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QUICK RESPONSE SYSTEMS WITH MINIMUM ORDER QUANTITY IN FASHION SUPPLY CHAINS

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CERTIFICATE OF ORIGINALITY

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Abstract

Both quick response (QR) strategy and minimum order quantity (MOQ) imposition are common practices in the apparel industry. With the use of technology, QR aims at reducing order lead time so that the retailer can be more responsive to market change; therefore the retailer is favourable to its adoption in general. By contrast, the manufacturer may hold a more reserved view on the strategy owing to the implementation cost and possible reduction of order size. For MOQ, the retailer normally would not welcome its imposition as it inevitably reduces his ordering flexibility; however, it justifies production set-up cost and provides certain guarantee of income for the manufacturer. These seemingly conflicting views between channel members on the two practices have prompted us to study their joint influence on the whole supply chain. To the best of our knowledge, little research, if not none, has been conducted to explore the integrated effect of QR and MOQ, especially their impact on the channel coordination issue. It is this gap in the literature that we set out to bridge in this thesis.

We employ both empirical and analytical modelling methodologies in this study. We first conduct in-depth interviews with two apparel companies to gain a basic

understanding of the current QR and MOQ practices in the apparel industry. We then conduct a structured questionnaire survey with industrialists to further explore their QR and MOQ practices. We formulate and test hypotheses to verify our proposed model on the relationship between QR and MOQ. In parallel, we also investigate QR systems with MOQ mathematically. Specifically we explore the retailer's optimal ordering policy under different QR-MOQ models. With industrial real data, we conduct numerical sensitivity analyses to investigate the impacts of MOQ(s) on the performance of individual channel members and the supply chain. We also tackle the challenge of channel coordination under these systems

We find that the optimal ordering policies under QR-MOQ systems are usually complicated because the corresponding expected profit-to-go functions are in general not uni-modal and there may exist multiple local maxima. We propose efficient solution schemes to find the global optimal ordering policies. In addition, our findings show that the presence of MOQ reduces the efficiency of the retailer, the manufacturer, as well as the supply chain in most cases. In light of this, we devise flexible supply contracts to help coordinate the supply chain.

We believe that this research provides important academic and managerial insights on the widely observed industrial practices of QR and MOQ. Our research findings fill part of an existing gap in the literature and advance knowledge in this important area. The research not only makes a significant contribution to the literature on supply chain management but also provides helpful guidance to practitioners for making more scientifically sound and wise decisions in supply chains with QR and MOQ.

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I had never thought of having the opportunity to purse a PhD degree before. Through these three years' study, I am glad that not only could I have advancement in my academic knowledge, but also I have gained a better understanding of myself.

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1. Introduction

1.1. Background of Study

In fashion industry, the highly volatile demand is notorious as a great challenge for inventory management professionals. Owing to the rapidly switching fashion trends and short product life cycle, the demand for fashion products are highly unpredictable and some fashion retailers have to tackle this problem by keeping an enormous level of inventory. Obviously, this measure is undesirable because over-stocking is expensive and the subsequent mark-downs for stock clearance near season end leads to significant reduction in the profits of fashion retailers. In light of it, practitioners in the apparel industry have been striving for different approaches to cope with the inventory problem. Quick Response (QR) is one of those strategies that help alleviate the practitioners' burden in this perspective.

Originated from the US apparel industry in the 1980's to increase its competitiveness against low-wage overseas companies, QR comprises a set of actions that aims at reducing the lead time in a supply chain (Chopra & Meindl, 2007, p.370). Essentially, with lead time reduction under QR, retailers can improve their forecast accuracy and better manage their inventory policies to match with the highly fluctuating demand, which in turn improve their performance. There are considerable amounts of literature reporting the benefits of QR adoption. For instance, under a government-funded Quick Response programme in the Australian textiles, clothing and footwear industry, the participant companies report significant improvement in their key performances, which include a double in their annual sales, percentage of business conducted and the inventory turnover ratio (Perry et al., 1999).

Despite the enormous amount of literatures on the topic, there are still rooms for investigation regarding successful implementation of QR. It has already been shown analytically that the retailer's expected order quantity under QR would usually be less than that without QR (Iyer and Bergen, 1997; Choi and Chow, 2008). This implies that the profit of the manufacturer also shrinks as a direct result of order quantity reduction. In addition, the necessary investment in information technology required for QR implementation and operations, as well as the increased difficulty to provide flexibility to the retailer, increase the manufacturer's reluctance to participate in QR. The issue arouses numerous literatures that aim at providing incentives and measures for the manufacturer to adopt QR. Some suggestions include the retailer's commitment on price and service (e.g. Iyer & Bergen, 1997; Choi & Chow, 2008).

Minimum order quantity (MOQ) imposition is a commonly adopted policy in the apparel industry. Owing to the economy of scales and justification for initial setup cost, many apparel manufacturers would only accept orders with quantity above a certain amount, i.e. the MOQ. Fashion retailers like Bossini and Giordano, for instance, used to aggregate their market demands in multiple regions in order to justify the MOQ requirements for re-ordering. When one browses through various e-commerce business-to-business sourcing portals on the internet such as *alibaba.com*, and *globalsources.com*, it is not difficult to find that many apparel suppliers state their minimum order requirement together with their product information.

1.2. Rationale of the Study

We have an interesting observation regarding the different attitudes between the fashion retailers and the manufacturers on both QR and MOQ in the apparel industry. On one hand, the retailer opts for implementation of QR so that he can better cope with the volatile market situation whereas the manufacturer have more reservation in adopting QR owing to the high initial investment cost and the doubts about whether QR can actually bring about any real benefit to them. On the other hand, the manufacturer normally prefers imposing MOQ on their buyers as it provides a certain guarantee to her income whilst the retailer normally would not welcome MOQ imposition as it hinders his ordering flexibility. These conflicting perceptions on QR and MOQ by the different channel members motivate us to explore more on these two topics.

Nevertheless, to the best of our knowledge, little, if not none, research has been conducted on the impact of MOQ on the fashion supply chains. Moreover, it appears that no investigation has been conducted on the relationship between QR adoption and MOQ. This is such a gap in the literature that motivates us to explore the relationship between the two in this thesis. In particular, it is our main interest to explore whether coordination can be achieved under QR with MOQ and if so how the coordinating mechanism works. Both academic and managerial insights can then be generated.

1.3. Research Objectives

Specifically, there are five main objectives of this thesis, namely:

(1) To obtain a clear picture regarding the current industrial practices and challenges of QR and MOQ in the Hong Kong apparel industry via industrial case studies;

(2) To examine empirically various pertinent issues regarding QR adoption and MOQ imposition (such as supplier-buyer relationship) via industrial survey;

(3) To analytically derive the retailer's optimal ordering policies under QR supply chains with MOQ under different scenarios;

(4) To investigate the impacts of MOQ on the performance of individual channel members and the whole supply chain; and

(5) To develop a mechanism that can enhance the coordination of QR supply chains under the MOQ constraint(s).

1.4. Outline of Methodology

Both empirical and analytical approaches are employed in this thesis. Specifically, we employ the following three approaches:

(1) In-depth personal interviews with two well-established apparel companies as target cases;

(2) A theory-driven empirical study in the form of a structured questionnaire survey with statistical analysis;

(3) Mathematical model formulation and optimization, supplemented by simulation experiments and numerical analysis.

Details of the individual approaches are presented in their respective chapters.

The rationale of employing these approaches is as follows. Being the first step in this study, the case studies can help us gain a clearer picture about the current practices of QR adoption and MOQ imposition in the apparel industry, as well as provide a solid foundation for our subsequent works. Afterwards, both theory-driven empirical study and analytical modelling research will be conducted to further investigate the relationship between the two practices in different dimensions.

The theory-driven empirical study involves formulation of a conceptual QR-MOQ model with reference to some existing theories in the supply chain management context, followed by a structured questionnaire survey. The design of the set of questionnaires will mainly focus on three aspects, namely: (a) obtaining empirical evidence regarding the prevalence of QR and MOQ in the apparel industry as well as the details of MOQ imposition; (b) understanding the perception of the industrialist respondents towards QR and MOQ imposition; and (c) verifying the conceptual QR-MOQ model we have formulated based on review of existing theories.

Started by formulation of the different QR-MOQ systems, the main focuses of the mathematical modelling research are: (a) deriving the retailer's optimal order policies under different QR-MOQ systems; (b) investigating the impacts of MOQ on the performance of the retailer, the manufacturer, and the supply chain; and (c) exploring the possibility of any mechanism that can achieve channel coordination.

We believe that by adopting the above methodology, not only can we fulfil the objectives for the three approaches individually, but also the three approaches can complement each other in providing a comprehensive understanding regarding the issues with QR-MOQ supply chains as a whole.

1.5. Significance of this Research

By having a better understanding on the relationship of QR and MOQ, and their respective impacts on channel coordination, we believe that fashion retailers can better assess their business environment and make appropriate decisions on the choice of strategies to be adopted that optimize their business performance. Upstream manufacturers can also be benefited by learning more about the impacts brought by these two important measures. Our findings also illustrate the role played by QR and MOQ on the respective supply chain and measures for achieving coordination are also discussed. By exploring the research problems from both mathematical modelling and empirical approaches, this thesis generates a number of important analytical and empirical managerial insights. This is our hope that this thesis would not only contribute by enriching the supply chain management literature but also providing some significant insights for better implementation of QR in the industry.

1.6. Organization of this Thesis

This thesis consists of eleven chapters and its organization is as follows. We first conduct a concise literature review on the related supply chain management context in Chapter 2. Then we report the details of the interview cases we have conducted with two apparel companies regarding their current practices related to QR and MOQ imposition in Chapter 3. In Chapter 4, we (i) discuss the conceptual model we have developed based on research on related theories to empirically study the relationship between QR and MOQ, (ii) present the design of a questionnaire survey, and (iii) discuss the findings from the analysis of the survey data. Serving as an introduction to the subsequent chapters on mathematical modelling, in Chapter 5 we present the analytical framework for the various QR-M*O*Q systems under study, as well as the list of notations to be adopted in the subsequent chapters. Then we derive the optimal ordering policy for the QR systems in the form of single-ordering with MOQ, dual ordering with MOQ only at earlier stage, and dual ordering with MOQ at both stages in Chapters 6, 7 and 8, respectively. Afterwards, we present the numerical analysis regarding the impacts of MOQ(s) on the channel members' performance under these systems in Chapter 9. Then, we explore the use of some dynamic MOQ policies to address the issue on channel coordination in Chapter 10. Finally we conclude with future research directions in Chapter 11.

2. Literature Review

This thesis concerns the relationship between Quick Response (QR) strategy and the practice of Minimum Order Quantity (MOQ) requirement, as well as the issue of channel coordination in fashion supply chains. In this chapter, we present a review on the various related topics in the research literature.

2.1. Quick Response (QR) Strategy

2.1.1 Origin and Definitions

First established in the 1980's in the US apparel sector to increase the industry's competitiveness over the low-wage overseas counterparts, Quick Response (QR) has been a well-established and widely-practiced inventory management strategy in various industries. With its core objective to respond quickly to market changes and shorten ordering lead times (Hammond, 1990; Iyer and Bergen, 1997), QR has been widely applied in places all around the world with different names. For instance, it is called "Sen-ko-te-hai" in Japan (HKTDC 1999). The benefits brought about by QR are reported to be especially substantial in the supply chains whose products have short life cycles and are subject to highly volatile demand (Fisher et al., 1994; Fisher et al., 2001). As a result, QR is a popular measure in fashion supply chains.

There are a wide variety of descriptions about the definitions of QR (Lowson et al., 1999). From the textiles and clothing perspective, Hunter (1990) defines QR as integration of all parts in the fashion supply chain (from fibre, textile, clothing manufacture, to retail), with the use of updated hard and soft technologies, into a "consumer responsive whole" that provide the best quality at each stage. Fairbairn (1997) suggests another version of the definition of QR as "*a technology-driven sourcing technology based on a cooperation relationship between retailer and supplier that seeks to minimize slack resources (i.e. time and inventory) in the supply chain*". The main concept behind the strategy is that: by shortening the order lead time, a greater portion of production can be arranged according to the initial demand observed (Fisher & Raman, 1996).

A substantial amount of literatures have been dedicated to QR strategy over the past two decades (Birtwistle et al., 2006b). The approaches that they took include: mathematical models (e.g., Iyer and Bergen, 1997; Al-Zubaidi and Tyler, 2004; Sethi et al., 2005; Cheng and Wu, 2005; Chen et al., 2006; Choi and Chow, 2008), face-to-face interviews (e.g. Birtwistle et al., 2006a and 2006b) and questionnaire surveys (e.g. Frazier et al., 1994; Fiorito et al., 1998; Shin et al., 2000; Giunipero et al., 2001; Heikkila, 2002; Handfield and Bechtel, 2002; Birtwistle et al., 2003; Fernie and Azuma, 2004). A most recent review on the strategy can also be found in Choi and Sethi (2010).

2.1.2 Benefits and Disadvantages of QR

It is generally agreed that firms increasingly adopt QR strategy as a means to enhance their competitiveness. Such competitiveness is illustrated by the significant improvements in the participants' business performance reported in a government-funded QR programme for the Australian textile, clothing and footwear industry (Perry et al., 1999; Perry & Sohal, 2000). Results of a questionnaire survey on the specialty retailers in the United States also assert that QR adoption could improve a firm's performance (Palmer & Markus, 2000). QR is also believed to be an effective strategy for apparel firms to sustain in the business where demand is highly volatile and competition is vigorous. Fairbairn (1997) demonstrate empirically that increase in environment uncertainty induces retailing firms in the US to adopt QR to improve their performance. Simultaneously, through implementation of QR, a retailer's organization structure is also strengthened (in term of integration, performance control and operations decentralization) and buyer-supplier relationship improved (Fairbairn, 1997).

A main drawback for QR adoption is the investment in the related technology during the initial implementation stage. For the manufacturers, they may be sceptical to the possible erosion of their profit margin owing to the additional services they have to provide to the retailer for QR adoption, such as labelling and price tags (Birtwistle et al., 2006b). Besides, the decrease in the retailer's order quantity after QR adoption may also cause a reduction in the manufacturer's profit (Iyer and Bergen, 1997; Choi and Chow, 2008). Therefore, appropriate incentives may be needed to align the benefits of the channel members under a QR supply chain.

2.1.3 Information Sharing and Supporting Technology in QR

Information sharing between channel members forms the core concept of QR strategy. In particular, an efficient information sharing scheme can effectively alleviate the bullwhip effect (Lee et al., 1997). First quantified by Lee et al. (1997), the bullwhip effect refers to the phenomenon that fluctuation in orders increases as they move upstream in a supply chain (Chopra and Meindl, 2007, p.509). Since then, many researchers have been exploring the value of information on the supply chain performance. Whereas some researchers hold the opinion that the retailer gain no benefits from sharing information (Lee et al., 2000; and Wu ad Cheng, 2008), there are also others believe that information sharing is beneficial to both the retailer and manufacturer (e.g. Cachon and Fisher, 2000). In particular, the benefits of information sharing to the manufacturer include a reduced expected cost (Cheng and Wu, 2005; and Wu and Cheng, 2008) and a lower inventory level (Wu and Cheng, 2008).

In order to enhance effective information sharing, implementation of technology such as Point of Sale (POS) equipment, Universal Product Code (UPC) and Automatic Checkout Machines (ACM) to monitor different business processes and document mistakes is deemed essential (Larson and Lusch, 1990; Birtwistle et al., 2006b). These devices can strengthen communication between the retailer and the supplier through unbiased tracking so that each member can be held accountable for fulfilling their commitments (Giunipero et al., 2001). Nowadays, with the advance in technologies, such as RFID technology and mobile computing (Cheng and Choi, 2010), many new technology-intensive practices have been developed and is commonly adopted to enhance information sharing in a supply chain. A few examples of such innovative practices include collaborative planning, forecasting and replenishment (CPFR), and vendor-managed inventory (VMI).

Firstly termed in the supply chain management context by Ireland and Bruce (2000), CPFR involves supply chain agents working together to decide the optimal inventory planning, forecasting and replenishment policies. When the trust between channel members grows, they can cooperate more closely as if they belong to one single entity and the supplier acts on behalf of the buyer in managing and replenishing inventory automatically. A number of literature works have asserted the benefits of the two practices on the supply chain performance. For instance, CFPR can result in reduction in supply chain variance (Aviv, 2001) whereas VMI can reduce the inventories for individual channel members (Johnson and Scudder, 1999) and enhance total supply chain efficiency (Kiesmuller and Broekmeulen, 2010). In reality, one can also find successful stories for VMI implementation in many fabulous companies, such as Procter & Gamble and Wal-Mart, TAL and JC Penny (Simchi-Levi et al., 2008, p.255). On the other hand, a number of literature works raise out the concern for the supplier in adopting these practices. For instance, the supplier should be sufficiently flexible to implement CPFR successfully (Aviv, 2007) whereas she may experience a greater fluctuation in her profit when adopting VMI (Dong and Xu, 2002).

2.1.4 Information Updating

Another feature in QR is the use of information updating to improve the demand forecast accuracy. In the inventory management literature with unknown parameters for the demand distribution, Bayesian approach has been widely-adopted to construct scientific and analytical model for studying the use of information. Research of inventory decision-making models with Bayesian information updates can be dated back to the 1950s (e.g. Dvoretzky et al., 1952; Scarf, 1959; and Murray and Silver, 1966). Afterwards, a great number of the researchers (e.g. Azoury and Miller, 1984; and Azoury, 1985) study different structural properties and features of the Bayesian inventory models.

There are two main concepts behind the Bayesian Decision Theory, namely: subjective probability and information update. Under the Bayesian approach, "*any uncertainty that is present in a decision problem regarding the value of specific variables or quantities can be expressed in terms of a joint distribution for those values*" (Cyert & DeGroot, 1987, p.7). Such probability is initially assessed in a subjective manner, e.g. from past history or the experience of the decision maker. Afterwards with the new information available, the probability will be re-assessed to reflect the updated situation.

In practice, QR is commonly implemented in the form of postponed ordering or dual ordering flexibility so that the retailers can observe the market before making their ordering decision closer to the season launch. In the context of supply chain management, the use of information update for single-period single-stage or two-stage inventory decision making problems is another important area which received a lot of attention. For example, Iyer and Bergen (1997) are the first to study QR in the form of a single-period single-ordering system. Afterwards, Gurnani and Tang (1999) and Choi et al. (2003) independently study the two-stage ordering problems with information updating and uncertain ordering cost under different model settings. They explore the case under which the retailer can place orders from the manufacturer at two distinct time points. Issues such as expected value of information have been investigated in Gurnani and Tang (1999), whilst Choi et al. (2003) explore the impacts on the service level and profit uncertainty after adopting the two-stage optimal ordering policy. Other works related to the use of information and quick response in supply chains include Bourland et al. (1996), Fisher and Raman (1996), Lau and Lau (1997), Eppen and Iyer (1997), Donohue (2000), Sethi et al. (2001), Bensoussan et al. (2004), Choi et al. (2004), Cheng and Wu (2005), Chen et al. (2006), Choi et al. (2006), Choi (2007), and Taylor and Xiao (2010).

2.1.5 QR and Facility Location

Whereas the order processes between the retailer and the manufacturer are crucial when adopting QR, the internal transportation and flow of merchandise (e.g. from shipment received in the warehouses to individual retail stores) also affects the responsiveness of the retailer. Since such efficient merchandise flow within the premises of the retailer may be attributed by the proper location of the warehouses and the number of trucks for delivery between warehouse and retail stores, we conduct a brief literature review on facility location in this section.

Traditionally, for the sake of obtaining analytical solutions, facility location problems have been limited to static and deterministic problems under which all input parameters (such as demands, distances, and travel times) are treated as known whilst outputs are in the form of a one-time solution only (Owen and Daskin, 1998). However, facilities such as distribution centres and warehouses generally function for a very long period of time whilst the environment in which they operate may change considerably and all input parameters (e.g. demands, cost, and travelling time) may become extremely uncertain as time elapsed. Therefore the approaches to facility location problem have turned to consider optimization under uncertainty recently (Snyder 2006). For instance, Tapiero (1971) studies the dynamic location-allocation problem that considers possible facility capacities and shipping costs in a deterministic setting. By taking the supply and demand as known and given in aggregate terms for the planning horizon, the author formulates the problem by dynamic programming. Under the optimality conditions, the author derives the facility locations (in the form of Euclidean coordinates), allocations of demands to sources and the quantity to be shipped between facilities and demand points.

Recently, Schwarz et al. (2006) investigate the joint decision problem of routing and inventory management in a two-echelon supply chain that consists of a cross-docking warehouse and multiple retailers. With stochastic retail demand, fixed travel times between pair of system sites, periodic replenishment from the warehouse and dynamic inventory allocation to retailers along the way according to the inventory status of the retailers pending receipt of allocations, the authors aim at minimizing the total expected cost of the system over an infinite time horizon. The authors show that if inventory holding (incurred on both the warehouse and the vehicle) and backorder-penalty costs are considered, the optimal "static" route (i.e. the vehicle must travel the same route every time) depends on the mean and the variance of the customer demand. On the other hand, if those transportation-related costs are excluded, then the optimal dynamic routing policy (i.e. the route may change from one replenishment cycle to another) strives at balancing one's ability to respond to the inherit system uncertainties against those system uncertainties that are induced by changing routes.

2.1.6 QR and Minimum Order Quantity (MOQ)

To the best of our knowledge, the first and the only literature works that relate QR to MOQ are those concerns the celebrated case of Sport Obermeyer Ltd, a US fashion sport skiwear manufacturer and distributor (Fisher et al., 1994; Fisher and Raman, 1996; Fisher et al., 1997). When illustrating how the program of accurate response had been implemented in the company, it was reported that the company had to meet production minimums for each style (Fisher et al. 1994). By formulating the QR approach as a two-period model with the total and first-period demand as a bivariate normal, Fisher and Raman (1996) provide a method to estimate the parameters for the demand probability function as well as a model that can determine the optimal production quantity that minimizes the total cost of over production and under production with the presence of minimum production constraints. In their paper they employ real data from Sport Obermeyer to illustrate the impacts of various operating levers for improving response capability, Fisher et al. (1997) show that stock-out and markdown cost increases as the minimum order quantity increases. On the other hand, the authors also suggest that reduction in lot sizes would induce more frequent product changeovers, and in turn may result in lower productivity and higher probability of defects. Therefore, when setting up the minimum production quantities, one has to take into consideration of the trade-offs between cost and productivity / quality.

Despite the above, we observe that these papers focus on the impacts of MOQ under QR on the buyer only. How MOQ affects the performance of the supplier, and most importantly, the whole supply chain implementing QR, remains unknown.

