligned}$$

since $\bar{r}$ is the most inefficient type, we can set $t(\bar{r}) = 0$:

$$\begin{aligned}
-t(r) &= \int_r^{\bar{r}} (U'(q) - x)q_r(x)dx \\
&= \int_r^{\bar{r}} dU(x) - \int_r^{\bar{r}} xdq \\
&= U(\bar{r}) - U(r) - (xq(x))_r^{\bar{r}} + \int_r^{\bar{r}} qdx \\
&= U(\bar{r}) - \bar{r}q(\bar{r}) - U(r) + rq(r) + \int_r^{\bar{r}} qdx \Rightarrow \\
t(r) &= U(r) - rq(r) - \int_r^{\bar{r}} qdx
\end{aligned}$$

Let us check that this transfer makes the retailer to tell the truth:

$$\begin{aligned}
\pi_R(r', r) &= U(q(r')) - rq(r') - U(q(r')) + r'q(r') + \int_{r'}^{\bar{r}} qdx \\
&= (r' - r)q(r') + \int_{r'}^{\bar{r}} qdx
\end{aligned}$$

then differentiate over r':

$$\frac{d\pi_R(r',r)}{dr'} = (r'-r)q_{r'}(r') + q(r') - q(r')$$
$$= (r'-r)q_{r'}(r')$$

We also need to make sure that the second-order condition is also satisfied:

$$\frac{d^2\pi_R(r',r)}{(dr')^2} = q_{r'}(r') + (r'-r)q_{r'r'}(r')$$

Since $r' = r$ the second-order condition is satisfied as long as $q(r)$ is decreasing (monotonicity property of the optimal solution).

Thus, the retailer's profit is

$$\pi_R(r,r) = \int_r^{\bar{r}} q(x)dx$$

Although it appears that $q(x) > 0$ and, therefore, the retailer's profit is positive, we still need to show this.

The supplier seeks to find q so as to maximize his profit, of course:

$$\pi_S = t - sq(r)$$
$$= U(q(r)) - (r+s)q(r) - \int_r^{\bar{r}} q(x)dx$$

unfortunately, we cannot do much with this expression and have to looks at the supplier's expected profit:

$$E[\pi_S] = \int_{r_0}^{\bar{r}} \left(U(q(r)) - (r+s)q(r) - \int_r^{\bar{r}} qdx \right) h(r)dr$$
$$= \int_{r_0}^{\bar{r}} \left(U(q(r)) - (r+s)q(r) \right) h(r)dr + \int_{r_0}^{\bar{r}} \left(- \int_r^{\bar{r}} q(x)dx \right) h(r)dr$$

next, let us make some transformations of the second term:

$$\begin{aligned}
&\int_{r_0}^{\bar{r}} \left(-\int_{r}^{\bar{r}} q(x)dx \right) h(r)dr = \\
&= -\int_{r_0}^{\bar{r}} \int_{r}^{\bar{r}} h(r)q(x)dxdr \\
&= -\iint\limits_{x\in[r_0,\bar{r}],r\in[r_0,\bar{r}],x\geq r} h(r)q(x)dxdr \\
&= -\int_{r_0}^{\bar{r}} q(x)dx \int_{r_0}^{x} h(r)dr \\
&= -\int_{r_0}^{\bar{r}} q(x)H(x)dx \\
&= -\int_{r_0}^{\bar{r}} q(r)\frac{H(r)}{h(r)}h(r)dr
\end{aligned}$$

then we have

$$E[\pi_S] = \int_{r_0}^{\bar{r}} \left(U(q(r)) - (r + s + \frac{H(r)}{h(r)})q(r) \right) h(r)dr.$$

To find q we can maximize the integrand point-wise, for each r :

$$U'(q) = r + s + \frac{H(r)}{h(r)} \tag{1.23}$$

Also, $q(r)$ must be monotonously decreasing in r. Differentiate the previous equation w.r.t. to r to find

$$q_r = \frac{1}{U''(q)} \left(1 + \frac{d}{dr} \left(\frac{H(r)}{h(r)} \right) \right)$$

Since, by assumption, $U(q)$ is concave, then if $\frac{H(r)}{h(r)}$ is increasing in r the second-order condition is satisfied.

Thus, in case of uniform demand and uniform cost $[r_0, 1]$, where $U(q) = q - \frac{q^2}{2}$ we have

$$\begin{aligned}
1 - q &= r + s + (r - r_0) \Rightarrow \\
q &= 1 - r - s - (r - r_0) \\
&= 1 - 2r + r_0 - s
\end{aligned}$$

second, it makes sense to exclude all r when the integrand is negative, i.e. we need to pick up $\bar{r}$:

$$\begin{aligned}U(q(\bar{r})) - \left(\bar{r} + s + \frac{H(\bar{r})}{h(\bar{r})}\right) q(\bar{r}) = 0 \Rightarrow& \\ q - \frac{q^2}{2} &= (r + s + (r - r_0))\, q \Rightarrow \\ \bar{r} &= \frac{1}{2}(1 - s + r_0)\end{aligned}$$

However, this is exactly the same value that turns the order quantity to zero. Therefore the inefficient types were, in fact, automatically excluded by q itself.

To complete our derivations, we need to calculate how much the retailer pays:

$$\begin{aligned}t(r) &= U(r) - rq(r) - \int_r^{\bar{r}} q dx \\ &= q - \frac{q^2}{2} - rq - \int_r^{\frac{1}{2}(1+r_0-s)} q dx \\ &= (r - r_0 + s)(1 - 2r - s + r_0) \\ &= (r - r_0)q + sq \Leftrightarrow && (1.24) \\ t(q) &= \frac{1}{2} q (s - r_0 + 1 - q) && (1.25)\end{aligned}$$

For the purposes of comparing the optimal contract and the wholesale price contract let us calculate the supplier's expected profit under the optimal contract:

$$\begin{aligned}\Pi_S^{OC} &= \frac{1}{1 - r_0} \int_{r_0}^{\frac{1}{2}r_0 - \frac{1}{2}s + \frac{1}{2}} \left(q - \frac{q^2}{2} - (r + s + (r - r_0))q\right) dr \\ &= \frac{1}{12} \frac{(1 - r_0 - s)^3}{(1 - r_0)}.\end{aligned}$$

Finally, since

$$\Pi_S^{WH} = \Pi_S^{CC}\big|_{\lambda=1} = \frac{2}{27} \frac{(1 - r_0 - s)^3}{(1 - r_0)}$$

the optimal contract proves uniformly better than the most desirable for the supplier contingent contract:

$$\frac{\Pi_S^{OC}}{\Pi_S^{WH}} = \frac{1}{12} \Big/ \frac{2}{27} = \frac{9}{8}.$$

There is, of course, no surprise in that the optimal contract proves better. The question was by how much.

1.3.7 Sensitivity to assumptions

Our finding that under complete information the contingent contract performs only at the level of the Double Marginalization benchmark seems rather intuitive. At the same time, the result obtained under incomplete information, namely that the party having all the bargaining power should offer a contract that "generously" gives away all *apparent* profit of the channel, does not offer a simple explanation and seems puzzling. There is a possibility that this result is an artifact of the technical assumptions that we made about the environment. In this situation a robustness check would be appropriate, if not necessary.

The difference between complete and incomplete information environments comes through the assumption of uniform distributions of costs. At the limit, when cost uncertainty vanishes, one arrives at the complete information. Therefore, in the numerical experiment we test whether and how reducing variability of costs affects the results.

To go beyond a simple robustness check we introduce another factor: limited misrepresentation. By assumption, the supervisory verification technology was completely incapable to impose any limits on misrepresentation. This is, of course, an extreme case. In fact, one may argue that it may be able to impose at least some limits on parties' reports. In the numerical experiment we, therefore, use truncated distributions assuming that parties' can only report costs within distribution ranges.

Overall, we run six numeric experiments. Each numeric experiment has a $5 * 5 * 5$ full factorial design. Two factors were different ranges of costs and the third was the value of λ. Specifically, the factors were chosen as in Table 1.1.

For, example, in Experiment 5 for each of the 125 combinations of factor levels, costs of both parties were drawn from distributions that were obtained from a normal with mean value $\frac{1}{2}$ and standard deviation equal to $\frac{range}{6}$ (the distribution was truncated according

	Costs' Distributions	Costs' ranges	Retailer's share
Experiment 1	Uniform	[0,.2];[.2,.4];[.4,.6];[.6,.8];[.8,1]	$0, \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1$
Experiment 2	Uniform	[.4,.6];[.3,.7];[.2,.8];[.1,.9];[0,1]	-"-
Experiment 3	Tr. Normal, σ =range/4	[0,.2];[.2,.4];[.4,.6];[.6,.8];[.8,1]	-"-
Experiment 4	Tr. Normal, σ =range/4	[0,.2];[.2,.4];[.4,.6];[.6,.8];[.8,1]	-"-
Experiment 5	Tr. Normal, σ =range/6	[.4,.6];[.3,.7];[.2,.8];[.1,.9];[0,1]	-"-
Experiment 6	Tr. Normal, σ =range/6	[.4,.6];[.3,.7];[.2,.8];[.1,.9];[0,1]	-"-

Table 1.1: Factors and their levels

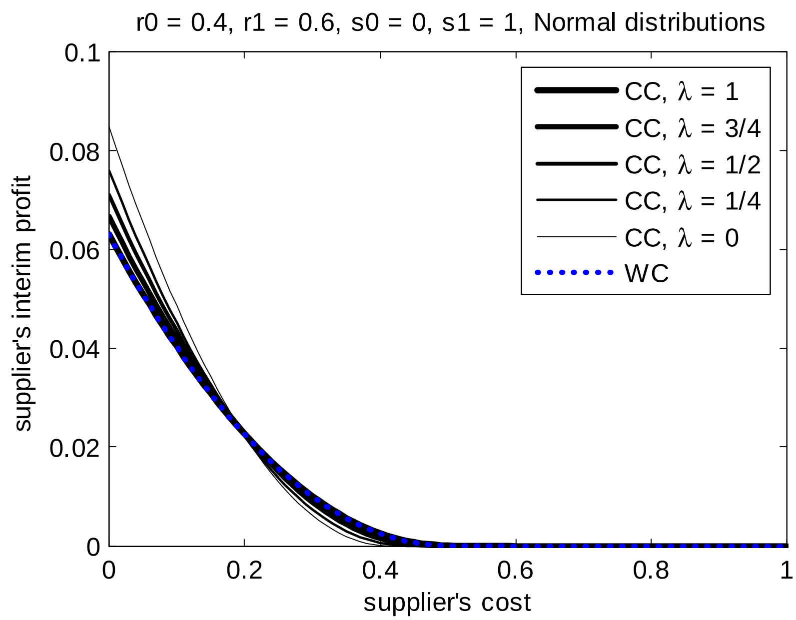

Figure 1.4: Supplier's profit under different contrtacts when sum of costs can exceed market price.

to the chosen ranges and renormalized). In all cases, means were set in the middle of supports. Since the goal was to make qualitative assessments, the choice of factor levels seems sufficient, if not exhaustive. Two observations summarize our numerical results. All the following figures depict the supplier's interim profit as a function of the supplier's cost, s.

First, Figure 1.4 presents a typical case when the costs' ranges allow a possibility that the sum of costs may exceed market price. This makes cost reports effectively unrestricted and this is the case that our model analyzes. Qualitatively, in all such cases results are

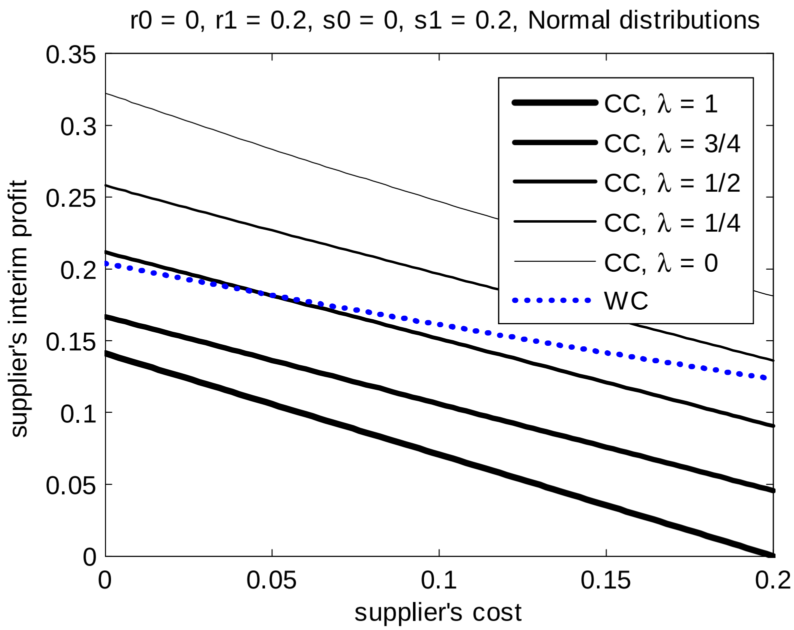

Figure 1.5: When misrepresentation is restricted, the outcomes converge to those of the standard theory.

similar to Figure 1.1, regardless of particular distribution form. Quantitatively, however, when variance is low the point where the $\lambda = 1$ curve crosses curves with $\lambda < 1$ shifts significantly to the right (see Figure 1.4). As the result, $\lambda = 1$ is dominated by $\lambda = 0$ almost everywhere, except when the cost is high but at that range the difference is negligible. That is, by lowering the variance, one approaches the complete information environment where $\lambda = 0$ clearly maximizes the supplier's profit. These observations suggest that the results' inversion is primarily due to the variability of costs rather than a choice of the distribution shape.

Second, Figure 1.5 demonstrates the effect of imposing limits on misrepresentation. Here, costs are known to be within narrow ranges and parties cannot report costs outside these ranges. Since information rents are relatively small, the major factor that determines the parties' profits is their shares in the *apparent* profit of the channel. This case approximates the environment of the standard bilateral monopoly and, not surprisingly, the supplier does much better by choosing $\lambda = 0$.

Overall, the numerical results show that the model is fairly robust with respect to the functional form of the distributions of cost. They also suggest that two key factors are the variability of costs and limits on admissible misrepresentation. When upper bounds of costs sum up to the market price or above, the reports, in effect, become unrestricted. Under these circumstances, misspecification of costs makes a bigger impact on each party's profit than the way they split the *apparent* part of the channel profit. Once benefits from trade become certain and *apparent* profit increases, misspecification of costs can only mitigate disparity in profits. Therefore, complying with the conventional wisdom, at some point, the supplier is strictly better off requesting all the *apparent* profit.

1.4 Summary

This study addresses certain aspects of contracting that are likely to arise under information sharing. It analyzes the case when supply chain parties are forced to use contracts that are contingent on reported costs. As the empirical evidence suggests, such situations are typical in the real world.

Our results show that the supply chain is not able to operate efficiently under these circumstances. In particular, we find that when there is complete information between supply chain partners, the performance of the supply chain is only at the level of the Double Marginalization benchmark. The case of incomplete information is more convoluted. A general result is, again, inefficient outcomes. However, some results obtained under specific distributional assumptions are not straightforward. On one hand, the party taking all *apparent* profit of the supply chain has a dominant strategy not to misrepresent cost. On the other hand, its *ex-ante* profit is higher by as much as 50% when this party, instead, gives away all (!) *apparent* profit and earns only information rents. Also, this arrangement is strategically equivalent to the wholesale price contract that might be offered in the standard bilateral monopoly case. Thus, for a contracting party the difference between complete and incomplete information environments is the different course of the optimal actions. Under complete information, each party is better off by accruing all *apparent* profit of the channel, whereas under incomplete information it should do just the opposite. The numerical simulations that we conduct to clarify what is driving this phenomenon indicate, in accord with intuition, that the primary reason is not the shape of the distribution but the amount of uncertainty. As variability of costs decreases, and the environment becomes closer to one with complete information, the optimal profit share changes.

By design, our model is almost extreme. This has an advantage that all peculiarities of the contracting game can be detected more clearly. The results, of course, are subject to limitations that follow from the model assumptions. Apart from the purely technical assumptions that we made to derive closed-form results and illustrate some counterintuitive phenomena arising in the problem, the most crucial assumption was that parties have unlimited ability to misrepresent costs. Realistically, there are always some limitations on the extent of misrepresentation. At the limit, if the verification technology of the supervision authority is good and parties have only quite limited possibility for cost misrepresentation, our model converges to the standard case of bilateral monopoly. However, as our study suggests, even relatively small possibilities for misrepresentation may play a big role if the upper limits of allowable cost reports sum up to the market price or above. In fact, modeling the retailer as a price-taker (as in the standard Newsvendor model), implicitly assumes a competitive environment in which prices are close to costs (random variables) and, therefore, there is a chance that total costs may exceed the market price even without misrepresentation.

This study contributes to the existing body of research in different ways. First, it contributes to the contracting literature by analyzing a richer environment than most of the traditional contracting models. Specifically, contracting takes place in presence of a third that holds incorrect beliefs about the information structure of the game. Second, this environment has been constructed based on empirical evidence to account for conditions that most companies are well familiar with. The normative theories typically ignore studying environments that, from the normative perspective, should not even exist. Nevertheless, they do. The real world is not perfect. This study, also normative, aims to provide some guidance in practical cases. Third, it contributes to the literature on information sharing, since the latter, as the literature suggests, may trigger use of conditional contracts.

As a managerial insight, we offer our main result, i.e., inefficiency of contingent contracts. Entering conditions that may improve the information regime, but, at the same time, may lead the third parties to believe in verifiability, need not be an optimal decision. We would like to reiterate, though, that this is based on our interpretation of available facts. The same facts can be interpreted and modeled in different ways. A peculiarity of any descriptive model of contracting is that details of contracting games are typically unknown to an outsider. Therefore, any analysis necessarily involves more guesswork and hinges on the way one fills in the gaps. An interested reader should compare results delivered by different models and see which are robust and could be used to yield good intuition.

Chapter 2

Fairness and coordination failures in supply chain contracts

2.1 Introduction

In a supply chain that typically consists of individual self-interested firms decentralized decisions may result in outcomes that are inefficient from system-wide perspective, such as, for example Double Marginalization. Over years, a number of studies addressed supply chain coordination and proposed a great variety of contracting arrangements to eliminate misaligned incentives. Most of coordinating contracts, however, share two commonalities. The party offering a contract can coordinate the channel and extract all profit of the other party. From a theory standpoint, the problem has been successfully solved, and the only remaining question seemed to be a choice among many equally good, or sometimes even equivalent, coordinating contracts. This, of course, was seen as a purely empirical question.

Empirical studies of coordinating contracts, accomplished mostly in the recent years, came with a surprising and persistent observation: coordinating contracts fail to coordinate. Even more so. Somewhat ironically, such contracts perform approximately at a level of the Double Marginalization benchmark. The standard theory, in essence, was proposing a choice among many almost equally failing coordinating contracts.

One regularity, discovered in laboratory experiments, was that poor performance of coordinating contracts is primarily due to contract rejections. Instances when a party, considering terms of the contract proposed by another party, refuses to trade happen too often. At the same time, when trade takes place, the outcome is almost as efficient as the

	Relatively equitable outcomes	Inefficient outcomes rejections
Experiments	Yes	Yes
Standard theory	No	No
Fairness & complete information about preferences	Yes	No
Fairness & incomplete information about preferences	Yes	Yes

Table 2.1: What theory might explain experimental data?

standard theory predicts. While there are several competing explanations of behavioral factors that cause rejections, it is clear that some factor is missing in the theory because the standard theory predicts no rejections. Another important regularity is that when a trade takes place, contracting parties split profits notably more equally than the standard theory predicts.

Virtually all analytical models that propose coordinating contracts assume perfectly rational, profit-maximizing firms. A theory that might explain both rejections and equitable outcomes will have to significantly deviate from the assumptions of the standard theory. The theory, developed further, keeps the rationality assumption, but dismisses the assumption of profit-maximizing behavior by introducing disutility from unfair outcomes.

Still, this is not enough because under complete information there should be no rejections. The party offering a contract can always make a proposal that (i) maximizes the total profit of a supply chain, and (ii) splits the total profit in a way that ensures participation of the other party. But rejections are possible when there is incomplete information about preferences. The party offering a contract does not know how much another party cares about unfair outcomes. Then, any contract that suggests less than fair outcomes, has a chance to be rejected if the party, deciding whether to accept it or not, has sufficiently strong fairness concerns. Table 2.1 summarizes this reasoning.

This study presents a theoretical and an experimental analysis of a serial dyadic supply chain in which both a supplier and a retailer can be fair-minded. Our theory aims to understand implications of fairness concerns for supply chain coordination. It is rather general and encompasses the standard theory as well as some other models as special cases. The theory makes specific predictions that allow testing them experimentally. Therefore, one goal of the experiment was to falsify the theory. Another, an equally important goal, was to test if a major competing theory assuming bounded rationality can explain the data.

Our theory starts by extending the Cui et al. (2007) model of the wholesale price contract to include incomplete information about fairness considerations. Interestingly, we find that many important properties of the complete-information wholesale price contract still hold under incomplete information. First, just like under complete information, it coordinates the channel if the retailer is sufficiently averse to advantageous inequality and the supplier knows this (but not exactly how much). Second, regardless of what the supplier knows about the retailer, the equilibrium wholesale price involves no rejections. Even if the supplier wrongly assumes the retailer does not care much about fairness, whereas the retailer is extremely averse to disadvantageous inequality, the retailer still accepts the contact. From the coordination perspective, it is important that with the wholesale price contract the supplier can get at most one half of the channel first-best profit. We then derive a mechanism that is optimal for the supplier. This mechanism can take the form of a two-part tariff (TPT), or a minimum-order-quantity (MOQ) contract. It is conditionally efficient, that is, if accepted, it results in the first-best channel profit. However, it also implies rejections and, therefore, inefficiency. For the supplier, considering a choice between a wholesale price contract and an optimal contract, the latter turns out to be a dominant choice. By choosing it, the supplier can ensure at least a half of the channel first-best profit, whereas relying on a wholesale price contract the supplier can get at most one half of the first-best profit. Overall, our theory suggests that under incomplete information about fairness the supplier is likely to use the optimal contract rather than the wholesale price contract.