2.2. Channel Coordination

2.2.1 Buyer-Supplier Relationship

Apart from the effective use of modern technology, successful implementation of QR programmes requires extra effort and cooperation from all channel members. Larson and Lusch (1990) suggest that retailers and suppliers should treat each other as a partner to pursue mutual goals. In reality, such a cooperative spirit is not easy to accomplish as it requires complete trust between trading partners (Giunipero et al., 2001) whereas a stable relationship between channel members is related to achieving the goals of quality improvement in the supply chain as well (Lai et al., 2005). Sullivan and Kang (1999), Giunipero et al. (2001), Fiorito et al. (1998) and Fernie and Azuma (2004) investigate the differing views of retailers and suppliers on QR. While they found that most companies agree that QR practices are useful, many firms still have prejudice and doubts about QR's actual value. Consequently, measures must be taken to help building trust between the parties engaged in QR practices as mutual trust between trading partners provides the basis to resolve the above issues.

Both practical wisdom and academic research reflect that a good buyer-supplier is beneficial to a company's performance (see, e.g. Frazier et al, 1994; Carr and Pearson, 1999; Jap, 1999; Narayanan & Raman, 2004; Narasimhan & Nair, 2005; and Paulraj et al., 2008). Yet there exists a wide variety of perspectives to explore the nature of buyer-supplier relationship. For instance, Narasimhan & Nair (2005) consider the buyer-supplier relationship architecture from the buyer's perspective as a combination of "*quality expectations from suppliers*", "*information sharing and trusts with suppliers*" and "*supply chain proximity*" – the last defined as " *the physical closeness between the buying and the supplying firms and the Just-In-Time measures taken by firms for improved and synergistic performance*". Paulraj et al. (2008) assert "*inter-organization communication*" as a relational competency which depends on the duration of the relationship, network governance and information technology adopted within the dyad. On the other hand, Handfield and Bechtel (2002) suggest that suppliers' investments in site-specific and human-specific assets can lead to greater trust from their buyers.

Regardless to the context of the relationship orientation, it is generally believed that successful deployment of QR programmes is greatly attributed to the good buyer-supplier relationship between channel members in the supply chain.

2.2.2 Channel conflict

There are a variety of the definitions of the term "coordination". Lariviere (1999, p. 235) suggests that a contract is able to coordinate the supply chain if it allows "the decentralized system to perform as well as a centralized one". Alternatively, Chropra and Meindl (2007, p. 295) posit that a supply chain is said to be coordinated if all channel members perform to maximize the total supply chain profits. From the game-theory perspective, Cachon (2003) defines a coordinating mechanism as a set of supply chain optimal actions that itself is also a Nash equilibrium. Apart from the above, there is another class of literature taking the view that a coordinating contract is the one that can improve the performance of the supply chain (e.g. Jeuland and Shugan, 1983; Lariviere, 1999, p. 235; Tsay et al., 1999, p. 305), or in other words, that can achieve Pareto improvement (e.g. Iyer and Bergen, 1997).

Unfortunately, individual members are primarily concerned about their own objectives. Together with the effect to double marginalization (Spengler, 1950) and the bullwhip effect (Lee et al., 1997), the optimal decisions made by individual supply chain agents are usually sub-optimal for the whole supply chain. Ideally, formation of a centralized supply chain (i.e. one with all decisions done by a supply chain coordinator whose decision objective is to achieve supply chain optimum) can tackle the coordination issue. However, development of the dyad requires such a huge amount of capital and technology that few companies can actually accomplish. As a result, researchers strive for developing different measures to resolve the conflicts of interests amongst channel members.

2.2.3 Contracts for coordination

Supply contract is a commonly adopted tool that can achieve channel coordination. By aligning individual's interests with the whole supply chain performance, supply chain contracts advocate channel members to act for their own benefits, which at the same time, is also for the supply chain optimum. A considerable amount of research has been conducted to identify the different types of contracts and their respective benefits and drawbacks (e.g. Whang, 1995; Lariviere, 1999; Tsay et al., 1999; and Cachon, 2003). Amongst the various types of coordinating contracts, the buyback, revenue sharing, quantity flexibility, sales rebate and quantity-discount are the popular ones that draw ongoing investigation and discussion.

Various literature works focus on devising different kinds of supply contracts that can coordinate a QR supply chain. It has been shown that backup agreement (Eppen and Iyer, 1997), buyback with price premium (Donohue, 2000) and option (Barnes-Schuster et al. 2002) are effective supply contract capable of achieving channel coordination in a QR supply chain. There are also a number of different analyses on the various coordination mechanisms for supply chains with information updating (e.g. Huang et al., 2005; Chen et al., 2006; Choi, 2006; Özer et al., 2007; and Thomas et al., 2009).

2.3. Minimum Order Quantity (MOQ)

To take advantage of economies of scale, it is a common practice of manufacturers to impose a minimum quantity requirement (MOQ) on orders. Such an MOQ imposition is particularly prevalent in the apparel industry. A well-studied example of MOQ practice in the literature includes the US fashion skiwear manufacturer Sport Obermeyer Ltd (see Fisher & Raman, 1996; and Hammond & Raman, 1996).

Being a parameter that a supply contract may usually capture, MOQ takes different forms, depending on the purpose of its imposition. For instance, it may appear as periodic commitments that allows the supplier and the buyer to share and reduce the uncertainty of the order process for raw materials, or as quantity commitments to “ensure markets” for the supplier as well as to “ensure supply” for the buyer (Anupindi and Bassok, 1999). Anupindi and Bassok (1997) provide an excellent classification of contracts with different forms of quantity commitment. Below we focus on the literature works that concern the two common commitment-types of contracts, namely: total quantity commitments, and quantity flexibility.

2.3.1 Total Minimum Quantity Commitment (TMQC) Contracts

With a total minimum quantity commitment (TMQC) contract, a buyer agrees at the beginning of the planning horizon that his cumulative order quantities across all periods in the horizon will exceed a certain minimum quantity (Anupindi and Bassok, 1999). In the literature, Bassok and Anupindi (1997), and Chen and Krass (2001) concern this type of contract and we review them one by one below. Under a single-product periodic-review inventory system with stochastic demand, Bassok and Anupindi (1997) derive the buyer’s optimal purchasing policy that minimizes his total cost under a TMQC contract. Specifically, the TMQC contract is characterized by a {purchase cost, minimum total quantity} pair that specifies the corresponding unit purchase cost if the buyer guarantees to buy a certain minimum total quantity. The authors show that the optimal ordering policy is characterized by two order-up-to levels, namely: one for periods when the total quantity commitment has not been fulfilled, and the other for periods after the total quantity commitment has been satisfied, whereas both are in the form of multiple-period newsvendor solutions without TMQC. The authors also demonstrate that, with its simple and easy-to-compute nature, the optimal policy can also help the buyer to evaluate different menus of contracts of similar kinds to facilitate contract negotiation and supplier selection. Later on, Chen and Krass (2001) extend the problem of Bassok and Anupindi (1997)'s to consider the case that the as-ordered (i.e., purchase after commitment is fulfilled) purchase cost is different from that of the commitment purchase. Despite the more complicated cost structure, the authors found that the structure of the optimal ordering policies is in fact similar to that of Bassok and Anupindi (1997)'s .

2.3.2 Quantity Flexibility (QF) Contracts

With total quantity commitment contract, it is not uncommon that the supplier may offer some kind of flexibility for the buyer to adjust his total purchase quantity over the whole planning horizon (Anupindi and Bassok, 1999). In the literature, a number of works have been devoted to the study of such quantity flexibility (QF) contracts (e.g. Bassok et al., 1997; Tsay, 1999; Tsay and Lovejoy, 1999; Huang et al., 2005; and Wu, 2005) and we review them one by one as follows.

Bassok et al. (1997) consider the case that the buyer under a QF contract can purchase at quantities that may deviate from his original commitments with improved demand information as time elapsed. The authors formulated a heuristic algorithm that helps the buyer to determine the optimal updated commitments and order quantities at each ordering period. Applying the heuristic to a real case provided by IBM Printer System Company, the authors illustrate that the worth of flexibility brought about by such contract can result in considerable reduction (~70%) in the monthly expected holding cost of the company.

Tsay (1999) and Tsay and Lovejoy (1999) explore the relationship between QF contract and supply chain performance. Specifically, Tsay (1999) derives the conditions of the contract parameters (namely: the transfer price, the retailer's minimum commitment and the external manufacturer's maximum coverage) under which the supply chain can obtain efficiency gain that can be shared by both channel members. The author suggests that such QF contract in fact provides a trade-off between flexibility and unit purchase cost for the retailer. Under a multi-echelon setting, Tsay and Lovejoy (1999) explore the effect of flexibility brought about by a

QF contract on inventory levels and the pattern of forecast and order variability transfer along the supply chain. The authors observe that QF contracts may potentially mitigate the bull-whip effect as they can "dampen the transmission of order variability" along the supply chain. On the other hand, the authors assert that increased in output flexibility would normally result in higher inventory costs and therefore suggest careful inventory management should be in phase with management of process flexibility.

Later on, both Huang et al. (2005) and Wu (2005) investigate the QF contracts with demand forecast updates. Huang et al. (2005) consider a two-stage system under which the buyer is allowed to adjust his initial commitment based on the updated demand forecast at the later stage but such adjustment incurs a fixed and a variable cost. With uniformly distributed demand (and forecast updating), the authors determine the critical value of contract exercise cost above which the buyer would not sign the QF contracts. In his study of QF contracts under multiple Bayesian information updating processes, Wu (2005) posits a different conclusion from Iyer and Bergen (1997) that both the retailer and the manufacturer can be beneficial by adopting QR (with Bayesian information updating).

2.3.3 Inventory Systems with MOQ

Traditionally, MOQ, in its simplest form, commonly appears in the literature with problems such as lot sizing, economic order quantity (EOQ), and batch ordering problems (see, e.g. Graves et al., 1993). Recently there have been research works studying the inventory problem under the existence of MOQ and stochastic demands (e.g. Robb and Silver, 1998; Zhao and Katehakis, 2006; Zhou et al., 2007; Erhan Kesen et al., 2010, Kiesmuller et al., 2010) and we review them one by one below.

Robb and Silver (1998) model the situation when the distributor's / retailer's optimal replenishment quantity falls below the minimum quantity required by the vendor and propose an order decision algorithm to help the buyer to decide whether to order or not in this situation. Despite not being a globally optimal algorithm, the authors demonstrate numerically that such algorithm works well when the periodic demand is relative low compared with the MOQ. Later on, Zhao and Katehakis (2006) consider a single-item stochastic inventory system with MOQ over finite and infinite time horizons under the discounted cost criterion and show that the optimal policies for such systems are complicated, which hinders their applications in practice. In the light of this, Zhou et al. (2007) further propose a heuristic algorithm to find the optimal control policy for a single-item periodic-review stochastic inventory system with MOQ and linear costs. Kiesmuller et al. (2010) study a single-item single-stage inventory system and they find that the optimal order policy with the existence of MOQ is complicated. They hence propose the use of an easy-to-use policy for which the optimal re-order level is determined by a Markov Chain approach. Most recently, Erhan Kesen et al. (2010) consider an inventory system with MOQ in which the buyer can either place a quantity smaller than the MOQ and pay a penalty, or give up ordering and lose the sales for that period. They show that the optimal value of the lost sales in this case is the inflexion point of the lost sales penalty and quantity penalty functions.

Note that all the above research works concerns the periodic-review inventory policy for single echelon (i.e. the buyer) whilst many of them are proposing heuristics algorithms to solve the problems. Apparently, it remains unknown what the optimal ordering policy would be for the newsvendor-type products with MOQ consideration and how the presence of MOQ may affect the performance of the supplier and the whole supply chain.

2.4. Summary

In this chapter we have conducted literature review on the topics of quick response (QR), channel coordination, and minimum order quantity (MOQ). As far as we know, it appears that no existing literature has been devoted to the relationship amongst the three topics. With the prevalence of the three issues in the apparel industry, it is of practical importance and significance to bridge the gap in the current literature regarding the performance of a QR supply chain with MOQ consideration. Therefore the objectives of this thesis study were formulated as stated in the previous chapter.

3. Current Practice of Quick Response and MOQ Imposition in the Apparel Industry: Case Studies with Hong Kong Apparel Companies

Being a starting point of the research work, in this chapter we gain an understanding on the current practice of QR and MOQ imposition in the apparel industry. Specifically, we conduct personal interviews with two apparel companies to learn about their order processes. We also discuss the need of lead time reduction and the issue of MOQ imposition in the industry.

3.1. Magenta Wardrobe Fashion Associates Ltd (Magenta)

Established in 1995, Magenta supplied women's and men's wear collections to various department stores in Hong Kong, such as Sogo, Jusco and Seiyu, on a wholesale basis under the brand names of "Magenta" and "Cyan". Later on, the company became an ODM supplier to the Baleno Group and became a strategic partner of the group for developing the brand "ebase" in 2001. As of 2010, there are over 300 "ebase" stores in various commercial locations in Hong Kong, China and

South East Asia, providing over 3,000 fashionable styles on an annual basis (www.magenta.com.hk).

According to Mr Percy Yung, the Managing Director of Magenta, the order lead time for Magenta's merchandise has reduced to 60-90 days over the recent years. Whereas the order lead times for fabrics and other raw materials are somewhat fixed and uncontrollable, Magenta has been striving hard to streamline its internal processes to further shorten the production lead time. At present, individual processes are isolated, which hinder information flow. In particular, when changes in schedules and production details take place during the course of production, it takes an enormous amount of time to make the necessary amendments. Meanwhile, the company is developing an information system to link up the individual processes and expects that the new system will help reduce redundant work significantly. Being the "middleman" in the fashion supply chain, Magenta is well aware of the importance of information sharing amongst channel members. On the one hand, it needs updated market information from retail outlets for design and production planning; on the other hand, it needs to keep its suppliers informed about any changes in production planning. In the light of this, Magenta is seriously considering the adoption of information technology to link up with the POS systems of its retailers, as well as to share information with its suppliers in a prompt and timely manner. Magenta believes that a good retailer-supplier relationship is the key to success in the highly competitive apparel industry nowadays. To facilitate the production process, the company currently shares style information with individual suppliers through a sophisticated information system. In the long run, Magenta plans to select “focus suppliers” that can provide ODM services and become strategic partners of the company.

3.2. PG Limited[1]

Established in 1989, PG Limited is a Hong Kong-based SME apparel manufacturer that focuses its business on cut and sewn knitwear and basic woven shirts and trousers. In terms of seasonality, half of PG Limited’s merchandise is fashionable items whilst the other half is of basic styles. With the head office located in Hong Kong, PG Limited has three overseas factories, two in Vietnam and one in Cambodia. Over 90% of their customers are branded retailers and distributors in North America, examples of which include Meryns, JC Penny and Columbia. Over 5,000,000 pieces of merchandise are produced and sold by PG Limited every year, which accounts for an annual sales turnover of around US$13,000,000.

[1] PG Limited is a fictitious name for the company per request of the interviewee.

PG Limited is well aware of the industry-wise reduction in order lead time from 90-120 days to 60-90/75 days over the past 5 years. It is well known that improvements in raw materials/product shipment schedules and advances in technology for fabric and clothing production have contributed significantly to order lead time reduction. Nevertheless, PG Limited also reflects on the problems that may occur that lengthen the production process, causing delay to the original schedule. Fabric quality problem is one of such causes of delay whilst customers' sudden requests for changes in product design, order quantity and delivery schedule are other frequent reasons causing disturbance to the original production schedule.

PG Limited talked about a specific case whereby one of their long-term distributor customers (hereafter referred as Brand X) requested a shorter order lead time. Brand X requested to postpone its order placing time so that it can gather the order details from its wholesale/retail customers after their selling campaigns and make a more accurate ordering plan. Brand X used to provide some production forecasts for PG Limited's reference but such forecasts tended to be not so accurate. On the other hand, PG Limited had to arrange packaging, wash labels and stock allocation for different markets for Brand X with the allocation plans provided by Brand X. However, to cope with the sudden demand changes in various markets, Brand X frequently changed its allocation plans and delivery instructions. As a result, PG Limited had to redo the packaging to meet the updated requirements. Though PG Limited could charge back the extra cost for repackaging in some cases, redundant workload was wasted and errors would occur. In view of this, PG Limited did not object to Brand X's order placing postponement provided that the order lead time does not fall below the threshold level of 75 days, which is the minimum production time PG Limited requires. If any client requires shortening the order lead time to less than 75 days, PG Limited demands the client to commit to the aggregated quantities of the styles using specialized fabrics at least 10 days before confirmation of order details, so that PG Limited can arrange fabric ordering in advance in order to "shorten" the overall order lead time.

Minimum order quantity (MOQ) is another issue in the order process for PG Limited. The company would request their client to place order more than a certain quantity, i.e. the MOQ while the values of the MOQ is determined on the case-by-case basis. A number of factors affect PG Limited's determination of the MOQ which include: (1) the "material MOQ" as imposed by the upstream material suppliers (e.g. mainly the fabric suppliers); (2) material transportation cost; (3) productivity of their own factories and (4) complexity of production for individual styles.

PG Limited considers the material MOQ the most important factor for determining its own MOQs. Doing business in an industry that is concerned about fashion and style, apparel companies are offering a great variety of products in terms of styles, cutting and fabrics. These fashionable apparel products are normally produced and sold in a comparatively small quantity. Therefore the use of the respective fabrics is generally smaller. Yet the manufacturers have to order fabric in the yardage that fulfills the fabric suppliers' requirement. To PG Limited, since some of their brand-name clients have their own designated fabric suppliers, the issue of fabric MOQ is generally resolved. On the other hand, when doing business with other buyers that don't have frequent orders, the company has to make sure that their order quantity should fulfill the minimum fabric order requirement to justify their fabric ordering. There are cases that the company would accept an order that is below the material MOQ. If the merchandises are made of specific fabrics that are seldom used in other styles, the company has to seek ways to utilize the leftover fabrics. After storage of these kinds of leftover fabrics for a long time, the company will either sell them at salvage markets or throw them away. In either case, the company experiences a loss in the purchase cost of the fabrics.

The main concern for the above-mentioned factors for MOQ determination is to justify the production cost of processing an order. It is natural as every company is aiming at making profit for doing business. There are also some other uses of the MOQ by the apparel companies. Some apparel companies may treat the MOQ as a kind of measure to increase their profit. By requiring a larger MOQ, these companies can have a guarantee of greater income. On the other hand, some manufacturer may use imposition of a large MOQ as a polite way to decline an order. There are cases that some clients may place an order of complicated styles that a manufacturer may not have interests to process. In order to turn down the order whilst not hurting the future relationship with the client, the manufacturer may request for a large MOQ that she anticipates her client would not accept. In the case that the client does accept the MOQ requirement, the manufacturer would earn comparatively more.

It is not easy for PG Limited to have every client agreeing to their proposed MOQ. Whereas some apparel manufacturers may impose a surcharge in case their buyers cannot fulfill their specified MOQs, PG Limited would negotiate with many of their buyers for the final mutually-agreed MOQ. However, even upon negotiation, some clients may play tricks not to follow the MOQ requirement. PG Limited shared an experience of their dealing with a brand-name client Y. Despite having the MOQ agreement in place, Y requested in the course of production to “split” his order into two separate “shipments” with a considerable amount of time lapse between the two shipments. As mentioned earlier, one of the main factors for PG Limited to consider for MOQ setting is the productivity of their factories. Since the shipments are physically handled as two separate orders, PG Limited spent more resources than expected in terms of the initial set-up and the extra manpower to handle the additional shipment, those of which were not included when they determined the MOQ for the order.

3.3. Summary

In this chapter we have explored the current industrial practices associated with QR and MOQ imposition in the Hong Kong apparel industry. We have interviewed two companies to gain an understanding of their business practices. We have found that they have fully recognized the importance of order lead time reduction and have adopted various measures pertinent to their own situations to strive for lead time reduction (and hence moving towards QR) (see Table 3.1). On the other hand, we have also learnt the reasons for MOQ imposition in the apparel industries and the various factors that affect apparel manufacturers in setting the MOQs (see Table 3.2). We could see that MOQ imposition is an important issue as it concerns both the profit of the manufacturer and the retailer. Its smooth imposition also depends on negotiation and relationship between the channel agents.

Further to these case studies, we will explore the relationship between QR and MOQ both empirically and analytically. To be specific, we will empirically explore in more details the relationship between QR and MOQ imposition through formulation of a theory-driven conceptual model and a questionnaire survey in Chapter 4 whereas we will mathematically explore the impacts of MOQ on the performance of the channel members and the supply chain under a QR system in Chapters 5 to 10.

4. Relationship between Quick Response Adoption and Minimum Order Quantity in the Apparel Industry: An Exploratory Study

To the best of our knowledge, apparently no empirical studies have been conducted on the relationship between QR strategy and MOQ. To bridge such a gap in the literature, we conduct this study with the following objectives:

(a) to obtain empirical evidence of the prevalence of MOQ and QR in the apparel industry;

(b) to understand the practice and general perception of MOQ amongst different channel members; and

(c) to develop a model that conceptualizes the relationship between QR and MOQ and to assess their impacts on the business performance of apparel firms.

4.1. Conceptual QR-MOQ Model

Figure 4.1 depicts the conceptual model we formulated to guide this study. In the following we discuss the theoretical grounds that underpin our proposed model.

4.1.1 MOQ Imposition and Buyer-supplier Relationship

Network theory concerns the evolution and benefits of building and maintaining amicable relations among entities in a network as a means to cope with uncertainty (Thorelli, 1986). Applying network theory to the parties in a supply chain, which operates in an increasingly uncertain world, we see that channel members seek to establish good buyer-supplier relationships with a view to enjoying a higher degree of reliability among the members concerned. In particular, in the fashion apparel industry, *guanxi* (i.e., relationship) and trust play significant roles in the success of a variety of supply chain management practices (see, e.g. Dickson and Zhang, 2004 for more discussions).

MOQ imposition is often regarded as a supply chain management practice adopted by apparel suppliers to benefit from economy of scale in processing orders. With MOQ imposition by the supplier, buyers have to commit to order sizes that exceed a threshold quantity, i.e., the MOQ. Applying network theory in this context, we see that when the buyer and the supplier establish a congenial relationship with (and have trust in) each other, the buyer will accept MOQ imposition more readily, thus making easier for the supplier to impose such a requirement on the buyer. Conversely, if both members are loosely tied, the buyer would be more reluctant to accept the MOQ requirement, rendering it difficult for both members to achieve a commonly agreed contract term. Therefore, we posited that:

H1: Good buyer-supplier relationship facilitates MOQ imposition.

4.1.2 QR Adoption and Buyer-supplier Relationship

There is a considerable body of the strategy literature devoted to studying channel member relationship and business flexibility. Fairbairn (1997) suggested that QR adoption enhances buyer-supplier relationship in terms of flexibility, degree of information sharing, and solidarity. Conversely, many researchers propose that buyer-supplier relationship plays an antecedent role in creating supply chain responsiveness. Frazier et al. (1994) posited that as the buyer-supplier mutual trust increases, the supplier would tend to be more risk-taking “in terms of committing to investments dedicated assets”. Perry et al. (1999) stated that cooperation within a supply chain plays a significant role in improving responses to orders and reducing pipeline wastage and delay. Similarly, Handfield and Bechtel (2002) asserted that suppliers obtaining a higher level of buyer trust tend to have a higher level of responsiveness. Shin et al. (2000) suggested in their model that long-term buyer-supplier relationship, as a key component of supply management efforts, improves the delivery performance of both the supplier and the buyer. Therefore, we postulated that:

> *H2: Good buyer-supplier relationship has a direct positive impact on QR adoption.*

4.1.3 MOQ Imposition and QR Adoption

Both MOQ imposition and QR are widely adopted in the apparel industry. Nevertheless, there is apparently a paucity of literature that relates both. From a comprehensive search of the strategy literature, we see that transactional cost economics and agency theory may shed some light on the relationship between the two practices.

There is an argument from the profit-seeking perspective that the supplier may be reluctant to adopt QR. This may be attributed to analytical findings that the suppliers may be worse off with QR adoption (e.g., Iyer & Bergen, 1997; Choi & Chow, 2008). In other words, the benefits brought about by QR to the supply chain may not be shared by suppliers. To properly address this issue, agency theory suggests the use of award structures to align members' interests. From the perspective of the supplier, MOQ imposition may provide an incentive for it to participate in QR. Despite the fact that the buyer will reduce its order quantity by adopting QR programme, the existence of MOQ guarantees minimum revenue for the supplier. Therefore, we argued that:

H3m: MOQ imposition encourages supplier's adoption of QR.

For the buyer, MOQ imposition would at first appear to be a burden as it compels the buyer to order no less than the MOQ level, thus diminishing the flexibility brought about by QR. On the other hand, as argued above, the buyer's acceptance of MOQ imposition may encourage the supplier to be involved in QR implementation. According to transaction cost economics, when channel members make business decisions, they should focus on the total long-term costs, rather than the relatively short-term transaction costs, in order to maximize performance (Ketchen & Hult, 2007). We believe that the various benefits the buyer derives from successful QR adoption (e.g. lead time reduction and updated market information) may outweigh the relatively minor inflexibility caused by the MOQ requirement. Therefore, we proposed that:

H3r: QR adoption facilitates buyer's acceptance of MOQ imposition.

From the discussion in Sections 4.2.1 and 4.2.2, we argue that a good buyer-supplier relationship may facilitate both MOQ imposition and QR adoption, which is desirable for the supplier and the buyer, respectively. Combining with the above argument regarding the relationship between MOQ imposition and QR adoption, we further speculate that a strong tie between channel members may facilitate the alignment of their individual interests (which may be opposing to each other). Therefore we hypothesized that:

H4: Good buyer-supplier relationship serves as a mediating factor between MOQ imposition and QR adoption.

4.1.4 MOQ Imposition and Business Performance

Apparently there is no empirical study conducted on the relationship between MOQ imposition and a company's business performance. From the perspective of the supplier, the main purpose of imposing an MOQ requirement is to justify the initial set-up cost and to enjoy economy of scale in purchasing raw materials. By setting a minimum order requirement, the supplier can ensure that the revenue from each order is adequate to guarantee profitability. Therefore, we proposed the following hypothesis:

H5m: MOQ imposition has a positive effect on supplier's business performance.

On the contrary, the imposition of MOQ reduces the buyer's ordering flexibility. In particular, the buyer normally has to make its ordering decisions subject to some budget constraints. With MOQ consideration, the buyer may need to change its business priority to one that focuses on serving larger demand necessitated by devoting an adequate budget to fulfil the MOQ requirement. For businesses characterized by highly volatile demand (such as the apparel industry), the costs of under-stocking and over-stocking can be enormous. Therefore, we argued that:

H5r: MOQ imposition has an adverse effect on buyer's business performance.

4.1.5 QR Adoption and Business Performance

The benefits brought about by QR to the buyer have been well documented by both industrialists and researchers (e.g., Iyer & Bergen, 1997; Fairbairn, 1997; Perry et al., 1999; Birtwistle et al., 2003; Choi & Chow, 2008). Therefore, we speculated that:

H6r: QR adoption has a positive effect on buyer's business performance.

From the supplier's perspective, analytical findings have shown that QR adoption may not be entirely beneficial as the optimal order quantity may be smaller caused by more "precise" ordering and reductions in safety stock (e.g. Iyer & Bergen, 1997; Choi & Chow, 2008). Besides, several empirical studies have found that the supplier is mainly concerned about the costs incurred in installing IT systems to enable QR and reductions in profit margin caused by additional services like labelling and providing price tags (e.g., Birtwistle et al., 2003; 2006b). However, there are few empirical studies on the direct relationship between QR adoption and the supplier's business performance. Therefore, we proposed hypothesis:

H6m: QR adoption has an adverse effect on supplier's business performance.

As we shall propose in Sections 5.2.3 and 5.2.4, MOQ imposition may increase the supplier's willingness to adopt QR as with MOQ its revenue is guaranteed. Therefore, we argue that MOQ imposition may facilitate QR adoption, which in turn improves the supplier's performance. From the buyer's perspective, although MOQ imposition may adversely affect the buyer's performance, it may also encourage the supplier's QR adoption, which in turn improves the buyer's business performance. Combining the two opposing effects, we argue that the benefits of QR adoption (which is facilitated by the buyers' acceptance of MOQ imposition) outweigh the drawback from MOQ imposition. In short, we speculate that by adopting QR together with MOQ imposition, the interests of both channel members are aligned, resulting in a win-win situation. Therefore, we suggested the following hypothesis:

H7: QR adoption with MOQ imposition has a positive impact on an apparel company's performance.

A summary of the hypotheses developed with the model is listed in Table 4.1.

4.2. Measurement Model Development

We present in the following how the measurement models of the various constructs are developed.

4.2.1 QR adoption:

We used 20 questions to assess the level of QR implementation in the respondent companies. These 20 questions, originally suggested by KSA (1997) for assessing three stages of QR implementation, were adapted from Birtwistle et al. (2003).

4.2.2 MOQ Imposition:

To the best of our knowledge, there was apparently no prior empirical research conducted on MOQ imposition. Therefore, we developed our own questions for this section. We conceptualize the prevalence of MOQ imposition by asking the respondents whether their companies impose MOQ (for supplier respondents) or they have to face MOQ imposition (for the buyer respondents), as well as the percentage of products (in term of style and volume) having MOQ requirement. We also explore the factors affecting the supplier's setting of MOQ and whether both parties would negotiate the final setting of the MOQ. Besides, we attempt to collect respondents' opinion about their perception of MOQ imposition.

4.2.3 Buyer-seller relationship:

We conceptualized buyer-seller relationship with reference to the framework suggested by Ganesan (1994). In his study on the determinants of long-term orientation in buyer-seller relationship, Ganesan (1994) showed that buyer-seller relationship is affected by: (a) dependence, (b) perceived dependence, (c) trust in terms of credibility and (d) satisfaction with past outcomes. In this study we adapted the measurement items from Ganesan (1994) on these four areas to measure the level of buyer-seller relationship.

4.2.4 Performance:

The business performance items were adapted from Ward and Duray (2000). Respondents were asked to indicate their perceptions of their companies' business performance in terms of market share and sales growth.

Once prepared, the draft of the set of questionnaire was reviewed by representatives from both the academics and industry to ensure that the questionnaire is appropriately designed. After modification of the layout and elaboration of certain terminology, the finalized set of questionnaire employed for data collection is enclosed as Exhibit 4.1 in Appendix A.

4.2.5 Data Collection

We distributed the set of questionnaires to the students of several part-time MBA/MA classes of a local university, as well as various "educated" industrialists[2] through our personal networks, from September 2009 to September 2010. The reason for our employment of this kind of non-probability sampling is not just for convenience. In fact it is a necessary approach to ensure that we could collect a certain number of feedbacks for a meaningful analysis. We had an experience of conducting a similar mail (and email) survey before with a sample frame adapted from the online directory of the HKTDC (Hong Kong Trade Development Council) portal but in vain owing to the extremely low response rate. In addition, as reflected by the returned questionnaires, we also found that many of them were incomplete and we even worried if the questions were well-understood by the respondents who

[2] These educated industrialists refer to those who are knowledgeable about the industry practices through both industrial experience and formal tertiary education.

might not understand some terminologies well. As a result, in order to obtain a reasonably large sample size and also ensuring the respondents know the questions well[3], we adopt the present collection method.

Apart from the concern of sample size, we believe that these respondents are the appropriate target for this survey. These respondents are both knowledgeable about the industry practices (being the industrialist themselves) as well as having the basic concept of QR and supply chain management. These ensure that they can understand the set of questionnaire properly and provide information to an accurate degree.

4.3. Findings and Discussion

Amongst the 122 sets of questionnaires collected, 7 sets had a considerable number of missing data and were judged unusable, thus yielding a sample size of 115. We employ the statistical software, SPSS 16.0, for data analysis and present our findings in the following sub-sections.

4.3.1 Sample Characteristics

Profile information of respondents, as shown in Table 4.5.1, indicates that the companies for which the respondents are diversified in their business natures, and

[3] Under our current data collection scheme, we would make sure the respondents understand the questions by a briefing and we would answer their questions when they had any doubts on any terminologies.

some have multiple operations like being retailer, wholesaler and distributor at the same time. In general, the two most common types of business are retailer and manufacturer, each constitutes around 30% of the sample. Neglecting those who did not provide the sales information (around 15% of the sample), our respondents' companies have an average annual sales revenue in the range of HK$501-1000 million and an average number of employees in the range of 100-500. Over 50% of respondents are managerial grade or above, with director or owner of the companies being more than 10% of the sample. According to their job responsibilities, 59 respondents are categorized as buyers whilst the remaining 56 are classified as suppliers, which constitute 51% and 49% of the sample, respectively.

4.3.2 MOQ imposition

Apparently no empirical research has been conducted regarding MOQ imposition; therefore, we are particularly interested in exploring the practice in more details. Table 4.5.2 summarizes the findings from our survey.

Our survey findings reflect that MOQ imposition is in fact prevalent in the Hong Kong apparel industry. Around 90% of the buyer respondents' companies are being imposed with MOQ whereas over 90% of the supplier respondents' companies impose MOQ on their clients. Amongst those with MOQ imposition, most of the respondents have different MOQs for different products (around 90%) whilst around 60% of them would have the same MOQ for the same product in general. In terms of product styles, nearly half of these respondents' companies (48%) have over 80% of their products with MOQ requirement and amongst them, over three-quarter of them (or 37% of the whole sample) are in general having all products with MOQ requirement. In quantity, more than 35% of the buyer respondents and supplier respondents, respectively, have an average MOQ equals more than half of their order quantity or production quantity. Regarding the setting of the MOQ, approximately half of the buyer respondents and the supplier respondents reverted that the final decision of MOQ is agreed upon negotiation between the two parties, whereas less than 10% of all respondents advised that their MOQs are based on the MOQs for the material ordering.

Regarding the factors affecting their setting of MOQ, majority of the supplier respondents (80%) considered the MOQ for materials ordering as an important factor that affects their MOQ imposition on their clients whereas nearly half of the respondents agreed that production capacity and production cost are also crucial in determining the MOQ (Table 4.5.3). From this we can see that the size of the MOQ in a large extent relates to the quantity threshold required for a production to be feasible.

To check whether the existence of MOQ may hinder the buyer respondents from order placing, we require them to rate the frequency of not ordering a product style owing to MOQ constraint from a scale from 1 to 7, with 1 representing “never” whilst 7 representing “every time”. The mean score of this question is 3.65 with a standard deviation of 1.42. The result of the two-tailed t-test suggests that this mean score has no significant difference from the neutral scale rate of 4 (Table 4.5.4). Whereas the result suggests that the buyer’s frequency of failing to order due to MOQ is not very serious (when compared with the worst value of 7), it is neither a welcoming signal to the buyer (when compared with the ideal value of 1). One may perceive that the score near to 4 suggests that there may be half of the chance a buyer may not be able to place an order for a desirable style owing to the MOQ constraint. In particular, fashionable apparel items usually have a more specialized customer base, and it is common for the apparel companies to employ the marketing approach to make them more exclusive. As a result, these trendy items are usually sold in comparatively smaller quantity. It would cause a substantial loss to the companies if they cannot order for a potential fashionable item owing to failure in abiding by its MOQ constraint.

We further explore whether different channel members have different perceptions regarding: (i) the practice of MOQ imposition, and its impact on (ii) buyer-supplier relationship and (iii) the channel members' profit, as well as (iv) the co-existence of MOQ imposition and QR. Correspondingly, we design four statements and ask the respondents to rate between 1 to 7 regarding their degree of agreement regarding these four areas, with 1 being "strongly disagree" and 7 being "strongly agree". Results of the t-tests on the mean scores of these four statements indicate that both the supplier and the buyer respondents do not consider MOQ imposition would deteriorate the buyer-supplier relationship. They are also neutral to the proposal of complementing QR with MOQ imposition. By contrast, the two groups have significantly different opinions regarding MOQ imposition and its impacts on their profits. Our findings match with the common intuition that the supplier respondents have a higher preference to impose MOQ on their clients than the buyer group. Besides, buyer respondents are slightly concerned about the possible negative impact of MOQ on their profit whilst the supplier respondents have a stronger belief that MOQ imposition can help improve their profit (see Table 4.5.5).

On the other hand, we compare these mean scores between the group of respondents currently practicing MOQ imposition and the group of those without MOQ. The results of the independent t-tests indicate that the buyer respondents currently having MOQ imposition have no significant difference in their opinion from those without MOQ constraints. By contrast, the supplier respondents currently imposing MOQ have a significantly higher degree of preference to MOQ imposition than those not imposing MOQ (see Tables 4.5.6). This piece of findings may suggest that for supplier respondents who are not imposing MOQ, their decision for not imposing MOQ may solely due to their own preferences and the buyer's possible reluctance to MOQ imposition may not be a concern for their decision.

4.3.3 Effect of firm size

The size of a company may have impact on its' strategy and relationship with other channel partners. To check whether the firm size has any effect on the constructs we intended to quantify, we compare individual item mean scores amongst different sales group before conducting further analysis. To be specific, respondents are classified into three groups according to their annual sales revenue, namely: *low-sale* (with annual sales revenue equal or below HK$1000 million), *high-sale* (with annual sales revenue above HK$1000 million) and *unclassified* (those did not provided their companies' annual sale information). Table 4.5.7 shows the mix of respondents under this classification. Then we compute the mean scores of individual items amongst the three groups for the suppliers and the buyers, respectively [see Tables

4.5.8(a) and (b)]. Afterwards we conduct analysis of variance (ANOVA) to compare the mean scores of the three groups.

The ANOVA results indicate that there are no significant differences on the mean scores of all the items amongst the three supplier groups except for the below items regarding QR practices, namely: QR02, QR04, QR12, and QR17. Yet as one will see in the next sub-section, these items are not included in the pool of items that account for the reliability of the construct "QR practice". Therefore, we can conclude that the firm size has no apparent effect on the measurement of the construct in our sample and we can treat all three supplier groups as a single set for further analysis.

Different conclusion is drawn regarding the effect of firm size on the buyer groups' responses. The ANOVA results show that there are significant differences in the mean scores amongst the three buyer groups for the below items, namely: QR03, PDP01, CR01, CR02, and PF01. Pro-hoc tests further reveal that the mean scores of these items of the high-sale buyer group are significantly different from those of the two other groups. As a result, we need to perform our analysis to the three buyer group separately. However, for the low-sale buyer and the unclassified buyer groups, the reliability of the constructs are below the acceptable threshold (<0.6). Therefore, except for Sub-section 4.5.4 which concerns the respondents' level of QR adoption, we will focus on the analysis for the high-sale buyer group only for the buyer's model.

4.3.4 QR Adoption

Tables 4.5.9(a) and (b) present the mean and standard deviation of the score of individual QR items for the buyer and supplier respondents, respectively. We found that the buyer respondents have 11 items out of 20 with mean scores significantly greater than the neutral score of 4 whereas the supplier respondents have only 3 items out of 17 (3 QR items are related to practice of the buyer only; therefore there are only 17 QR items for measuring the supplier's level of QR adoption). The findings suggest that our buyer respondents have a higher level of QR adoption than the supplier counterparts. Next we proceed to investigate whether MOQ imposition would cause difference in the adoption level of individual QR items between the two respondent groups but no statistically significant evidence has been found to support this proposition.

Since we adopt the same scale items to measure the level of QR adoption as in the survey reported in Birtwistle et al. (2003), it would be interesting to compare our result with theirs. Birtwistle et al. (2003) conducted the survey to explore the degree of QR implementation in 30 British fashion retailers. However, unlike their adoption of the five-point Likert scale, we employ the seven-point Likert scale as our measurement tool in this survey. As a result, we cannot compare the values of the mean scores directly between the two studies.

Despite this, direct observation on the range of the mean scores between the two studies (see Table 4.5.10) may suggest that our survey has a considerably higher mean scores in the following items related to the use of the internet, namely: *the use of Internet for communication* (QR01), *online communication amongst head office stores and distribution centres (QR05, 05 and 20).* Specifically, the mean scores of our retailer respondents on these items range from 4.85 to 5.23 (well above our neutral score of 4) whereas those in Birtwistle et al. (2003) range from 2.77-3.9 (c.f. with their neutral score of 3). This result is reasonable as the prevalence of the use of the internet has been intensified over the past decade. Since there is at least a seven-year time lapse between the two studies, it is not surprising to find that more retailers nowadays are equipped with the internet as the main channel for communication for both internal and external parties..

On the other hand, both our retailer respondents and those in Birtwistle et al. (2003) appear to have relatively higher degree of adoption in the following two items, namely: *barcode scanning at SKU levels* (QR18) and *close relationship with the supplier* (QR13). In particular, the mean scores of these two items for our respondents are 6 and 5.31, respectively (compared with the neutral score of 4), whereas those for the respondents in Birtwistle et al. (2003) are 4.68 and 4.6, respectively (compared with their neutral score of 3). The use of the point-of-sale (POS) systems in retail operations have well been established for decades. Therefore it is natural that the two groups of retailer respondents score high for this item. The relatively high mean scores in the other item (namely, QR18) reflect that both groups are well aware of the importance to establish a good buyer-supplier relationship.

Similarly, both groups of the retailer respondents score relatively low in the items which are representatives for the most sophisticated (Stage-3) QR adoption: "*We have QR teams to meet with the supplier*" (QR15), "*We provide stock-out data to the supplier*"(QR16) and "*We provide sales data to the supplier*"(QR17). This observation suggests that the two groups of respondents may need to work on these directions in order to enhance their responsiveness to the uncertain market environment.

4.3.5 Scale Reliability

As a standard procedure in statistical analysis, we need to perform reliability analysis to ensure that a scale can "consistently reflect the construct it is measuring" (Field 2005, p. 666) and it is commonly measured by Cronbach's alpha. Tables 4.5.11 (a) and (b) state the items that are included for making reliable constructs for the supplier group and the high-sale buyer group, respectively. For both groups, we observe that the Cronbach's alphas for all constructs are well above 0.8 except for the construct "*Creditability*" (which have a Cronbach's alpha of 0.752 for the supplier group, and 0.720 for the high-sale buyer group, respectively). With respect to the commonly adopted threshold of 0.7, we are confident that the stated items provide reliable measures for their respective constructs.

4.3.6 Model Testing – Suppliers

Being able to examine a series of inter-related dependence relationship simultaneously (e.g. Hair et al., 1998, p. 583; Ho, 2006, p.281], structural equation modelling (SEM) is an appropriate tool for our model testing. We test our proposed model for the supplier by SEM using the software AMOS 16.0. As suggested by the literature [e.g. James et al. 1982, Maruyama 1998, both quoted in Swafford et al. 2006], we adopt a two-step approach by first performing confirmatory factor analysis (CFA) on the various constructs, followed by performing SEM on the relations amongst the various constructs based on our proposed model. By separately analyzing the measurement models and the structural model, model identification can be ensured if all the measurement models are identified.

Similar to the approach in Swafford et al. (2006), we employ (i) the chi-square statistics, (ii) the root mean square error of approximation (RMSEA), (iii) the goodness-of-fit index (GFI), and (iv) comparative fit index (CFI) to examine how well our measurement models fit to the data. Results of these goodness-of-fit tests (summarized in Table 4.5.12) indicate that some measurement models do not have acceptable fit. In particular the constructs *QR Adoption* (QR) and *Satisfaction* (SAT) do not pass the chi-square tests even though they have high value in the GFI and CFI. Such inconsistency of goodness-of-fit results may be attributed to the insufficient sample size. Although there is no single rule specifying the sample size requirement, a minimum ratio of at least five respondents per each estimated parameter is recommended, with a ratio of ten respondents per estimated parameter being appropriate (Hair et al., 1998; Ho, 2006). Our supplier group consists of 56 respondents whereas the measurement models of QR and SAT consist of 19 and 13 parameters, respectively. As a result, it is not unnatural that our data fit poorly to these measurement models.

In fact, even if we ignore the inconsistency of those goodness-of-ft tests in the measurement models and proceed with analysis for the structural model with SEM, poor fit and insignificant parameter estimates are obtained. To be specific, our structural model consists of a second-order construct, namely: *Relationship*;

following a similar step, we perform CFA on this construct with the four related first-order constructs, namely: *Satisfaction*, *Dependence*, *Perceived Dependence,* and *Creditability* (Figure 4.5.1). Again we obtain a significant p-value for the chi-square statistics despite that GFI lies within the range of 0.05 to 0.08 and CFI exceeds 0.9. Afterwards, we obtain the structural model (depicted in Fig. 4.5.2) that exhibits a poor fit to the data (p-value for chi-square statistics=0.000, RMSEA=0.147, GFI=0.585 and CFI=0.654). A further inspection on the model shows that the estimate of the regression weights of the construct *Relationship* on QR, and the regression weight estimate of QR on *Performance* are insignificant (Table 4.5.13).

Since our sample size does not support the use of SEM, we employ other statistical tools for our model testing. To be specific, as our model comprises two levels of relationship, namely: (i) the effect of *Relationship* (measured by the four independent variables, namely: *Satisfaction*, *Dependence*, *Perceived Dependence*, and *Creditability*) on *QR adoption*, and (ii) the effect of *QR adoption* on *Performance*. We perform separate regression analyses to test for the above two relationships.

Just as for other statistical analyses, sample size plays an influential role in regression analysis. A rule of thumb is that the ratio of sample data to independent variables “should never fall below 5 to 1” and it is “desirable to have around 15-20 observations for each independent variables” (Hair et al., 1998, p.166) . Having four independent variables in our first regression model, it would then desirable to have a sample size of around 60-80, therefore our sample size of 59 supplier respondents are deemed sufficient for performing regression analysis.

To proceed to our analysis, we define the mean score of individual variables for a respondent by taking the average of the scores of the respective items that passed the reliability test, i.e. those listed in Table 4.5.11(a). Afterwards, we make use of these mean scores as the observations for regression analysis and the results are shown in Tables 4.5.14 and 4.5.15. As shown in Table 4.5.14, there is no significant evidence that any of the four independent variables quantifying buyer-supplier relationship has impact on the level of QR adoption of our supplier respondents. In other words, Hypothesis H2 and H4 are not supported. On the other hand, as reflected in Table 4.5.15, the level of QR adoption of our supplier respondents has a statistically significantly positive impact on their performance ($\beta = 0.267$, significant at 0.05 level). Therefore Hypothesis H6m is rejected in the sense that the level of QR adoption brings positive effect to the performance of the supplier respondents.