Our experimental design serves two purposes. One goal is to compare performance of the wholesale price contract and the optimal contract. Thus, it includes treatments that allow to measure and compare their performance. Although, as in other studies (ex. Ho

& Zhang (2008)), a coordinating contract fails to coordinate the channel, the supplier still makes higher profit with a coordinating contract. Consistent with our theory, the wholesale price contract almost never gets rejected when the retailers have no outside option, whereas introduction of an outside option increases the rejection rate. Another goal is to discriminate between our theory and theories assuming bounded rationality. The latter predict inefficiencies due to "errors" of both the supplier and the retailer. That is, the contracting parties are expected to choose the contract parameters suboptimally and "errors", made by the retailer, may lead to rejections. To investigate this type of predictions the experiment includes other treatments. First, one with an automated retailer programmed to play profit-maximizing best-response. Under these circumstances, human suppliers show almost no "noisy" behavior and reveal no fairness concerns. They quickly learn how to maximize their profit and perfectly coordinate the channel. Another treatment allows testing bounded rationality as the cause of rejections directly. Here, human retailers can refuse to trade but cannot enforce fair outcomes by rejecting a contract (so that both parties would make zero profit). In a case of rejection the retailer makes zero profit but the supplier receives a decision that maximizes the retailer's profit. The data provides virtually no support for bounded rationality. The retailers overwhelmingly accept offers as long as they can make any positive profit, no matter how small. Similarly to the treatment with the computerized retailers, suppliers quickly learn how to maximize their profits, coordinate the channel and show very little propensity to treat the retailers fairly. In contrast, in those treatments where the retailers can enforce fair outcomes (by rejecting a contract) the amount of rejections is dramatically different and bounded rationality does not explain this.

The rest of this Chapter is organized as follows. Section 2.2 presents a review of relevant literature. Section 2.3 develops a model of channel coordination when parties are fair-minded but their fairness concerns are private information. Section 2.4 describes the experimental design, protocol, hypotheses and results. Section 2.5 summarizes the paper, offers directions for future research, and discusses managerial implications of this work.

2.2 Literature review

The first analysis of bilateral monopoly that illustrates Double Marginalization is due to Bowley (1928). In a supplier-retailer supply chain use of a wholesale price contract leads to the inefficient outcome. Since then, many studies addressed this problem and a variety of contacting arrangements that overcome Double Marginalization followed. For the comprehensive reviews of such schemes, known as coordinating contracts, see Tsay et al. (1998) and Cachon (2003). For example, quantity discount (Jeuland & Shugan (1983)), two-part-tariff (Moorthy (1987)), buyback- (Pasternak (1985)) and revenue-sharing contracts, when appropriately constructed, induce the decentralized decision-makers to make decisions maximizing the total profit of the supply chain.

Started only recently, the experimental studies of coordinating contracts produced two main results consistent across different experiments (ex., Lim & Ho (2007) and Ho & Zhang (2008)). First, the coordinating contracts fail to coordinate the channel and, to a large extent, this failure is due to the rejections. Second, the distribution of the channel profit was more equitable than the standard theory predicts. As a main result of these experiments, it became clear that profit-maximizing behavior cannot explain the outcomes and there are behavioral factors making significant impact.

One way towards a theory that could better explain the experimental data is to abstract from the exact nature of behavioral factors. Thus, bounded rationality hypothesis (building on Thurstone (1927), Luce (1959) and McFadden (1974)) postulates that, because of different factors, hidden for an outside observer, people seem to behave as though they are prone to make random mistakes but the probability of any particular choice is proportional to the amount of utility one derives from this choice. In Game Theory literature, McKelvey & Palfrey (1995) operationalize this idea by the concept of Quantal Response Equilibrium (QRE). However, despite bounded rationality hypothesis proved useful and powerful in many settings (ex. see Su (2008), Bruyn & Bolton (2008) and references therein), there is empirical data that this hypothesis alone cannot explain. For example, in the Ultimatum Game experiments (see Guth et al. (1982)), the responders reject offers that give them below 30% of the "pie" with probability close to one (see Roth et al. (1991)). However, according to the bounded rationality view, any positive offer should be accepted with the probability exceeding 1/2. Bolton & Zwick (1995) demonstrate clear limitations of explanatory power of bounded rationality hypothesis experimentally. They modify the Ultimatum Game by removing the responder's option to punish the proposer by rejecting an offer and find that lacking a possibility to enforce a fair "both get nothing" outcome, the responders behave as profit-maximizers. Lim & Ho (2007) come to the same conclusion analyzing their contracting experiment. Fitting a random utility model to the data, they find that bounded rationality alone does not have much explanatory power.

The opposite approach is to identify specific factors driving contracting outcomes and introduce them into theory explicitly. Thus, Ho & Zhang (2008) report from their experiment that loss-aversion is one of those factors and propose an analytical model that allows for loss-aversion. Loch & Wu (2008), also in experiment, find that general social preferences, such as status and partnership also significantly affect contracting outcomes. Yet, by now, there seem to be a consensus, at least in the economics literature, that a key factor in nearly all bargaining situations has to do with the relative outcomes. Not in the least part it is due to Ochs & Roth (1989) who demonstrated that subjects frequently prefer smaller but more equitable outcomes to the bigger, but unfair ones. In other words, people clearly care about fairness. For a comprehensive review of history and research in this direction, see Fehr et al. (n.d.). Bolton (1991) was the first to propose an analytical model that incorporates fairness concerns. Further on, Fehr & Schmidt (1999) and Charness & Rabin (2002) proposed the alternatives. Bruyn & Bolton (2008) compare several models that account both for fairness and bounded rationality and fit them to the existing experimental data on the Ultimatum Game. They find not only that the fairness-based models provide an excellent fit but also that such models have significant out-of-sample (i.e. predictive) power. Cui et al. (2007) propose an analytic model of contracting in presence of fairness concerns and find that the impact of fairness on contracting outcomes can be as big that a wholesale price contract, a classic cause of Double Marginalization, can coordinate the channel.

However, neither the model of Cui et al. (2007) nor that of Fehr & Schmidt (1999) nor that of Charness & Rabin (2002)) can explain rejections in contracting. The reason is that those models are models of complete information. To explain rejections, one could extend these models by incorporating bounded rationality, as Bruyn & Bolton (2008) did. Alternatively, as Forsythe et al. (1994) and Bolton & Ockenfels (2000) argue, how much players care about fairness is their private information, there is heterogeneity and, therefore, this is a problem of incomplete information. However, they do not propose any specific model. The model of this chapter is aiming to fill the gap.

2.3 Analytical Results

The model we develop below seeks to explain several regularities of contracting experiments that standard theory fails to explain. These are, primarily, more equitable profit split and rejections. By incorporating fairness considerations into a standard complete information model one can explain equitable outcomes but not rejections (because the party proposing a contract can always make an offer that the other party will just barely accept). By extending the standard model via incorporating probabilistic choice (QRE) one can predict rejections but not dramatically different rejection rates under circumstances that differ in only one respect: whether fair outcomes can be enforced or not. At the same time, a model with incomplete information about preferences for fairness can explain both.

2.3.1 The model

We consider a bilateral monopoly setting with a supplier, who produces an infinitely divisible good at constant cost c per unit, and a retailer, who faces a linear demand function $q = d(p) = A - Bp$. For the reader's convenience, we use notation that seems most common. Thus, q is the amount of product sold, p is the market price, A and B are market constants. The supplier moves first and makes a take-it-or-leave-it offer to the retailer. The retailer either accepts the contract or rejects. Introducing fairness concerns into the model involves two modifications of the standard model, which assumes that both players care only about their own earnings. First, fairness concerns must enter the utility functions. To this end, we use Fehr & Schmidt (1999) two-player specification, that is the same specification used by Cui et al. (2007) with the assumption that the fair outcome, which Cui et al. (2007)

allow to be an arbitrary fraction γ, is the equal split. Let π_R and π_S denote the retailer's and the supplier's profit resulting from the retailer's acceptance or rejection of a contract. Then, the retailer's utility (the supplier's utility is analogous) is

$$U(\pi_R, \pi_S|\alpha, \beta) = U_R = \pi_R - \alpha\left[\max\left(\pi_S - \pi_R, 0\right)\right] - \beta\left[\max\left(\pi_R - \pi_S, 0\right)\right]. \tag{2.1}$$

Here, $\alpha \geq 0$ measures the retailer's disutility from earning less than the supplier (the disadvantageous inequality), and $\beta \geq 0$ measures the retailer's disutility from earning more than the supplier (the advantageous inequality). Previous research (Bolton (1991), Forsythe et al. (1994), Fehr & Schmidt (1999), Bruyn & Bolton (2008)) suggest that amount of positive reciprocity is very small so that it might be sufficient to consider a limiting case of $\beta = 0$. However, keeping in mind importance of positive reciprocity (Loch & Wu (2008), Cui et al. (2007)) on supply chain performance, we consider general case. We should mention, though, that in our experiment subjects also show very little positive reciprocity .

Second, the extent to which a particular retailer is concerned with the relative outcomes is this retailer's private information. Therefore, we proceed with the information asymmetry model following the approach of Bolton & Ockenfels (2000) to model bargaining as a Bayesian game, where players' types reflect their social preferences. Specifically, we assume that when the supplier offers a contract he knows only distributions of α and β but not their realizations that are private information of the retailer. Since the retailer moves second, it is irrelevant what she knows about the supplier's preferences. She makes her decision under complete information. As is common in the information asymmetry literature, we refer to the pair of individual characteristics of a player (α, β) as a type. Yet, for brevity, most of our statements refer to only α or β, implying that the other can be anything. Subscripts and superscripts used throughout the chapter are self-explanatory. For example, FB stands for "first-best".

In the rest of this section we proceed as follows. First, motivated by the Cui et al. (2007) finding that a wholesale contract can coordinate the channel, we study how this changes with information asymmetry in order to see if this contract could be appealing to the supplier. Interestingly, many of the properties of the wholesale price contract carry over to the setting with information asymmetry and, moreover, are almost distribution-free. In particular, this contract can still coordinate the channel under certain conditions and, regardless of how strongly the retailer is concerned about unfair outcomes, and what the supplier knows about the retailer's attitude towards fairness, the contract never gets rejected. For the sake of expositional convenience, we conduct a detailed analysis of a limiting case of a profit-maximizing supplier. Then, exploiting the fact that the utility of a supplier with fairness concerns never exceeds his profit, we are able to make use of these results in a general case of the utility-maximizing supplier. Second, we characterize a supplier's optimal contract and show that from the supplier's perspective, it is a dominant choice over a wholesale price contract. Similarly to wholesale pricing, aversion to unfair outcomes facilitates coordination here as well. If the supplier is sufficiently averse to advantageous inequality, he will offer a contract that coordinates. Otherwise, we demonstrate general impossibility of coordination.

2.3.2 The wholesale price contract

Under the wholesale price contract the supplier offers a uniform price w per unit, the retailer chooses market price p and orders $q = d(p)$. As a result, the supplier earns $\pi_S = (w - c)\, d\,(p)$ and the retailer earns $\pi_R = (p - w)\, d\,(p)$. If the retailer rejects, by ordering $q = 0$, both earn zero. For the time being we assume that neither party has an outside option but we will later relax this assumption. To characterize an equilibrium of this sequential-moves game, we use backward induction. That is, we need to look at the retailer's decision first and then analyze the supplier's decision in the light of the retailer's best-response. For the retailer, since she makes the decision under complete information, one can directly apply results of Cui et al. (2007) without re-deriving them (and using $\gamma = 1$):

$$p(w) = \begin{cases} \frac{A+Bw}{2B} - \frac{\beta(w-c)}{2(1-\beta)} & if \quad w \leq w_2 \\ 2w - c & if \quad w_2 < w \leq w_1 \\ \frac{A+Bw}{2B} + \frac{\alpha(w-c)}{2(1+\alpha)} & if \quad w_1 < w \leq w_0 \\ \frac{A}{B} & if \quad w_0 < w \end{cases}, \tag{2.2}$$

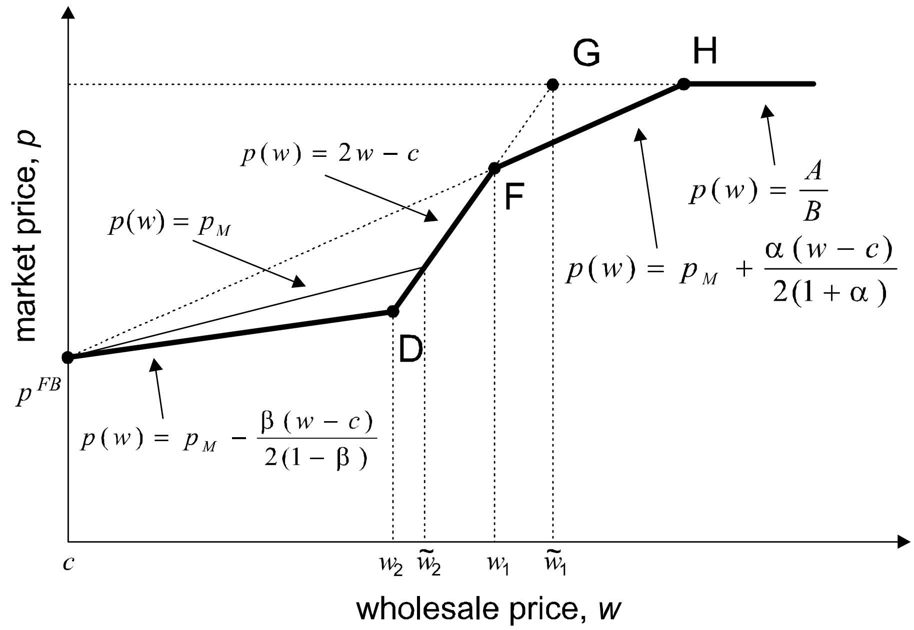

Figure 2.1: The retailer's best-response.

where

$$w_0 = \frac{A + A\alpha + B\alpha c}{B(1+2\alpha)} > w_1 = \frac{A + 2Bc + \alpha(A + Bc)}{B(3+2\alpha)} > w_2 = \frac{A + 2Bc - \beta(A + Bc)}{B(3-2\beta)}$$

Expression (2.2) is piecewise linear and consists of several parts. For $w < w_2$, the best-response price is lower than that of a profit-maximizing retailer. When $w_2 < w < w_1$ the retailer chooses market price that results in 50-50 profit split. If $w > w_1$ the retailer sets a price higher than a profit-maximizer would do. The offer may even get rejected (if $w > w_0$), what would never happen under complete information. An observation that proves convenient is that the behavior of the best response when $w > w_1$ as well as the value of w_1 itself do not depend on β and, similarly neither w_2 nor the behavior of the best-response when $w < w_2$ depend on α.

We plotted this best-response price of a retailer for arbitrary α and β in Figure 2.1 with a thick solid line, which is piecewise linear and consists of several parts. For $w < w_2$, the best-response price is lower than that of a retailer without fairness concerns because the retailer acts under the advantageous inequality. Segment DF corresponds to the 50/50 split. On FH segment the retailer chooses the price above the price that a profit-maximizing retailer would choose. Finally, the line to the right to point H corresponds to zero order quantity. When w is above the $w-$coordinate of the point H, the retailer is better off rejecting such offers because a rejection results in zero utility, whereas any $q > 0$ results in negative utility.

Note that the locations of points F and H depend on α. As α goes from zero to infinity, point F moves along 50/50 line from point D to point G and point H moves to G. Denote the $w-$coordinate of point D when $\beta = 0$ and the $w-$coordinate of point G as

$$\tilde{w}_2 \equiv w_2|_{\beta=0} = w_1|_{\alpha=0} = \frac{A+2Bc}{3B} \text{ and } \tilde{w}_1 \equiv w_1|_{\alpha=\infty} = \frac{A+Bc}{2B}. \tag{2.3}$$

One can verify that $\tilde{w}_2$ is the only wholesale price that induces any retailer, regardless of α and β, to respond with a 50-50 profit split, whereas $\tilde{w}_1$ is the supplier's optimal price if the retailer were a pure profit-maximizer.

Notice, Cui et al. (2007) assume $\beta \in [0, 1)$. However, extending the analysis to $\beta \geq 1$ is straightforward and, although (2.2) assumes $\beta \in [0, 1)$, all further statements made regarding "big" values of β, for example $\beta \geq \frac{1}{2}$, mean $\frac{1}{2} \leq \beta \leq \infty$.

The equilibrium

The complete information equilibrium has a number of properties. In particular, it is never optimal for the supplier to set $w > \tilde{w}_1$, the retailer's profit share is at least as big as when the retailer does not have any fairness concerns but, most importantly, as soon as the retailer is sufficiently averse to the advantageous inequality, the wholesale contract coordinates the channel. And, of course, there are no rejections. Interestingly, these properties remain valid under incomplete information also.

At this point it is convenient to make some observations that facilitate further proofs.

Lemma 1 *For any fixed w, (i) the retailer's best response price is (weakly) increasing in α, whereas (ii), the supplier's profit is decreasing in α.*

Proof. The first part follows directly from (2.2). Therefore, the resulting market demand decreases in α and, since w is fixed, the supplier's profit decreases also. ■

Other things being equal, when $\beta = 0$, the supplier is better off by dealing with less fair-minded retailers and would only benefit if all retailers were profit-maximizers ($\alpha = 0$). In this case, the supplier setting $w > \tilde{w}_2$ earns more than the retailer and (a well known standard result) by charging the optimal wholesale price $w = \tilde{w}_1$ the supplier earns $\pi_S = \frac{(A-Bc)^2}{8B}$, a half of the channel first-best profit. However, since we are considering a general case when types $\alpha \neq 0$ have non-zero measure, Lemma 1 has the following corollary:

Corollary 4 *If the supplier charges $w \geq \tilde{w}_2$, his profit is strictly less than a half of the first-best channel profit.*

Thus, the only (if any) possibility for the supplier to obtain a half of the first-best profit is by means of w that induces 50-50 profit split. The result coming from Cui et al. (2007) specifies conditions when this is possible under complete information. We only reformulate it allowing for the incomplete information and, for the reader's convenience, provide a brief proof.

Proposition 6 *(Cui et al. (2007)) The wholesale price contract coordinates the channel under incomplete information if and only if all the retailer's types are sufficiently averse to the advantageous inequity: $\beta \geq \frac{1}{2}$.*

Proof. Given Corollary 4, it follows that with a wholesale price contract the supplier can get at most one half of first-best channel profit. By setting $w = w^{FB} : (p^{FB} - w^{FB}) = (w^{FB} - c)$ the supplier induces all types $\beta \geq \frac{1}{2}$ to respond with $q = q^{FB}$ and obtains exactly a half of it. Since there are no any other types, $w = w^{FB}$ coordinates the channel. ■

Another important property of the wholesale price contract that is of interest on its own is its robustness to the supplier's ignorance. As the next proposition shows, regardless whether the supplier knows the true distribution of the retailer's type or holds an absolutely wrong belief, the price he sets according to his belief incurs no rejections.

Proposition 7 *Incomplete information does not affect rejection rate. In the equilibrium, the supplier charges $w \leq \tilde{w}_1$ and sees no rejections.*

Proof. First, consider the supplier's profit from dealing with an arbitrary retailer's type α if the supplier raises the wholesale price from $\tilde{w}_1$ to $\tilde{w}_1 + \delta$ (where $\delta > 0$) . The retailer, if α is big enough, may reject the offer so that the supplier incurs a loss. If not, the result will be (using (2.2)):

$$\pi_S(\tilde{w}_1 + \delta) - \pi_S(\tilde{w}_1) = -\frac{1}{2}\frac{\delta}{\alpha + 1}\left(\alpha(A - Bc) + B\delta(1 + 2\alpha)\right).$$

Since the RHS is negative $\forall\alpha$, setting $w > \tilde{w}_1$ is not optimal.

Second, from (2.2), the retailer's best-response price is increasing in α and decreasing in β. Therefore, the type most prone to rejecting has $\alpha = \infty$ and $\beta = 0$, its best-response is increasing in w, and the lowest wholesale price that this type rejects is $w = \tilde{w}_1$. However, this is the only type that rejects $w = \tilde{w}_1$ and its measure is zero. But, as we have just proven above, in the equilibrium $w \leq \tilde{w}_1$. Therefore, the equilibrium rejection rate is zero. Since this proof does not assume knowledge of the true distribution of the retailer's type, it holds for any belief the supplier may have. ■

In reality, the rejection rate may be positive because of various factors left outside of the model. For example, there usually exists some minimum tradable amount (a box, a pallet, ...) so that when w is close enough to $\tilde{w}_1$ the retailer's best-response order quantity may be smaller than the minimum tradable amount and the rejection results. In our experiment, the minimum tradable amount was not an issue but we still see that some (less than 2%) percentage of offers gets rejected even when w does not exceed $\tilde{w}_1$. A more accurate model, less subject to such residual discrepancies, could be developed in two ways. First, introducing non-linear terms into the retailer's utility should make the model more precise. Second, when w is close to $\tilde{w}_1$ and α is high, the retailer's best-response order quantity, as well as the resulting utility, may be very small. Therefore, other forms of bounded rationality, assumed away in the model, are likely to start playing a role and may lead to rejections. Following the usual QRE approach, one can allow for other behavioral factors by including an extra random term into the utility function (for a recent example see Su (2008)). Another (may be even more substantial) reason for rejections is the retailer's outside option.

Proposition 8 *If the retailer has an outside option $R > 0$ (in terms of utility), then due to incomplete information, the rejection rate can be positive.*

Proof. The type most prone to rejections is $\alpha = \infty$ and for any w that lies between $\tilde{w}_2$ and $\tilde{w}_1$ she chooses the market price on the 50-50 line (where $p = 2w - c$). Therefore, the retailer's utility equals to her profit and the offer gets rejected when the wholesale price is high enough so that

$$\pi_R = (A + Bc - 2Bw)(w - c) < R$$

The cut-off wholesale price, $\hat{w}$, is given by the larger root of the quadratic equation

$$(A + Bc - 2Bw)(w - c) = R.$$

However, $w > \hat{w}$ gets rejected not only by the type $\alpha = \infty$ but also, since the retailer's utility (from (2.1) and (2.2)) is continuous and decreasing in both α and w, by a non-zero measure of sufficiently high types. ∎

To illustrate this proposition, start with a standard model of the profit-maximizing retailer ($\alpha \equiv 0$,$\beta \equiv 0$). The supplier's optimal offer is $w = \tilde{w}_1$. Next, consider a modification: apart from $\alpha = 0$, there is a very (arbitrary) small $\epsilon > 0$ mass of types close to $\alpha = \infty$. To ensure their participation the supplier would have to offer $\hat{w}$ but this is not optimal because the overwhelming majority has $\alpha = 0$. Therefore, the supplier's optimal offer is still $w = \tilde{w}_1$ and implies the rejection rate of $\epsilon > 0$.

An approximate characterization of the equilibrium

Although the results we obtained above address our research questions to the degree we need, in particular we observed impossibility of coordination unless the retailers are sufficiently fair-minded, we found it possible to shed more light on efficiency of wholesale pricing under incomplete information regarding preferences for fairness. Propositions presented in this section relate to the approximate characterization only but for brevity statements do not include words "approximate characterization".