It remains to test the impact of MOQ imposition on the degree of buyer-supplier relationship, the level of QR adoption and the company of the supplier respondents. In our questionnaire we require the supplier to state whether they impose MOQ on the buyers they considered for measuring the buyer-supplier relationship (i.e. question 3.3 in the questionnaire). There are 43 supplier respondents imposing MOQ on their clients under consideration and 11 not imposing MOQ on the concerned clients, with 2 respondents failing to provide their MOQ imposition status. We then compare the mean scores of the various constructs between the MOQ group and the no-MOQ group but no significant differences are reported (Table 4.5.16). In other words, all the MOQ-related hypotheses for the supplier respondents are not supported.

4.3.7 Model Testing – High-sale Buyers

Since the sample of the high-sale buyer respondents is less than that of their supplier counterparts (sample size = 27), it can be expected that the sample does not provide an acceptable fit for SEM. In fact, we perform CFA of the various constructs with the data of this sample and found that the measurement model for the construct *Creditability* is not admissible; or more specifically, some variance estimates are negative. As a result, we cannot proceed with further analysis for the high-sale buyer group by SEM.

Similar to the approach for the supplier respondents, we define the mean score of individual variables for a respondent by taking the average of the scores of the respective items that passed the reliability test, i.e. those listed in Table 4.5.11(b). Then we perform regression analyses to investigate whether there is statistically significant relationship between the various *Relationship*-related variables and the level of *QR adoption*, and that between *QR adoption* and *Performance*. As the sample size to the number of independent variables are greater than the minimum ratio of 5 to 1, it is still appropriate to adopt the analysis. Results of the regression analyses indicate that the two hypothesis relationships are not statistically significant (see Tables 4.5.17 and 4.5.18). Therefore, Hypotheses H2, H4 and H6r are not supported.

Finally, we test the impact of MOQ imposition on the degree of buyer-supplier relationship, the level of QR adoption and the company of the high-sale buyer respondents. Within the 27 high-sale buyer respondents, 18 are having MOQ imposed by their concerned suppliers whereas the remaining 9 respondents do not have the issue of MOQ. We compare the mean scores of the various constructs between the MOQ group and the no-MOQ group but there is no statistically significant evidence to state that MOQ imposition has impact on the various variables except for the level of QR adoption (Table 4.5.19). In particular, results of the t-tests suggest that the mean score of *QR adoption* for the high-sale buyer respondents with MOQ imposition is significantly greater than that of the no-MOQ respondents. Hence Hypothesis 3r is supported.

4.4. Summary

In this chapter we study empirically the practice of QR adoption and MOQ imposition in the Hong Kong apparel industry in the form of a questionnaire survey. Started by presenting the theory-driven conceptual model we have formulated regarding the relationship between QR and MOQ imposition, we outlined the development of the set of questionnaire that was used for data collection. Then we presented the general findings about the level of QR adoption and MOQ imposition of the respondents.

We observed that a high proportion of respondents are imposing MOQ or being imposed with MOQ by their business partners. From the comparison of the scores on individual QR-related practice, the buyer respondents are in general involving in QR practice in a more comprehensive way than the supplier respondents.

We also compared the level of involvement of our retailer respondents in QR-related practices with the respondents in Birtwistle et al. (2003). Owing to the advance in technology as well as the increased awareness of the strategy, our retailers scored considerably higher in certain technology-related and inventory-management-related QR practices. By contrast, our retailers involved considerably less degree in automatic replenishment process than the respondents in Birtwistle et al. (2003). This may worth further investigation how we can encourage such implementation.

We intended to perform structural equation modelling (SEM) to verify our conceptual model. Owing to the time limit and the inherently low response rate of the population, we have collected a total of 115 responses, which comprises of 59 buyers and 56 suppliers. Such a sample size may not be adequate for conducting certain types of statistical analyses. In particular, since buyers with different annual sales revenues have significant difference in various measurement items, we have to employ the data from the high-sale buyer respondents only for analyzing the buyer's model. As a result, our sample size is not sufficient for us to perform SEM for model verification as intended. Alternatively, we performed regression analysis and t-tests on our survey data for hypothesis testing. As shown in Table 4.6.1, which summarizes the results of all hypotheses testing, our survey provided statistically significant evidence that QR adoption can bring about positive impact on a supplier's performance. Also the high-sale buyer respondents with MOQ imposition were also found to have a significantly higher level of QR adoption than those without MOQ. These findings may provide justification for the supplier to consider QR adoption and for the buyer to consider acceptance of MOQ as a token for their supplier to adopt QR.

Through this questionnaire survey, we have acquired a deeper understanding of the practice of MOQ in the apparel industry. Our findings have provided the empirically grounded evidence about the prevalence of MOQ imposition in the apparel industry, the factors affecting suppliers' settings of MOQ, as well as the perceptions of different channel members regarding MOQ imposition and QR. Being the first empirical study on the topic, we hope that our work may arouse interests of other researchers to further pursue the relationship between QR and MOQ imposition in the apparel supply chains.

5. Mathematical Model Formulation

Apart from the empirical studies we have conducted in the previous two chapters, we investigate analytically the impact of MOQ imposition on QR strategy. Specifically we formulate implementation of QR in the form of various ordering policies and study the impacts of MOQ(s) on the retailer's ordering decisions and performance of the supply chain and its members. In this chapter, we present the conceptual framework of QR implementation, the various ordering systems under investigation, the definition of channel coordination and the list of notations to be used in the remaining chapters of this thesis.

For the ease of presentation, *we employ the male pronoun for the retailer and the female pronoun for the manufacturer in the remaining chapters of the thesis*.

5.1. Bayesian Information Updating Process

One of the most essential elements in QR is information updating. In this thesis we employ Bayesian Theory to formulate the information updating process of a QR system. Using the normal observation process (with known variance) and normal prior demand distribution, we divide the planning horizon into two distinct stages.

Information observed in the first stage is used to revise the distribution parameters via Bayesian approach.

We employ this Bayesian information updating model for various reasons. First, this information updating model is classic and popularly used in the literature (which includes very recent and old papers published in the most prestigious journals such as Management Science, e.g. Iyer & Bergen, 1997; Eppen & Iyer, 1997; and Taylor & Xiao, 2010). Employing it thus allows us to reveal the impacts of MOQ by directly comparing our new findings with the literature. Second, this model allows us to generate more analytical insights, especially related to the impacts brought by demand uncertainty because we can investigate the related issues by looking at the standard deviation of the demand distribution.

We describe the details of the information updating process as follows. We consider a time line for a newsvendor retailer with two ordering time points, namely: Stage 0 and Stage 1. Stage 0 is far in advance before the beginning of a selling season whilst Stage 1 is much closer to the start of selling season. We denote the predicted demand of the seasonal product at Stage 0 by x_0, which is normally distributed with mean θ and variance δ, where θ is also uncertain and follows a normal distribution with mean μ_0 and variance d_0. Thus the unconditional prior distribution of x_0 is a normal distribution with mean μ_0 and variance $\sigma_0{}^2 = (d_0 + \delta)$:

$$x_0 \sim N(\mu_0, \sigma_0{}^2). \qquad (5.1)$$

Between Stage 0 and Stage 1, we collect an observation about x_0 (e.g. the sales performance of a closely related pre-seasonal product) and denote it by $\hat{x}_0$. By Bayesian Theory, the updated distribution of θ is now $\theta \sim N(\mu_1, d_1)$, where

$$\mu_1 = \left(\frac{d_0}{d_0 + \delta}\right)\hat{x}_0 + \left(\frac{\delta}{d_0 + \delta}\right)\mu_0, \qquad (5.2)$$

$$d_1 = d_0\delta/(d_0 + \delta). \qquad (5.3)$$

Let x_1 be the predicted demand of the seasonal product at Stage 1. Denote $\sigma_1{}^2 = (d_1 + \delta)$ and $\sigma_\mu{}^2 = d_0{}^2/(d_0 + \delta)$. Then the (conditional) posterior distribution of x_1 given $\hat{x}_0$ is:

$$x_1 | \hat{x}_0 \sim N(\mu_1, \sigma_1{}^2), \qquad (5.4)$$

Correspondingly, the unconditional distribution of μ_1 is:

$$\mu_1 \sim N(\mu_0, \sigma_\mu{}^2). \qquad (5.5)$$

5.2. Notation

For easy reference, below is the list of cost-revenue parameters, decision variables and special functions that appears in the formulation in the subsequent chapters. Definition of those variables and functions that are specific to individual models are presented in the respective chapters.

r	:	Unit retail price
h	:	Net unit holding cost (after deducting the salvage value from the inventory holding cost) for the left-over items at the season-end
c_k	:	Unit ordering cost for the retailer at Stage *k, k=0,1*
m_k	:	Unit production cost for the manufacturer at Stage *k, k=0,1*
$s_k = (r - c_k)/(r + h)$	:	Newsvendor critical value for the retailer at Stage *k, k=0,1*
$s_k^{SC} = (r - m_k)/(r + h)$	:	Newsvendor critical value for the supply chain at Stage *k, k=0,1*
M_k	:	Minimum order quantity required by the manufacturer at Stage *k, k=0,1*

Q_k : Order quantity placed by the retailer at Stage *k, k=0,1*

$f(\cdot)$: pdf of the corresponding argument

$\phi(\cdot)$: Standard normal pdf

$\Phi(\cdot)$: Standard normal cdf

$\psi(a)=\int_a^\infty (z-a)\phi(z)dz$: Standard normal right linear loss function

5.3. Ordering Systems

In this thesis we study the impacts of MOQ(s) on the retailer's ordering decisions and performance of channel members under various ordering policies. We describe these ordering policies as follows.

(1) The old system:

Under the old system, since the order lead time is long, the retailer can only place order once at a time point far in advance before the selling season starts (Stage 0), there is no information updating process; therefore, the retailer can only make use of the prior demand estimate for his ordering decision.

(2) QR (single ordering) with MOQ system (referred as QRS-MOQ system):

Under the QRS-MOQ system, the retailer has only one ordering opportunity but he can postpone his ordering to a time point that is much closer to the season launch (Stage 1). Then, the retailer can make use of the time between Stage 0 and

Stage 1 to observe from the market the sales performance of some closely-related pre-seasonal products to update his demand forecast. At Stage 1, the retailer can then make his ordering decision based on the updated posterior demand estimate, which is believed to be more accurate.

(3) QR (dual ordering) with Stage-0 MOQ (referred as QRD-MOQ-I system):

Under the QRD-MOQ-I system, the retailer has two ordering opportunities, one at Stage 0 and the other at Stage 1. Specifically, the retailer makes his first ordering decision at Stage 0 based on the prior demand estimate and MOQ consideration. Then after observing from the market, he obtains the posterior demand forecast and places another order at Stage 1 to better cope with the updated market situation. By doing so, the retailer has more flexibility in his order placing. On the other hand, to justify the initial production set-up cost and other concerns, the manufacturer imposes an MOQ requirement at Stage 0. As a result, the retailer's ordering policy may alter to cope with this MOQ constraint.

(4) QR (dual ordering) with Stage-0 and Stage 1 MOQ (referred as QRD-MOQ-II system):

The ordering process under the QRD-MOQ-II system is the same as that in the QRD-MOQ-I system, except that the retailer has to face the MOQ constraint at both Stages 0 and 1.

(5) The centralized QR system (single ordering) (referred as the centralized QRS system):

It refers to the benchmark system analogue to that of the QRS-MOQ system under which both channel members are coordinated centrally and the supply chain is optimal with its expected profit maximized.

(6) The centralized QR system (dual ordering) (referred as the centralized QRD system):

It refers to the benchmark system analogue to that of the QRD-MOQ-I and the QRD-MOQ-II systems under which both channel members are coordinated centrally and the supply chain is optimal with its expected profit maximized. We consider that the MOQ constraints at both stages are satisfied under the centralized QRD system.

5.4. Channel Coordination

There are a variety of versions for the definition of channel coordination employed in the supply chain management literature (e.g. Cachon, 2003, Gan et al., 2004). Most of them share the same opinion that the supply chain should be most efficient under channel coordination. In terms of expected profit, the supply chain should attain its maximum expected profit under channel coordination. Whereas a strategy can maximize the supply chain profit, it may not necessarily ensure that all channel members are beneficial at the same time. In this thesis, we consider the context of channel coordination to include both supply chain expected profit (SCEP) maximization and Pareto improvement. We present the details of these two conditions in the below sub-sections.

5.4.1 Supply Chain Expected Profit (SCEP) Maximization

A commonly agreed condition for channel coordination is maximization of SCEP. This maximum SCEP is usually referred to the maximum amount the centralized supply chain system can obtain. Accordingly, in this thesis, a strategy is said to be able to *maximize SCEP* if and only if it can induce the supply chain to achieve the maximum SCEP of its corresponding centralized supply chain.

5.4.2 Pareto Improvement

There is a general perception that MOQ imposition would increase the profit of the manufacturer but reduce that of the retailer. By contrast, opposite opinion holds for the impacts of QR on the two agents. Therefore we would like to explore in this thesis the conditions under which QR strategy with MOQ would make both channel members better off when compared with the traditional approach.

Given that the retailer orders at his optimal newsvendor quantity, the retailer expected profit (REP) and that of the manufacturer (MEP) under the old system are given by the below, respectively:

$$ER_{Old} = (r - c_0)\mu_0 - (h + c_0)\sigma_0\Phi^{-1}(s_0) - (r + h)\sigma_0\psi[\Phi^{-1}(s_0)], \qquad (5.6)$$

$$EM_{Old} = (c_0 - m_0)[\mu_0 + \sigma_0\Phi^{-1}(s_0)]. \qquad (5.7)$$

We define the concept of Pareto improvement as follows: A strategy is said to be *Pareto improving* if and only if the expected profits of the retailer and that of the manufacturer after adopting the strategy are no smaller that stated in (5.6) and (5.7) respectively, with at least one of the expected profits being strictly larger.

5.4.3 Our Definition of Channel Coordination

In this thesis, we define the concept of channel coordination in the following way: A strategy is said to be able to *coordinate* the supply chain if and only if it can: (i) maximize the supply chain expected profit; and (ii) be Pareto improving for both the retailer and the manufacturer.

5.5. Summary

As an introduction for the mathematical modeling component of the thesis, this chapter provided the mathematical modeling framework for our study of the relationships between QR and MOQ imposition in the subsequent chapters. We presented the Bayesian information updating process, the various ordering systems to be studied, as well as the definitions of channel coordination employed in our study. In the following chapters, we proceed to investigate the impacts of MOQ on the ordering policies and the performance of channel members under various QR systems.

6. QR (Single Ordering) with MOQ (The QRS-MOQ System)

In this chapter we consider a retailer-manufacturer fashion supply chain that adopts Quick Response in the form of single ordering with an MOQ constraint. Specifically, the retailer is allowed to postpone his ordering decision after observing market information closer to the season launch at Stage 1 under the condition that the manufacturer requires the order quantity to meet (or exceed) M_1. Under this scenario we first derive the optimal ordering policy for the retailer. Afterwards, we investigate what the optimal values of the MOQ are for the retailer and the manufacturer, respectively, and discuss the findings.

6.1. Optimal Ordering Policy under QRS-MOQ

We start by considering the retailer's optimal ordering decision without MOQ. At Stage 1, after μ_1 is observed, the retailer's expected profit for ordering a quantity Q_1 is given by:

$$ER_1^{QRS}(Q_1 | \mu_1)$$

$$= r\left[\int_{-\infty}^{Q_1} x_1 f(x_1)dx_1 + \int_{Q_1}^{\infty} Q_1 f(x_1)dx_1\right] - h\int_{-\infty}^{Q_1}(Q_1 - x_1)f(x_1)dx_1 - c_1 Q_1$$

$$= (r+h)\mu_1 - (h+c_1)Q_1 - (r+h)\sigma_1\psi[(Q_1 - \mu_1)/\sigma_1]. \tag{6.1}$$

It can be easily shown that $ER_1^{QRS}(Q_1|\mu_1)$ is a strictly concave function in Q_1. The first-order condition thus provides the optimal order quantity, $\hat{Q}_1^{QRS}$, for the retailer:

$$\hat{Q}_1^{QRS} = \mu_1 + \sigma_1\Phi^{-1}(s_1), \tag{6.2}$$

and the maximum expected profit he can obtain is given by:

$$ER_1^{QRS}* = ER_1^{QRS}(\hat{Q}_1|\mu_1)$$

$$= (r-c_1)\mu_1 - (h+c_1)\sigma_1\Phi^{-1}(s_1) - (r+h)\sigma_1\psi[\Phi^{-1}(s_1)]. \tag{6.3}$$

Correspondingly, at Stage 0, the maximum expected profit the retailer anticipates is:

$$ER^{QRS}* = (r-c_1)\mu_0 - (h+c_1)\sigma_1\Phi^{-1}(s_1) - (r+h)\sigma_1\psi[\Phi^{-1}(s_1)]. \tag{6.4}$$

Now under the QRS-MOQ system, the retailer can order with a quantity of $\hat{Q}_1^{QRS}$ at Stage 1 if $\hat{Q}_1^{QRS}$ fulfils the MOQ requirement, i.e. $\hat{Q}_1^{QRS} \geq M_1$, or equivalently $\mu_1 \geq M_1 - \sigma_1\Phi^{-1}(s_1)$; otherwise, he should either increase his order quantity up to the MOQ, or give up ordering. Note that for $M_1 \leq \sigma_1\Phi^{-1}(s_1)$, we have $\mu_1 \geq 0 \geq M_1 - \sigma_1\Phi^{-1}(s_1)$; therefore, the retailer can always order at $\hat{Q}_1^{QRS}$. Now we focus on the case that $M_1 > \sigma_1\Phi^{-1}(s_1)$ when the retailer's optimal order quantity fails to abide by the MOQ requirement.

To make his decision, the retailer would first calculate whether his expected profit by ordering up to the MOQ meets his minimum profit target known as the *reservation expected profit* $J_R \geq 0$. This *reservation expected profit* refers to the minimum amount of expected profit with which the retailer will place an order. To avoid trivial case, J_R is smaller than $ER_1^{QRS}*$ and $ER^{QRS}*$ (or else the retailer will not order even without MOQ). Define:

$$\hat{\mu}_1^{QRS} = \arg_{\mu_1 \geq 0}\left\{ ER_1^{QRS}(M_1 | \mu_1) = J_R, \textit{ where } M_1 > \sigma_1 \Phi^{-1}(s_1) \right\}. \tag{6.5}$$

We can derive Proposition 6.1 which states the optimal ordering policy for the retailer under the QRS-MOQ system.

Proposition 6.1:

(a) $0 < \hat{\mu}_1^{QRS} < M_1 - \sigma_1 \Phi^{-1}(s_1)$;

(b) The optimal ordering quantity for the retailer under QRS-MOQ is given by:

(i) If $M_1 \leq \sigma_1 \Phi^{-1}(s_1)$, $Q_1^{QRS}* = \hat{Q}_1^{QRS}$;

(ii) If $M_1 > \sigma_1 \Phi^{-1}(s_1)$,

$$Q_1^{QRS}* = \begin{cases} \hat{Q}_1^{QRS} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) & \textit{if } \mu_1 \geq M_1 - \sigma_1 \Phi^{-1}(s_1) \\ M_1 & \textit{if } \hat{\mu}_1^{QRS} < \mu_1 < M_1 - \sigma_1 \Phi^{-1}(s_1) \\ 0 & \textit{if } \mu_1 \leq \hat{\mu}_1^{QRS} \end{cases}. \tag{6.6}$$

As shown in Proposition 6.1, the optimal ordering quantity relies on the revised expected demand upon information updating and also the size of MOQ. It is more complicated than the case without MOQ (see Iyer & Bergen, 1997). As a remark, the retailer will choose not to accept the MOQ imposition at Stage 0 if M_1 is too large (especially in the presence of J_R). Let

$$\overline{Q}_1^{QRS} = \arg_{Q_1 > \hat{Q}_1^{QRS}} \left\{ ER^{QRS}(Q_1) = J_R \right\}. \tag{6.7}$$

where

$$ER^{QRS}(Q_1) = (r+h)\mu_0 - (h+c_1)Q_1 - (r+h)\sigma_1\psi[(Q_1-\mu_0)/\sigma_1], \tag{6.8}$$

is the expected profit that the retailer anticipates at Stage 0 when the order quantity at Stage 1 is Q_1.

Notice that $ER^{QRS}(Q_1)$ is also strictly concave in Q_1 and attains its maximum (which is equal to $ER^{QRS}*$) at $E[\hat{Q}_1^{QRS}] = \mu_0 + \sigma_1\Phi^{-1}(s_1)$. Similar to the argument in the proof of Proposition 6.1, $ER^{QRS}(M_1) < J_R$ for $M_1 > \overline{Q}_1^{QRS}$. Thus at Stage 0 the retailer would only accept an MOQ in the range of $0 \le M_1 \le \overline{Q}_1^{QRS}$.

6.2. Impacts of MOQ on Performance of Channel Members

From the above discussion, we can observe that MOQ imposition would complicate the retailer's ordering decision, and in turn affects the manufacturer's revenue. A common belief is that the retailer normally does not welcome MOQ imposition as it would hinder his ordering flexibility. By contrast, the manufacturer prefers having MOQ as it can justify the production set-up cost as well as provide a guarantee of income. However, whether MOQ imposition can be beneficial to the whole supply chain is controversial. To verify such belief as well as to reveal the impacts of MOQ on the supply chain's performance, we explore in this section how MOQ imposition affects the expected profit of the supply chain agents.

Proposition 6.2 states the impacts of MOQ on the retailer expected profit (REP) under the QRS-MOQ system.

Proposition 6.2:

(a) The expected profit that the retailer anticipates at Stage 0 under the QRS-MOQ system is a non-increasing function in M_1*;*

(b) The optimal MOQ for the retailer is given by: $0 \le M_1^{QRS,R*} \le \sigma_1 \Phi^{-1}(s_1)$.

Proposition 6.2 confirms analytically the reason that explains why the retailer should not welcome MOQ because a larger MOQ means a smaller (or non-increasing) expected profit for the retailer.

On the other hand, the expected order quantity under the QRS-MOQ system is given by:

$$EQ^{QRS-MOQ}(M_1)$$

$$= \int_{\hat{\mu}_1^{QRS}}^{M_1-\sigma_1\Phi^{-1}(s_1)} M_1 f(\mu_1) d\mu_1 + \int_{M_1-\sigma_1\Phi^{-1}(s_1)_1}^{\infty} [\mu_1 + \sigma_1\Phi^{-1}(s_1)] f(\mu_1) d\mu_1$$

$$= M_1[1-\Phi(\rho_1)] + \sigma_\mu \psi(\xi_1), \qquad (6.9)$$

where $\xi_1(M_1) = [M_1 - \sigma_1\Phi^{-1}(s_1) - \mu_0]/\sigma_\mu$, (6.10)

and $\rho_1(M_1) = (\hat{\mu}_1^{QRS} - \mu_0)/\sigma_\mu$. (6.11)

Correspondingly, the manufacturer expected profit (MEP) and its first derivative are expressed as follows, respectively:

$$EM^{QRS-MOQ}(M_1) = (c_1 - m_1) * EQ^{QRS-MOQ}(M_1)$$

$$= (c_1 - m_1)\{M_1[1 - \Phi(\rho_1)] + \sigma_\mu \psi(\xi_1)\}. \quad (6.12)$$

$$dEM^{QRS-MOQ}/dM_1$$

$$= (c_1 - m_1)\left\{[\Phi(\xi_1) - \Phi(\rho_1)] - \frac{1}{\sigma_\mu} M_1 \phi(\rho)\left[1 - \frac{s_1}{\Phi[(M_1 - \hat{\mu}_1)/\sigma_1]}\right]\right\}. \quad (6.13)$$

Unfortunately, $EM^{QRS-MOQ}$ may not be concave. To be specific, its first derivative can take very different forms depending on the value of M_1. As a result, we will explore the properties of MEP via numerical analysis, which is presented in Chapter 9.