Moving from one extreme, when the retailers are strongly averse to disadvantageous inequality, to another, when aversion to unfair outcomes is mild, one can derive an approximate characterization of the equilibrium. To this end, consider the case when almost all density of the type distribution is concentrated around zero. Clearly, in the case, the optimal wholesale price will be close to $\tilde{w}_1$ and the proportion of types that respond to this price on the 50-50 line will be very small. That is, under this assumption, most of the retailers respond with

$$p_L(w) = \frac{A + Bw}{2B} + \frac{\alpha\,(w - c)}{2\,(1 + \alpha)}, \tag{2.4}$$

where subscript L stands for "low aversion".

Under these conditions, the supplier may solve an approximate problem:

$$\begin{aligned}
&\max_{w}(w - c)E\left[d(p(w))\right] \\
&s.t. \\
&p_L(w) = \frac{A + Bw}{2B} + \frac{\alpha\,(w - c)}{2\,(1 + \alpha)}.
\end{aligned}$$

To solve this problem, first eliminate the constraint by substituting $p(w)$ into the objective function

$$d(p_L(w)) = \frac{A - Bw}{2} - \frac{B\,(w - c)}{2}\frac{\alpha}{\alpha + 1}.$$

Notice that, when $\alpha > 0$ the ratio $\frac{\alpha}{\alpha+1}$ is concave for $\alpha > 0$ and, by Jensen's inequality,

$$\begin{aligned}
E\left[d(p_L(w))\right] &= \frac{A - Bw}{2} - \frac{B\,(w - c)}{2}E\left[\frac{\alpha}{\alpha + 1}\right] \\
&> \frac{A - Bw}{2} - \frac{B\,(w - c)}{2}\frac{E\left[\alpha\right]}{E\left[\alpha\right] + 1}.
\end{aligned}$$

Thus, one may equivalently think of a supplier facing a representative retailer with $\alpha' < E[\alpha]$ such that $\frac{\alpha'}{\alpha'+1} = E\left[\frac{\alpha}{\alpha+1}\right]$.

Next, it is straightforward to show that the optimal wholesale price is given by

$$w_L = \frac{A + Bc}{2B} - \frac{(A - Bc)\alpha'}{2B(1 + 2\alpha')} \tag{2.5}$$

and, in particular, is highest when $\alpha' = 0$. That is, the supplier charges the highest wholesale price when she thinks she is dealing with a profit-maximizing retailer.

Given this wholesale price, a retailer will respond with a market price that depends on her value of the fairness parameter α and this permits to obtain another results, the expected market price.

Proposition 9 *If the supplier knows the distribution of the fairness parameter then the expected market price under the resulting contract equals to that of the wholesale price contract when the retailer is a profit-maximizer.*

Proof. Substituting 2.5 into 2.4and taking the expectation gives

$$E[p_L] = \frac{1}{4B}\left(3A + Bc\right),$$

which can be recognized as the retail price under the wholesale price contract without fairness considerations. ■

We would like to mention that this result is not as strong as the previous one. It assumes that the supplier, in fact, knows the distribution of the fairness parameter.

However, knowing the expected market price is not enough to make any conclusions regarding channel efficiency. The next proposition covers the gap.

Proposition 10 *The expected efficiency of the wholesale contract is lower when the retailer is fair-minded.*

Proof. The realized channel profit is given by

$$\pi_C = (p_L(w_L) - c)d(p_L(w_L)).$$

Taking the expectation one obtains

$$E[\pi_C] = \frac{3\left(A - Bc\right)^2}{16B}\left(1 - \frac{Var[\frac{\alpha}{1+\alpha}]}{3\left(E[\frac{\alpha}{1+\alpha}] + 1\right)^2}\right).$$

In this product, the first term (factor) is exactly the channel profit when the retailer is a profit-maximizer and the second term (factor), which is due to the distribution of the fairness parameter, is less than unity. ∎

We would like to make two observations at this point. First, notice that the negative term in the last expression is likely to be small. The reason is that its numerator, $Var[\frac{\alpha}{1+\alpha}]$, tends to be a small number, compared to the denominator, and, therefore, the impact of the second term, if not completely negligible, can be difficult to detect in an experiment. In numerical simulations with uniform, exponential and truncated normal (to ensure positive values of α) typical values of the second factor are of 10^{-4} or 10^{-3} order of magnitude and we could not find a combination of parameters that would make it bigger that 0.02. In fact, it is a remarkable observation. The efficiency does depend on the distribution of the fairness coefficient but its impact on the efficiency is practically negligible regardless of the distribution form.

Although the results obtained in this approximation are very intuitive and well anticipated they provide more formal support for intuition.

2.3.3 The supplier's choice of a contract

Regarding the supplier, as it follows from the previous analysis (Corollary 4 and Proposition 6), the most important implication of wholesale pricing is that the supplier's profit cannot exceed one half of the channel first-best profit. Of course, wholesale pricing is not the only option available to the supplier. He might also consider more flexible contracts, such as a general quantity-discount contract or a multi-block tariff or even an extreme case of a two-block tariff, a minimum order quantity (MOQ) contract. Our further analysis proceeds as follows. First, we show that the supplier is at least as well off by using contracts that are more flexible than wholesale pricing, as with wholesale pricing. Second, we focus on implications of fairness concerns for coordination. We show that although the supplier will coordinate the channel when he is sufficiently averse to advantageous inequality, coordination may not be possible otherwise. Our analysis covers both a discrete two-type case, which additionally serves as a useful illustration of some structural properties of the problem, as well as the continuous case, as presumably a more realistic one.

In what follows, we assume that the supplier's utility function has the same form as (2.1), only π_R and π_S are reversed. As we mentioned earlier, there is some empirical evidence that the suppliers act mostly as profit-maximizers. Furthermore, we directly test this assumption in our experiment and find that the suppliers do not significantly deviate from it. On the other hand, *a priori* they should be no different from the retailers and, therefore, we should give them the same consideration. In the analysis below we assume that the supplier's utility function has the same form as (2.1), only π_R and π_S change places. To distinguish the supplier's fairness parameters the retailers, we use subscripts S and R when necessary.

Flexible contracts: preliminary observations

Implications of using more flexible contracts are important because, as we will see shortly, the supplier is better off with flexible contracts than with wholesale pricing. The underlying reasoning is immediate, but to make it explicit, we present it as the following lemma.

Lemma 2 *Using flexible contracts, the supplier warrants himself at least one half of the first-best channel profit.*

Proof. Let $C^{FB/2} = \{q^{FB}, t^{FB/2}\}$ denote a contract with quantity equal to the first-best and the transfer sum that splits the channel profit equally between parties. Such a contract will always be accepted and each party will make exactly one half of the first-best channel profit. Note that $C^{FB/2}$ is a special case of a (pooling) contract, $C^P = \{q^{FB}, t\}$, which, in turn, is a special case of a general quantity-discount contract, $C^{QD} = \{q, t(q)\}$. Therefore, generally,

$$U_S(.|C^{QD^*}) \geq U_S(.|C^{P^*}) \geq U_S(.|C^{FB/2}) = \frac{1}{2}\pi_C^{FB},$$

where C^{QD^*} and C^{P^*} denote optimal contracts. ■

This implies that the supplier operates under advantageous inequality, while the retailer has to deal with disadvantageous inequality. Formally, we come to the following.

Corollary 5 *Under the optimal C^{P^*} and C^{QD^*} contracts, parameters α_S and β_R, along with their distributions, are irrelevant.*

These preliminary observations make two points. First, using flexible contracts, the supplier earns (both in terms of utility and profit) at least one half of the first-best channel profit and, as a consequence, the retailer acts under disadvantageous inequality. Second, wholesale pricing is inferior to flexible contracts. This property of wholesale pricing is not necessarily a bad news for coordination because fairness can still promote coordination.

Proposition 11 *When $\beta_S \geq \frac{1}{2}$, the supplier's optimal contract is $C^{FB/2}$.*

Proof. Suppose the supplier offers some arbitrary quantity discount contract, C^{QD}, and the retailer of type α chooses the quantity-transfer (q_α, t_α). The amount of utility that the supplier incurs from this deal is

$$U_S(q_\alpha, t_\alpha) = \pi_S - \beta\left(\pi_S - \pi_R\right) = \left(1 - \beta\right)\pi_S + \beta\pi_R.$$

When $\beta \geq \frac{1}{2}$, the marginal contribution of the supplier's profit is smaller than the marginal contribution of the retailer's profit since $(1 - \beta) \leq \beta$. Therefore, maximizing his utility, the supplier increases the retailer's share as much as possible, provided it does not exceed his own. That is, he makes $\pi_R = \pi_S$. Then, by choosing $q = q^{FB}$, he maximizes both terms. Finally, since this reasoning applies to all α, the optimal contract is $C^{FB/2}$. ■

Similarly to coordination under wholesale pricing, here both parties also share channel profit equally. Recall, coordination under wholesale pricing was driven by the retailer's aversion to the advantageous inequality. Here, it is driven by the supplier's aversion. However, when the supplier is not sufficiently concerned with treating the retailer fairly, coordination may not be possible.

Lemma 3 *Any separating contract is inefficient.*

Proof. By contradiction. Suppose there exists a separating contract, which is efficient, $\{q^{FB}, t\left(\alpha\right)\}$, such that type α' chooses $\{q^{FB}, t\left(\alpha'\right)\}$ and type α'' chooses $\{q^{FB}, t\left(\alpha''\right)\}$.

However, since the retailer's utility is decreasing in t, both types will choose the same contract with the smallest transfer. Therefore, contrary to our presumption, this contract is not separating. ■

Thus, the only (if any) possibility to attain efficiency is by means of a pooling contract. However, as we prove below, an optimal pooling contract may eliminate some too fair-minded types from participation, i.e., in general, it is also inefficient.

Contracting with a two-type retailer

This special case when the retailer's fairness parameter can take only two values is interesting not as much from the practical standpoint as from an academic perspective. In particular, it is useful in two regards. First, to establish a general impossibility result it suffices to prove it in a special case. Second, studying this simple case facilitates understanding of the structural properties of the problem at hand.

We assume there are two types of retailers, so $\alpha \in \{\alpha_l, \alpha_h\}$; $\alpha_l < \alpha_h$ (unobservable by the supplier), with probabilities ρ and $(1-\rho)$, respectively. In addition, since this part is not pursuing generality, we restrict the analysis to the profit-maximizing supplier.

Let (q_l, t_l) and (q_h, t_h) be the contracts meant to be chosen by the low- and high types, such that q_l, q_h are the order quantities and t_l, t_h the transfer payments from the retailer to the supplier. Suppose that the supplier wants both types to participate and, therefore, has to solve the following:

$$\max_{q_l,t_l,q_h,t_h} \rho\pi_S(q_l,t_l) + (1-\rho)\pi_S(q_h,t_h) \tag{2.6}$$

$$s.t.$$

$$U_R(q_l,t_l|\alpha_l) \geq 0 \tag{IRCl}$$

$$U_R(q_h,t_h|\alpha_h) \geq 0 \tag{IRCh}$$

$$U_R(q_l,t_l|\alpha_l) \geq U_R(q_h,t_h|\alpha_l) \tag{ICCl}$$

$$U_R(q_h,t_h|\alpha_h) \geq U_R(q_l,t_l|\alpha_h) \tag{ICCh}$$

Here we use notation $U_R(q,t|\alpha) \equiv U_R(\pi_R(q,t), \pi_S(q,t)|\alpha) \equiv (pq-t) + \alpha(pq-t-(t-cq))$

for a more concise exposition.

Lemma 4 *In the optimal contract IRCh and ICCl are binding.*

Proof. Suppose $\{q_l, t_l\}$ and $\{q_h, t_h\}$ are optimal. Then at least one of the participation constraints must be binding. Otherwise, it would be possible to increase the supplier's expected profit by increasing both t_l and t_h without violating any of the ICC. Changing α_l to α_h in the RHS of the ICCl does not increase the RHS and implies the following:

$$(p_l q_l - t_l) + \alpha_l(p_l q_l - t_l - (t_l - cq_l)) \geq (p_h q_h - t_h) + \alpha_h(p_h q_h - t_h - (t_h - cq_h)) \Leftrightarrow$$
$$U_R(q_l, t_l|\alpha_l) \geq U_R(q_h, t_h|\alpha_h). \tag{2.7}$$

Therefore, by the last inequality, IRCh is binding.

Next, in case the optimal contract is pooling, ICCl is trivially binding. Suppose the optimal contact is separating. In case $\pi_S(q_h, t_h) > 0$, it follows from (2.7) that (IRCl) is not binding. Then, the other constraints that contain t_l are ICCl and ICCh (after rearranging the terms):

$$p_l q_l (\alpha_l + 1) + c\alpha_l q_l - (2\alpha_l + 1) t_l \geq 0 p_h q_h (\alpha_l + 1) + c\alpha_l q_h - (2\alpha_l + 1) t_h$$
$$p_h q_h (\alpha_h + 1) + c\alpha_h q_h - (2\alpha_h + 1)t_h \geq p_l q_l (\alpha_h + 1) + c\alpha_h q_l - (2\alpha_h + 1)t_l.$$

Since, by increasing t_l, one can only violate the first of the two constraints, it must be binding. Otherwise, t_l would not be optimal. In case $\pi_S(q_h, t_h) = 0$, (recall, IRCh is binding) either $p_h = c$ or $p_h = \frac{A}{B}$, i.e. the supplier "shuts down" high types and deals with low types only. Therefore, ICCl reduces to IRCl and, since t_l is optimal, both are binding. ■

Intuitively, whether the optimal contract is pooling or not, should depend on the proportion of low types. When it is high enough, it may be better for the supplier to deal with low (efficient) types only, extracting their entire surplus.

Proposition 12 *In the optimal separating contract* $\pi_S(q_h, t_h) = 0$.

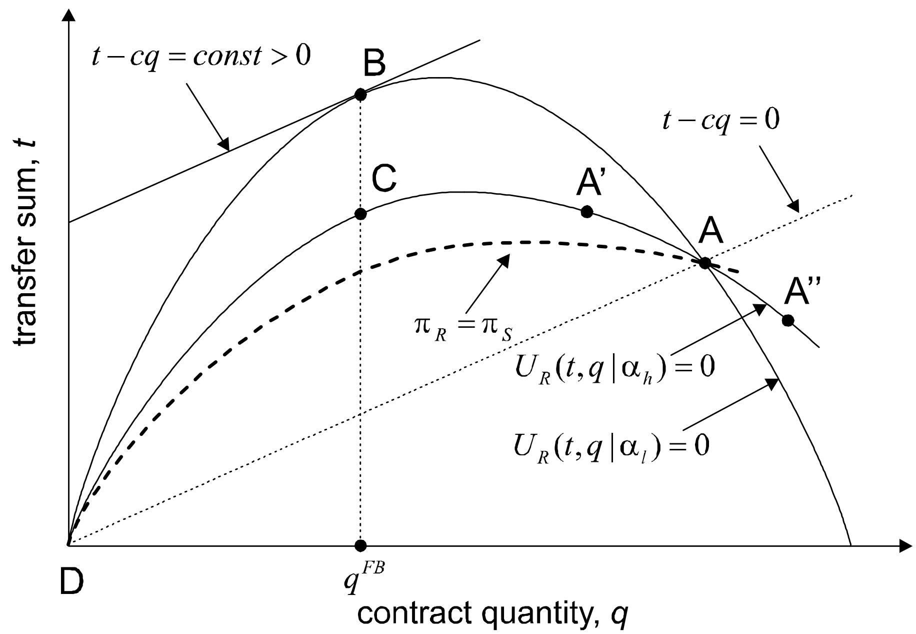

Figure 2.2: Indifference curves and possible contracts

Proof. The result obtains by using results of Lemma (4) to solve (2.6) with the Lagrange method. ■

That is, the optimal contact has a "bang-bang" property. It can only be either pooling or separating with a complete shutdown of high (inefficient) types. In fact, under very special circumstances, these two contracts may be equally good for the supplier. However, such circumstances are rather peculiar and provide virtually no useful insight. Having made this reservation, we are going to ignore this possibility further.

To illustrate the intuition behind these findings we refer to Figure 2.2. The supplier's indifference curves are straight lines $t - cq = const$ (their slope equals to c). Thus, supplier's profit increases as we move northwest. The lower solid-line parabola is the indifference curve $U_R(q, t|\alpha_h) = 0$ and the upper solid line parabola is the indifference curve $U_R(q, t|\alpha_l) = 0$. Retailer's utility increases as we move down. Note that all indifference curves $U_R(q, t|\alpha_l)$ and $U_R(q, t|\alpha_h)$ intersect at points D (the origin) and A (where $t = cq, p = c$ and profits are zero) regardless of the value of α and indifference curves corresponding to higher types are flatter. The dashed parabola is the 50-50 curve. The slope of the indifference curve for the retailer with the fairness coefficient α equals to

$$-\frac{\frac{\partial U_R}{\partial q}}{\frac{\partial U_R}{\partial t}} = \frac{(A - Bc - 2q)(1+\alpha)}{B(1+2\alpha)} + c. \tag{2.8}$$

Note that the multiplier in front of the fraction turns to zero at $q = q^{FB} = \frac{1}{2}(A - Bc)$ and the slope at this point equals to c regardless of α.

Thinking of a separating contract, one possibility is a pair (B, A''). The low type chooses B, the high type chooses A'' and none has incentives to choose the opposite. However, offering A'' is not optimal for the supplier (negative profit). By offering A instead of A'' the supplier moves northwest and does strictly better (zero profit). However, moving further may not be optimal. Thus, offering A' would break this separating contract because the low type retailer would do strictly better by choosing A' rather than B. The supplier could, of course, prevent the low type retailer from switching to A' by offering an appropriately chosen contract somewhere between points B and C. However, by Proposition 12, this is not optimal. Thus, the best the supplier can do with a separating contract is to offer either A or D to high types and B to low types (there is nothing that might preclude the supplier from setting B at $q = q^{FB}$). Since the supplier's profit from contracts A and D is zero, the supplier might as well ignore them, that is shut down high types completely. Offering to the high types a contract which lies on the $U_R(q, t|\alpha_h) = 0$ anywhere strictly between D and A leads to a pooling contract. Clearly, in this case the best choice is C, where $q = q^{FB}$.

Overall, the supplier has only two options that can be optimal:

1. A pooling contract at C, where $q = q^{FB}$.

2. A separating contract with B and either A or D, which outcome is equivalent to dealing with low types only and setting $q = q^{FB}$.

In both cases $U_R(q, t|\alpha_h) = 0$. Thus, the optimal contract implies that (i) the high type gets zero utility from participation, (ii) both pairs (t, q) are located on the low type indifference curve and, (iii) $q_l = q^{FB}$. The choice depends on ρ, the proportion of low types. When ρ is big enough, the supplier will be better off with the separating contract.

Before we proceed to the case of the continuum of types recall that we have been assuming $\beta = 0$. However, for the purpose of comparing wholesale pricing with an optimal contract this is not a limiting assumption because of the following.

Proposition 13 *In the optimal contract the supplier's profit is no smaller than that of a participating retailer.*

Proof. Consider the highest type, α_h, that is participating in the optimal contract. The higher α_h, the higher profit share of the retailer. However, the contract that splits the channel profit evenly ensures participation of all possible types, even with $\alpha_h = \infty$. A more generous contact cannot increase participation but decreases the supplier's profit. Therefore, it is not optimal and the supplier will not offer a contract that might put the retailer under the advantageous inequality. Hence, the level of the retailer's positive reciprocity, β, is immaterial. ■

Contracting when the retailer's type is continuous and $\beta_S < \frac{1}{2}$

The distribution of parameter α_R is, of course, an empirical question. However, as of now, we are not aware of empirical evidence that might suggest anything specific. While the two-type case analyzed above is clearly an extreme, we consider it is relevant to assume the type is drawn from some generic continuous distribution with density $f(\alpha)$.

Referring to the revelation principle, there is no loss of generality in considering only direct truth-telling mechanisms and finding an optimal contract by solving the following problem:

$$\max_{q(\alpha,)t(\alpha),A} \int_A U_S(q(\alpha), t(\alpha)) f(\alpha) d\alpha \tag{2.9}$$

$$s.t. \forall \alpha \in A:$$

$$\alpha = \arg\max_x U_R(q(x), t(x) | \alpha)$$

$$U_R(q(\alpha), t(\alpha) | \alpha) \geq 0.$$

As a rule, solutions to similar problems reported elsewhere in the literature are non-linear and not very intuitive. In our case, despite the fact that marginal utilities for money of both players depend on their types, the optimal contract turns to be very simple.

Proposition 14 *The supplier's optimal contract is pooling and conditionally efficient (i.e. $q = q^{FB}$).*

Proof. Instead of solving (2.9) consider a relaxed problem:

$$\max_{t(\alpha),q(\alpha),\bar{\alpha}} \int_0^{\bar{\alpha}} U_S\left(q\left(\alpha\right), t\left(\alpha\right)\right) f\left(\alpha\right) d\alpha$$

$$s.t.$$

$$\left(\left(1+\alpha\right)\left(A+Bc-2q\left(\alpha\right)\right)-Bc\right)\frac{dq\left(\alpha\right)}{d\alpha} = B\left(1+2\alpha\right)\frac{dt\left(\alpha\right)}{d\alpha}$$

This is an optimal control problem with a constraint given by a differential equation. The upper limit of integration, $\bar{\alpha}$, is a free variable but we ignore this, assuming it is fixed, thus further simplifying the problem.

To begin, expand $U_S\left(q, t\right)$ and form the Lagrangian:

$$L = f\left(x\right)\left(\left(1-\beta\right)\left(t\left(x\right)-cq\left(x\right)\right)+\beta\left(\frac{A-q\left(x\right)}{B}q\left(x\right)-t\left(x\right)\right)\right)$$
$$+\lambda\left(x\right)\left(\left(\left(1+x\right)\left(A+Bc-2q\left(x\right)\right)-Bc\right)\dot{q}-B\left(1+2x\right)\dot{t}\right),$$

where $\dot{q} \equiv \frac{dq(x)}{dx}$, $\dot{t} \equiv \frac{dt(x)}{dx}$ and $\lambda\left(x\right)$ is a Lagrange multiplier. Then, under usual assumptions of differentiability, solve Euler-Lagrange equations:

$$\frac{d}{dx}\frac{\partial L}{\partial \dot{t}} - \frac{\partial L}{\partial t} = 0$$
$$\frac{d}{dx}\frac{\partial L}{\partial \dot{q}} - \frac{\partial L}{\partial q} = 0.$$

The first of these gives

$$f\left(x\right)\left(2\beta-1\right)-B\left(2\lambda\left(x\right)+\left(1+2x\right)\frac{d\lambda\left(x\right)}{dx}\right)=0, \tag{2.10}$$

whereas the second brings

$$\begin{aligned}&((A-2q(x)+Bc)(x+1)-Bc)\frac{d\lambda(x)}{dx}+\\&(A-2q(x)+Bc)\lambda(x)-\\&((A-2q(x)+Bc)\beta-Bc)\frac{f(x)}{B}=0.\end{aligned}\tag{2.11}$$

Solving (2.10) for $\frac{d\lambda(x)}{dx}$ and plugging the result into (2.11) gives

$$(A-Bc-2q(x))(f(x)(x-\beta+1)+B\lambda(x))=0.$$

This condition is satisfied when either

$$A-Bc-2q(x)=0,\tag{2.12}$$

i.e. $q=q^{FB}$, implying pooling, or

$$f(x)(1+x-\beta)+B\lambda(x)=0.\tag{2.13}$$

Next, substitution of $f(x)$ from (2.13) into (2.10) gives a differential equation for $\lambda(x)$,

$$\frac{1-2\beta}{1+x-\beta}\lambda(x)=\left(2\lambda(x)+(1+2x)\frac{d\lambda(x)}{dx}\right),$$

with the unique solution (up to a constant multiplier C_1)

$$\lambda(x)=\frac{C_1}{x-\beta+1}.$$

This, in turn, implies that

$$f(x)=-\frac{BC_1}{(x-\beta+1)^2}.\tag{2.14}$$

In other words, for this particular density function there exists an additional candidate solution. However, since this density function contains β, which is also a continuous random variable, the situation when the supplier faces the retailer whose type distribution exactly matches the supplier's type is a zero-probability event and can be safely ignored. Thus, the only viable solution is (2.12). ■

This proof relies on usual differentiability and continuity assumptions and, generally speaking, does not apply in the case when the distribution of types is discrete. For example, when the retailer's type can take only one of two values, one can demonstrate that under certain conditions there exists a separating contract which works for the supplier as well as the optimal pooling contract. However, as Proposition 14 shows, even the smallest diffusion of mass points destroys this equivalence, and, therefore, we do not analyze the discrete case.