6.3. Summary

In this chapter, we studied the impacts of MOQ on QR in the form of the QRS-MOQ system. We derived the retailer's optimal ordering policy under the system and noticed that the existence of the MOQ would complicate his ordering decision. With further investigation on the retailer expected profit function, we confirmed analytically that the MOQ has an adverse effect on the retailer expected profit (REP) unless it is sufficiently small. For the manufacturer, on the other hand, a larger MOQ does not always result in a larger profit as the manufacturer expected profit (MEP) function is not always increasing in the MOQ. Owing to the complicated expression of the first derivative of the MEP function, it is difficult for us to analyze mathematically the impact of the MOQ on MEP. We will resolve this issue by numerical studies, which are presented in Chapter 9.

7. QR (Dual Ordering) with Stage-0 MOQ (The QRD-MOQ-I System)

In this chapter we consider a retailer-manufacturer fashion supply chain that adopts Quick Response in the form of dual ordering flexibility with a Stage-0 MOQ constraint. Specifically, the retailer is given two ordering opportunities (denoted by Stage 0 and Stage 1) for an apparel product before the season starts. At Stage 0, he places an order based on the prior demand forecast. Then, between Stage 0 and Stage 1, he can observe from the market and by the Bayesian information updating process to obtain a more accurate posterior demand forecast for his ordering decision at Stage 1. Meanwhile, the manufacturer only imposes an MOQ constraint at Stage 0, but not Stage 1. This particular case is of course a special case while it does rather fit some real world scenarios. For example, for many mass market retail brands, when they place an order to the manufacturer at the very beginning (i.e. Stage 0), the manufacturer usually imposes an MOQ on the ordering. If the order size satisfies the MOQ constraint, the manufacturer will accept the order and proceed with the production. It is rather interesting to note that the manufacturer will usually reserve more materials for production as a buffer. It is reported that the reserve may range from 20% to 33% of the seasonal commitment for some branded manufacturers. (See Eppen and Iyer 1997). Thus, a small order placed after Stage 0 (e.g., at Stage 1) can still be entertained (as if there is no MOQ at Stage 1). As a remark, the literature has shown that the dual-ordering system is reduced to a single-ordering one when the Stage-1 purchase cost is no greater than the Stage-0 purchase cost (see Choi et al. 2003). To avoid the trivial cases we consider the case that the unit purchase at Stage 1 is greater than that at Stage 0 (i.e. $c_1 > c_0$).

7.1. The Optimal Ordering Policy

Let $ER_1^{QRD}(Q_1 | Q_0, \mu_1)$ be the retailer's expected profit when ordering a quantity Q_1 at Stage 1, given that he has ordered a quantity Q_0 at Stage 0 whilst the posterior demand mean is revealed to be μ_1. Then, we have:

$$ER_1^{QRD}(Q_1 | Q_0, \mu_1) = r\int_{-\infty}^{Q_0+Q_1} x_1 f(x_1) dx_1 + r\int_{Q_0+Q_1}^{\infty} (Q_0 + Q_1) f(x_1) dx_1$$

$$- h\int_{-\infty}^{Q_0+Q_1} (Q_0 + Q_1 - x_1) f(x_1) dx_1 - c_1 Q_1 . \qquad (7.1)$$

It can be shown that ER_1^{QRD} is strictly concave in Q_1 and the optimal ordering quantity at Stage 1, denoted by $Q_1^{QRD^*}$, is given by:

$$Q_1^{QRD^*} = \begin{cases} 0 & for \;\; \mu_1 \le Q_0 - \sigma_1 \Phi^{-1}(s_1) \\ \hat{Q}_1^{QRD} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - Q_0 & for \;\; \mu_1 > Q_0 - \sigma_1 \Phi^{-1}(s_1) \end{cases}, \qquad (7.2)$$

Working backwards, the retailer expected profit (REP) when ordering a quantity Q_0 at Stage 0 (without the MOQ constraint), can be expressed as:

$$ER^{QRD}(Q_0)$$

$$= \int_{-\infty}^{Q_0-\sigma_1\Phi^{-1}(s_1)} ER_1^{QRD}(0 \mid Q_0, \mu_1) f(\mu_1) d\mu_1$$

$$+ \int_{Q_0-\sigma_1\Phi^{-1}(s_1)}^{\infty} ER_1^{QRD}(\hat{Q}_1^{QRD} \mid Q_0, \mu_1) f(\mu_1) d\mu_1 - c_0 Q_0 . \tag{7.3}$$

Then, by simple calculus, we have:

$$dER^{QRD}(Q_0)/dQ_0$$

$$= (c_1 - c_0) + (r - c_1)\Phi(\xi_2) - (r + h)\int_{-\infty}^{\xi_2(Q_0)} \Phi\left(\frac{Q_0 - \sigma_\mu \gamma - \mu_0}{\sigma_1}\right)\phi(\gamma) d\gamma , \tag{7.4}$$

where $\xi_2(Q_0) = [Q_0 - \sigma_1 \Phi^{-1}(s_1) - \mu_0]/\sigma_\mu$. (7.5)

It can be shown that ER^{QRD} is a strictly concave function in Q_0 and the optimal ordering quantity at Stage 0 (without the MOQ constraint) is given by:

$$Q_0^{QRD}* = \max\{\, 0 \,,\, \hat{Q}_0^{QRD} \,\} , \tag{7.6}$$

where

$$\hat{Q}_0^{QRD} = \arg_{Q_0}\{\, dER^{QRD} / dQ_0 = 0 \,\} . \tag{7.7}$$

Now with the Stage-0 MOQ constraint, denoted by M_0, the retailer has to check whether his optimal order decision fulfils this MOQ constraint.

Case I: $\hat{Q}_0^{QRD} \geq M_0$

Since the Stage-0 MOQ constraint is fulfilled, the retailer can order $\hat{Q}_0^{QRD}$ that gives him the maximum expected profit.

Case II: $\hat{Q}_0^{QRD} < M_0$

In this case, the retailer is not allowed to order $\hat{Q}_0^{QRD}$ because of the MOQ constraint. It has left him two alternatives: either he should order up to M_0 to fulfil the MOQ constraint, or give up ordering at Stage 0 (i.e., order nothing). Such a decision depends on which option gives the retailer the larger expected profit. We shall see in the following that the property of ER^{QRD} gives us insights on how the retailer can determine his optimal decision in this case.

As mentioned before, ER^{QRD} is a concave function in Q_0 and by the definition of $\hat{Q}_0^{QRD}$, ER^{QRD} is a decreasing function for $Q_0 > \hat{Q}_0^{QRD}$. Let

$$\overline{Q}_0^{QRD} = \arg_{Q_0 > \hat{Q}_0^{QRD}} \{ ER^{QRD}(Q_0) = ER^{QRD}(0) \}. \tag{7.8}$$

In other words, $\overline{Q}_0^{QRD}$ is such an order quantity that the corresponding REP is equal to that when he orders nothing at Stage 0. Next, let us consider the following two scenarios:

Case II (a): $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$

By the decreasing property of ER^{QRD} in the range of $Q_0 \in (\hat{Q}_0^{QRD}, \infty)$, we have $ER^{QRD}(M_0) > ER^{QRD}(\overline{Q}_0^{QRD})$. In other words, the REP when ordering M_0 is greater than that when ordering $\overline{Q}_0^{QRD}$, which by definition is also equivalent to ordering nothing at Stage 0. Thus the retailer should order M_0 in this case to yield a greater expected profit.

<u>Case II (b)</u>: $\hat{Q}_0^{QRD} < \overline{Q}_0^{QRD} \le M_0$

In this case, we have $ER^{QRD}(M_0) \le ER^{QRD}(\overline{Q}_0^{QRD})$. In other words, the retailer's expected profit when ordering M_0 is smaller than that when ordering $\overline{Q}_0^{QRD}$, which by definition is also equivalent to ordering nothing at Stage 0. Thus the retailer should order nothing at Stage 0 in this case in order to obtain a greater expected profit.

We summarize the optimal ordering decision algorithm under QRD-MOQ-I system in Algorithm 7.1.

Algorithm 7.1:

The optimal ordering quantities at Stage 0 and Stage 1 under the QRD-MOQ-I system are given by the following equations, respectively:

$$Q_0^{QRD-MOQ-I}* = \begin{cases} \hat{Q}_0^{QRD} & for \quad 0 \le M_0 \le \hat{Q}_0^{QRD} \\ M_0 & for \quad \hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD} \\ 0 & for \quad M_0 \ge \overline{Q}_0^{QRD} \end{cases}, \tag{7.9}$$

$$Q_1^{QRD-MOQ-I}* = \begin{cases} \hat{Q}_1^{QRD-MOQ-I} & for \quad \mu_1 > Q_0^{QRD-MOQ-I} * - \sigma_1 \Phi^{-1}(s_1) \\ 0 & for \quad \mu_1 \le Q_0^{QRD-MOQ-I} * - \sigma_1 \Phi^{-1}(s_1) \end{cases}, \tag{7.10}$$

where $\hat{Q}_0^{QRD}$ and $\overline{Q}_0^{QRD}$ are defined in (7.7) and (7.8), respectively, and

$$\hat{Q}_1^{QRD-MOQ-I} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - Q_0^{QRD-MOQ-I} * . \quad (7.11)$$

7.2. Impacts of the Stage-0 MOQ on the Supply Chain Performance

In this section, we explore how the manufacturer's MOQ imposition at Stage 0 affects the performance of the overall supply chain. Here we focus on the two performance measures, namely, the expected total order quantity and the expected profits of the channel members. Specifically, we compare (1) the retailer's expected total order quantity, as well as (2) the expected profits of the retailer, the manufacturer, and the whole supply chain, under MOQ constraint with those under the "no-MOQ case". Then we investigate the relationship between the MOQ and such differences.

From the discussion in the previous section, the retailer's ordering decision is the same no matter there is an MOQ condition or not when $\hat{Q}_0^{QRD} \geq M_0$. Therefore it remains to study the scenario when: $\hat{Q}_0^{QRD} < M_0$.

7.2.1 Expected Total Order Quantity

Case (I): $0 \leq M_0 \leq \hat{Q}_0^{QRD}$

In this case, the MOQ requirement is satisfied; therefore, the retailer's order quantity at Stage 0 is $\hat{Q}_0^{QRD}$. Then, at Stage 1, depending on the posterior demand distribution, the retailer will either order nothing or $\hat{Q}_1^{QRD} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - \hat{Q}_0^{QRD}$.

Thus the retailer's expected total order quantity without MOQ is given by:

$$EQ^{QRD}$$

$$= \int_{-\infty}^{\hat{Q}_0^{QRD} - \sigma_1 \Phi^{-1}(s_1)} \hat{Q}_0^{QRD} f(\mu_1) d\mu_1 + \int_{\hat{Q}_0^{QRD} - \sigma_1 \Phi^{-1}(s_1)}^{\infty} (\hat{Q}_0^{QRD} + \hat{Q}_1^{QRD}) f(\mu_1) d\mu_1$$

$$= \hat{Q}_0^{QRD} + \sigma_\mu \psi[\xi_2(\hat{Q}_0^{QRD})], \qquad (7.12)$$

where ξ_2 was defined in (7.5).

Case (II): $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$

As discussed in the previous section, the retailer's optimal order quantity at Stage 0 under this case is M_0. Accordingly, the retailer's expected total order quantity is given by:

$$EQ^{QRD-MOQ-I}(M_0)$$

$$= \int_{-\infty}^{M_0 - \sigma\ \Phi^{-1}(s_1)} M_0 f(\mu_1) d\mu_1 + \int_{M_0 - \sigma\ \Phi^{-1}(s_1)}^{\infty} [\mu_1 + \sigma_1 \Phi^{-1}(s_1)] f(\mu_1) d\mu_1$$

$$= M_0 + \sigma_\mu \psi[\xi_2(M_0)]. \qquad (7.13)$$

Case III ($\hat{Q}_0^{QRD} < \overline{Q}_0^{QRD} \le M_0$):

In this case the retailer will order nothing at Stage 0 as such policy provides him a greater expected profit. Accordingly, the optimal order quantity at Stage 1 is $\mu_1 + \sigma_1 \Phi^{-1}(s_1)$ given the updated posterior distribution mean μ_1. Thus the retailer's expected total order quantity in this case is given by:

$$EQ^{QRD-MOQ-I}(M_0)$$

$$= \quad E[\mu_1 + \sigma_1 \Phi^{-1}(s_1)] = \mu_0 + \sigma_1 \Phi^{-1}(s_1) . \qquad (7.14)$$

Proposition 7.1 gives us the relationship between the expected total order quantities and the Stage-0 MOQ.

Proposition 7.1:

Given $\hat{Q}_0^{QRD} < M_0$. We have:

(a) $EQ^{QRD-MOQ-I}(M_0) > EQ^{QRD}$ for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$; and

(b) $EQ^{QRD-MOQ-I}(M_0) \le EQ^{QRD}$ for $\hat{Q}_0^{QRD} < \overline{Q}_0^{QRD} \le M_0$.

According to Proposition 7.1, imposing a reasonable Stage-0 MOQ condition (namely: $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$) will lead the retailer to order more on average. However, if the MOQ is set too aggressively (i.e. $M_0 \ge \overline{Q}_0^{QRD}$), there will be an adverse effect that the retailer will on average order less than the case without the MOQ condition.

7.2.2 Expected Profits of Channel Members

Next, we proceed to investigate the effect brought about by imposing an MOQ constraint at Stage 0 on the expected profit of the channel members. The retailer expected profit (REP), the manufacturer expected profit (MEP) and the supply chain expected profit (SCEP) are expressed in the following equations, respectively:

$$ER^{QRD-MOQ-I}(M_0)$$

$$= \begin{cases} ER^{QRD}(\hat{Q}_0^{QRD}) & \text{for } 0 \le M_0 \le \hat{Q}_0^{QRD} \\ ER^{QRD}(M_0) & \text{for } \hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD} \\ ER^{QRD}(0) & \text{for } M_0 \ge \overline{Q}_0^{QRD} \end{cases}, \quad (7.15)$$

$$EM^{QRD-MOQ-I}(M_0)$$

$$= \begin{cases} EM^{QRD}(\hat{Q}_0^{QRD}) & \text{for } 0 \le M_0 \le \hat{Q}_0^{QRD} \\ EM^{QRD}(M_0) & \text{for } \hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD} \\ (c_1 - m_1)[\mu_0 + \sigma_1 \Phi^{-1}(s_1)] & \text{for } M_0 \ge \overline{Q}_0^{QRD} \end{cases}, \quad (7.16)$$

where $EM^{QRD}(Q_0) = (c_0 - m_0)Q_0 + (c_1 - m_1)\sigma_\mu \psi[\xi_2(Q_0)]$, (7.17)

is the MEP function under the dual-ordering system without MOQ consideration.

$$ESC^{QRD-MOQ-I}(M_0)$$

$$= ER^{QRD-MOQ-I}(M_0) + EM^{QRD-MOQ-I}(M_0). \quad (7.18)$$

We first explore the effects brought about by MOQ on REP. As mentioned in Section 7.2, ER^{QRD} is a concave function in Q_0 and it attains its maximum at $\hat{Q}_0^{QRD}$. Then, for $M_0 > \hat{Q}_0^{QRD}$, we have $ER^{QRD-MOQ-I}(M_0) < ER^{QRD} *$, where

$ER^{QRD}* = ER^{QRD}(\hat{Q}_0^{QRD})$ is the maximum REP the retailer can attain without MOQ consideration. In other words, REP will always decrease when the Stage-0 MOQ is greater than the optimal Stage-0 order quantity without MOQ consideration. Thus when only the expected profit is considered, the retailer will not welcome MOQ imposition at Stage 0.

There is no definite answer whether the Stage-0 MOQ would bring about an increase in MEP as the later is also affected by the manufacturer's profit margins at the two stages. Proposition 7.2 summarizes some observations about the relationship between these values.

Proposition 7.2:

(a) If $M_0 < \overline{Q}_0^{QRD}$ and $(c_1 - m_1) \le (c_0 - m_0)$, then

$EM^{QRD-MOQ-I}(M_0) \ge EM^{QRD}(\hat{Q}_0^{QRD})$;

(b) If $M_0 \ge \overline{Q}_0^{QRD}$ and $(c_1 - m_1) \le (c_0 - m_0)$, then

$EM^{QRD-MOQ-I}(M_0) < EM^{QRD}(\hat{Q}_0^{QRD})$.

Proposition 7.2 provides us some important insights on how the manufacturer should offer the purchase cost to the retailer at the two stages in order to make herself better off under different ranges of Stage-0 MOQ. When

$\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$, as long as the increase in the unit purchase cost between the two stages (i.e. $c_1 - c_0$) is no larger than the increase in the production cost (i.e. $m_1 - m_0$), the manufacturer will experience an increase in her MEP in the presence of the Stage-0 MOQ. A possible explanation for this phenomenon is as follows. As discussed in Section 7.2, the retailer will order up to M_0 at Stage 0 in this case. By Proposition 7.1, the expected total order quantity will also increase in this case, which may result in any of the below two situations: either (1) the increase in the Stage-0 order quantity does not affect the retailer's order decision at Stage 1, resulting in an increase in the order quantities at both stages; or (2) the increase in the Stage-0 order quantity results in a decrease in Stage-1 quantity, yet the latter is out-weighted by the former. In either case, the manufacturer will earn more if her Stage-0 profit margin is larger than the Stage-1 one.

On the other hand, when $M_0 \geq \overline{Q}_0^{QRD}$, the retailer will postpone all his order placing to Stage 1. Thus if the manufacturer has a smaller Stage-1 profit margin than the Stage-0 one, she will expectedly earn less with the presence of MOQ. Nevertheless, the inverse may not be true as the increase in the manufacturer's Stage-1 expected profit may not be able to compensate for the loss due to the drop in the expected total order quantity.

Finally, it is even more difficult to observe the impacts of the Stage-0 MOQ on SCEP. For $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$, the reduction in REP has a counter-effect on the gain in EP; therefore the resultant impact on SCEP, which is the sum of REP and MEP, is unknown. Propositions 7.1 and 7.2, on the other hand, suggest that the manufacturer should avoid setting a too aggressive Stage-0 MOQ (i.e. $M_0 \geq \overline{Q}_0^{QRD}$) with her Stage-0 profit margin larger than the Stage-1 one. The supply chain will perform worse in this case owing to the reduction in the expected total order quantities, REP and MEP.

7.3. Optimal Values of the Stage-0 MOQ

In this section, we investigate the optimal values of the Stage-0 MOQ from the manufacturer and the retailer's perspectives.

Direct observation from (7.16) suggests that $EM^{QRD-MOQ-I}$ is not differentiable at $M_0 = \overline{Q}_0^{QRD}$; besides, the first derivative of the MEP function is given by:

$$dEM^{QRD-MOQ-I} / dM_0$$

$$= \begin{cases} 0 & \text{for} \quad 0 \leq M_0 \leq \hat{Q}_0^{QRD} \\ [(c_0 - m_0) - (c_1 - m_1)] + (c_1 - m_1)\Phi[\xi_2(M_0)] & \text{for} \quad \hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD} \\ 0 & \text{for} \quad M_0 \geq \overline{Q}_0^{QRD} \end{cases}, \quad (7.19)$$

From (7.19) we observe that $EM^{QRD-MOQ-I}$ is constant for $0 \leq M_0 \leq \hat{Q}_0^{QRD}$ and $M_0 \geq \overline{Q}_0^{QRD}$ whereas its trend depends on the profit margins at the two stages for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. Proposition 7.3 provides a way to determine the maximum MEP, which in turn can help determine the optimal Stage-0 MOQ from the manufacturer's perspective.

Proposition 7.3:

Under the QRD-MOQ-I system:

(a) For $(c_0 - m_0) \geq (c_1 - m_1)$, the MEP function is strictly increasing in M_0 for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. The manufacturer obtains a greater expected profit as M_0 is closer to $\overline{Q}_0^{QRD}$ and the greatest possible MEP is close to $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$.

(b) For $(c_0 - m_0) < (c_1 - m_1)$. Let $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ be the limit of $EM^{QRD-MOQ-I}(M_0)$ when M_0 approaches to the left-hand side of $\overline{Q}_0^{QRD}$.

(i) If $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ is the largest compared with $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$ and $EM^{QRD-MOQ-I}(0)$, then the manufacturer obtains a greater expected profit as M_0 is closer to $\overline{Q}_0^{QRD}$ and the greatest possible MEP is close to $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$.

(ii) If $\lim_{M_0 \to \bar{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ is not greater than either $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$ or $EM^{QRD-MOQ-I}(0)$, then the maximum value of $EM^{QRD-MOQ-I}$ is either $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$ or $EM^{QRD-MOQ-I}(0)$, whichever is greater.

Proposition 7.3 implies: (1) the optimal Stage-0 MOQ for the manufacturer, if exists, is not unique; and (2) determination of the optimal Stage-0 MOQ(s) for the manufacturer depends on the values of $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$, $EM^{QRD-MOQ-I}(0)$ and $\lim_{M_0 \to \bar{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ only. Specifically, if $\lim_{M_0 \to \bar{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ is the greatest amongst the three values, then it is always desirable for the manufacturer to assign M_0 as close to $\bar{Q}_0^{QRD}$ as possible to obtain a greater expected profit [which can be close $\lim_{M_0 \to \bar{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$]. On the other hand, if $\lim_{M_0 \to \bar{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ is not the largest (or not the only largest) amongst the three values, then it is always better for the manufacturer to choose a more "extreme" Stage-0 MOQ: either it should be no greater than $\hat{Q}_0^{QRD}$ [in case $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$ is the greatest], or it should exceed $\bar{Q}_0^{QRD}$ [in case $EM^{QRD-MOQ-I}(0)$ is the largest].

Next, Proposition 7.4 states the optimal value of the Stage-0 MOQ from the retailer's perspective, which analytically confirms the common belief that the retailer does not welcome MOQ imposition.

Proposition 7.4:

The optimal value of M_0 from the retailer's perspective is: $0 \le M_{0,R}^{QRD-MOQ-I} * \le \hat{Q}_0^{QRD}$.