While optimality of a pooling contract does not seem a straightforward result, conditional efficiency of an optimal pooling contract is intuitive. For any given q and t, the retailer's utility (2.1) is decreasing in α_R. Therefore, if type $\hat{\alpha}_R$ participates, so do all lower types, $\alpha_R < \hat{\alpha}_R$. Suppose $\hat{\alpha}_R$ is the highest participating type. Since the supplier's utility is increasing in t, his problem can be equivalently seen as a problem of choosing a point on the retailer's indifference curve $U_R(q, t|\hat{\alpha}_R) = 0$ that maximizes the utility that the supplier derives from dealing with this type. Clearly, it is point with $q = q^{FB}$.

Properties of the optimal pooling contract

Given optimality of a pooling contract, the supplier's problem reduces to a one-dimensional problem of finding an optimal transfer that maximizes the supplier's expected utility:

$$\max_t \tilde{U}_S(t) \equiv E[U_S(q^{FB}, t|\beta)] = U_S(q^{FB}, t|\beta) \Pr\left[U_R(q^{FB}, t|\alpha_R) \geq 0\right]. \tag{2.15}$$

Proposition 15 *In general, the optimal transfer eliminates some high types from participation and the supplier's expected utility is higher than one half of the first-best channel profit.*

Proof. Consider a case $\alpha \in [0, \infty)$. First, note that

$$\tilde{U}_S\left(t^{FB/2}\right) = \frac{\pi^{FB}}{2} > \tilde{U}_S\left(t^{FE}\right) = 0.$$

where $t^{FB/2}$ is the transfer that splits the channel profit equally and t^{FE} is the transfer that fully extracts the retailer's profit. Zero expected utility follows because t^{FE} makes the retailer's profit equal to zero and any retailer will surely reject such a contract unless $\alpha_R = 0$. Let $\hat{\alpha}(t)$ be a cut-off type for a given transfer: $U_R\left(q^{FB}, t|\alpha_R\right) \geq 0, \forall \alpha_R \leq \hat{\alpha}(t)$. From the definition of U_R follows that $\hat{\alpha}(t)$ is monotone decreasing and continuously differentiable. With our choice of the distribution support, $\hat{\alpha}(t^{FB/2}) = \infty$. Second, $\tilde{U}_S(t)$ is differentiable and

$$\left.\frac{d\tilde{U}_S(t)}{dt}\right|_{t=t^{FB/2}} =$$

$$= \left.\left(\frac{dU_S\left(q^{FB}, t|\beta\right)}{dt} F\left(\hat{\alpha}(t)\right) + U_S\left(q^{FB}, t|\beta\right) f\left(\hat{\alpha}(t)\right) \frac{d\hat{\alpha}(t)}{dt}\right)\right|_{t=t^{FB/2}}$$

$$= (1-2\beta) F(\infty)) + \frac{\pi^{FB/2}}{2} f(\infty) \frac{d\hat{\alpha}(t)}{dt}$$

$$= 1 - 2\beta > 0$$

because $F(\infty) = 1$ and $f(\infty) = 0$. Hence, it follows that $\tilde{U}_S(t)$ is maximized at some $t^* \in (t^{FB/2}, t^{FE})$ and $\tilde{U}_S(t^*) > \frac{\pi^{FB}}{2}$. This also implies $\hat{\alpha}(t^*) < \infty$, that is rejections. ■

Although this proof encompasses all possible cases of arbitrary finite supports and might seem very general, it requires continuity of $f(\alpha)$. Otherwise, as we will see below in the example with a uniform distribution, it does not apply.

Next, intuition suggests that in case the supplier is a pure profit-maximizer, the rejection rate may be higher than otherwise.

Proposition 16 *The rejection rate is highest when* $\beta_S = 0$.

Proof. Expanding $U_S\left(q^{FB}, t|\beta\right)$, re-write the objective function of (2.15):

$$\begin{aligned}&(1-\beta)(t - cq^{FB}) \Pr\left[U_R(t, q^{FB}|\alpha_R) \geq 0\right] \\ &+ \beta(p^{FB}q^{FB} - t) \Pr\left[U_R(t, q^{FB}|\alpha_R) \geq 0\right]\end{aligned} \tag{2.16}$$

When $\beta = 0$ this objective reduces to that of the profit-maximization problem, a special case of (2.15), which is maximized at some $t = t^P$ and its derivative at this point is zero.

In case $0 < \beta < \frac{1}{2}$, derivative of (2.16) is negative at any $t \geq t^P$ because the second term is monotone decreasing in t. Therefore, (2.16) is maximized at some $t^U < t^P$. Hence, rejection rate is highest when $\beta = 0$. ■

An appealing property of the optimal pooling contract is its simplicity. It can be implemented with just a minimum order quantity contract with $q_{min} = q^{FB}$ and the wholesale price w that makes the transfer sum $t = q_{min}(w - c)$ such that the highest participating type is indifferent between participating and not. This only requires to solve a one-dimensional maximization problem.

Efficiency of the optimal contract Since the optimal contract is conditionally efficient, that is, once accepted it results in the first-best channel profit, the only source of inefficiency are rejections. Specifically,

$$E[\pi_C] = \pi_C^{FB} \Pr\left[U_R(t^*|\alpha) \geq 0\right]$$

The probability of rejections depends on the distribution of α and needs not be low. Therefore, it is plausible that the efficiency of the optimal contract will not differ very much from that of the wholesale price contract. A direct comparison of the efficiency of these two contracts is complicated by the fact that the channel profit in both cases is distribution-dependent.

The numerical examples To give a sense of how the optimal contract may work in specific instances we provide several numerical examples.

Consider parameters we used in the experiment: $d(p) = 100 - p$ and $c = 20$. For these parameters, the first-best order quantity $q^{FB} = 40$, implying the retail price of $p = 100 - 40 = 60$. This implies the total supply chain revenue of $40 \times 60 = 2400$, the total supply chain cost of $40 \times 20 = 800$, and the total supply chain profit (to be divided between the two players) of $2400 - 800 = 1600$. With these parameter values and when the supplier is a profit-maximizer (as mainly supported by experiment data), (2.15) becomes

$$t^* = \arg\max_t (t - 800) \Pr\left[\alpha \leq \frac{2400 - t}{2\,(t - 1600)}\right]. \tag{2.17}$$

and can be solved as soon as the distribution of types is specified.

Uniform distribution. If the supplier believes the retailer's type is drawn from the uniform distribution, $U(0, h)$, finding the optimal transfer amounts to solving

$$\max_t (t - 800)\frac{1}{h}\int_0^{\frac{2400-t}{2(t-1600)}} dx$$

$$s.t.$$

$$\frac{2400 - t}{2\,(t - 1600)} \leq h.$$

The constraint appears in the formulation because the highest possible type is h and it cannot be optimal to ensure participation of higher types because they do not exist. In other words, the optimal transfer cannot be lower than it is needed to ensure participation of type h. Solving this problem, one can show that the constraint is always binding. This means that the supplier chooses a contract such that all types participate, regardless of h, implying zero rejections. Hence, in this example the optimal contract coordinates.

Gamma distribution. Now consider the gamma distribution with the scale parameter of $\frac{1}{4}$ and the shape parameter of 2. Solving the supplier's problem (here $F(.)$ denotes the cdf)

$$t^* = \arg\max_t (t - 800) F\left(\frac{2400 - t}{2\,(t - 1600)}; \frac{1}{4}, 2\right)$$

gives $t^* = 1870$. This corresponds to $w^* = 46.75$, the highest participating type $\alpha = 0.98$ and the rejection rate of $1 - F(0.98; \frac{1}{4}, 2) \approx 16\%$. These values are fairly close to our experimental observations and the rejection rate is also in-line with the Ho & Zhang (2008) and Lim & Ho (2007) rejection rates.

	standard theory	bounded rationality	fairness: Cui et al	fairness this theory
wholesale pricing	rejections $-$ efficiency $-$ fair $\pm$	rejections $+$ efficiency $-$ fair $\pm$	rejections $-$ efficiency ? fair $\pm$	rejections $-$ efficiency ? fair $\pm$
optimal contract	rejections $-$ efficiency $+$ fair $-$	rejections $+$ efficiency $-$ fair $\mp$	rejections $-$ efficiency $+$ fair $\mp$	rejections $+$ efficiency $-$ fair $\mp$
connotations:	$+$,$-$, $\pm$, $\mp$ and ? stand for "yes", "no", "somewhat", "a little", "may happen"			

Table 2.2: Predictions made by competitng theories

2.4 The experiment

2.4.1 Experimental design

The goal of the experiment was to test which of several competing theories best explains the outcomes of contracting experiments. Table 2.2 summarizes testable predictions those theories make.

Note, first of all, that both the standard theory and the theory of Cui et al. (2007) assume complete information about preferences and, therefore, predict that no rejections should ever happen. Therefore, in the case of the optimal contract both predict no rejections and full efficiency, whereas both bounded rationality and our theory predict rejections and efficiency loss. Thus, systematic rejections, or lack of thereof, can separate these two groups of theories. Relatively equal profit shares, if observed in the data, can separate the standard theory from the rest. The most challenging is the task to separate bounded rationality from our theory that assumes incomplete information. Both make somewhat similar predictions. To separate them, one needs to introduce conditions where fairness concerns play no role. A version of the optimal contract, with the eliminated option to enforce a fair zero-zero outcome by rejecting a profitable offer, accomplishes this task. Two different treatments, based on this approach, allow us to separate our theory and bounded rationality hypothesis. In one treatment, the retailers are human subjects. In another, a computer programmed as a profit-maximizer plays the retailer's role. Table 2.3 presents the design of the experiment,

	Can retailer reject a profitable offer?	
	Yes	No
Human retailer	WP WP-out MOQ	MOQ-D
Computerized retailer		MOQ-A

Table 2.3: The experimental design

consisting of five treatments.

Abbreviations, given in the table, denote treatments as following:

1. WP: a standard wholesale price contract.

2. WP-out: a wholesale price contract but the retailer has an outside option. This treatment tests our theory prediction that an outside option is likely to increase the rejection rate.

3. MOQ: a standard minimum-order quantity contract, optimal both under complete and incomplete information about preferences for fairness.

4. MOQ-D: by rejecting a profitable offer the retailer earns zero. For the supplier, such a rejection has no consequences. The computer steps in and responds in a way that would maximize the retailer's profit, i.e., accepts the offer. In the abbreviation, D stands for "Dictator[1]".

5. MOQ-A: the computer plays a profit-maximizing retailer. In the abbreviation, A stands for "Automated".

Together, MOQ and MOQ-D test bounded rationality theory, which predicts the same rejection rate in both treatments. Together, MOQ-A and MOQ-D test whether and how much the suppliers want to treat the retailers fairly.

[1]The "Dictator Game" is a simple bargaining game, similar to the Ultimatum Game. The difference between them is that in the former the responder have no say at all, simply collecting whatever the proposer gives. Our MOQ-D treatment is, in fact, closer to another modification of the Ultimatum Game, the "Impunity Game", studied by Bolton and Zwick (1995).

2.4.2 Experimental Protocol

In all treatments subjects played for 40 periods. Every subject participated in only one treatment. In MOQ-A computers played retailers and suppliers were human participants. In the beginning of MOQ, MOQ-D, WP and WP-out treatments subjects were randomly assigned a role (either a supplier or a retailer) and stayed in the same role during the experiment. In addition, participants were divided in groups of six and were randomly matched with some other person from the same group every period. Participants, mostly undergraduate students of different majors from the Penn State University, were recruited via on-line recruiting system.

Participants were paid according to the profits they made in the experiment. Average earnings were $25 but those who played suppliers, especially in MOQ-D treatment, earned significantly more than those who played retailers. The experiment took place at the Laboratory for Economic Management and Auctions (LEMA) at the Penn State Smeal College of business, during the Fall semester of 2007 and the Spring semester of 2008.

Upon arrival, participants took places in visually isolated cubicles in the computer laboratory, and read written instructions (see Appendix) describing the rules of the game. After all participants finished the reading, we read the instructions aloud, to insure common knowledge about the rules of the game. We also answered any questions at that point, prior to the start of the game.

We programmed the computer interface using the z-Tree system (Fischbacher (2007)). As a part of their computer interfaces, both the suppliers and the retailers had specialized calculators. For the suppliers, the calculator could compute and display, for any combination of q_{min} and w (only w in the wholesale price treatments) the retailer's profit-maximizing decision, and the resulting earnings for both players. Suppliers were free to try different combinations of of q_{min} and w as much as they wanted before submitting their final decision. For the retailers (in the MOQ and the wholesale price treatments) the calculator could compute, for any q they entered, the resulting earnings for both players. Retailers were free to try different q's as much as they wanted before submitting their final decision. They also had a "Reject" button that resulted in the earnings of 0 for the supplier and either

	WP & WP-out	MOQ, MOQ-A & MOQ-D
wholesale price, w	60	60
order quantity, q or $q_{\min}$	20	40
supplier's profit	800	1600
retailer's profit	400	0
rejection rate	0	0
efficiency	75%	100%

Table 2.4: Standard theory predictions

the earnings of 0, or 200 in the wholesale price treatment with the retailer outside option. Retailers in the MOQ-D treatment observed the q the computer entered on their behalf. They had an "Accept" and a "Reject" button. The "Reject" button did not affect the supplier's earnings but resulted in 0 earnings for the retailer.

2.4.3 Experimental Hypotheses

With the parameters chosen for the experiment, $A = 100, B = 1, c = 20$ the standard theory (which is convenient to use as a benchmark) makes predictions summarized in Table 2.4.

These baseline predictions constitute the first hypothesis.

Hypothesis 1. *The standard theory explains the data.*

Recall, the utility function, specified in the model, is asymmetric in the amount of disutility that players experience under advantageous and disadvantageous inequalities. Since retailers in the MOQ-A and MOQ-D treatments cannot punish the supplier for an unfair offer by rejecting an offer and making the supplier to earn zero, purely profit motivated suppliers should fully extract profits in both, the MOQ-A and MOQ-D treatments, but not in the MOQ treatment, where the retailer has the ability to reject small offers forcing the supplier to earn zero. Any positive offers in the MOQ-A treatment must be due to noise. These considerations give us the following:

Hypothesis 2. *The suppliers do not experience disutility from advantageous inequality and are not prone to making mistakes.*

A question of particular interest is whether rejections are a consequence of preference for fairness rather than errors. Retailers can reject offers in both, MOQ and MOQ-D treatments, but these rejections only punish suppliers in the MOQ treatment. The impact of a rejection on the retailer's profit is exactly the same in the two treatments, however, whereas the impact on the supplier's profit is dramatically different. This allows us to separate retailers' mistakes from the preference for fairness. If rejections occur because of fairness, the rejection rates should be higher in the MOQ treatment than in the MOQ-D treatment and higher in the WP-out treatment than in the WP treatment.

Hypothesis 3. *The retailers reject offers due to fairness concerns rather than by mistake.*

2.4.4 Experimental results

Table 2.5 (adopted from Katok & Pavlov (2009)) presents the results of our experiment. For convenience, the column "Standard Theory" contains predictions of the standard theory. Theoretical benchmarks for the wholesale price contract are reported in parenthesis. When a number on the top line of a cell is in bold font, it means that the variable is significantly different from its theoretical benchmark, at a 5% level.

Theoretical Benchmarks: Hypothesis 1

Since there is a significant amount of learning in our experiment, it is useful to compare our data with theoretical benchmarks both, at the beginning and at the end of the session. Below we summarize the analysis related to Hypothesis 1, comparing our data to theoretical benchmarks.

- In MOQ-A and MOQ-D (where retailers cannot punish the suppliers by rejections), a match between predictions of the standard theory and the data is nearly perfect. That is, the data lens strong support to Hypothesis 1.

- In all three MOQ treatments suppliers offer conditionally efficient contracts. When accepted, such a contract leads to the efficient outcome, and, if there were no rejections, it would coordinate. This also supports Hypothesis 1.

		Treatment				
Average (standard error)	Standard Theory‡	MOQ	MOQ-A	MOQ-D	WP	WP-Out
Wholesale Price (w)	60 (60)	**53.26 47.10** (1.93)	57.61 57.89 (1.24)	58.66 57.63 (1.78)	58.45 **52.17** (1.35)	**55.40 51.79** (1.18)
Minimum Order Quantity (q_{min})	40 (0)	34.65 38.85 (2.96)	38.63 42.09 (1.02)	38.99 40.14 (0.82)		
Order Quantity (q)	40 (20)	**25.35 32.41** (3.35)	38.40 42.03 (0.98)	38.27 40.47 (0.95)	**17.15** 20.60 (1.12)	19.07 20.73 (1.19)
Proportion of offers rejected	0 (0)	**0.29 0.17** (0.0683)	0.0094 0.0002 (0.0055)	**0.3354** 0.109 (0.0983)	**0.077** 0.000 (0.0221)	**0.161** 0.042 (0.0308)
Retailer's relative offer	0 (0.33)	**0.26 0.33** (0.0299)	**0.086** 0.000 (0.025)	**0.069** 0.052 (0.0342)	0.356 **0.427** (0.016)	**0.394 0.431** (0.015)
Efficiency ($\frac{\pi_S+\pi_R}{1600}$)	100% (75%)	**0.65 0.80** (0.0.0762)	**0.957** 0.99 (0.014)	**0.959** 1.02 (0.009)	**0.638** 0.737 (0.032)	**0.687** 0.754 (0.0301)
Supplier's Profit (π_S)	1600 (800)	**742.6 869.0** (99.1)	**1406** 1583 (49.2)	**1412** 1544 (55.8)	**626.1 653.6** (24.2)	**615.9 656.0** (24.4)
Retailer's Profit (π_R)	0 (400)	**309.2 413.8** (54.7)	**125.3** 1.4 (37.4)	106.2 85.5 (54.2)	395.6 **525.8** (34.4)	**484.5 550.2** (32.2)
N (Groups)		360 (9)	640 (16)	360 (9)	360 (9)	480 (12)

Entries in the table are average values at the beginning and the end of the session.‡— Standard theoretical benchmarks (without fairness) for the MOQ contract (wholesale price contract in parentheses).

Table 2.5: Summary of experimental results

- Average order quantities and efficiency are consistent with the standard theory in all treatments except MOQ. In the latter, the data clearly rejects Hypothesis 1.

- The rejection rates in MOQ-A and MOQ-D (where retailers could not punish the suppliers by rejecting offers) are not different from zero. However, in all the treatments where the retailers can punish, rejection rates are above zero in the beginning, but, in the WP treatment, converge to zero at the end. Again, the MOQ treatment is the one in which the data strongly contradicts Hypothesis 1.

- The relative shares of the profit that suppliers offer in MOQ-A and MOQ-D are consistent with Hypothesis 1. However, in MOQ, WP, and MP-out, the outcomes are more equitable than the standard theory predicts so that the data rejects Hypothesis 1.

- The supplier's profit, π_S, is in line with Hypothesis 1 in MOQ-A and MOQ-D. In the other treatments it is below the standard theory benchmarks.

- The retailer's profit π_R is also in line with Hypothesis 1 in MOQ-A and MOQ-D, whereas in the other treatments it is above the standard theory benchmarks.

To summarize, as long as retailers cannot reject profitable offers, i.e. punish the supplier for making a small offer, the standard theory predictions are nearly perfect. Suppliers in those treatments quickly learn to coordinate the channel and extract virtually all the channel profit. Whenever a retailer's rejection affects the supplier, the results deviate from theoretical benchmarks. In WP and WP-out, though, the observed discrepancies are moderate. Only earnings are distributed somewhat more equitably and the rejection rates are different between WP and WP-out. However, in MOQ treatment standard theory cannot predict anything, apart from the order quantity.

Supplier Motives: Hypothesis 2

The key observations illuminating the suppliers' preferences are the following:

- In MOQ-A and MOQ-D suppliers perfectly coordinate the channel, showing no propensity for mistakes.

- The retailers' profit share in MOQ-A is zero, whereas in MOQ-D it is very small but positive.

However, the difference between offers in MOQ-A and MOQ-D seems small enough so that one can say that the suppliers mainly act as profit-maximizers.

Retailer motives: Hypothesis 3

If retailers reject because of errors then rejection rates should not differ in the MOQ and the MOQ-D treatments. But if rejections are primarily due to the desire to be treated fairly, rejections in the MOQ treatment should be significantly higher. The data show that:

- By the end of the session, the rejection rate in MOQ decreases to 17%.

- By the end of the session, the rejection rate in MOQ-D is about 10%.

However, of the 79 rejections in the MOQ-D treatment, 77 were for offers that were exactly zero, and only 2 were for positive offers. That is, the rejection rate of positive offers is essentially zero. It is clear that bounded rationality does not provide an explanation.

2.4.5 Discussion

A key point of Cui et al. (2007) was that positive reciprocity is beneficial for coordination. A supplier, facing a retailer with sufficiently strong aversion to the advantageous inequality, can coordinate the channel with just a wholesale price contract. If, instead, it is the supplier that is sufficiently averse to the advantageous inequality, he can coordinate the channel using a minimum order quantity contract. However, in MOQ and MOQ-D treatments nothing prevents the suppliers to be as generous as they want but they do not demonstrate much positive reciprocity. Unfortunately, direct testing of the retailers' positive reciprocity is problematic; there are only several observations that allow making any judgments on this account. Thus, in WP treatment there were three cases when the suppliers offered $w = 40$, a price that would result in the first-best outcome if the retailers had enough positive reciprocity. However, in these, as well as in several cases when the suppliers offered $w < 40$, the retailers acted as pure profit-maximizers or very close to that. Overall, our data does not provide any evidence of sufficiently strong aversion to the advantageous inequality. In the light of Loch & Wu (2008) experiment, this is not a surprising result. We did not try to induce or support any positive reciprocity, whereas they primed their subjects for positive reciprocity but did not observe coordination either.

To contrast the role of fairness and bounded rationality as the key factors of the contracting outcomes, Figure 2.3 (adopted from Katok & Pavlov (2009)) breaks down the outcomes into the following five categories:

- The "50-50" category: the retailer earns at least 40% of the total channel profit.
- The "Retailer High" category: the retailer earns between 20% and 40% of the channel profit.

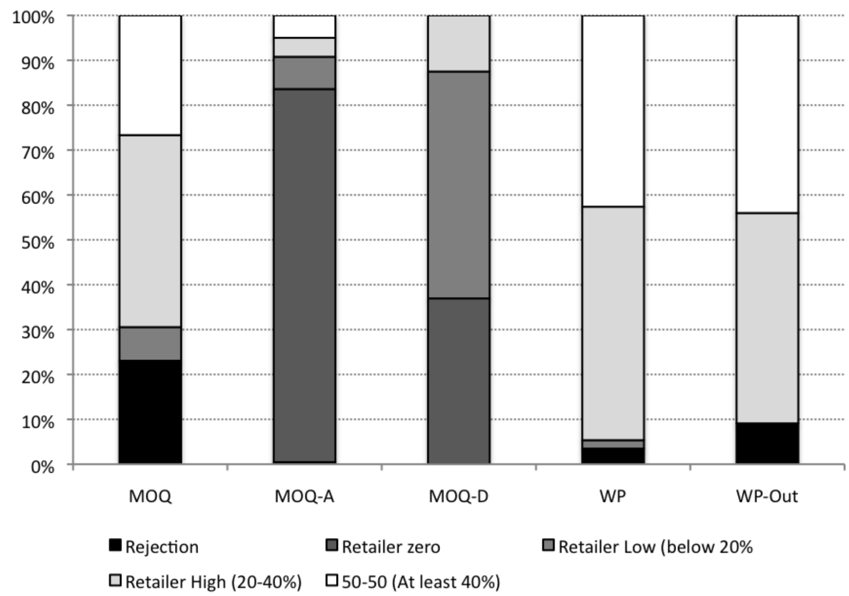

Figure 2.3: The retailers' profit shares in different treatments

- The "Retailer Low" category: the retailer earns less than 20% of the profit.
- The "Retailer Zero" category: the supplier offers exactly 0% of the channel profit to the retailer.
- The "Reject" category: the retailer rejects an offer.

The choice of coloring scheme on Figure 2.3 reflects how well (in relative terms) the retailers are doing. The darker color, the smaller their profit share, with the exception of black color that we use to indicate rejected offers.

Regarding the hypothesis of bounded rationality, it predicts that the rejection rates in MOQ and MOQ-D should be the same. However, the data speaks differently. While in MOQ almost 1/4 of all offers were rejected, the percentage of rejected offers in MOQ-D is basically zero. Thus, the data mainly rejects the bounded rationality hypothesis.

Fairness, instead, organizes the data very well. To begin with, observe the difference in the retailer's shares in MOQ-A and MOQ-D. Although it is small, it clearly indicates some amount of altruism on the suppliers' part. At the same time, disutility from disadvantageous inequality has much stronger effect. In those treatments where the retailer can enforce a fair "zero-zero" outcome by rejecting a contract (MOQ, WP and WP-out), the retailer's profit share is substantive. In the most instances, it falls into categories "50-50" "Retailer High". It is not that surprising in WP and WP-out, where the standard theory predicts that the retailer's share will be 1/3 (although, in fact in nearly half of cases the retailer's share was above 40%). But in MOQ, where the standard theory predicts the retailer's share should be zero, we still see that the retailer's share is above 20% in 90% of accepted contracts. In contrast, whenever the retailers could not punish the suppliers by rejecting offers (MOQ-A and MOQ-D treatments), the retailers' profit shares are close to zero.

2.5 Summary

Supply Chain Coordination has been widely recognized as one of the most important goals of Supply Chain Management. Analytical models propose a variety of means to achieve coordination and, in particular, coordinating contracts. According to theory, using a coordinating contract, the first-mover should be able both to induce a coordinated outcome (first-best) and to extract all of the other party's profit. However, experimental testing of such contracts revealed several systematic deviations from these predictions. First, the efficiency is significantly lower than the first-best. Second, a contract's poor performance is primarily due to rejections, non-existing in the theory. Third, parties tend to split the channel profit closer to "50-50" than to "100-0". Such persistent discrepancies between the standard theory and experiment call for further exploration of contracting in supply chains. This study aims to improve our understanding of the behavioral factors that affect contracting outcomes, and seeks to allow for them theoretically.

Past experimental studies identified several behavioral factors as having significant impact on contracting outcomes, such as loss-aversion, social preferences in general, fairness and bounded rationality. Although the amount of available empirical evidence overwhelmingly suggests that fairness is a very (if not the most) important one, there is always some room for bounded rationality. On one hand, rejections, observed in the experiments, may seem very much like noise. On the other hand, how much of this noise should be considered real noise and how much can be attributed to other factors, such as fairness, is an empirical question having implications for theory. Therefore, our experiment was specifically designed to discriminate between fairness and bounded rationality. To this end, in two treatments (MOQ-A and MOQ-D) we removed an option to enforce fair outcomes by a rejection. As the result, we were able to isolate a single most important reason of rejections in contracting experiments – fairness. Apart from that, we found very little altruism and virtually no "errors". These experimental results lay down the foundation for our model, justifying its most essential assumptions.

Regarding modeling, it is clear that a complete information model, (ex., Cui et al. (2007)) can only explain part of the experimental data, namely more fair profit split relatively to the standard theory prediction. At the same time, such a model cannot explain rejections and, therefore, cannot help in explaining coordination failures. Thus, an incomplete information model proves the only viable possibility. Intuitively, it is a clear choice. Indeed, not only retailers (responders) are inherently different in how strongly they care about unfair outcomes but, importantly, their fairness concerns are unobservable, i.e. private information. We proceed along the lines of Bolton & Ockenfels (2000) and model these fairness concerns introducing the retailer's type, a continuous random variable. The supplier, when making an offer, knows only its distribution.

The main analytical results are the following. First, the supplier's optimal contract is pooling. Second, it is conditionally efficient. That is, the supplier uses a contract with the minimum order quantity set to the first-best quantity. The retailer's best response, in case she accepts the contract, is to order the first-best quantity. Therefore, rejections are the only source of inefficiency. The supplier's optimal contract presents a careful trade-off between surplus extraction and rejections. Under the optimal contract the rejection rate is strictly above zero and the contract efficiency is always below the first-best. An appealing feature of the optimal contract is simplicity. Knowing the optimal quantity, which is distribution-free, computing the optimal transfer becomes a straightforward one-dimensional optimization problem. The concrete number, of course, depends on the distribution of the retailers' types. Third, we analyzed a wholesale price contract and although the complete characterization of its equilibrium requires assuming the specific functional form of the types' distribution, we established two properties of the equilibrium that are distribution-free. One is that the supplier never sets the wholesale price above the price he would set dealing with a profit-maximizing retailer. Another is that the rejection rate is zero if the retailer has no outside option. Our experimental observations are in line with the model's predictions.

This study contributes to the supply chain coordination literature in two ways. First, and most importantly, it shows that because of fairness concerns coordination becomes a problem of incomplete information. Hence, as a general result of contracting under information asymmetry, neither coordination nor full surplus extraction is possible. Second, the supplier will be better off with the optimal profit-maximizing contract than with a wholesale price contact. Therefore, although a wholesale price contract can, in principle, coordinate despite incomplete information, the supplier will not choose it.

Chapter 3

Competition and Contracting in Supply Chains

3.1 Introduction

Supply chain members, the independent firms, concerned with maximization of their own profits, may fail to obtain a system-wide optimal outcome. The most widely cited early example that illustrates this point is due to Spengler (1950). In his model, members of a successive monopoly (a bilateral monopoly) end up making decisions that are not Pareto-optimal. Cachon (2003) comments on this case of Double Marginalization: "in this serial supply chain there is coordination failure because there are two margins and neither firm considers the entire supply chain's margin when making a decision". Supply chain management emerged primarily as a managerial paradigm that strives to promote system-optimal solutions and, in particular, to develop incentive structures that induce decentralized decision makers to make system-wide optimal decisions. Most of supply chain literature, therefore, deals with one or another aspect of coordination. The analyzed settings range from the simplest bilateral monopoly with deterministic or stochastic demand, to rather elaborated ones that involve price dependent stochastic demand, competition on one or both sides of the supply chain, multiple periods, different replenishment options, etc.. Although, as a general result, one can always coordinate a supply chain under complete information, the optimal schemes turn to be sensitive to the specific details of the environment. In other words, the appropriate pricing schemes, generically, must be designed on a case-by-case basis. Hence, the observed variety of coordinating contracts in the literature.

However, coordinating contracts is not the only means that can be used to induce optimal decisions. Recall, the emphasis of the Spengler's paper was not on Double Marginalization as such, but to show that it results when previously competing retailers merge and horizontal competition among retailers disappears. In practice, many situations include some amount of horizontal competition. Retailers, serving the same market with the same product or close substitutes, have to compete for customers. Retailers, buying from the same supplier, frequently have to compete for the supply contract. An automaker, replacing an authorized dealer, induces competition among dealerships. Importantly, in presence of competition, even a wholesale price contract, considered the least flexible and powerful pricing scheme, sometimes even a cause of Double Marginalization, suffices for coordination. In a classical model of Bertrand (1883) two identical suppliers compete for one retailer. Competition forces suppliers to sell at cost, so that the retailer's incentives are not distorted by the suppliers' margins and the Pareto-optimal outcome obtains. An important but barely mentioned feature of this instance of coordination is the extremely low informational demands. The retailer can be completely ignorant of the suppliers' costs. For the perfect competition to arise it is sufficient that the suppliers know each others' costs. In other words, in presence of competition wholesale pricing becomes a simple and, importantly, robust coordination mechanism that does not require nearly as much information as traditional, competition-free, coordinating contracts.

Apart from simplicity and low informational demands, there are other reasons why relying on competitive coordination mechanisms may produce better results than using isolated one-on-one coordinating contracts. First, in the competitive setting fairness concerns make no impact. Regardless of how much a particular retailer cares about fairness, enforcing a fair zero-zero outcome is not possible by rejecting a contract and, therefore, no matter how unfair, the offer will be accepted. Second, models studying coordination of a dyadic channel usually assume that one party, usually it is a supplier, can make a "take-it-or-leave-it" offer to another. However, in the bilateral monopoly credibility of such an offer is questionable. Machlup & Taber (1960) seem to consider the very possibility of the "take-it-or-leave-it" offer under bilateral monopoly inappropriate (p.111): "*We may guess that the writers who* *made this assumption carried over a technique that proved useful in the analysis of unilateral monopoly, without due examination, to the case of bilateral monopoly*". Indeed, if a rational supplier can credibly commit to face a possible "leave-it" decision, this means that there are many other retailers' out there and they all are equally good to choose from. Therefore, an assumption of a credible "take-it-or-leave-it" offer is just a shortcut, standing for competitive environment. Still, this shortcut, while relying on competition implicitly, loses some important features of explicit competition.

Our model, studying coordination of a supply chain that consists of one supplier and several retailers, is different from most other models that consider competitive environments in one respect. We assume away natural competition between the retailers. Each of them operates on a market completely separated from the other markets[1]. The only source of competition is the supplier that refuses to trade with the "worst" retailer(s). By losing some market(s) the supplier forces all the retailers to give up all their profit. In reality, retailers' markets frequently overlap to some extent. In this case, by excluding a retailer from trade the supplier is not losing its demand completely. Therefore, assuming isolated markets allows obtaining a lower bound on efficiency of the competition-based coordination mechanisms. We focus on the case of limited heterogeneity among retailers. In general, retailers could differ on a variety of dimensions: market size, costs, etc. We only allow for heterogeneity in terms of market size. On one hand, considering heterogeneity only along one dimension is a limitation of our model. On the other hand, having sufficiently many retailers the supplier can partition them in categories based on their similarity and treat each category separately as a homogeneous group. This is not a new idea, though. In practice, some partitioning does take place: certified dealer, authorized dealer, exclusive dealer, etc.

The rest of this chapter is organized as following. Section 3.2 positions our study with respect to related literature. Section 3.3 presents a model of supply chain coordination by

[1] In this respect, a model of Ingene & Parry (1995) is similar to ours. The difference is that they study channel coordination under full information only and retailers are heterogeneous. Although they allow the supplier to exclude retailers from trade they find that a two-part tariff generically cannot cope with double marginalization: the supplier can coordinate the channel by selling at cost but in the equilibrium he chooses not to.

means of simple contracts and induced competition. Section 3.4 describes the experiment conducted to test predictions of the standard theory and our model. Section 3.5 summarizes this study.

3.2 Literature review

The problem of double marginalization, or, more precisely, the problem of the channel coordination[2], has gained a significant attention in the economics, marketing and supply chain literatures. For comprehensive reviews, see Tirole (1988), Moorthy (1993) and Cachon (2003). In the supply chain literature, the pricing schemes inducing optimal decisions are known as coordinating contracts. Such schemes can be very simple, such as, for example linear two-part-tariff contracts, or, as in Chen et al. (2001), have to be very complicated, and, potentially, difficult or costly to implement. Furthermore, coordinating contracts designed for a particular environment tend to fail when transplanted into a different one. For example, Bernstein & Federgruen (2005) demonstrate that a buy-back contract that works perfectly when the retailer's only decision is the order quantity fails when pricing also becomes an option.

Competition within a supply chain has been addressed by many researchers. Thus, Moorthy (1993) notes (p. 182): "The more interesting issues in channel competition arise from the effect of downstream (retail) competition on relations between the manufacturer and the retailers". Mahajan & van Ryzin (2001*b*) analyze a model of the two-echelon supply chain in which a monopolist retailer stocks products from horizontally competing suppliers. When the retailer has rights to manage inventory (RMI) then two suppliers suffice to fully coordinate the channel. They engage in Bertrand competition and in the equilibrium sell their products to the retailer at cost. Competition on the supply side is not that severe when it is suppliers who manage the retailer's inventory (called vendor-managed inventory, or VMI) but, nevertheless, the channel profit approaches first-best as the number of suppliers increases. Mahajan & van Ryzin (2001*a*), considering a model parallel to that

[2] The term "Double Marginalization" is commonly used to indicate a coordination failure. However, double marginalization as such does not imply inefficient outcomes. For examle, in a quantity-discount contract there are also two margins but, when properly designed, this contact coordinates the channel.

of Lippman & McCardle (1997), show that in the equilibrium retailers overstock, and as the number of retailers increases their profits approach zero. The model does not have a supplier in it, though. Cachon (2003) presents a model with one supplier and many identical retailers. In his (and similar) models, competition takes place because the product goes to one market. He finds that the supplier can coordinate the channel with just a wholesale price contract and make a positive profit. Although in the equilibrium the supplier does not offer a channel-efficient contract, as the number of retailers increases the channel profit approaches first-best.

Although the aforementioned literature seems to suggest that the role of competition, as a means of coordination, is at least as important as the role of appropriate pricing schemes, in some cases researchers seem to ignore it even in highly competitive environments. For example, Ingene & Parry (1995) analyze a setting with one supplier and multiple heterogeneous retailers which are monopolists on their markets. Notably, although in their model the number of retailers, who participate in the channel is the supplier's decision variable, they suggest, as means of coordination, coordinating contracts. Interestingly, as the motivating examples, they name Chevrolet and Sherwin-Williams who count their retail outlets in thousands. Iyer (1998), analyzing a spatial model with heterogeneous retailers says: "For the manufacturer this means designing a contract . . . .". However, this is not the only option. Trivedi (1998) makes a remarkable observation (p. 907): "The introduction of competition in the marketplace removes this bilateral monopoly... . Retail competition thus becomes a substitute for other methods of channel coordination".

3.3 The Model

3.3.1 The environment

The supplier, facing N retailers who operate on the non-overlapping markets, have two distinct possibilities. First, he can consider each retailer separately, so that the whole supply chain would look like N parallel and independent channels. Second, despite no horizontal competition between the retailers is taking place naturally, he can make them complete for the right to get the product. In the second case, he can commit (by means of a public announcement) not to deal with $K < N$ retailers who order the lowest quantities. Such a commitment means that the supplier is going to lose K/N part of the total market. This is a clear downside. However, an upside is that competition may facilitate coordination of the remaining $N - K$ channels, which might not be possible otherwise. The model presented below investigates a trade-off between treating each retailer separately and inducing competition among them. In what follows we consider cases of complete and incomplete information as well as heterogeneous retailers.

3.3.2 Environment, notation and terminology

In this model, a supplier produces a single good and has no direct access to the marketplace. Instead, he sells the product to one or more (so far homogeneous) retailers, each a monopolist on an isolated market. The manufacturer incurs a cost $c > 0$ and we normalize retailers' costs to zero. The retailer's reservation level is $\pi_R^0 > 0$. Each market is characterized by a downward-sloping (strictly decreasing) demand function, $q = d(p)$, where $p > 0$ is the retail price per unit. If the trade takes place, the supplier (S) and the retailer (R) earn π_S and π_R so that the channel (C) total surplus is sum of two profits:

$$\pi_C = \pi_S + \pi_R.$$

All information is common knowledge except for the market scaling factor that we introduce later.

We will also use superscripts to denote values resulting from various optimization problems, so for example, $\pi_C(p^{FB})$ is the first-best channel surplus, whereas $E[\pi_S^{MOQ-I}]$ is the supplier's expected profit resulting from the Minimum Order Quantity (MOQ) contract under incomplete information (I).

When we call an outcome efficient or inefficient, we mean that the channel surplus in that case is equal to or, respectively, smaller than the first-best channel surplus. We model the process as a two-stage game in which the supplier moves first and makes a "take-it-or-leave-it" offer to the retailers, and the retailers move second by specifying an order quantity

q. As the solution concept we use the subgame-perfect equilibrium. The parameters of this environment are such that contract variables can be chosen in a way that makes trade a (weakly) better outcome for both parties than no-trade.

Retailers' heterogeneity: scaling factors

To allow for the possibility of heterogeneous retailers we use scaling factors. Consider a market with a continuum (of mass one) of customers whose willingness to pay is drawn from the distribution $F(x)$. The demand function is then

$$d(p) = 1 - F(p)$$

because the RHS is the proportion of customers whose willingness to pay is above p. For a continuum of customers of size Z, whose willingness to pay is drawn from the same distribution, demand is given by

$$Z\left(1 - F(p)\right) = Zd(p).$$

In our model, we assume that markets can be different in their sizes but not in the distribution of the willingness to pay. This assumption is likely to be violated if populations are different in their income structure or occupation (ex. agricultural VS industrial). However, in other cases, ex. consider two towns in agricultural areas, distributions of willingness to pay may be very similar and only markets' sizes will differ.

Thus, by saying that retailers i and j are different we mean different market sizes:

$$Z_i d(p) \neq Z_j d(p).$$

3.3.3 Single channel benchmarks

First-Best

The first-best outcome obtains in the situation when the manufacturer can access markets directly. The game reduces to the classic monopoly problem of choosing the optimal price:

$$p^{FB}(c) = \arg\max_p \pi_S = \pi_C \equiv (p - c)d(p) \tag{3.1}$$

Since, by assumption, the demand function is strictly monotone the objective function is unimodal and there exist a unique optimal solution.

When the supply chain parties act autonomously, it is well known that the decentralized decision-making may cause double marginalization and special contractual arrangements are required to avoid inefficient outcomes.

The Wholesale Price Contract

One of the possibilities for the supplier to arrange the trade is to offer a constant wholesale price per unit, $w \geq c$. We refer to this as a wholesale price contract (WP). When w is small enough, so that the retailer finds it beneficial to accept the offer, the retailer's best-response is to order $q = d(p(w))$ where the retail price is

$$p(w) = \arg\max_x (x - w)d(x) \tag{3.2}$$

Given the retailer's best-response function, $p(w)$, the supplier chooses the optimal wholesale price w^{WP} by solving:

$$w^{WP} = \arg\max_w (w - c)d(p(w)). \tag{3.3}$$

where $p(w)$ is given by (3.2)

Lemma 5 *(i)* $p(y) \equiv \arg\max_x (x - y)d(x)$ *is a strictly increasing function of* y *and, (ii),* $\pi(y) \equiv \max_x (x - y)d(x)$ *is a strictly decreasing function of* y*.*

Proof. Consider $y_1 < y_2$. Let p_1 and p_2 be maximizers of the corresponding problems. Part (i) is proven as follows: Uniqueness of $p(y)$ follows from unimodality. Then, from the uniqueness and unimodality, the following two inequalities hold:

$$(p_1 - y_1)d(p_1) > (p_2 - y_1)d(p_2)$$
$$(p_2 - y_2)d(p_2) > (p_1 - y_2)d(p_1)$$

Adding them gives

$$(y_1 - y_2)\left(d\left(p_1\right) - d\left(p_2\right)\right) < 0.$$

Hence, $d\left(p_1\right) > d\left(p_2\right)$ and, since $d(x)$ is monotone, $p_1 < p_2$.
For the part (ii), uniqueness implies:

$$(p_1 - y_1)d(p_1) > (x - y_1)d(x) = (x - y_2)d(x) + (y_2 - y_1)d(x), \forall x \neq p_1 \Rightarrow$$
$$(p_1 - y_1)d(p_1) > (p_2 - y_2)d(p_2) + (y_2 - y_1)d(p_2) \Rightarrow$$
$$(p_1 - y_1)d(p_1) > (p_2 - y_2)d(p_2)$$

■

Note that for the retailer to make a positive profit, the retail price must be strictly higher than the wholesale price: $p(w) > w$. Also, the retailer's problem (3.2) is structurally the same as (3.1), with w instead of c, which leads to the following conclusion:

Proposition 17 *The retailer places the first-best order if and only if the wholesale price faced by the retailer is equal to the supplier's cost. More precisely,*

$$q^{WP} = d(p^{FB}),$$

if and only if $w = c$.