7.4. Summary

In this chapter we investigated the impact of MOQ imposition on the QRD-MOQ-I system. We started by deriving the optimal ordering policies under this system. Then we explored the effects of the Stage-0 MOQ (M_0) on the expected total order quantities and the expected profits of various channel members.

We noticed that the REP function under QRD-MOQ-I system is non-increasing in M_0, which accounts for the retailer's reluctance to accept MOQ imposition. On the other hand, the effect of MOQ imposition on the manufacturer, and in turn the optimal choice of the MOQ(s), varies and it largely depends on the difference between her profit margins at the two stages. Taking its effects on both agents into consideration, it is therefore difficult to determine how MOQ imposition would affect the supply chain performance.

8. QR (Dual Ordering) with Stage-0 and Stage-1 MOQ (The QRD-MOQ-II System)

In this chapter we derive the retailer's optimal ordering policy under a quick response system in the form of dual order flexibility with both stages imposed with a MOQ constraint. In particular, we consider the case that the Stage-1 MOQ is non-zero (or more accurately: $M_1 > 0$). (The case with $M_1 = 0$ is in fact the same as the QRD-MOQ-I system, which was discussed in the previous chapter.)

8.1. Optimal Ordering Policy

As mentioned in the previous chapter, the optimal Stage-1 order quantity without Stage-1 MOQ consideration is given by (7.2), which is repeated below for easy reference:

$$Q_1^{QRD} * = \begin{cases} \hat{Q}_1^{QRD} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - Q_0 & if \quad \mu_1 > Q_0 - \sigma_1 \Phi^{-1}(s_1) \\ 0 & if \quad \mu_1 \le Q_0 - \sigma_1 \Phi^{-1}(s_1) \end{cases}$$

Now with the MOQ condition, the manufacturer will accept the order from the retailer only if the order quantity exceeds or equals the Stage-1 MOQ (i.e. $\hat{Q}_1^{QRD} \ge M_1 > 0$). This happens when $\mu_1 \ge M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1)$. Obviously, if $0 \le M_1 \le \sigma_1 \Phi^{-1}(s_1) - Q_0$, we always have $\mu_1 \ge 0 > M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1)$. In other words, the retailer's optimal order decision at Stage 1 remains unchanged under the presence of such a Stage-1 MOQ constraint. For the remaining of this chapter, unless otherwise specified, we only consider the case that $M_1 > \sigma_1 \Phi^{-1}(s_1) - Q_0$.

When $Q_0 - \sigma_1 \Phi^{-1}(s_1) < \mu_1 < M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1)$, the retailer's optimal ordering quantity is less than the Stage-1 MOQ. Thus the retailer has to decide whether he should order nothing at Stage 1 or increase his order quantity to M_1 to fulfill the MOQ condition. To do so, he should consider which gives him a higher expected profit.

For any given Q_0 and μ_1, the expected profit at Stage 1 is expressed as below:

$$ER_1(Q_1; Q_0, \mu_1)$$

$$= \int_{-\infty}^{Q_0+Q_1} r x_1 f(x_1) dx_1 + \int_{Q_0+Q_1}^{\infty} r(Q_0 + Q_1) f(x_1) dx_1 - \int_{-\infty}^{Q_0+Q_1} h[x_1 - (Q_0 + Q_1)] f(x_1) dx_1$$

$$- c_1 Q_1, \tag{8.1}$$

Then the expected profit at Stage 1 when ordering M_1 and that when ordering nothing can be written as follows, respectively:

$$ER_1(M_1; Q_0, \mu_1) = (r+h)\mu_1 - hQ_0 - (h + c_1) M_1$$

$$- (r+h)\sigma_1 \psi[(M_1 + Q_0 - \mu_1)/\sigma_1], \tag{8.2}$$

$$ER_1(0; Q_0, \mu_1) = (r+h)\mu_1 - hQ_0 - (r+h)\sigma_1 \psi[(Q_0 - \mu_1)/\sigma_1]. \tag{8.3}$$

Let $\eta(\mu_1; M_1, Q_0)$ be the difference between the two, i.e.

$$\eta(\mu_1; M_1, Q_0) = ER_1(M_1; Q_0, \mu_1) - ER_1(0; Q_0, \mu_1)$$

$$= (r+h)\sigma_1[\psi\left(\frac{Q_0 - \mu_1}{\sigma_1}\right) - \psi\left(\frac{M_1 + Q_0 - \mu_1}{\sigma_1}\right)] - (h + c_1)M_1. \qquad (8.4)$$

Lemma 8.1: (a) $\eta(\mu_1; M_1, Q_0)$ is an increasing function in μ_1;

(b) $\lim_{\mu_1 \to -\infty} \eta(\mu_1; M_1, Q_0) < 0$ and $\lim_{\mu_1 \to \infty} \eta(\mu_1; M_1, Q_0) > 0$.

Lemma 8.1 implies that $\eta(\mu_1; M_1, Q_0) = 0$ has a unique solution in μ_1. We denote this solution by $\hat{\mu}_1^{QRD}(Q_0, M_1)$,i.e.

$$\hat{\mu}_1^{QRD}(Q_0, M_1) = \arg_{\mu_1}\{\, \eta(\mu_1; M_1, Q_0) = 0 \,\}. \qquad (8.5)$$

From (8.5), the value of $\hat{\mu}_1^{QRD}(Q_0, M_1)$ depends on Q_0 and M_1 . For the ease of notation, from now on we simply denote the function by $\hat{\mu}_1^{QRD}$ without the corresponding arguments.

Lemma 8.2 states some of the properties of $\hat{\mu}_1^{QRD}$ that are useful for deriving the subsequent optimal ordering decision.

Lemma 8.2:

(a) $Q_0 - \sigma_1\Phi^{-1}(s_1) < \hat{\mu}_1^{QRD} < M_1 + Q_0 - \sigma_1\Phi^{-1}(s_1)$;

(b) $\hat{\mu}_1^{QRD} = Q_0 + g(M_1)$ for some function g that is purely in M_1.

Lemma 8.2(a) provides a guideline for the retailer to decide on his order quantity based on the market situation if the optimal Stage-1 order quantity is less than the Stage-1 MOQ. Specifically, if the retailer observes that $Q_0 - \sigma_1 \Phi^{-1}(s_1) < \mu_1 \le \hat{\mu}_1^{QRD}$, then his expected profit of ordering nothing at Stage 1 is larger than that of ordering M_1, i.e. $ER_1(M_1; Q_0, \mu_1) < ER_1(0; Q_0, \mu_1)$. In other words, he will order nothing at Stage 1. On the contrary, if $\hat{\mu}_1^{QRD} < \mu_1 < M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1)$, then ordering up to M_1 will be more profitable on average and thus the retailer's optimal order quantity in this case is M_1.

Theorem 8.1 summarizes the above discussion regarding the optimal ordering decision algorithm at Stage 1.

Theorem 8.1: At Stage 1 (given μ_1 and Q_0), the optimal order quantity at Stage 1 under the QRD-MOQ-II system is given by:

(a) For $0 \le M_1 \le \sigma_1 \Phi^{-1}(s_1) - Q_0$:

$$Q_1^{QRD-MOQ-II} * = Q_1^{QRD} * = \begin{cases} \hat{Q}_1^{QRD} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - Q_0 & if \quad \mu_1 > Q_0 - \sigma_1 \Phi^{-1}(s_1) \\ 0 & if \quad \mu_1 \le Q_0 - \sigma_1 \Phi^{-1}(s_1) \end{cases}$$

(b) For $M_1 > \sigma_1 \Phi^{-1}(s_1) - Q_0$:

$$Q_1^{QRD-MOQ-II}* = \begin{cases} \hat{Q}_1^{QRD} & if \quad \mu_1 \geq M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1) \\ M_1 & if \quad \hat{\mu}_1^{QRD} < \mu_1 < M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1) \\ 0 & if \quad \mu_1 \leq \hat{\mu}_1^{QRD} \end{cases}$$

(Q.E.D.)

We proceed to determine the ordering quantity at Stage 0. Again, for $0 \leq M_1 \leq \sigma_1 \Phi^{-1}(s_1) - Q_0$, the ordering decision algorithm is the same as in the QRD-MOQ-I system, which was discussed in the previous chapter. Now, we focus on the case $M_1 > \sigma_1 \Phi^{-1}(s_1) - Q_0$. For a given Q_0 and μ_1, the expected profit-to-go at Stage 1 is expressed in the following three cases:

(1) When $Q_1^{QRD-MOQ-II}* = 0$, the retailer's expected profit-to-go at Stage 1 is:

$$ER_1(0; Q_0, \mu_1) = (r+h)\mu_1 - hQ_0 - (r+h)\sigma_1 \Psi[(Q_0 - \mu_1)/\sigma_1], \tag{8.6}$$

(2) When $Q_1^{QRD-MOQ-II}* = M_1$, the retailer's expected profit-to-go at Stage 1 is:

$$ER_1(M_1; Q_0, \mu_1)$$

$$= (r+h)\mu_1 - hQ_0 - (h+c_1)M_1 - (r+h)\sigma_1 \Psi[(M_1 + Q_0 - \mu_1)/\sigma_1], \tag{8.7}$$

(3) When $Q_1^{QRD-MOQ-II}* = \hat{Q}_1^{QRD}$ (in this case $\hat{Q}_1^{QRD} \geq M_1$), the retailer's expected profit-to-go at Stage 1 is:

$$ER_1(\hat{Q}_1^{QRD}; Q_0, \mu_1)$$

$$= (r - c_1)\mu_1 + c_1 Q_0 - (h + c_1)\sigma_1 \Phi^{-1}(s_1) - (r+h)\sigma_1 \Psi[\Phi^{-1}(s_1)]. \tag{8.8}$$

Next, we perform dynamic programming back to Stage 0 with a known μ_0. Observe that the posterior mean μ_1 is a continuous random variable, the expected profit at Stage 0, $ER^{QRD-MOQ-II}(Q_0, M_1)$, is hence given by the following after taking expectations:

$$ER^{QRD-MOQ-II}(Q_0, M_1)$$

$$= \int_{-\infty}^{\hat{\mu}_1^{QRD}} ER_1(0; Q_0, \mu_1) f(\mu_1) d\mu_1 + \int_{\hat{\mu}_1^{QRD}}^{M_1+Q_0-\sigma_1\Phi^{-1}(s_1)} ER_1(M_1; Q_0, \mu_1) f(\mu_1) d\mu_1$$

$$+ \int_{M_1+Q_0-\sigma_1\Phi^{-1}(s_1)}^{\infty} ER_1(\hat{Q}_1^{QRD}; Q_0, \mu_1) f(\mu_1) d\mu_1 - c_0 Q_0 . \quad (8.9)$$

Correspondingly, the first derivative of $ER^{QRD-MOQ-II}(Q_0, M_1)$ w.r.t. Q_0 is given by:

$$\partial ER^{QRD-MOQ-II}(Q_0, M_1) / \partial Q_0$$

$$= (c_1 - c_0) + (r - c_1)\Phi[\xi_2(M_1, Q_0)]$$

$$-(r+h)\{\int_{-\infty}^{\rho_2(M_1, Q_0)} \Phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$+\int_{\rho_2(M_1, Q_0)}^{\xi_2(M_1, Q_0)} \Phi[(M_1 + Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz\} , \quad (8.10)$$

where $\xi_2(M_1, Q_0) = [M_1 + Q_0 - \sigma_1\Phi^{-1}(s_1) - \mu_0]/\sigma_\mu$, (8.11)

$$\rho_2(M_1, Q_0) = (\hat{\mu}_1^{QRD} - \mu_0)/\sigma_\mu . \quad (8.12)$$

A study on the first and the second derivatives of $ER^{QRD-MOQ-II}(Q_0, M_1)$ shows that the function may not be strictly concave in Q_0. Alternatively we explore some properties of the function that are useful for determining the optimal Stage-0 order quantity under the QRD-MOQ-II system. We state them in Lemmas 8.3 -8.5 below .

Lemma 8.3:

(a) $\lim_{Q_0 \to -\infty} \{\partial ER^{QRD-MOQ-II} / \partial Q_0\} > 0$ and $\lim_{Q_0 \to \infty} \{\partial ER^{QRD-MOQ-II} / \partial Q_0\} < 0$;

(b) There exists at least one value of Q_0 such that $\partial ER^{QRD-MOQ-II} / \partial Q_0 = 0$;

(c) $ER^{QRD-MOQ-II}$ is strictly concave for $Q_0 > \overline{Q}_0 = M_1 + \mu_0 + \sigma_1 \Phi^{-1}(s_1)$.

Lemma 8.4: $ER^{QRD-MOQ-II}$ is strictly decreasing for a sufficiently large Q_0.

Lemma 8.5: There exists at least one local maximum for $ER^{QRD-MOQ-II}$.

Lemmas 8.4 and 8.5 ensure that $ER^{QRD-MOQ-II}$ has a finite set of positive local maximum(s). Specifically, we learn that the function has at most one local maximum for $Q_0 \geq \overline{Q}_0$. To determine the other positive maximums, we can narrow down the range of Q_0 for solving the first-order condition, namely between 0 and $\overline{Q}_0$.

Consequently, we can determine the optimal Stage-0 order quantity under the QRD-MOQ-II system according to the following rationale by checking whether there is any local maximum attained at some quantity that is larger than the Stage-0 MOQ.

Case 1: None of the local maximums are attained at a quantity that is larger than M_0

By Lemma 8.3, we know that $ER^{QRD-MOQ-II}$ is strictly decreasing for $Q_0 \geq M_0$ and that ordering at M_0 provides the greatest REP amongst all the quantities that satisfy the Stage-0 MOQ requirement. In this case, the retailer is left with two choices: order up to M_0 or order nothing at Stage 0. To make the decision, the retailer needs to compare between $ER^{QRD-MOQ-II}(M_0)$ and $ER^{QRD-MOQ-II}(0)$. If $ER^{QRD-MOQ-II}(M_0) > ER^{QRD-MOQ-II}(0)$, then the retailer will be more profitable by ordering at M_0; otherwise, if $ER^{QRD-MOQ-II}(M_0) \leq ER^{QRD-MOQ-II}(0)$, then he will be better off by ordering nothing at Stage 0.

Case 2: There exists at least one local maximum that is attained at a quantity greater than M_0.

Let $\hat{Q}_{0,\max}^{QRD-MOQ-II}$ be the quantity at which the greatest local maximum in the range $Q_0 \geq M_0$ is attained. Since $\hat{Q}_{0,\max}^{QRD-MOQ-II} \geq M_0$, it satisfies the MOQ requirement. Then the retailer needs to compare amongst $ER^{QRD-MOQ-II}(\hat{Q}_{0,\max}^{QRD-MOQ-II})$, $ER^{QRD-MOQ-II}(M_0)$ and $ER^{QRD-MOQ-II}(0)$:

(a) If $ER^{QRD-MOQ-II}(\hat{Q}_{0,\max}^{QRD-MOQ-II}) > \max\{ER^{QRD-MOQ-II}(M_0), ER^{QRD-MOQ-II}(0)\}$, then the retailer will be more profitable by ordering at $\hat{Q}_{0,\max}^{QRD-MOQ-II}$;

(b) If $ER^{QRD-MOQ-II}(M_0) \geq ER^{QRD-MOQ-II}(\hat{Q}_{0,\max}^{QRD-MOQ-II})$ and $ER^{QRD-MOQ-II}(M_0) > ER^{QRD-MOQ-II}(0)$, then he will be better off by ordering M_0 at Stage 0; or

(c) If $ER^{QRD-MOQ-II}(0) \geq \max\{ER^{QRD-MOQ-II}(\hat{Q}_{0,\max}^{QRD-MOQ-II}), ER^{QRD-MOQ-II}(M_0)\}$, then he will be better off by ordering nothing at Stage 0.

We present the rationale of finding the optimal quantities at Stage 0 and Stage 1 in Algorithm 8.1 below.

Algorithm 8.1: The optimal dual ordering decision policy for the retailer with MOQ constraints at both stages is given by the following algorithm.

At Stage 0:

(1) Obtain the following data:

a) prior demand distribution parameters (i.e. μ_0, d_0, δ);

b) cost-revenue parameters at the two stages (i.e. r, c_0, c_1, h); and

c) MOQs required at the two stages (i.e. M_0, M_1).

(2) Solve the system of simultaneous equations (8.5) and (8.10) for $\hat{Q}_0^{QRD-MOQ-II}$ and $\hat{\mu}_1^{QRD}$.

(3) Define the set **S** that contains all the local maximum(s) that are greater than M_0, i.e.

$$\mathbf{S} = \{ \hat{Q}_0^{QRD-MOQ-II} > M_0 : \partial ER^{QRD-MOQ-II} / \partial Q_0 \Big|_{\hat{Q}_0} = 0 ; \partial^2 ER^{QRD-MOQ-II} / \partial Q_0{}^2 \Big|_{\hat{Q}_0} < 0 \}.$$

(4) Check if **S** is an empty set.

a) If yes, go to Step (6);

b) If **S** is not an empty set, then let:

$\hat{Q}_{0,\max}^{QRD-MOQ-II} = \underset{\hat{Q}_0^{QRD-MOQ-II} \in \mathbf{S}}{\arg\max} \{ ER^{QRD-MOQ-II} (\hat{Q}_0^{QRD-MOQ-II}) \}$ and go to Step (5).

(5) Compare the values of $ER^{QRD-MOQ-II} (\hat{Q}_{0,\max}^{QRD-MOQ-II})$, $ER^{QRD-MOQ-II} (M_0)$ and $ER^{QRD-MOQ-II} (0)$.

a) If $ER^{QRD-MOQ-II} (\hat{Q}_{0,\max}^{QRD-MOQ-II}) > \max\{ ER^{QRD-MOQ-II} (M_0), ER^{QRD-MOQ-II} (0) \}$, then, $Q_0^{QRD-MOQ-II} * = \hat{Q}_{0,\max}^{QRD-MOQ-II}$ and go to Step (7); or

b) If $ER^{QRD-MOQ-II} (M_0) \geq ER^{QRD-MOQ-II} (\hat{Q}_{0,\max}^{QRD-MOQ-II})$ and $ER^{QRD-MOQ-II} (M_0) > ER^{QRD-MOQ-II} (0)$, then $Q_0^{QRD-MOQ-II} * = M_0$ and go to Step (7); or

c) If $ER^{QRD-MOQ-II} (0) \geq \max\{ ER^{QRD-MOQ-II} (\hat{Q}_{0,\max}^{QRD-MOQ-II}), ER^{QRD-MOQ-II} (M_0) \}$, then $Q_0^{QRD-MOQ-II} * = 0$ and go to Step (7).

(6) Compare the values of $ER^{QRD-MOQ-II} (M_0)$ and $ER^{QRD-MOQ-II} (0)$.

a) If $ER^{QRD-MOQ-II}(M_0) > ER^{QRD-MOQ-II}(0)$, then $Q_0^{QRD-MOQ-II}* = M_0$ and go to Step (7); or

b) If $ER^{QRD-MOQ-II}(M_0) \leq ER^{QRD-MOQ-II}(0)$, then $Q_0^{QRD-MOQ-II}* = 0$ and go to Step (7).

(7) For the given Q_0*, calculate $\hat{\mu}_1^{QRD}* = \hat{\mu}_1^{QRD}(Q_0*, M_1)$. Proceed to algorithm at Stage 1.

Between Stage 0 and Stage 1:

Make a market observation, $\hat{x}_0$.

At Stage 1:

(1) Input sample sales data $\hat{x}_0$.

(2) Update parameters based on the observed market information to obtain the posterior demand distribution (i.e. μ_1, d_1).

(3) Check if $M_1 > \sigma_1 \Phi^{-1}(s_1) - Q_0^{QRD-MOQ-II}*$.

a) If $0 \leq M_1 \leq \sigma_1 \Phi^{-1}(s_1) - Q_0^{QRD-MOQ-II}*$, go to Step (4);

b) If $M_1 > \sigma_1 \Phi^{-1}(s_1) - Q_0^{QRD-MOQ-II}*$, go to Step (5).

(4) According to the updated μ_1, determine the Stage-1 order quantity from one of the following cases:

a) If $\mu_1 \le Q_0^{QRD-MOQ-II}* - \sigma_1 \Phi^{-1}(s_1)$ then $Q_1^{QRD-MOQ-II}* = 0$; or

b) If $\mu_1 > Q_0^{QRD-MOQ-II}* - \sigma_1 \Phi^{-1}(s_1)$, then

$Q_1^{QRD-MOQ-II}* = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - Q_0^{QRD-MOQ-II}*$.

(5) According to the updated μ_1, determine the Stage-1 order quantity from one of the following cases:

a) If $\mu_1 \le \hat{\mu}_1^{QRD}*$, then $Q_1^{QRD-MOQ-II}* = 0$; or

b) If $\hat{\mu}_1^{QRD}* < \mu_1 < M_1 + Q_0^{QRD-MOQ-II}* - \sigma_1 \Phi^{-1}(s_1)$,

then $Q_1^{QD-MOQ-II}* = M_1$; or

c) If $\mu_1 \ge M_1 + Q_0^{QRD-MOQ-II}* - \sigma_1 \Phi^{-1}(s_1)$, then

$Q_1^{QRD-MOQ-II}* = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - Q_0^{QRD-MOQ-II}*$. (Q.E.D.)

9. Numerical Analysis

Having developed the analytical derivation, we conduct numerical analysis to verify our analytical findings in the previous chapters and further explore the impacts of the various QR-MOQ systems. We first base on some real industry data to estimate the parameters to be employed in our numerical analysis. Then with the help of the software Mathematica and Microsoft Excel, we construct the graphs of various expected profit functions to have a further idea about their properties, as well as deriving the optimal order quantities under different systems and parameters for further analysis.

9.1. Parameter settings

The parameters we employed for the numerical studies were based on the real data of a US ladies' wear brand M in Hong Kong. 19 different styles of dressy blouse were available for the 2005 Spring/Summer Collection in the Hong Kong shop. The purchase costs of these styles ranged from USD10.6 to USD 35.8 (average USD15.54) whilst the retail prices from HKD 490 to HKD 1,630 (average

HKD736.67), resulting in an average mark-up of 6.12. The mean and the variance of the seasonal sales quantity for these 19 styles are 38.95 and 128.31, respectively.

There is no information about the corresponding production cost for the manufacturer. According to the personal interview with the Senior Merchandiser of PG Limited (details stated in Chapter 3), the manufacturer normally would aim at ~15% profit margin when preparing quotation. We take it as a benchmark to calculate back the average production cost from the average purchase cost.

To investigate the performance of the various QR-MOQ systems under different revenue-cost parameters, we consider different values for the following parameters:

(1) Unit retail price: $r = \{75, 37.5\}$;

(2) Unit production cost ratios [i.e. $(m_1 - m_0)/m_0$]: $MR = \{5\%, 10\%, 15\%\}$; and

(3) Unit purchase cost ratios [i.e. $(c_1 - c_0)/c_0$]: $CR = \{5\%, 10\%, 15\%\}$.

For simplicity, we set the reservation retailer expected profit for the QRS-MOQ system as zero, i.e. $J_R = 0$.

Table 9.1 summarizes the parameters adopted for this numerical study.

9.2. Expected profits of channel members under different QR-MOQ systems

9.2.1 The QRS-MOQ System

Figs. 9.2.1 and 9.2.2(a)-(b) depict the REP and the MEP functions under the QRS-MOQ system for different sets of cost-revenue parameters, respectively. As shown in Fig. 9.2.1, the REP decreases as M_1 (the Stage-1 MOQ) increases until it reaches $\overline{Q}_0^{QRS}$ over which the retailer is not willing to place any order and the REP drops to zero. Apparently variation in MR and CR does not have great effects on the form of the REP. The function is more sensitive to the change in r; apart from a significant drop in the expected profit, the MOQ threshold that the retailer is willing to accept (i.e. $\overline{Q}_0^{QRS}$) is smaller with a smaller r. It is natural as the retailer will be more conscious about not holding too much inventory as the possible profit margin is smaller (with a smaller r).

As discussed in Chapter 6, apparently the MEP function under the QRS-MOQ system does not have much neat analytic properties. From Figs. 9.2.2(a) and (b), one may suspect the smooth appearance of the function would suggest it to be concave. However, we found that its first derivative function exhibits some wave-form look, which indicate that the function is not concave. Besides, the changes in MR and CR also have significant impacts on the MEP function. Intuitively, MEP is larger with a smaller MR and a larger CR as the manufacturer enjoys a greater profit margin in either case. There is also a great difference in the MEP for different r. As a larger retail profit margin will induce the retailer to order more, in turn the manufacturer can also enjoy a greater profit.

9.2.2 The QRD-MOQ-I system

As discussed in Chapter 7, both the REP and MEP function under the QRD-MOQ-I system are piecewise functions. They are both horizontal when $0 \le M_0 \le \hat{Q}_0^{QRD}$ or $M_0 \ge \overline{Q}_0^{QRD}$. As shown in Fig.9.2.3, REP is decreasing for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$; a larger CR implies that this range of MOQ is larger and the difference in the REP between the cases of ordering at $\hat{Q}_0^{QRD}$ and ordering nothing at Stage 0 is also greater.

As depicted in Figs. 9.2.4(a) and (b), the MEP function is increasing in the range of $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. The difference in the MEP when retailer orders $\hat{Q}_0^{QRD}$ and that when he orders nothing depends on the MR and CR. Whereas we proved in Proposition 7.2 that when CR is smaller than MR, it is less profitable for the manufacturer if she sets a more aggressive MOQ, Figs 9.2.4(a) and (b) suggest that the inverse of Proposition 7.2 may also be true. Specifically, when CR is greater than MR, then it is more profitable for the manufacturer to set a more aggressive M_0 to push the retailer to place all his order quantities at Stage 1 so that she can enjoy a greater profit.

9.2.3 The QRD-MOQ-II system

Taking the MOQs at both stages into consideration, the REP function under the QRD-MOQ-II system is complicated and can vary a great deal with different cost-revenue parameters. Fig. 9.2.5 depicts some examples of the various forms that this REP function can take. Specifically we consider the case when $M_0 = 0$ and $M_1 = \alpha M$, where $M = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ and $0.1 \le \alpha \le 1$. Then by varying the value of α, we investigate how the REP function exhibits with different values of M_1. From Fig. 9.2.5, we observe that M_1 has significant impact on the form of the function. Specifically, the function tends to be more concave with a small value of M_1(or α). As M_1 increases, the REP function tends to take a more wave-form look and the retailer may accept a higher M_1 as it may provide him a greater profit in some cases. Anyhow, the function is decreasing for sufficiently large M_1. This suggests that the retailer would still reject an aggressive Stage-1 MOQ.

Correspondingly, the MEP function also changes significantly with different values of M_1. Fig. 9.2.6 suggests that the function appears to be convex for small M_1. As M_1 increases, the function may take a “S”-shape form.

We further explore how the relationship between M_0 and M_1 affects the REP and MEP. Specifically, we consider the case that the sum of the MOQs the manufacturer requires at the two stages is fixed, i.e. $M_0 + M_1 = M$, with $M_1 = \alpha M$ and $M_0 = (1-\alpha)M$, where $M = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ is constant for a fixed MR, and $0.1 \le \alpha \le 1$. Figs. 9.2.7(a), (b) and Fig. 9.2.8(a), (b) depict the REP and MEP functions under different values of α , MR and CR.

In general, we observe from Figs 9.2.8(a) and (b) that the REP is larger with a small M_1 (correspondingly, a small α). As M_1 increases, the REP decreases in general. On the other hand, under a number of values of the MR and CR, it appears that the REP function consists of two segments, with the cutting point roughly corresponds to the case that M_1 is close to M_0 (or correspondingly, α equals 0.4 or 0.5). However, when the CR is high enough (e.g. 15% in our numerical studies), the REP appears to follow a smoother trend with the change in the weight between M_1 and M_0.

A more complex situation is observed for the impact on the MEP regarding the change in proportion between M_1 and M_0 , together with the change in cost-revenue parameters [see Fig. 9.2.8(a) and (b)]. Apparently if the MR and CR are the same or CR is sufficiently large, the MEP is more stable to the different mix of M_1 and M_0. However, when CR=10%, a larger mix for M_1 may have impact on the MEP, depending on the corresponding value of MR. A possible reason is that with this value of CR, it is more profitable for the retailer to postpone all his ordering to Stage 1 to fulfill the larger Stage-1 MOQ. When MR is smaller than CR, the manufacturer is more profitable with all production happens at Stage 1; by contrast, when MR is smaller than CR, her MEP would decrease owing to the smaller profit for Stage-1 production.

9.3. Channel Coordination

9.3.1 SCEP maximization

Figs. 9.3.1 (a, b) – 9.3.3 (a, b) depict the SCEP function under the various QR-MOQ systems with comparison to the SCEP under their corresponding centralized systems. Although under various sets of cost-revenue parameters, the SCEP of these systems can be very close to their corresponding centralized system benchmarks when the MOQ is very small (as reflected by the closeness of the two lines in these figures), all these functions lie below the corresponding centralized SCEP benchmarks. In order words, our numerical studies suggest that the various QR-MOQ systems under study cannot achieve SCEP maximization.

On the other hand, except for the QRD-MOQ-I system, as the MOQ increases, the SCEP functions under the various systems are no greater than the values of that without MOQ. This suggests that in general MOQ imposition would deteriorate the supply chain efficiency. Besides, we also observe that SCEP functions for all the three systems are non-increasing when the MOQ(s) are aggressively large. This implies that the manufacturer should not impose a too aggressive MOQ for the sake of the whole supply chain.

Interestingly, we observe that under certain revenue-cost parameter settings and with a moderate value of the Stage-0 MOQ ($\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$), the SCEP under the QRD-MOQ-I system is greater than that without MOQ [see Figs. 9.3.2(a) and (b)]. A closer look at these figures indicates that such increase occurs when the value of MR is smaller than that of CR, i.e. the manufacturer has a smaller Stage-1 profit margin than her Stage-0 one. A possible reason to this counter-intuitive phenomenon is as follows. As shown in Proposition 7.2, the manufacturer enjoys a gain in MEP compared with that in the "No-MOQ" case when the $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$ and $(c_1 - m_1) \le (c_0 - m_0)$. Such increase in MEP may outweigh the decrease in REP of the retailer, resulting in an overall increase in the SCEP of the system. Therefore, by properly setting of the Stage-0 MOQ and Stage-1 purchase cost, the manufacturer can enhance the supply chain efficiency under the QRD-MOQ-I system.

9.3.2 Pareto Improvement

Despite their failure to achieve SCEP maximization, we are still interested to explore whether the various QR-MOQ systems can achieve Pareto improvement under the decentralized situation. We summarize our findings in Table 9.3.1. In general, Pareto improvement is feasible under the QRD-MOQ-II systems for all scenarios we have explored whereas for the QRS-MOQ and QRD-MOQ-I systems, there may be some cases that we fail to achieve Pareto improvement with MOQ imposition.

For the QRD-MOQ-II system, under all sets of cost-revenue parameters employed in this numerical analysis, we can find a range of M_0 that can make both channel members better off with different values of M_1 [see Tables 9.3.4(a) and (b)]. For the QRD-MOQ-I system, the retailer can always be made better off with a suitable choice of M_0. By contrast, when CR is too small, even MOQ imposition cannot help the manufacturer to be better off [see Tables 9.3.3(a) and (b)]. A slightly different situation happens in the QRS-MOQ system. The retailer and the manufacturer can always find a range of M_1 that can make their own selves better off under all scenarios we have studied; yet the two ranges may not always overlap (it happens most frequently when MR is large). As a result Pareto improvement is not always feasible [see Tables 9.3.2(a) and (b)].

9.4. Effect of Demand Uncertainty

One of the main contributions of QR to its adopters is the reduction in demand uncertainty owing to the possibility of information updating. In this section we explore whether different levels of the prior demand uncertainty have impacts on the various QR-MOQ systems. In this numerical study, we consider three different levels for d_0, the prior demand mean uncertainty, namely: $d_0 = \{90, 95, 100\}$. Correspondingly, the three values represent approximately 4%, 2% and 0% of reduction in the demand mean standard deviation, respectively.

Specifically, under each set of cost-revenue parameters, we determined the optimal Stage-0 order quantity and/or other variable that are need for calculating the Stage-1 order quantity. Since Stage-1 ordering decision depends on the value of μ_1, which is realized only after having the observed data $\hat{x}_0$, we simulated 1000 runs of μ_1 from the probability distribution $N(\mu_0, \sigma_\mu)$ and the corresponding demand x_1 from the probability distribution $N(\mu_1, \sigma_1)$. The 95% confidence intervals for the simulated μ_1 and x_1 are $35.41 \pm 1.96 * 9.11$, and $35.20 \pm 1.96 * 11.22$, respectively. For each pair of $\{\mu_1, x_1\}$ we determine the corresponding Stage-1 optimal order quantity under the various QR-MOQ systems, then calculate the corresponding profits of the channel members and the whole supply chain. We take $M_1 = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ for the QRS-MOQ system and $M_0 = \hat{Q}_0^{QRD}$ for the QRD-MOQ-I system. For the QRD-MOQ-II system, we employ the same set-up of M_0 and M_1 as in the previous sections, i.e. $M_0 + M_1 = M$, with $M_1 = 0.2M$ and

$M_0 = 0.8M$, where $M = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ [As a remark, we choose $\alpha = 0.2$ as it provides the maximum SCEP in most cases according to our numerical result].

Basing on these 1000 simulated demands, we calculated the profits of the retailer, the manufacturer, and the supply chain, respectively as follows:

$$PR = r\min\{ Q_0 * + Q_1 *, x_1 \} - h\max\{ Q_0 * + Q_1 * - x_1 , 0 \} - c_0 Q_0 * - c_1 Q_1 * , \quad (9.1)$$

$$PM = (c_0 - m_0) Q_0 * + (c_1 - m_1) * Q_1 * , \quad (9.2)$$

$$PSC = PR + PM . \quad (9.3)$$

Afterwards, we calculate the mean and the standard deviation of these measures under these 1000 instances.

Tables 9.4.2, 9.4.3 and 9.4.4 present the average retailer profit, average manufacturer profit and average supply chain profit under the various systems at different levels of c based on our simulation experiment, respectively. Apparently, the change in d_0 induces little change to these values, especially for $r = 75$.

9.5. Mean-risk aspects of QR-MOQ systems

Finally, we compare the performance of the various QR-MOQ systems from the mean-risk perspective. Choi and Chow (2008) point out that QR is beneficial to the retailer whilst the manufacturer may be worse off in terms of both expected profit and variance of profit. Here we explore numerically whether any of the QR-MOQ systems can make both channel members better off from the mean-risk perspective.

The same set of 1000 simulated demand data employed in Section 9.6 were used to calculate the profits of the two channel members and the supply chain and the results are summarized in Tables 9.5.1 (a, b), 9.5.2 (a, b) and 9.5.3 (a, b), respectively.

For the retailer, our numerical findings suggest that the QRD and QRD-MOQ-I system can provide him a greater profit on average whereas under the QRS system his variation in profit would be the smallest [see Tables 9.5.1(a) and (b)]. From the mean-risk perspective, therefore, if the retailer is very risk-averse (conservative), he may prefer the QRS system as it yields the lowest variance of profit, even though his corresponding profit is not the greatest. On the other hand, QRD-MOQ-I system is a desirable approach for the retailer if he is risk-averse with a higher risk acceptance threshold. This is because the system can increase his average profit whilst reduce the standard deviation of profit comparing with the old system. By contrast, the QRS-MOQ system is less desirable to the retailer as it may not necessarily provide a greater profit than the old system whilst the variance of profit is larger.

The manufacturer may hold a different opinion from the retailer's. If she is highly risk-averse, then the manufacturer would prefer the old system under which her variance of profit is zero. On the other hand, if the manufacturer is willing to bear a certain amount of risk, then amongst the various systems under study, the QRS-MOQ system provides the smallest variance of profit whereas it provides the greatest profit in many scenarios [see Tables 9.5.2(a) and (b)].

From the perspective of the whole supply chain, there is no strict preference on a particular system as none has dominating advantages in both the expected profit and the variance of profit [see Tables 9.5.3(a) and (b)]. Therefore the final choice of the system depends on the decision makers' attitude between profit and risk. One may suggest the adoption of the QRS system as it provides a greater average profit and a smaller variance of profit when compared with the old system. On the other hand, for one who can accept a certain level of risk, the QRD-MOQ-I system may be a suitable choice as it provides a greater average profit than the QRS system whereas the variance of profit is comparable to that in the old system.

9.6. Summary

In this chapter we conducted numerical analysis to explore numerically the impacts of MOQ imposition on the performance of the channel members and the supply chain. We studied graphically some of the properties of the REP and the MEP function in the various systems. Then, we addressed the issue of channel coordination in the various QR-systems and explored whether the level of prior demand mean uncertainty has any impact on performance of these systems. Finally we compared the various systems from the mean-risk perspective and discussed the preference of these systems under different risk attitudes.

10. Quick Response with Dynamic MOQ Policy

Based on the speculation that the MOQ agreed in Stage 0 may hinder the full use of the updated market information brought about by QR adoption, we propose the use of a “dynamic MOQ policy” (DMP) in which the specific MOQ value in the supply contract depends on the updated information, i.e. μ_1. This contract is an innovative one. We believe that it can be implemented in practice for the case when the manufacturer and the retailer are working closely together with information sharing measures such as forecast sharing, and the popular collaborative planning, forecasting and replenishment (CPFR) scheme.

In the following, we present how the use of DMP can achieve channel coordination in a QR system. Specifically, we consider a (postponed) single-ordering QR system in Section 10.2 and prove how adoption of DMP can achieve channel coordination. In Section 10.3, we investigate the use of DMP in a dual-ordering QR system and derive the necessary and sufficient conditions for channel coordination. Afterwards we conduct numerical analysis to verify the above findings in Section 10.4 and summarize the results in Section 10.5.

10.1. Quick Response (Single Ordering) with Dynamic MOQ Policy (QRS-DMP)

A natural choice for the dynamic MOQ that depends on the updated information, μ_1, and is possible for achieving SCEP maximization would be:

$$\tilde{M}_1^{QRS} = \mu_1 + \sigma_1 \Phi^{-1}(s_1^{sc}). \tag{10.1}$$

In fact, Proposition 10.1 shows that by imposing an MOQ of a size of $\tilde{M}_1^{QRS}$, the supply chain expected profit (SCEP) is equal to the centralized benchmark.

Proposition 10.1:

The SCEP under QRS-DMP is the same as that under the centralized system.

It remains to show that QRS-DMP can also lead to Pareto improvement for both the retailer and the manufacturer. Before doing so, define:

$$c_1^M = m_1 + (c_0 - m_0)[\mu_0 + \sigma_0 \Phi^{-1}(s_0)]/[\mu_0 + \sigma_0 \Phi^{-1}(s_1^{sc})], \tag{10.2}$$

$$c_1^R = \{ c_0[\mu_0 + \sigma_0 \Phi^{-1}(s_0)] + h[\sigma_0 \Phi^{-1}(s_0) - \sigma_1 \Phi^{-1}(s_1^{sc})]$$

$$+ (r+h)\{\sigma_0 \psi[\Phi^{-1}(s_0)] - \sigma_1 \psi[\Phi^{-1}(s_1^{sc})]\}\}/[\mu_0 + \sigma_1 \Phi^{-1}(s_1^{sc})]. \tag{10.3}$$

Then, Proposition 10.2 states the conditions for Pareto improvement under QRS-DMP.

Proposition 10.2:

With QRS-DMP:

(a) the manufacturer is not worse off under QR with MOQ if and only if $c_1 \geq c_1^M$ *;*

(b) the retailer is not worse off under QR with MOQ if and only if $c_1 \leq c_1^R$.

Proposition 10.2 provides the guideline on the situation in which the manufacturer and the retailer will not be worse off. This, together with Proposition 10.1, can help to derive how QRS-DMP can achieve coordination. Define:

$$g(m_1) = (m_1 - m_0)\mu_0 + (h + m_1)\sigma_1\Phi^{-1}(s_1^{sc}) - (h + m_0)\sigma_0\Phi^{-1}(s_0)$$

$$+ (r + h)\{\sigma_1\psi[\Phi^{-1}(s_1^{sc})] - \sigma_0\psi[\Phi^{-1}(s_0)]\}\,. \qquad (10.4)$$

Corollary 10.1 gives an analytically sufficient condition for employing QRS-DMP to coordinate the supply chain.

Corollary 10.1:

Channel coordination can be achieved by QRS-DMP with $\tilde{M}_1^{QRS}(\mu_1) = \mu_1 + \sigma_1\Phi^{-1}(s_1^{sc})$ *for any* $c_1^M < c_1 < c_1^R$ *if and only if* $m_1 \in \{m_1 : g(m_1) < 0\}$.

10.2. Quick Response (Dual Ordering) with Dynamic MOQ and Subsidy (QRD-DMPS)

10.2.1 Development of QRD-DMPS

Recall that the optimal Stage-1 and Stage-0 order quantities under the centralized QRD system are given by the following, respectively:

$$Q_{1,\mathrm{SC}}^{QRD}* = \begin{cases} \hat{Q}_{1,\mathrm{SC}}^{\mathrm{QRD}} = \mu_1 + \sigma_1 \Phi^{-1}(s_1^{SC}) - Q_0 & if \;\; \mu_1 \geq Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC}) \\ 0 & if \;\; \mu_1 < Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC}) \end{cases}, \tag{10.5}$$

$$Q_{0,SC}^{QRD}* = \max\{0, \hat{Q}_{0,SC}^{QRD}\}, \tag{10.6}$$

where, as mentioned in the previous chapter, $\hat{Q}_{0,SC}^{QRD}$ satisfies the first-order condition: $\partial ECSC^{QRD} / \partial Q_0 \Big|_{Q_{0,SC}^{QRD}*} = 0$, with

$$\partial ECSC^{QRD} / \partial Q_0 = (m_1 - m_0) + (r - m_1)\Phi[\xi_3^{SC}(Q_0)]$$

$$- (r+h)\int_{-\infty}^{\xi_3^{SC}(Q_0)} \Phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz\,. \tag{10.7}$$

$$\xi_3^{SC}(Q_0) = [\,Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC}) - \mu_0\,]/\sigma_\mu\,. \tag{10.8}$$

Similarly, the optimal Stage-1 and Stage-0 order quantities for the retailer under the decentralized system are, respectively:

$$Q_1^{QRD}* = \begin{cases} \hat{Q}_1^{\mathrm{QRD}} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) - Q_0 & if \;\; \mu_1 \geq Q_0 - \sigma_1 \Phi^{-1}(s_1) \\ 0 & if \;\; \mu_1 < Q_0 - \sigma_1 \Phi^{-1}(s_1) \end{cases}. \tag{10.9}$$

$$Q_{0,}^{QRD}* = \max\{0, \hat{Q}_0^{QRD}\}, \tag{10.10}$$

where $\hat{Q}_0^{QRD}$ satisfies the first-order condition: $\partial ER^{QRD} / \partial Q_0 \Big|_{\hat{Q}_0^{QRD}} = 0$, with

$$\partial ER^{QRD} / \partial Q_0 = \quad (c_1 - c_0) + (r - c_1)\Phi[\xi_3(Q_0)]$$

$$- (r+h)\int_{-\infty}^{\xi_3(Q_0)} \Phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz \,. \qquad (10.11)$$

$$\xi_3(Q_0) = [\, Q_0 - \sigma_1 \Phi^{-1}(s_1) - \mu_0] / \sigma_\mu \,. \qquad (10.12)$$

In case that either $Q_{0,SC}^{QRD}*$ or $Q_0^{QRD}*$ is zero, the system is reduced to a single-ordering one. From the discussion in Section 10.2, we can adopt QRS-DMP to achieve channel coordination. According to (10.9), when $Q_0 \le \sigma_1 \Phi^{-1}(s_1)$, $\mu_1 \le 0$, which does not happen in reality. As a result, we have $Q_{1,SC}^{QRD}* = 0$ and $Q_1^{QRD}* = 0$ in this case. In the remaining of this section, we will focus on the cases that $Q_{0,SC}^{QRD}* > 0$ and $Q_0^{QRD}* > \sigma_1 \Phi^{-1}(s_1)$.

Back to our investigation, if we can have the retailer order as exactly as (10.5) and (10.6) at Stage 1 and Stage 0, respectively, then the corresponding SCEP will be maximum and equal to that under the centralized system. Thus a natural choice of the dynamic MOQ at Stage 1 would be:

$$\tilde{M}_1^{QRD}(\mu_1, Q_0) = \hat{Q}_{1,SC}^{QRD} = \mu_1 + \sigma_1 \Phi^{-1}(s_1^{SC}) - Q_0 \text{ [4]}. \qquad (10.13)$$

However, from the perspective of the retailer, having $\tilde{M}_1^{QRD}$ does not necessarily lead him to order as (10.5). Firstly, by direct observation, for

[4] For the ease of presentation, we simply denote the function without its arguments in the remaining of the chapter.

$Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC}) < \mu_1 < Q_0 - \sigma_1 \Phi^{-1}(s_1)$, it is the best for the retailer not to order anything; but the optimal quantity for the supply chain for this range of μ_1 should be $\tilde{M}_1^{QRD}(\mu_1, Q_0) = \hat{Q}_{1,SC}^{QRD}$. Secondly, for $\mu_1 \geq Q_0 - \sigma_1 \Phi^{-1}(s_1)$, $\hat{Q}_1^{QRD}$ is always smaller than $\hat{Q}_{1,SC}^{QRD}$ but the retailer will only order up to $\tilde{M}_1^{QRD}$ if its corresponding expected profit exceeds that when he gives up ordering at Stage 1. Let

$$\tilde{\eta}(\mu_1, Q_0) = ER_1^{QRD}(\tilde{M}_1^{QRD}; Q_0, \mu_1) - ER_1^{QRD}(0; Q_0, \mu_1), \tag{10.14}$$

$$\hat{\mu}_1^{QRD-DMP}(Q_0) = \underset{\mu_1 > Q_0 - \sigma_1 \Phi^{-1}(s_1)}{\arg} \left\{ \tilde{\eta}(\mu_1, Q_0) = 0 \right\}, \tag{10.15}$$

where $ER_1^{QRD}(Q_1; Q_0\, \mu_1)$ is the retailer expected profit at Stage 1 when ordering Q_1 given the Stage-0 order quantity is Q_0 and the updated information is μ_1, which is expressed as below:

$$\begin{aligned} ER_1^{QRD}(Q_1; Q_0\, \mu_1) = \quad & (r+h)\mu_1 - (h + c_1)Q_1 - hQ_0 \\ & - (r+h)\sigma_1 \psi[(Q_1 + Q_0 - \mu_0)/\sigma_1. \end{aligned} \tag{10.16}$$

Lemma 10.1 asserts that $\hat{\mu}_1^{QRD-DMP}$ is unique and its first derivative with respect to μ_1 is equal to 1.