Proof. "If" part: If $w = c$, then (3.2) is fully equivalent to (3.1). Hence, both result in the same retail price and market demand.
"Only if" part: The demand $d(p)$ is strictly decreasing in p. Therefore, $q^{WP} = d(p^{FB})$

implies that $p(w) = p^{FB} = p(c)$. By Lemma 5, the retailer's best response, $p(w)$, is strictly increasing in w. Therefore,

$$p(w) = p^{FB} = p(c)$$

in turn implies that $w = c$. ■

As this proposition shows, WP will, in general, yield less profit to the supplier than the first-best. Specifically, in order to make positive profit from WP, the supplier must set $w > c$, but Proposition 17 assures that the result will be different from the first best outcome. Formally, we state the following:

Proposition 18 *If the first best profit is strictly positive, then (i) any wholesale price contract gives the supplier a strictly lower profit. In addition, (ii), if the supplier makes a positive profit from a wholesale price contract with price w, then that wholesale price contract is inefficient; in particular, $d(p(w)) < d(p^{FB})$.*

Proof. Part (i). To start, problem (3.3) cannot deliver the first-best profit. To see this, by adding and subtracting the same term, re-write its objective function as

$$\pi_S^{WP}(w,c) = (w-c)d(w) + \left[(w-c)(d(p(w)) - d(w))\right].$$

Now, notice that in this expression the first term can only be as high as the first-best. Since the retailer's participation implies $p(w) > w$, then the term in square brackets is negative as long as $w \neq c$. In case $w = c$ then the whole expression turns to zero. Therefore, the supplier makes either zero profit or strictly less than the first best profit.

Part (ii). By Proposition 17 the efficient outcome is only possible when $w = c$ but in this case the supplier's profit would be zero. Since, by assumption, $\pi(c) > \pi_R^0$ and by Lemma 5, $\pi(w)$ is strictly decreasing in w, this means that there exists $w^0 > c : \pi(w^0) = \pi_R^0$. Since $w^0 > c$, the supplier can make positive profit by offering w^0. Therefore, $w = c$ will never be offered and the outcome will be inefficient. ■

The Minimum Order Quantity Contract

One way to cope with the inefficiencies of the decentralized channel is to employ a minimum order quantity contract (MOQ). The supplier's offer now consists of two values, the wholesale price and the minimum order quantity: $\{w, q_{\min}\}$. Since for a given $w > c$ the retailer orders less than the first-best, the supplier can induce the retailer to order $q = d(p^{FB})$ only by setting $q_{\min} = d(p^{FB})$, giving us the following straightforward proposition:

Proposition 19 *In a minimum order quantity contract, the supplier should set the minimum order quantity $q_{\min}$ equal to the demand $d(p^{FB})$ that would be realized from using the first best retail price p^{FB}. More precisely, for any $q_{\min}$ and $w > c$, such that the retailer's participation is secured, the retailer orders first-best if and only if*

$$q_{\min} = d(p^{FB}).$$

Proof. Under MOQ contract the retailer's problem is similar to (3.2) but has an extra constraint:

$$\max_x (x - w)d(x)$$

$$s.t.$$

$$d(x) \geq q_{\min}$$

"If" part: When $q_{\min} = d(p^{FB})$ the retailer cannot order less than $d(p^{FB})$. To prove that the retailer orders $d(p^{FB})$, let us suppose the opposite. That is, suppose he finds it optimal to order more than $d(p^{FB})$, what means the constraint is not binding. However, if the constraint is irrelevant, the problem reduces to (3.2), which solution, $p(w)$, implies

$$d(p(w)) < d(p^{FB}), \forall w > c$$

(by Lemma 5). This contradicts our previous assumption.

"Only if" part: Suppose in the optimum the constraint is not binding. Then, by Proposition 17 and Lemma 5, the resulting order quantity is smaller than the first-best. Therefore, the retailer's order of $d(p^{FB})$ implies that the constraint is binding. Again, we have a contradiction. Hence, $q_{\min} = d(p^{FB})$. ■

The retailer's participation can be insured by a proper choice of $w \leq p^{FB}$(for example, if the retailer's reservation level is zero, then the supplier should set $w = p^{FB}$). More specifically, the supplier chooses w based on $(p^{FB} - w)d(p^{FB}) = \pi_R^0$. This way the supplier induces the retailer to serve the market efficiently and manages to extract all (but for the retailer's reservation level) profit from the retailer.

Incomplete Information

In this section we introduce incomplete information (I). Suppose that the supplier knows the structure of the retail market but not its size, so that the market demand is $D(p) = Zd(p)$, where $Z > 0$ is a non-degenerate random variable with a finite mean $E[Z]$. We assume that Z is not ex post verifiable and cannot be contracted upon. The retailer knows the realization of Z and her reservation level is also scaled by Z to $Z\pi_R^0$. The supplier does not know the realization of Z but does know its distribution.

This uncertainty in market size does not significantly change our analysis of the wholesale price contract. Problems (3.1), (3.2) and (3.3) are multiplied by Z, which is simply a scalar, and the solutions (prices) remain the same. Importantly, for the wholesale price contract, it does not matter for the supplier whether he knows Z or not. Thus, the wholesale price contract is robust to this type of uncertainty.

However, when Z is the retailer's private information, the supplier is no longer able to achieve efficiency by means of an MOQ contract. This is not surprising. In essence, the supplier is facing an adverse selection problem. Formally, we state the following:

Proposition 20 *The supplier's maximum expected profit that can be achieved under information asymmetry by means of a minimum order quantity contract is strictly smaller than* *the expected profit that can be achieved under full information:*

$$E[\pi_S^{MOQ-I}] = \beta E[Z]\pi_S^{FB}, \text{ where } 0 \le \beta < 1$$

where "MOQ-I" denotes the minimum order quantity contract under incomplete information.

Proof. Under complete information, the supplier knows Z and achieves the first-best profit of $Z\pi^{FB}$ by setting

$$q_{\min} = Zd(p^{FB}).$$

Therefore, for the expected profit under full information one obtains

$$E[\pi_S^{MOQ-F}] = E[z]\pi_S^{FB}.$$

Under information asymmetry, it is no longer possible for the supplier to set $q_{\min} = Zd(p^{FB})$ because he knows only distribution of Z but not Z itself. Therefore, for any $\{w > c, q_{\min} > 0\}$ with a positive probability either the retailer does not participate or she prefers not to serve the market efficiently. Hence,

$$E[\pi_S^{MOQ-I}] = \beta E[Z]\pi_S^{FB}, \text{ where } 0 < \beta < 1$$

(superscripts MOQ-I and MOQ-F indicate whether the supplier's profit belongs to the information asymmetry or the full information case). ■

The term $E[Z]\pi_S^{FB}$appears on the right-hand-side of because under full information the supplier can always achieve the first-best solution, scaled by a factor of Z.

Intuitively, by Proposition 19, the only way to induce the retailer to order the first-best quantity, $Zd(p^{FB})$, is to set $q_{\min} = Zd(p^{FB})$. However, this is not possible because Z is the retailer's private information. For the same reason, it is no longer possible for the supplier to extract the entire retailer's surplus.

3.3.4 Induced competition

Wholesale Price Contract

Specifically, the supplier offers a wholesale price, letting retailers freely choose order quantities, but announces that the K retailers (where $1 \leq K < N$) with the smallest orders, will be excluded from trade. Ties get broken according to any rule that gives each of the tied retailers a strictly positive chance of winning. We call this arrangement the wholesale price contract with competition (WPC).

At equilibrium, homogeneous retailers compete their profits away (down to the reservation level) and the supplier randomly selects $(N-K)$ of them to deal with.[3] Now the supplier can obtain the first-best from each of the chosen (or active) retailers. Formally,

Proposition 21 *The supplier's expected profit*

$$E[\pi_S^{WPC}(N-K)]$$

from wholesale pricing when N *potential retailers compete to become one of* $(N-K)$ *active retailers is*

$$E[\pi_S^{WPC}(N-K)] = (N-K)E[Z]\pi_S^{FB}.$$

Proof. Since in the equilibrium the retailers compete their profits away, the supplier has to solve the following problem:

$$\max_w (N-K)\, Z(w-c)d(p)$$

$$s.t.$$

$$Z\left((p-w)d(p) - \pi_R^0\right) = 0$$

First, notice that dropping Z does not change the problem. In addition, $(N-K)$ is another constant and can also be dropped from the objective function. Second, eliminate w from

[3]Heterogeneous retailers who were nearly homogeneous would nearly compete away all their profits and would make nearly the same decisions as homogeneous retailers, and the supplier would realize nearly the same surplus.

the objective by using the constraint. The resulting problem is

$$\max_p (p-c)d(p) - \pi_R^0,$$

which is equivalent to (3.1). Therefore the solution is first best and the supplier' expected profit is:

$$E[\pi_S^{WPC}(N-K)] = (N-K)E[Z]\pi_S^{FB}$$

■

Since the supplier's expected profit decreases in K it should be made as small as possible. For the competition to exist at least one retailer needs to be excluded. Hence, $K = 1$ is optimal.

Corollary 6 (to Proposition 21) *K = 1 is optimal.*

In reality, there may be reasons to commit to exclude more than one retailer. However, for any $K > 0$, if N is big enough then WPC outperforms any arrangement that does not make use of competition. Although in the next proposition we refer to MOQ-I its claim, clearly, holds for an optimal screening contract also:

Proposition 22 *For any non-degenerate distribution of the market scaling factor Z (i.e. the information is actually incomplete) and any fixed number of losing retailers K (and fixed values of the other parameters except N), if the number of potential retailers N is big enough, the supplier can do strictly better using wholesale pricing with competition (WPC) than using any minimum order quantity contract.*

Proof. It follows from equations and that

$$\lim_{N\to\infty} \frac{E[\pi_S^{WPC}(N-K)]}{NE[\pi_S^{MOQ-I}]} = \lim_{N\to\infty} \frac{(N-K)}{N\beta} = \frac{1}{\beta} > 1$$

■

For the example considered below, $\beta = 1050/1400$. In this case, WPC with $K = 1$ and MOQ yield the same expected profit of 4200 to the supplier when $N = 4$, and WPC yields a strictly higher expected profit whenever $N > 4$. Note that for both WP and WPC, the supplier's decisions are independent of the state of the markets. Moreover, he need not even be aware of the information asymmetry at all (let alone values of the scaling factor and their distribution). While this simplifies the supplier's decision, so that his offer does not depend on the market state, competition results in the retailers' offers reflecting the market state. As a result, with WPC the supplier will make the first-best profit on every market he did not exclude from trade.

3.3.5 Heterogeneous retailers

Consider isolated markets with demands

$$D_i = Z_i d(p) : Z_i \neq Z_j \text{ for } i \neq j.$$

Since Z_i is irrelevant to the i^{th} retailer pricing problem, the optimal market price, p^{FB}, is the same for all markets. Therefore, it is still possible to extract the retailers' profits by offering $w = p^{FB}$ given the supplier succeeds in inducing competition.

However, since optimal order quantities, $Z_i d(p^{FB})$ are different across retailers, it is not sufficient to make the retailers compete in order quantities. Instead, the supplier should arrange competition in terms of retailers' profits. In effect, the supplier needs to communicate to them that the one who offers the smallest fraction of profit will be excluded from trade. Therefore, in the equilibrium, all retailers give up 100% of their profits and one gets excluded.

It only remains to find an appropriate framing. In this case, framing competition in terms of quantities does not seem the most convenient. To make it working, the supplier would have to announce competition in terms of normalized (per capita) quantities, $\frac{q_i}{Z_i}$. Equivalently, the supplier may announce competition in terms of retailers' mark-ups, $(p_i - w)$. The retailer with the highest proposed mark-up over w gets excluded. To make the announced mark-ups binding, the supplier will have to use either retail price maintenance (RPM) or quantity forcing. In the latter case, by announcing its mark-up, the i^{th} retailer commits to buy

$$q_i = Z_i d(p_i).$$

Thus, heterogeneity does not prevent coordination by simple means. The same wholesale pricing with competition works. However, coordinating heterogeneous retailers is more demanding informationally. The supplier either needs to know each market size or to observe and control retail prices.

3.3.6 A numeric example used in the experiment

To illustrate the ideas, consider a specific example. Every retailer is facing market demand $d(p) = Z(100 - p)$ and her reservation level is $\pi_R^0 Z = 200Z$, where Z is a scaling factor. The supplier's per unit cost is $c = 20$.

Complete information

To begin with, set $Z \equiv 1$ and assume that the supplier knows this. The retail price that maximizes the profit of each channel, $\pi_C = (p-20)(100-p)$, is $p^{FB} = 60$. So that the optimal quantity to be sold is $q^{FB} = d\,(60) = 40$ units. The resulting (channel maximal) profit is $\pi_C^{FB} = 1600$. Since the supplier cannot access the market directly, the retailer's reservation level must be met and, therefore, the supplier's maximal profit is $\pi_S^{FB} = 1600 - 200 = 1400$.

MOQ contract One of the ways the supplier can secure this profit is to offer a MOQ contract. To find the optimal parameters for the MOQ contract supplier solves:

$$\max_{w, q_{\min}} (w - c) q_{\min}$$

$$s.t.$$

$$q_{\min}(p(q_{\min}) - w) \geq Z\pi_R^0 \Leftrightarrow ((100 - q_{\min}) - w)\, q_{\min} - 200 \geq 0$$

to obtain

$$w^{MOQ-F} = 55, q_{\min}^{MOQ-F} = 40.$$

Wholesale price contract If the supplier offers a WP with the wholesale price w,the retailer's best-response (derived by maximizing the retailer's profit, $\pi_R(w) = (r - w)(100 - r)$) is to order

$$q = \frac{1}{2}(100 - w).$$

The resulting supplier's profit is then

$$\pi_S = \frac{1}{2}(w - 20)(100 - w),$$

maximized at $w = \frac{1}{2}(100 + 20) = 60$. The retailer then orders $q = 20$ units and sells them on the market at price $r = 100 - 20 = 80$. Her profit is $(80 - 60) \times 20 = 400$, which meets the retailer's reservation level, and she accepts this offer. The supplier's profit is only $(60 - 20) \times 20 = 800$.

Wholesale price contract with competition If the supplier induces competition among retailers by announcing that there will be no trade with the retailer whose order is the smallest, then we have a wholesale price contract with competition. The supplier maximizes his profit by setting w so that by ordering $q = 40$ (the first best order quantity) and selling it at the retail price of 60, the retailer earns his reservation profit of $\pi_0 = 200$, i.e. $w = 55$. In the unique equilibrium of the resulting game all retailers order $q = 40$ and one of them is excluded from trade. The supplier loses one market completely but earns 1400 (the first-best profit) in each of the remaining markets. Therefore, with just three potential retailers it is strictly better for the supplier to use WPC (in this case he earns $1400 \times 2 = 2800$) than to deal with all three retailers and offer an optimal WP (in this case he makes only $800 \times 3 = 2400$).

Incomplete information

Under complete information, an MOQ is a better option than WPC because the supplier makes the first-best profit on every market. However, this is no longer true if we look at the problem in the incomplete information environment. Consider a two-type case where $Z \in \{z_L = \frac{1}{2}, z_H = \frac{3}{2}\}$ and $\Pr(Z = z_L) = \Pr(Z = z_H) = \frac{1}{2}$ (note that $E[Z] = 1$, just as in the full information case).

Wholesale price contracts (with and without competition) As we argued above, scaling factors are irrelevant under WP (and WPC). The resulting order quantity and the supplier's profit (from every non-excluded retailer) are simply scaled by Z and, therefore, in expectation the supplier earns the corresponding full-information profit multiplied by $E[Z]$:

$$E[\pi_S^{WP-I}] = E[Z]\pi_S^{WP-F} = 800$$

and

$$E[\pi_S^{WPC-I}] = E[Z]\pi_S^{WPC-F} = 1400.$$

Minimum order quantity contract One can show that an optimal MOQ contract:

1. either extracts all the retailers' profit when markets are high but retailers do not accept it when markets are low (shutdown of inefficient types)

2. or makes retailers' participation possible in both market states but extracts all profit from the retailers when markets are low.

We omit details because they are quite similar to the standard analyses of the adverse selection problem and refer interested readers to Salanie (1997) or Laffont & Tirole (1993). In fact, the whole argument applies to the optimal screening contract as well. The main insights are that in the presence of private information designing an optimal contract requires knowledge of the distribution of Z but, nevertheless, complete-information first-best is no longer achievable. In our environment, it is optimal to offer

$$\{w = 55, q_{\min} = \frac{3}{2} \times 40 = 60\}.$$

Retailers accept this offer only when markets are high. The supplier, when the offer is accepted, earns the first-best, $\frac{3}{2} \times 1400 = 2100$, but this happens only with probability $\frac{1}{2}$. When markets are low, this contract gives zero, and therefore the supplier's expected profit is $\frac{1}{2} \times 2100 = 1050$. Alternatively, if the supplier offers $\{w = 57.6, q_{\min} = 18.5\}$, retailers should accept this contract in both high and low markets, and each retailer orders $q = 18.5$ when markets are low and $q = 31.8$ when markets are high. The supplier's expected profit is $\left(\frac{1}{2} \times 18.5 + \frac{1}{2} \times 31.8\right)(57.6 - 20) = 945.6$,which is smaller than the profit from the contract designed to deal with high markets only. For the reader's convenience, we summarize the optimal contract parameters and the resulting expected profits in the Table 1.

3.4 The Experiment

The goal of our experiment is to compare different contracting mechanisms.

3.4.1 Experimental design

Overall, there are four treatments. In the experiment we manipulate two factors:

1. A form of contracting arrangement: wholesale price contract (WP), wholesale price contract with competition (WPC) and minimum order quantity contract (MOQ).
2. Information regime: full (F) and incomplete information (I).

Specific parameters of the environment were chosen as in the numerical example in section 3.3.6. For convenience, Table 3.1 presents a summary of the treatments along with the theoretical predictions. For the MOQ contract with incomplete information we provide theoretical benchmarks for the optimal contract designed to deal with the high markets only, as well as for the best contract designed to deal with both high and low market types. Although a supplier would do better by excluding low types, the gain over the best contract dealing with both types is relatively small.

In all treatments one supplier was facing three retailers, except for the control treatment, WP-1, where one supplier was dealing with one retailer. A similar treatment with three retailers is denoted by WP-3. This control treatment was included to reveal a possible change in the retailers' social preferences.

	w^*	q^*(low/high)	$E[\pi_S]$	$E[\pi_R]$
Wholesale price contract with competition (treatment WPC)	55	20/60	$2 \times 1400 = 2800$	200
Wholesale price contract (treatment WP-3) (control treatment WP-1)	60	10/30	$3 \times 800 = 2400$	400
Minimum order quantity - F (treatment MOQ-F)	55	40	$3 \times 1400 = 4200$	200
Minimum order quantity - I (treatment MOQ-I)	*	*	*	*
high types only	55	60	$3 \times 1050 = 3150$	150
both types	57.6	18.5/31.8	$3 \times 945.58 = 2837$	350

Table 3.1: Experimental design and theoretical predictions

3.4.2 Experimental protocol

In each treatment, except for WP-1, subjects were divided in three groups of 8 participants. Two subjects from every group were randomly assigned a role of a supplier and the rest were in the retailer's role. To avoid contamination with possible reciprocity effects, subjects kept the same roles for the duration of a session, each lasting for 40 periods. Every period suppliers and retailers from the same group were randomly re-matched. Subjects were assigned to different treatments at random and each participated in only one treatment. Overall, 120 subjects took part in the study.

Participants, mostly undergraduate students of different majors from the Penn State University, were recruited via on-line recruiting system. Participants were paid according to the profits they made in the experiment. The experiment was held at the Laboratory for Economic Management and Auctions (LEMA) at the Penn State Smeal College of business during November 2006 through June 2007. Upon arrival to the laboratory, participants were seated in visually isolated cubicles and read instructions (see Appendix) describing the rules of the game. After all participants finished reading, we read the instructions to them aloud to insure common knowledge about the rules of the game. Then we gave a quiz and went over its answers to make sure everyone understands the game. We also answered any questions prior to the start of the game. We programmed the computer interface using the z-Tree (Fischbacher (2007)). The experiment instructions and sample screen shots are presented in the Appendix B.

In all treatments, the supplier is the first mover. In WP-1,WP-3 and WPC treatments the supplier offers the per unit wholesale price w. In the MOQ treatments, the supplier offers w and $q_{\min}$. The software transmits the supplier's offer to the retailer and the retailer responds with the order quantity. The retailer also has an option to reject the contract, which causes the supplier to earn the profit of 0 from this retailer, and the retailer to earn $200Z$. Both the supplier and the retailer have access to a simple calculator that we programmed to help them with their decisions. Suppliers can enter different w's (and $q_{\min}$'s in MOQ treatments) and the system calculates the retailer's best reply to that offer. Retailers can enter different q's and the system calculates the retailer and the supplier profit corresponding to this decision.

3.4.3 Experimental hypotheses

We formulate the following research hypotheses dealing with the performance of these contracts.

Hypothesis 1 *Contract parameters and resulting (expected) profits will be as summarized in Table 3.1.*

Hypothesis 2 *Supplier profits will be higher under the wholesale-price contract with competition than without competition. Retailer profits will be lower with competition than without competition.*

Hypothesis 3 *The MOQ contract will deliver higher supplier profits and lower retailer profits than the wholesale price contract, with or without competition, under both complete and incomplete information.*

	w^* *th.*	w^* *exp*	q^* *th.*	q^* *exp*	$E[\pi_S]$ *th.*	$E[\pi_S]$ *exp*	$E[\pi_R]$ *th.*	$E[\pi_R]$ *exp*
WPC	55	53.7	40	**34.0**	2800	**2359.7**	200	**310.1**
WP-1	60	**53.6**	20	19.9	800	**636.5**	400	**518.6**
WP-3	60	**54.1**	20	**22.2**	2400	**2157.6**	400	**498.7**
MOQ-F	55	**49.3**	40	**29.8**	4200	**2462.2**	200	**498.7**
MOQ-I	-	-	-	-	-	-	-	-
high types	55	52.6	30	**23.3**	3150	**2181.7**	150	**543.5**
both types	57.6	52.6	25.1	23.3	2837	**2181.7**	350	543.5

Table 3.2: Theory predictions and experimental data

3.4.4 Experimental results

Statistical Analysis

Table 3.2 (adopted from Engelbrecht-Wiggans et al. (2007)) summarizes the average wholesale prices, order quantities, acceptance rates, and profits for each treatment over 40 rounds. In each case, we also indicate whether the average value is significantly different from its corresponding theoretical benchmark from Table 3.1 according to a t-test. If there is a statistically significant difference, the value is shown in bold font, ex. **49.3.** The unit of observation is a cohort, and each treatment consists of three independent cohorts.

The grand average values, of course, cannot convey all interesting details and, in particular, dynamics. On Figure 3.1 we plotted average wholesale prices offered by the suppliers in every period. Overall, the picture is clearly non-stationary. One can observe two distinct types of non-stationarity. First, in case of MOQ-F, the values decline over the first thirty periods and stabilize in the last ten periods. In other cases, there are no clearly visible trends in prices but their variability in the last twenty periods is lower than in the beginning. In other words, some learning is taking place and, in case of MOQ-F, suppliers clearly learn to be more generous, but to the certain limit.

Average order quantities, plotted on Figure 3.2, also present an interesting picture. While there are no visible trends in WP-1, WP-3 and MOQ-I, both in MOQ-F and WPC order quantities increase over time in the first thirty periods and in the last ten periods their pattern becomes stable. However, there are aspects that make MOQ-F and WPC

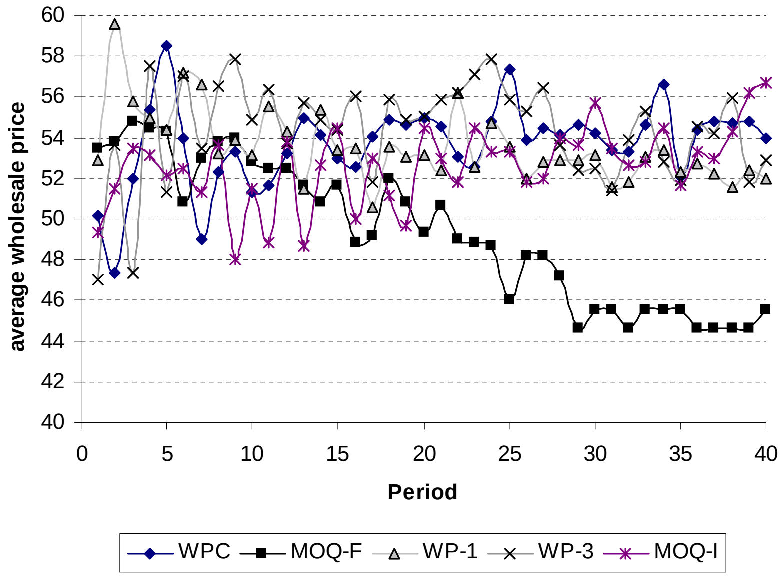

Figure 3.1: Dynamics of the wholesale prices

substantially different until the last ten periods. First, variability of the order quantities under WPC is notably lower. Second, in the first periods order quantities under WPC are higher than those under MOQ-F. In other words, order quantities under MOQ-F grow faster.

This significant amount of learning observed in the experimental data can be of interest on its own. For example, it is not obvious why there is so much learning in some treatments but virtually none in the others. However, our study has a different focus. In addition to the estimates obtained using data from all forty periods, we also made estimates using observations only from the last ten periods (when values and their variability become stationary). Although our experimental design was 2*4 (two levels of information and four different contracting arrangements), scaling factors (hence any information asymmetry) are irrelevant under the wholesale price contract. Therefore, we ran WP-1, WP-3 and WPC under complete information only. Thus, the only treatment with the incomplete information that we ran was MOQ-I and, for the purposes of statistical analysis, our design can be equivalently seen as 1*5. In our experiment, subjects that belong to a particular cohort

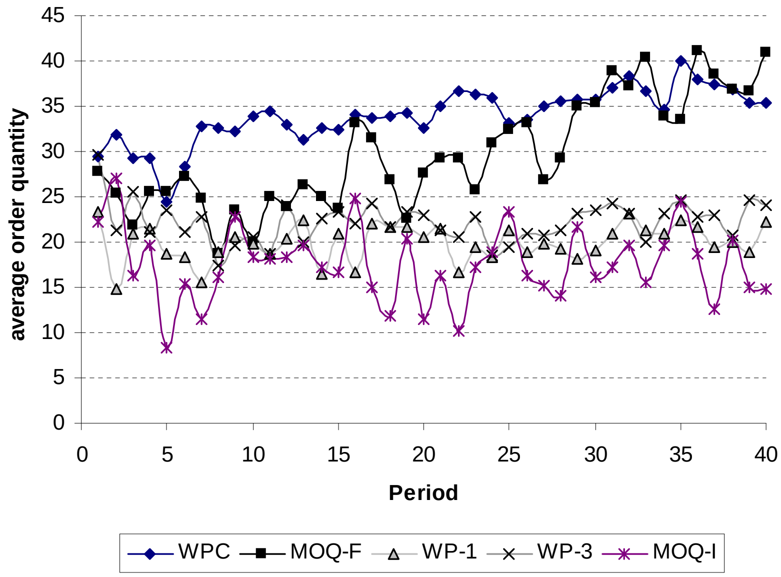

Figure 3.2: Dynamics of the order quantities

make several deals every period. The average value of, say, the order quantities observed within a cohort in a particular period, constitutes one observation. From period to period subjects remain in the same cohort, which, in turn, is a random draw from a population and, therefore, is a random factor. Since each cohort participated in only one treatment, it is also a nested factor. The statistical model we use to draw inferences is a mixed model with cohort nested within treatment:

$$y_{ijk} = \mu + \lambda_i + \beta_j(\lambda_i) + \varepsilon_{k(ij)}$$

where λ_i ($i = 1, ..., 5$, by the number of treatments) is a mean value of the variable of interest (wholesale price, order quantity, etc.) in the i^{th} treatment, $\beta_j(\lambda_i)$ is the effect of the j^{th} cohort in the i^{th} treatment ($j = 1, 2, 3$, by the number of cohorts within each treatment), $k = 1, ..., 10$ (the number of observations made on every cohort in each treatment). An idiosyncratic random term, $\varepsilon_{k(ij)}$, is assumed normal and *iid* between observations. A partial output from Minitab and JMP that were used to run the model is given in the Appendix, in section B.2. Although some estimates are somewhat different from those in

Table 3.2, they lead mainly to the same inferences.

Discussion

Referring to the Table 3.2, many of the theory predictions do not match the data. As a rule, wholesale prices are below theoretical. Keeping in mind that the wholesale price is just a means to transfer profit from the retailer to the supplier, this says that the retailers are gaining bigger share than the theory say they would. Yet, there is a remarkable exception: WPC, in which there is nearly a perfect match. At the same time, the observed order quantities are rather close to theory in all treatments except MOQ-I. As the result, we conclude that data provides only partial support for Hypothesis 1.

Regarding Hypothesis 2, a comparison of different types of the wholesale pricing, the data fully supports it. Both WP-1 and WP-3 perform very close to the theoretical benchmark. But WPC does so too. For the retailers, WPC is just a disaster. They literally compete their profits away, making twice less money than under WP-1 or WP-3.

Finally, the most interesting observations are related to Hypothesis 3. Going back to Figure 3.2, notice that the order quantities under MOQ-F and WPC in the last periods look nearly identical and very close to 40, which is first-best. Since the order quantities have direct implications for efficiency, one might expect that efficiency should be close to the theoretical. However, order quantities are not the only factor that determines efficiency. Rejections is another. Figure 3.3 shows average acceptance rates in different treatments across all 40 periods. The acceptance rates are so dramatically different between MOQ-F and WPC that the latter is only slightly less efficient than the former. Although, in fact, the acceptance rate under MOQ-F improves, this happens (see Figure 3.1) as the suppliers lower the wholesale prices. Apparently, to avoid high rejection rates the suppliers have to hold the wholesale price low. Overall, we conclude that Hypothesis 3 does find support in the data observed in the complete information case. Yet, under incomplete information, MOQ clearly fails. WPC outperforms it both in terms of efficiency and the supplier's profit. Interestingly, although the suppliers were able to construct nearly optimal contracts in all other treatments, in MOQ-I, instead, they seem to avoid using an optimal contract that calls

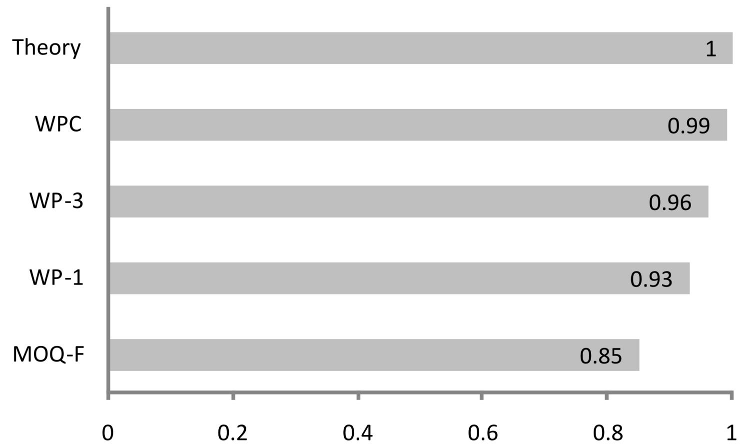

Figure 3.3: Acceptance rates

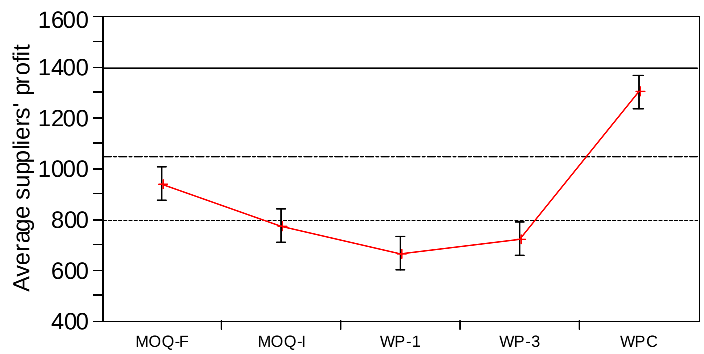

Figure 3.4: The supplier's profit per active channel

for dealing with high markets only and use a sub-optimal contract that makes possible for the retailers in both low- and high market states to participate. While we cannot completely reject Hypothesis 3 it is clear that MOQ contract performs very differently (in fact, worse) that the theory predicts.

The most important observation, perhaps, is that MOQ greatly deviates from theory, performing far worse than it should, whereas WPC behaves very close to the theory predictions. Thus, by sacrificing one retailer, WPC achieves nearly perfect coordination with the other two. At the same time, MOQ is inevitably inefficient. Apparently, the reason why

MOQ performs so badly has to do with the relative profit shares. As any other coordinating contract, MOQ is similar to the Ultimatum Game because the suppliers, in effect, propose a profit division, and retailers can (and do) reject unfair offers. In the WPC treatment, the retailers cannot gain anything by rejecting an unfair offer and willingly accept everything. The rejection rate in WPC is vanishingly small, only 1%. Therefore, the difference between WPC and MOQ is fundamental. WPC perfectly (and predictably) coordinates all channels by sacrificing one, while MOQ performs poorly (also predictably) in all channels. Recall, the starting point of our theory was the supplier's choice between using a coordinating contract in every channel and inducing competition. To help fully appreciate the supplier's possible decision, Figure 3.4 plots the supplier's profit per "active" channel (whiskers indicate 95% confidence intervals). The idea is that under WPC the supplier had three retailers but was dropping one. Therefore, the number of "active" channels under WPC was two, whereas in all other cases the number of "active" channels was equal to the number of channels. On the chart, one can see that in "active" channels WPC delivers substantially higher profit to the supplier than any other arrangement. In our experiment, three markets were not enough for WPC to outperform MOQ but the data suggests that with already four retailers the result would be different.

3.5 Summary and Conclusions

In his review of coordinating contracts, Cachon (2003) makes a remarkable observation: "Even though the wholesale price contract does not coordinate the supply chain, it is worth studying because it is commonly observed in practice. That fact alone suggests it has redeeming qualities". While theories of bilateral monopoly do not seem to have an explanation of this puzzle, we believe that in the real world contracting takes place in a much richer environment. Other factors, missing in the purified model of bilateral monopoly, are known to be important determinants of contracting outcomes. In particular, contract complexity, social preferences and information asymmetry. In addition, there is some horizontal competition usually involved.

This study aims to illuminate the role of competition in supply chain coordination. In the light of the general result of impossibility to coordinate a dyadic channel under information asymmetry, and consequently, in presence of social preferences (because they are unobservable, i.e. private information) coordinating contracts lose most of their appeal. We argue that competition can mitigate and sometimes even eliminate detrimental effect of those factors. Moreover, in cases when coordination is possible, it also eliminates a need in complex coordinating contracts. In fact, nothing more than a simple wholesale price contract is required. Competition does the entire coordinating job, whereas the wholesale price contract only serves as a means to transfer profit. Still, coordination via competition comes at cost. To induce competition, a supplier, facing multiple retailers whose markets do not overlap, has to commit not to deal with at least one of them. According to the standard theory, the supplier could instead use a coordinating contract and achieve coordination without sacrificing a part of the market. Therefore, a mechanism based on induced competition, might be seen as inferior.

However, in the experiment we find that by sacrificing one market, the wholesale pricing with competition almost perfectly coordinates the remaining ones and, in this part, by far outperforms coordinating contracts even under complete information. A primary reason, as discussed in Chapter 2, is due to fairness concerns. Retailers demand a substantial part of the supply chain profit for themselves and reject offers they perceive unfair. Because of this, coordinating contracts do not provide much gain over Double Marginalization benchmark. But competition alleviates the impact of fairness because none of the retailers can punish the supplier by rejecting a contract. In the equilibrium, regardless how much the retailers care about fairness, and how different they are in this respect, they compete their profits away allowing the supplier to coordinate the channel.

In our model, we allow for some information asymmetry by introducing a coefficient, drawn from some arbitrary distribution, scaling the size of all markets. This corresponds to the case when all markets exist in similar economic environments. That is, depending on whether the economy is good or bad, all the markets expand or shrink to the same extent. Although, in general, this is a limiting assumption, it serves to illustrate that under certain types of information asymmetry competition coordinates the supply chain as well. What makes competition even more attractive is its extremely low informational demands to the supplier. In fact, the supplier may not even know about the very existence of information asymmetry. Competition still coordinates the channel, whereas if the supplier wanted to treat each retailer separately, then, in order to design an optimal contract, he would have to know the distribution of the scaling factor but still would not be able to achieve coordination.

In conclusion, we would like to address the citation given above. As our results suggest, the fact that the wholesale price contract is widely observed in practice may be due not to redeeming qualities of the wholesale price contract as such, but due to redeeming qualities of mechanisms utilizing induced competition. Such mechanisms prove robust to different factors, such as information asymmetry or preferences for fairness, any of which suffices to destroy a coordinating contract.

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Appendix A

Supplementary material to Chapter 2

A.1 Instructions used in the experiment

We made the experiment instructions for different treatments as close to each other as possible, using MOQ instructions as a template. We provide them below, explaining what modifications we made for the other treatments.

Instructions

You are about to participate in decision-making experiment. If you follow these instructions carefully you can earn a considerable amount of money. Your earnings depend on your decisions as well as well as on the decisions of other participants.

The experiment lasts 40 periods. You will be randomly matched with another person in the room in each period.

> *(In the treatment with the automated retailer, MOQ-A, the last sentence was omitted)*

You are NOT allowed to communicate with the other participants during the session. If you have any questions, raise your hand and the experimenter will come to help you.

The Game Flow

In this experiment you will have one of two roles, either a supplier or a retailer. Each period one supplier and one retailer are matched together. The matching will change randomly every period. You will have the same role for the duration of the session. You will learn your role once the game starts.

(In the treatment with the automated retailer, MOQ-A, we changed this paragraph as follows: "In this experiment you have a role of a supplier and you will be dealing with a computerized retailer. You will have the same role for the duration of the session".)

A supplier produces a product that costs 20 tokens per unit. A retailer can then buy this product from the supplier and sell it on the market.

Each period starts with the supplier announcing a wholesale price, W, and the minimum order quantity, Qmin, to the retailer.

(In the treatments testing the wholesale price contract, WP and WP-out, any references to Qmin were removed.)

After the supplier makes the offer, the retailer decides how many units to order from the supplier at price W. The retailer cannot order any amount below Qmin. However, the retailer can also reject the offer.

What happens if the retailer accepts

If the retailer accepts the offer by ordering Q = Qmin then the retail price P at which the units are sold depends on the order quantity Q as follows:

P = 100-Q

The retailer's profit is then:

Retailer's Profit = (P-W)xQ

The supplier's total profit from the trade is:

Supplier's Profit = (W-20) x Q

What happens if the retailer rejects

If the retailer rejects both parties make zero profits in this period.

(For the treatment with the "dictator" supplier, MOQ-D, this part was modified appropriately: "If the retailer rejects then the retailer's profit is zero in this period. The supplier's profit is zero if by ordering any Q = Qmin the retailer

would incur losses. Otherwise, if the retailer rejected a profitable offer, that is by ordering some Q = Qmin the retailer could make profit, or, at least, break even, the supplier makes profit as if the retailer orders Q = Qmin at price W".)

Example 1.

(For other treatments, we modified examples and quizzes accordingly.)

Suppose the supplier offers W = 40 and Qmin = 50.

If the retailer accepts

Suppose the retailer accepts the offer and orders 50 units. Then

Supplier's profit = (40 – 20) x 50 = 20 x 50 = 1000.

When the retailer re-sells these 50 units on the market, the market price is

P = 100 – 50 = 50.

The retailer's profit will be

Retailer's profit = (P – W) x Q = (50 – 40) x 50 = 10 x 50 = 500.

If the retailer rejects

Both parties make zero profits.

Example 2.

Suppose the supplier offers W = 80 and Qmin = 30.

If the retailer accepts

Suppose the retailer accepts the offer and orders 30 units. Then

Supplier's profit = (80 – 20) x 30 = 60 x 30 = 1800.

When the retailer re-sells these 30 units on the market, the market price is

P = 100 – 30 = 70,

which is smaller than W = 80. The retailer's profit will be

Retailer's profit = (P – W) x Q = (70 – 80) x 30 = - 10 x 30 = - 300,

which is negative. Thus, for the retailer, ordering 30 units results in a loss.

If the retailer rejects

The retailer cannot order anything less than 30 because Qmin = 30. The retailer cannot avoid losses by ordering any Q = Qmin because ordering more than 30 makes the market price even lower than 70 whereas it has to be at least 80 for the retailer could avoid losses.

Therefore, this is not a profitable offer for the retailer. If the retailer rejects both parties make zero profits.

Information to help players make their decisions

(the screenshots are given further)

Your computer screens have a “Calculate” button that allows suppliers to try different combinations of W and Qmin without actually making an offer. After the supplier submits an offer, it appears on the retailer’s screen and now the retailer can try different Q’s before submitting a final decision.

For a supplier, the computer will calculate the Q that maximizes retailer’s profits and show both parties’ profits assuming that the retailer orders this amount.

Similarly, the retailers’ “Calculate” button allows them to try different order quantities before deciding on the order amount.

You can use the “Calculate” button as much as you need. Whenever you are ready to submit your decision, click on “Submit” button.

After both parties submit their decisions, profits are calculated, the period ends and the game proceeds to the next period.

How you will be paid

The session will involve 40 periods. Your total earnings from the 40 periods will be converted to US dollars at the rate of 1600 experimental tokens per dollar, added to your participation fee of $5 and paid to you in private and in cash at the end of the session. All earnings are confidential.

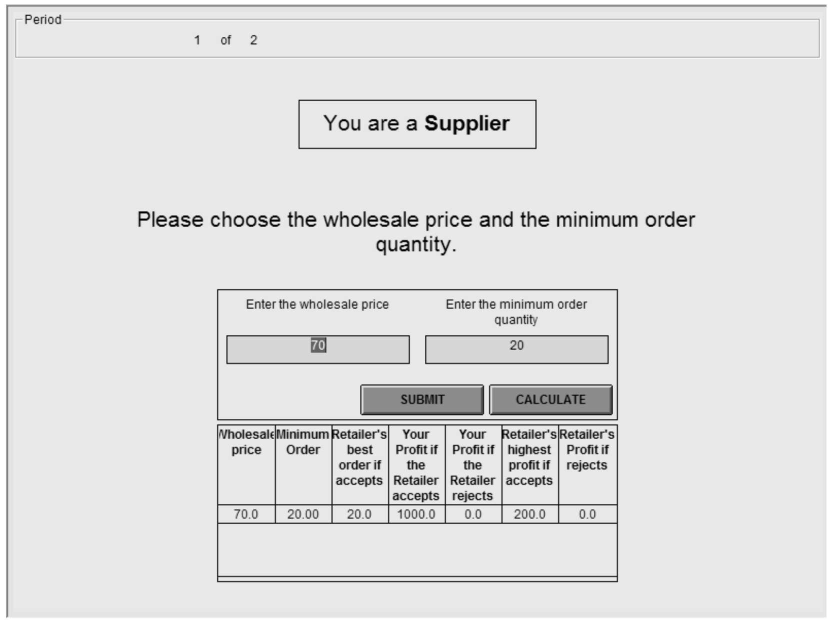
Quiz

The supplier offers W = 70 and Qmin = 20.

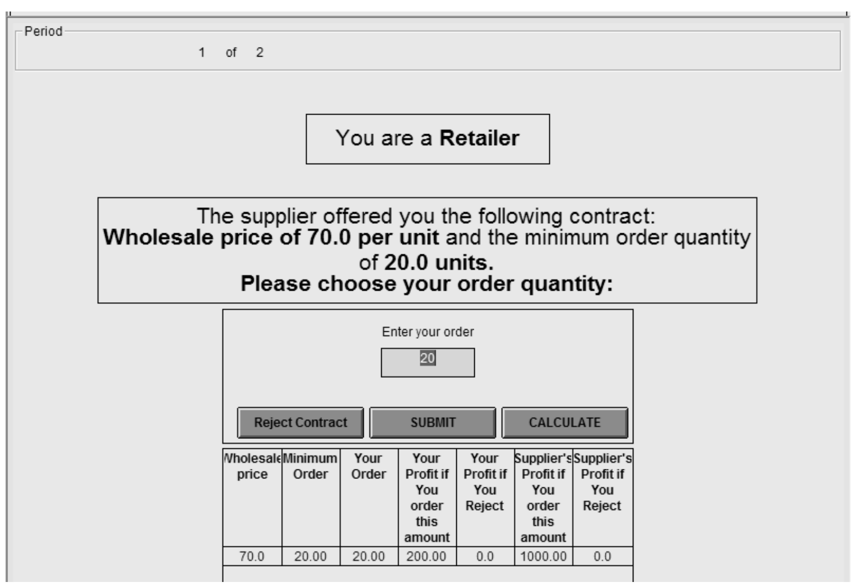
Questions:

1. Can the retailer order 19 units? (yes/no) _____
2. Can the retailer order 100 units? (yes/no) _____
3. Can the retailer reject? (yes/no) _____
4. What will be the retailer's profit if the retailer rejects? ________
5. What will be the supplier's profit is the retailer rejects? _______
6. What will be the supplier's profit is the retailer orders 20 units? _______
7. What will be the retailer's profit is the retailer orders 20 units? _______

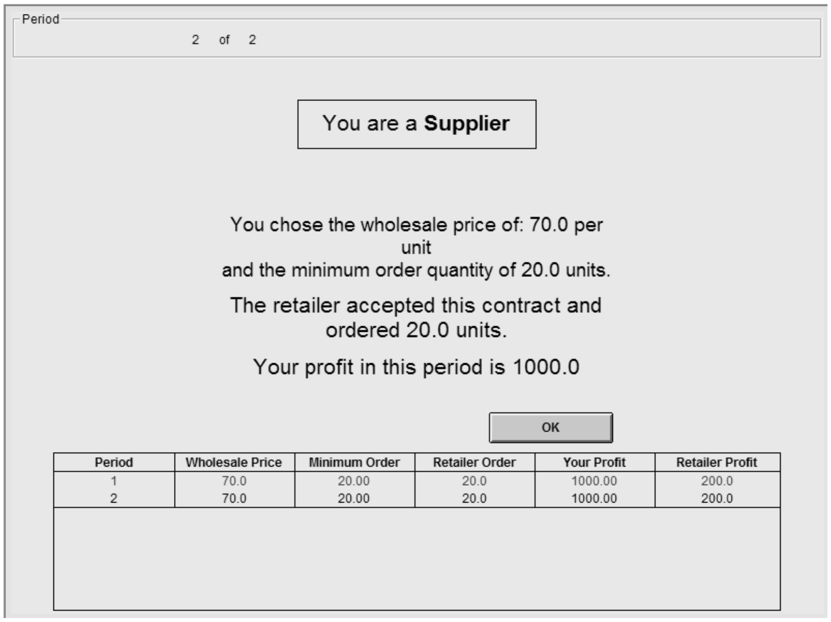
A.2 Screenshots (from the MOQ treatment)



The supplier's decision screen



The retailer's decision screen



The period summary screen

Appendix B

Supplementary material to Chapter 3

B.1 Experimental Instructions and Screen Shots

All participants were given sufficient time to read instructions and compute answers to the quiz questions. After that, the experimenter read instruction aloud and went over numeric examples and quiz questions using PowerPoint slides. All details of the supplier's and the retailer's decision screens and the way to use them were also explained to the participants.

B.1.1 Instructions used in experiments

You are about to participate in decision-making experiment. If you follow these instructions carefully you can earn a considerable amount of money. Your earnings depend on your decisions as well as well as on the decisions of other participants.

The experiment lasts 40 periods. You will be randomly matched with three other people in the room in each period.

You are NOT allowed to communicate with the other participants during the session. If you have any questions, raise your hand and the experimenter will come to help you.

The Game Flow

In this experiment you will have one of two roles, either a **supplier** or a **retailer**. Each round one supplier and three retailers are matched together. The matching will change randomly every round. You will have the same role for the duration of the session. You will learn your role after you log into the game software.

The supplier produces a product that costs 20 tokens per unit. Retailers sell this product on the market.

During each period the markets of all three retailers can be either of Type HIGH or of Type LOW. There is a 50/50 chance that the markets are all HIGH or all LOW in any given period. A HIGH or LOW market in any period has no effect on the type of the market in any other period (in other words, market type is random and independent).

Each retailer will know the type of his own market before he has to make a decision. The supplier does not know the type of the market for the retailers, but only that each type, HIGH or LOW, is equally likely.

Each round starts with the supplier announcing a wholesale price W and a minimum order quantity MOQ to all retailers.

After the supplier submits his wholesale price W and minimum order quantity MOQ, all three retailers simultaneously make their decisions. Each retailer has two options, either order some quantity Q that is at least as high as MOQ (but can be higher) or reject the supplier's proposal.

When a retailer rejects a proposal the retailer earns 100 tokens in a LOW market and 300 tokens in a HIGH market, in that round. The supplier earns 0 from the transaction with this retailer (but may well have positive earnings from transactions with the other two retailers)

When a retailer accepts the supplier's contract by placing an order Q (which is at least as high as MOQ) earnings are computed as follows:

For each retailer, the retail price P at which the units are sold depends on the order quantity Q and the type of market as follows:

In the HIGH type market: P = (150-Q) / 1.5

In the LOW type market: P = (50- Q) / 0.5

The retailer's profit is then:

Retailer's Profit = (P-W) x Q

The supplier's total profit from the interaction with the three retailers is:

Supplier's Profit = (W-20) x (Q1 + Q2 + Q3)

Where Q1 is the first retailer's order quantity, Q2 is the second and Q3 is the third. Note that if any of the retailers rejected the supplier's contract, this simply causes the corresponding Q's to be 0.

Example

Suppose the supplier offers W = 50 and MOQ = 20.

Suppose retailers have a HIGH type market. Suppose the three retailers order Q1 = 20, Q2 = 30 and Q3 = 40.

Supplier's total profit is (50 – 20) x (20 + 30 + 40) = 30 x 90 = 2700.

Retailer 1's retail price from Q1 = 20 is (150 – 20)/1.5 = 86.67 and his profit is (86.67 – 50) x 20 = 1333.33

Retailer 2's retail price from Q2 = 30 is (150 – 30)/1.5 = 80 and his profit is (80 – 50) x 30 = 900

Retailer 3's retail price from Q3 = 40 is (150 – 40)/1.5 = 73.33 and his profit is (73.33 – 50) x 40 = 933.20

Suppose instead retailer 1 chooses to reject the offer and retailers 2 and 3 place orders as above. Then:

Supplier's total profit is (50 – 20) x (0 + 30 + 40) = 30 x 90 = 2100.

Retailer 1's profit from rejecting the contract is 300

Retailer 2's retail price from Q2 = 30 is (150 – 30)/1.5 = 80 and his profit is (80 – 50) x 30 = 900

Retailer 3's retail price from Q3 = 40 is (150 – 40)/1.5 = 73.33 and his profit is (73.33 – 50) x 40 = 933.20

Information to help suppliers make their decisions

On the supplier's screen we provide a calculator that allows supplier to enter in possible W and MOQ and click the CALCULATE button. The calculator will then show the Retailer's order that will maximize the retailer's earnings given those W and MOQ for each market Type (or if the retailer is likely to reject because his or her earnings will be below 100 in LOW market and below 300 on HIGH market). The calculator will also show supplier's average profit which is simply the average of the supplier's profit from a LOW market type and a HIGH market type. Suppliers can use this calculator as many times as they wish in order to come up with the contract they would like to submit. The contract is transmitted to retailers by using the SUBMIT button.

Information to help retailers make their decisions

After the supplier makes his decision, the computer will display the wholesale price W and the minimum order quantity MOQ. The retailers' computer screens have a calculator that will allow them to enter in different order quantities. Pressing the CALCULATE button and automatically calculate their own profit, and the supplier's profit from their order.

If you are a retailer, you can use your calculator as many times as you want. When you are finished with the calculator you can make your decision by pressing the "Place Order" button to place the order or the "Reject Contract" button to reject the contract.

How you will be paid

The session will involve 40 periods. In each period you will be randomly matched with other people in the room, but you will have the same role, retailer or supplier, for all 40 periods. Your total earnings from the 40 periods will be converted to US dollars at the rate of 1600 experimental tokens per dollar, added to your participation fee of $5 and paid to you in private and in cash at the end of the session. All earnings are confidential.

Quiz

Question 1

Suppose a supplier offers the wholesale price W = 70 and MOQ = 10.

If one retailer orders Q1 = 20, what is his retail price IN LOW market? __________In HIGH market? ___________

What is his profit in LOW market? ___________________ In HIGH Market?

Suppose another retail orders Q2 = 10, what is his retail price IN LOW market? __________In HIGH market? ___________

What is his profit in LOW market? ___________________ In HIGH Market?

Suppose another retail orders Q3 = 15, what is his retail price IN LOW market? __________In HIGH market? ___________

What is his profit in LOW market? ___________________ In HIGH Market?

What is the supplier's profit if retailers 1 and 3 are in HIGH market and retailer 2 is in LOW market? ______________________

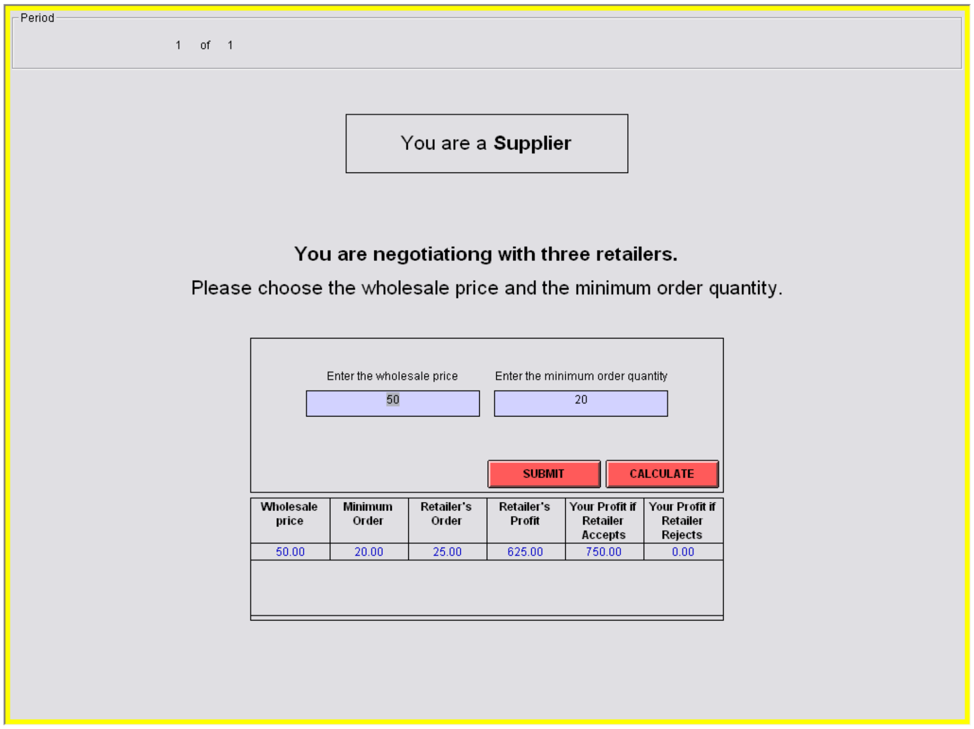
Question 2

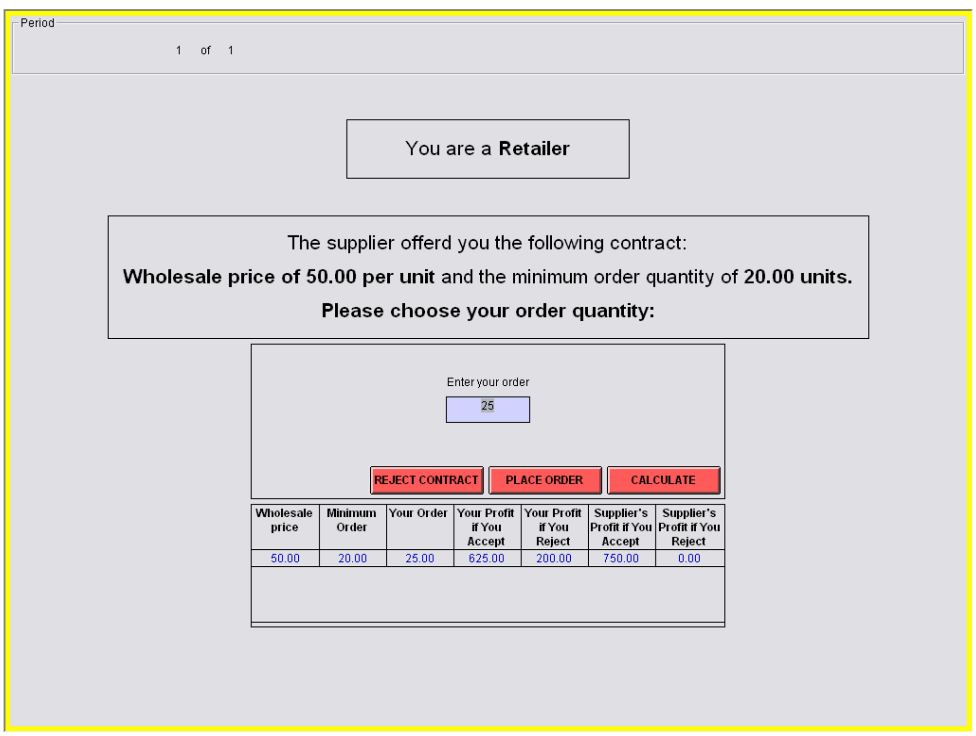
Suppose the supplier offers W = 40 and MOQ = 20.

In LOW market would a retailer make higher profit from ordering Q = 20 or Q = 50? Explain.

In HIGH market would a retailer make higher profit from ordering Q = 20 or Q = 50? Explain.

B.1.2 Sample screen shots





B.2 Statistical analysis

B.2.1 General Linear Model

General Linear Model: AvgW, AvgQ, ... versus Treatment, Cohort

Factor	Type	Levels	Values
Treatment	fixed	5	MOQ-F, MOQ-I, WP-1, WP-3, WPC
Cohort(Treatment)	random	15	1, 2, 3, 1, 2, 3, 1, 2, 3, 1, 2, 3, 1, 2, 3

Least Squares Means

	AvgW	AvgQ	AvgProfitSup	AvgProfitRet
Treatment	Mean	Mean	Mean	Mean
MOQ-F	45.08	37.83	2826.90	546.21
MOQ-I	53.87	17.80	2326.68	546.75
WP-1	52.32	21.09	667.69	545.86
WP-3	53.48	23.04	2173.53	529.08
WPC	54.27	36.96	2608.11	253.05

B.2.2 Wholesale prices

Analysis of Variance for AvgW, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	4	1756.95	1756.95	439.24	5.19	0.016
Cohort(Treatment)	10	846.05	846.05	84.60	21.98	0.000
Error	135	519.74	519.74	3.85		
Total	149	3122.74				

S = 1.96212   R-Sq = 83.36%   R-Sq(adj) = 81.63%

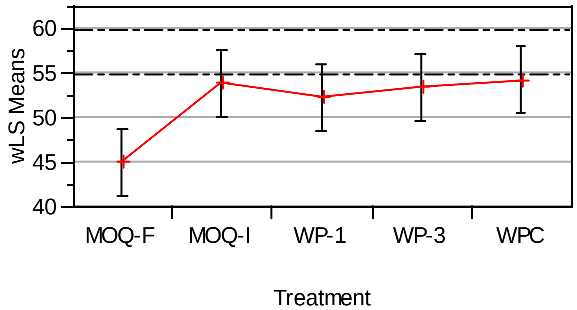
Term	Coef	SE Coef	T	P
Constant	51.8038	0.1602	323.36	0.000
Treatment				
MOQ-F	-6.7205	0.3204	-20.97	0.000
MOQ-I	2.0628	0.3204	6.44	0.000
WP-1	0.5175	0.3204	1.62	0.109
WP-3	1.6787	0.3204	5.24	0.000

LSMeans Differences Tukey HSD

Alpha=0.050

Level			Least Sq Mean
WPC	A		54.265333
MOQ-I	A		53.866667
WP-3	A		53.482500
WP-1	A	B	52.321333
MOQ-F		B	45.083333

Levels not connected by same letter are significantly different



Wholesale prices and 95% confidence intervals

B.2.3 Order quantities

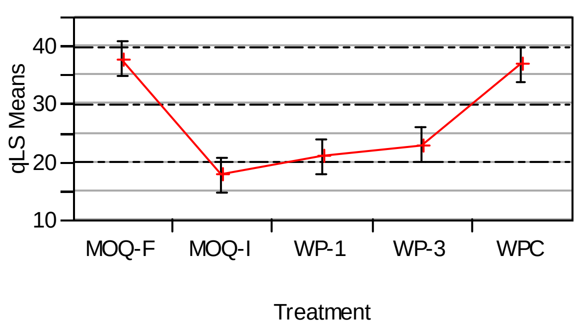
Analysis of Variance for AvgQ, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	4	10532.46	10532.46	2633.12	48.20	0.000
Cohort(Treatment)	10	546.31	546.31	54.63	3.36	0.001
Error	135	2194.32	2194.32	16.25		
Total	149	13273.10				

S = 4.03165   R-Sq = 83.47%   R-Sq(adj) = 81.75%

Term	Coef	SE Coef	T	P
Constant	27.3431	0.3292	83.06	0.000
Treatment				
MOQ-F	10.4847	0.6584	15.93	0.000
MOQ-I	-9.5431	0.6584	-14.50	0.000
WP-1	-6.2514	0.6584	-9.50	0.000
WP-3	-4.3058	0.6584	-6.54	0.000

```
LSMeans Differences Tukey HSD
Alpha=0.050

Level       Least Sq Mean
MOQ-F  A     37.827778
WPC    A     36.958833
WP-3     B   23.037278
WP-1     B   21.091667
MOQ-I    B   17.800000

Levels not connected by same letter are significantly different
```



Order quantities and 95% confidence intervals

B.2.4 Retailer's profit

```
Analysis of Variance for AvgProfitRet, using Adjusted SS for Tests

Source               DF    Seq SS    Adj SS   Adj MS     F       P
Treatment             4   2010131   2010131   502533   6.65   0.007
Cohort(Treatment)    10    755228    755228    75523   5.19   0.000
Error               135   1964996   1964996    14556
```

Total	149	4730355

S = 120.646   R-Sq = 58.46%   R-Sq(adj) = 54.15%

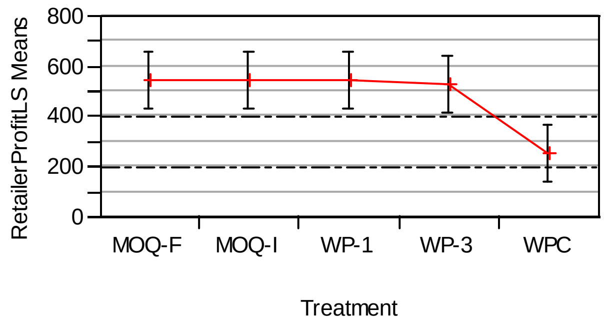
Term	Coef	SE Coef	T	P
Constant	484.189	9.851	49.15	0.000
Treatment				
MOQ-F	62.02	19.70	3.15	0.002
MOQ-I	62.56	19.70	3.18	0.002
WP-1	61.68	19.70	3.13	0.002
WP-3	44.89	19.70	2.28	0.024

LSMeans Differences Tukey HSD

Alpha=0.050

Level			Least Sq Mean
MOQ-I	A		546.75000
MOQ-F	A		546.20556
WP-1	A		545.86458
WP-3	A		529.07583
WPC		B	253.04894

Levels not connected by same letter are significantly different



Retailers' profits and 95% confidence intervals

B.2.5 Supplier's profit

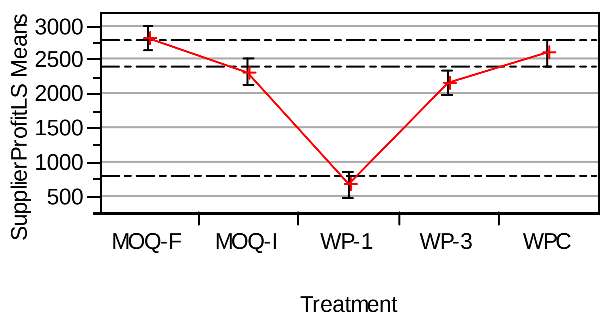
```
Analysis of Variance for AvgProfitSup, using Adjusted SS for Tests

Source              DF     Seq SS     Adj SS    Adj MS       F      P
Treatment            4   86782150   86782150  21695537  100.29  0.000
Cohort(Treatment)   10    2163249    2163249    216325    1.14  0.335
Error              135   25542288   25542288    189202
Total              149  114487687

S = 434.974   R-Sq = 77.69%   R-Sq(adj) = 75.38%

Term                   Coef  SE Coef       T      P
Constant            2120.58    35.52   59.71  0.000
Treatment
MOQ-F                706.32    71.03    9.94  0.000
MOQ-I                206.10    71.03    2.90  0.004
WP-1               -1452.89    71.03  -20.45  0.000
WP-3                  52.95    71.03    0.75  0.457
```

LSMeans Differences Tukey HSD

Alpha=0.050

Level					Least Sq Mean
MOQ-F	A				2826.9000
WPC	A	B			2608.1140
MOQ-I		B	C		2326.6833
WP-3			C		2173.5323
WP-1				D	667.6937

Levels not connected by same letter are significantly different



Suppliers' profits and 95% confidence intervals

B.2.6 Supplier's profit per active channel

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	P
Model	14	8175371	583955	26.2654	<.0001
Error	135	3001434	22233		
Total	149	11176804			

Parameter Estimates

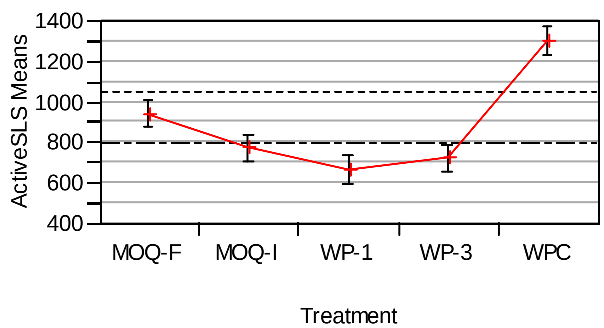
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	882.82453	12.17452	72.51	<.0001
Treatment[MOQ-F]	59.475472	24.34904	2.44	0.0159
Treatment[MOQ-I]	-107.2634	24.34904	-4.41	<.0001
Treatment[WP-1]	-215.1308	24.34904	-8.84	<.0001
Treatment[WP-3]	-158.3138	24.34904	-6.50	<.0001

LSMeans Differences Tukey HSD

Alpha=0.050

Level				Least Sq Mean
WPC	A			1304.0570
MOQ-F		B		942.3000
MOQ-I			C	775.5611
WP-3			C	724.5108
WP-1			C	667.6937

Levels not connected by same letter are significantly different



Suppliers' profits per active channel and 95% confidence intervals

Valery Pavlov

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CurriculumVitae

Research interests

Quantitative models in Supply Chain coordination and Operations Management; procurement mechanism design and negotiations; experimental economics, behavioral operations and decision-making in business environment.

Education

Ph.D. in Business Administration and Operations Research (dual title degree). (2009)

Smeal College of Business, The Pennsylvania State University, USA.

MS and BS in Engineering Physics (1989)

Moscow Institute of Physics and Technology, Moscow, Russia.

Professional memberships

INFORMS (2006-current)

Decision Sciences Institute (2008-current)

Working Experience

Head of Marketing Department. Steel EA, Moscow, Russia. (2001-2004)

CEO, co-owner. "Wholesaler's Weekly Market Guide", Moscow, Russia. (1993-1999)

Relevant computer skills (proficient / advanced user)

Math/stat: Matlab, Maple, GAMS, Scientific Workplace, JMP, Minitab

Programming languages: C, Microsoft Visual Basic, Pascal, Fortran, SQL

MS Office suite: Word, Excel, Access, PowerPoint