Lemma 10.1:

(a) $\tilde{\eta}(\mu_1, Q_0)$ is a strictly increasing function in μ_1 for $\mu_1 > Q_0 - \sigma_1 \Phi^{-1}(s_1)$;

(b) $\lim_{\mu_1 \to Q_0 - \sigma_1 \Phi^{-1}(s_1)} \tilde{\eta}(\mu_1, Q_0) < 0$ and $\lim_{\mu_1 \to \infty} \tilde{\eta}(\mu_1, Q_0) > 0$; and

(c) $d\hat{\mu}_1^{QRD-DMP} / dQ_0 = 1$.

Apart from proving the uniqueness of $\hat{\mu}_1^{QRD-DMP}$, Lemma 10.1 also provides a useful guideline for the retailer to make his ordering decision when facing the Stage-1 MOQ ($\tilde{M}_1^{QRD}$) when $\mu_1 \geq Q_0 - \sigma_1 \Phi^{-1}(s_1)$. To be specific, by the definition of $\hat{\mu}_1^{QRD-DMP}$ and Lemma 10.1(a), $\tilde{\eta}(\mu_1, Q_0) \leq 0$ for $Q_0 - \sigma_1 \Phi^{-1}(s_1) \leq \mu_1 \leq \hat{\mu}_1^{QRD-DMP}$. Therefore, it is more profitable for the retailer to order nothing at Stage 1 than to order up to $\tilde{M}_1^{QRD}$. Similarly, $\tilde{\eta}(\mu_1, Q_0) > 0$ for $\mu_1 > \hat{\mu}_1^{QRD-DMP}$. Thus it is more profitable for the retailer to order up to $\tilde{M}_1^{QRD}$ in this case. Proposition 10.3 summarizes the optimal Stage-1 ordering decision with the presence of $\tilde{M}_1^{QRD}$ as the Stage-1 MOQ.

Proposition 10.3:

Given the Stage-1 MOQ as $\tilde{M}_1^{QRD}$*, the optimal ordering policy for the retailer is given by:*

$$Q_1^{QRD-DMP}* = \begin{cases} \tilde{M}_1^{QRD} & if \quad \mu_1 > \hat{\mu}_1^{QRD-DMP} \\ 0 & if \quad \mu_1 \leq \hat{\mu}_1^{QRD-DMP} \end{cases}, \qquad (10.17)$$

where $\hat{\mu}_1^{QRD-DMP}$ *is defined by (10.15).* *(Q.E.D.)*

A straight comparison between (10.5) and (10.17) indicates that even imposition of $\tilde{M}_1^{QRD}$ cannot induce the retailer to order at the supply chain optimal quantity. Specifically, when $Q_0 - \sigma_1\Phi^{-1}(s_1^{SC}) \leq \mu_1 \leq \hat{\mu}_1^{QRD-DMP}$, the retailer will order nothing instead of ordering at the supply chain optimal quantity. To resolve this issue, we propose the manufacturer's offering of a sum of subsidy which equals the loss in the retailer expected profit for him to order at $\tilde{M}_1^{QRD}$ when compared to the case when he order nothing. We refer this contract as QRD-DMPS and state its details for Stage-1 ordering as follows:

The QRD-DMPS contract for Stage-1 ordering:

At Stage 1, given $Q_0 > 0$ *and* μ_1 *,*

1. *There is an MOQ requirement, namely:* $M_1 = \tilde{M}_1^{QRD}$ *for* $\mu_1 \geq Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC})$*, where* $\tilde{M}_1^{QRD}$ *is defined in (10.1); and*

2. *If* $Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC}) \leq \mu_1 \leq \hat{\mu}_1^{QRD-DMP}$*, the retailer has to order at* $\tilde{M}_1^{QRD}$*; in return the manufacturer would offer a sum of subsidy that equals* $-\tilde{\eta}(\mu_1, Q_0) = ER_1^{QRD}(0; Q_0, \mu_1) - ER_1^{QRD}(\tilde{M}_1^{QRD}; Q_0, \mu_1)$.

There is a reason behind our insistence of the retailer's ordering policy being exactly the same as that for the centralized supply chain. By doing so, we can ensure that the supply chain expected profit (SCEP) function under QRD-DMPS would be exactly the same as the corresponding SCEP under the centralized system. In turn, if we could ensure that the retailer will also order at the supply chain's optimal quantity at Stage 0, i.e. $Q_{0,SC}^{QRD}*$, we can achieve the objective of SCEP maximization (which also means achieving the most efficient and competitive supply chain).

10.2.2 SCEP Maximization under QRD-DMPS

To achieve SCEP maximization, we need to investigate how the retailer will order $Q_{0,SC}^{QRD}*$ at Stage 0. Consider the REP function under QRD-DMPS and its derivative, which are expressed below respectively:

$$
\begin{aligned}
& ER^{QRD-DMP}(Q_0) \\
= \; & \int_{-\infty}^{Q_0-\sigma_1\Phi^{-1}(s_1^{SC})} ER_1^{QRD}(0|\mu_1) f(\mu_1) d\mu_1 + \int_{Q_0-\sigma_1\Phi^{-1}(s_1^{SC})}^{\infty} ER_1^{QRD}(\tilde{M}_1^{QRD}|\mu_1) f(\mu_1) d\mu_1 \\
& - \int_{Q_0-\sigma_1\Phi^{-1}(s_1^{SC})}^{\hat{\mu}_1^{QRD-DMP}} \tilde{\eta}(\mu_1, Q_0) f(\mu_1) d\mu_1 - c_0 Q_0 \\
= \; & \int_{-\infty}^{\hat{\mu}_1^{QRD-DMP}} ER_1^{QRD}(0|\mu_1) f(\mu_1) d\mu_1 + \int_{\hat{\mu}_1^{QRD-DMP}}^{\infty} ER_1^{QRD}(\tilde{M}_1^{QRD}|\mu_1) f(\mu_1) d\mu_1 \\
& - c_0 Q_0 . \qquad (10.18)
\end{aligned}
$$

$$
\begin{aligned}
& \partial ER^{QRD-DMP} / \partial Q_0 \\
& = (c_1 - c_0) + (r - c_1)\Phi[\rho_3(Q_0)] - (r+h)\int_{-\infty}^{\rho_3(Q_0)} \Phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z) dz , \qquad (10.19)
\end{aligned}
$$

where

$$\rho_3(Q_0) = [\hat{\mu}_1^{QRD-DMP}(Q_0) - \mu_0]/\sigma_\mu . \qquad (10.20)$$

Similar to $ER^{QRD-MOQ-II}$, the REP function under the QRD-MOQ system, we found that $ER^{QRD-DMP}$ may not be strictly concave. In fact, as shown in Lemmas 10.2 to 10.4 below, some of the properties of $ER^{QRD-DMP}$ are similar to those of $ER^{QRD-MOQ-II}$.

Lemma 10.2:

(a) $\lim_{Q_0 \to -\infty} \{ \partial ER^{QRD-DMP} / \partial Q_0 \} > 0$ *and* $\lim_{Q_0 \to \infty} \{ \partial ER^{QRD-DMP} / \partial Q_0 \} < 0$*;*

(b) There exists at least one value of Q_0 *such that* $\partial ER^{QRD-DMP} / \partial Q_0 = 0$*;*

(c) $ER^{QRD-DMP}$ *is strictly concave for* $Q_0 > \tilde{Q}_0 = \mu_0 + \sigma_1 \Phi^{-1}(s_1)$.

Lemma 10.3:

$ER^{QRD-DMP}$ is strictly decreasing for a sufficiently large Q_0.

Lemma 10.4:

There exists at least one local maximum for $ER^{QRD-DMP}$.

Analogue to Lemmas 8.3 to 8.5 for the QRD-MOQ system, Lemmas 10.2 to 10.4 assert that $ER^{QRD-DMP}$ has a finite set of positive local maximum(s), with at most one of them lies in the range for $Q_0 \geq \tilde{Q}_0$. To determine the other positive maximums, we can narrow down the range of Q_0 for solving the first-order condition, namely between 0 and $\tilde{Q}_0$. If we do not need to consider the issue of SCEP maximization, we can determine the optimal Stage-0 order quantity under QRD-DMPS with an algorithm similar to Algorithm 8.1.

As mentioned previously, there is one more condition for achieving SCEP maximization under QRD-DMPS, namely: the retailer's order quantity at Stage 0 (denoted by $\hat{Q}_0^{QRD-DMP}$) is the same as the optimal supply chain Stage-0 quantity, $Q_{0,SC}^{QRD}*$. To make it feasible we may impose an MOQ requirement at Stage 0, namely $M_0 = Q_{0,SC}^{QRD}*$. But it requires: (i) $\hat{Q}_0^{QRD-DMP} \leq Q_{0,SC}^{QRD}*$ and (ii) ordering at $Q_{0,SC}^{QRD}*$ should be more profitable to the retailer than ordering nothing at Stage 0. For the latter condition, if the optimal Stage-0 order quantity for the retailer is zero, then the system is reduced to a single-stage QR system. We can always achieve channel coordination by offering him QRS-DMP. Therefore, it remains to check for the former condition. Proposition 10.4 provides a sufficient condition such that $\hat{Q}_0^{QRD-DMP} < Q_{0,SC}^{QRD}*$.

Proposition 10.4:

A sufficient condition for $\hat{Q}_0^{QRD-DMP} < Q_{0,SC}^{QRD}*$ *is given by:*

$$(c_1 - c_0) < (m_1 - m_0) - (r - m_1)\{\Phi[\rho_3(\hat{Q}_0^{QRD-DMP}) - \Phi[\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})]\}.$$

We may interpret the sufficient condition in Proposition 10.4 as requiring the difference between the purchase costs at the two stages being smaller than that between the production costs at the two stages. In general, from the retailer's perspective, if c_1 is not significantly larger than c_0, the retailer would comparatively order less at Stage 0 to reserve the quota for Stage 1 when he has a more accurate demand estimate. On the other hand, for the centralized supply chain, if m_1 is significantly larger than m_0, then the Stage-0 supply chain quantity would be larger to justify the trade-off between production cost and information update. Taking both effects into consideration may make it easier to satisfy the condition of $\hat{Q}_0^{QRD-DMP} < Q_{0,SC}^{QRD}*$.

In the below, we state the full details of QRD-DMPS, which include the requirements at both Stages 0 and 1.

The QRD-DMPS contract (full details):

<u>At Stage 0</u>:

1. *There is an MOQ requirement, namely:* $M_0 = Q_{0,SC}^{QRD}*$.

<u>At Stage 1</u>: Given the updated μ_1

1. *For* $Q_0 = 0$*:*

   There is an MOQ requirement, namely: $M_1 = \mu_1 + \sigma_1 \Phi^{-1}(s_1^{SC})$*;*

2. *For* $Q_0 > 0$*:*

   (a) *There is an MOQ requirement, namely:* $M_1 = \tilde{M}_1^{QRD}$ *for* $\mu_1 \geq Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC})$, *where* $\tilde{M}_1^{QRD}$ *is defined in (10.1); and* *(b)* *If* $Q_0 - \sigma_1 \Phi^{-1}(s_1^{SC}) \le \mu_1 \le \hat{\mu}_1^{QRD-DMP}$*, the retailer has to order at* $\tilde{M}_1^{QRD}$*; in return the manufacturer would offer a sum of subsidy that equals* $-\tilde{\eta}(\mu_1, Q_0) = ER_1^{QRD}(0; Q_0, \mu_1) - ER_1^{QRD}(\tilde{M}_1^{QRD}; Q_0, \mu_1)$.

10.2.3 Pareto Improvement under QRD-DMPS

To check whether QRD-DMPS can achieve channel coordination, it remains to check whether both the retailer and the manufacturer can be better off under the contract. By direct computation, the difference in REP and the difference in MEP after adopting QRD-DMPS from the old system (denoted by $\Delta ER^{QRD-DMPS}$ and $\Delta EM^{QRD-DMPS}$, respectively) are expressed below:

$$
\begin{aligned}
&\Delta ER^{QRD-DMPS} \\
=\ & ER^{QRD-DMPS} - ER^{Old} \\
=\ & (c_1 - c_0)(Q_{0,SC}^{QRD}* - \mu_0) - (h + c_1)\sigma_1 \Phi^{-1}(s_1^{SC}) + (h + c_0)\sigma_0 \Phi^{-1}(s_0) \\
& + (r + h)\{\sigma_0 \psi[\Phi^{-1}(s_0)] - \sigma_1 \psi[\Phi^{-1}(s_1^{SC})] - (h + c_1)\sigma_\mu \phi[\rho_3(Q_{0,SC}^{QRD}*)] \\
& - \Phi[\rho_3(Q_{0,SC}^{QRD}*)]\{(h + c_1)\sigma_\mu \xi_3^{SC}(Q_{0,SC}^{QRD}*) - (r + h)\sigma_1 \psi[\Phi^{-1}(s_1^{SC})]\} \\
& - (r + h)\sigma_1 \int_{-\infty}^{\rho_3(Q_{0,SC}^{QRD}*)} \psi[(Q_{0,SC}^{QRD}* - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz, \qquad (10.21)
\end{aligned}
$$

$$
\begin{aligned}
&\Delta EM^{QRD-DMPS} \\
=\ & EM^{QRD-DMPS} - EM^{Old}
\end{aligned}
$$

$$= \quad (c_0 - m_0)[\sigma_1 \Phi(s_1^{SC}) - \sigma_0 \Phi^{-1}(s_0)] + \sigma_\mu \xi_3^{SC}(Q_{0,SC}^{QRD}*)[(m_1 - m_0) - (c_1 - c_0)]$$

$$+ \sigma_\mu \xi_3^{SC}(Q_{0,SC}^{QRD}*)\{(h + c_1)\Phi[\rho_3(Q_{0,SC}^{QRD}*)] - (h + m_1)\Phi[\xi_3^{SC}(Q_{0,SC}^{QRD}*)]\}$$

$$+ (h + c_1)\sigma_\mu \phi[\rho_3(Q_{0,SC}^{QRD}*)] - (h + m_1)\sigma_\mu \phi[\xi_3^{SC}(Q_{0,SC}^{QRD}*)]$$

$$-(r + h)\sigma_1 \psi[\Phi^{-1}(s_1^{SC})]\{\Phi[\rho_3(Q_{0,SC}^{QRD}*)] - \Phi[\xi_3^{SC}(Q_{0,SC}^{QRD}*)]\}$$

$$+ (r + h)\sigma_1 \int_{\xi_3^{SC}(Q_{0,SC}^{QRD}*)}^{\rho_3(Q_{0,SC}^{QRD}*)} \psi[(Q_{0,SC}^{QRD} * - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz, \qquad (10.22)$$

where $\xi_3^{SC}(Q_0)$ and $\rho_3(Q_0)$ are defined in (10.8) and (10.20), respectively.

Pareto improvement requires that both $\Delta ER^{QRD-DMP} \geq 0$ and $\Delta EM^{QRD-DMP} \geq 0$, with at least one of the two inequalities being strict. Propositions 10.5 and 10.6 respectively state the sufficient conditions for the above inequalities to hold.

Proposition 10.5:

A sufficient condition for $\Delta ER^{QRD-DMP} > 0$ *is given by:*

$$(c_1 - c_0)\sigma_\mu \xi_3^{SC}(Q_{0,SC}^{QRD}*) + (h + c_0)[\sigma_0 \Phi^{-1}(s_0) - \sigma_1 \Phi^{-1}(s_1^{SC})]$$

$$+ (r + h)\{\sigma_0 \psi[\Phi^{-1}(s_0)] - \sigma_1 \psi[\Phi^{-1}(s_1^{SC})] - (h + c_1)\sigma_\mu \phi[\rho_3(Q_{0,SC}^{QRD}*)] > 0.$$

Proposition 10.6:

If (i) $\hat{\mu}_1^{QRD-DMP}(Q_{0,SC}^{QRD}*) < \mu_0$ *, (ii)* $c_1 - m_1 < c_0 - m_0$ *, and (iii)* $\sigma_1 \Phi^{-1}(s_1^{SC}) > \sigma_0 \Phi^{-1}(s_0)$*, then* $\Delta EM^{QRD-DMP} > 0$.

Some of the sufficient conditions stated in Proposition 10.6 are related to the cost-revenue parameters of the manufacturer. Specifically, if the manufacturer's production cost after QR adoption is much smaller than the Stage-0 purchase cost he offers to the retailer [$m_1 < c_0$ implies that $s_1^{SC} > s_0$; if such a difference is sufficiently large, we will have $\sigma_1 \Phi^{-1}(s_1^{SC}) > \sigma_0 \Phi^{-1}(s_0)$]. Besides, if the manufacturer has a smaller profit margin in Stage 1 ($c_1 - m_1 < c_0 - m_0$), then it is highly probable that the manufacturer will be better off under QRD-DMPS.

10.3.Numerical Analysis

To further illustrate insights on coordination, we adopt the same parameters in the numerical analysis presented in Chapter 9 to explore numerically the effects of using a dynamic MOQ policy on the supply chain performance.

10.3.1 The QRS-DMP system

We start by checking how sensitive channel coordination can be achieved under the QRS-DMP system for different values of the production cost according to Proposition 10.1. As depicted in Table 10.3.1, we found that DMP can achieve channel coordination in all the cases of cost-revenue parameters presented except when MR=15%. The result asserts that the use of DMP can achieve channel coordination for both moderately-priced and higher-end products in most production environment. We further explore the amount that the two channel members gain under DMP. Under different values of MR, we calculate REP and MEP for different values of c_1 that lies within the range between c_1^M and c_1^R and the results are depicted in Tables 10.3.2(a) and (b). As suggested by Corollary 10.1, both REP and MEP under DMP are greater than those under the old system for the purchase cost bounded between c_1^M and c_1^R. We observe that such increase in the expected profit is more significant for the manufacturer than the retailer. In some cases the former can even achieve more than 1.5 times of the expected profit under the old system (e.g. in Table 10.2(a) when $MR = -10\%$, $c_1 = c_1^R$, $r = 75$). The gain in the agents' expected profit depends on the choice of c_1, which is agreed upon negotiation between the supply chain agents. Naturally the supply chain agent having a greater bargaining power would choose c_1 that is more favourable to oneself. Yet so long as $c_1^M \le c_1 \le c_1^R$, the supply chain is the most efficient. In this case c_1 in fact serves as a measure to partition the gain in SCEP owing to DMP. We also notice that for the same r and c_1, the gain in the expected profit for individual agents increases as the production cost decreases. It is intuitive as the corresponding centralized supply chain expected profit increases with reduction in the production cost. Therefore channel members can share more from the increased gain. A less intuitive observation is that with the same production cost, the increase in the expected profit from the old system is more significant for a system with a smaller r. A possible reason is that the increase in the service level (i.e. from s_0 to s_1^{sc}), which is more significant with a smaller r, amplifies the difference between the expected profit of the old system and the one under QRS-DMP. Hence under a similar production environment, the benefit brought by adopting QRS-DMP would be more conspicuous for moderate-priced products than the higher-end ones.

10.3.2 The QRD-DMPS system

Tables 10.3.3(a) and (b) show whether SCEP maximization is feasible under the QRD-DMPS system. Unlike the QRS-DMP system, we observe that QRD-DMPS system may not always achieve SCEP maximization. Specifically, when CR is sufficiently large compared with MR, the optimal retailer's order quantity at Stage 0 (i.e. $\hat{Q}_0^{QRD-DMPS}$) would be greater than the supply chain optimal quantity (i.e. $\hat{Q}_{0,SC}^{QRD}*$). As a result, the QRD-DMPS system fails to induce the retailer to order at supply chain's optimal quantities to maximize the SCEP.

On the other hand, Tables 10.3.4(a) and (b) indicate that Pareto improvement may not be always feasible either under the QRD-DMPS system. We observe that the retailer is always better off with all the sets of parameters under study. By contrast, the manufacturer may suffer from reduction in her expected profit under the QRD-DMPS system when compared with the old system. A possible reason may lie on the provision of the subsidy to the retailer in order to have his cooperation in ordering placing at Stage 1. Although the amount of the subsidy is relatively small compared with the REP, it is not negligible for the manufacturer in the light of her smaller profit margin. As a result, Pareto improvement is feasible only for the cases when CR is sufficiently larger than MR.

Taking both issues into consideration, Table 10.3.5 states which sets of cost-revenue parameters can achieve channel coordination un the QRD-DMPS system. From the above discussion, it can be expected that QRD-DMPS system may not be able to coordinate in all scenarios under study. In fact, we found that when the retail price is high ($r=75$ in our case), the QRD-DMPS system can never coordinate the system. Nevertheless, for those cases that fail to achieve coordination, the supply chain efficiency is very high (more than 99.9% in all cases). Hence we believe that QRD-DMPS system is still a feasible and highly effective approach to enhance supply chain efficiency whilst at the same time ensuring both channel members would be better off.

10.4.Summary

In this chapter we proposed an innovative use of the dynamic MOQ to tackle the issue of channel coordination in QR systems.

For the singe-ordering system, we derived the optimal value of production cost and the purchase cost that can maximize the SCEP. Then, we stated the sufficient condition that enables the QRS-DMP system to coordinate the supply chain. Our numerical analysis also verifies that the dynamic MOQ policy can achieve channel coordination in almost all the scenarios we have studied.

For the dual-ordering system, with the provision of a subsidy to the retailer, we outlined the development of the QRD-DMPS system that can maximize the SCEP and derived sufficient conditions under which Pareto improvement is possible. Our numerical analysis reflects that QRD-DMPS may not be able to achieve channel coordination in every scenario under study. However, we found that the supply chain efficiency for these non-coordinating cases are very high, thus suggesting the use of the QRD-DMPS system is an effective approach to optimize the supply chain.

11. Conclusion

This chapter starts with a summary on the major findings of this thesis study, followed by managerial insights we obtained from these findings. Afterwards we discuss how this thesis study has contributed to the current literature. We end this chapter by pinpointing some limitations of this research and propose suggestions for future research.

11.1. Major Findings

This thesis has investigated the relationship between QR and MOQ, the two common practices in the apparel industry on which the retailer and the manufacturer usually have conflicting views.

In order to obtain a clear picture regarding the current industrial practices and challenges of QR and MOQ in the Hong Kong apparel industry, we started this thesis with case studies of two well established apparel companies, namely: Magenta and PG Limited. From the case studies, we have found that they have fully recognized the importance of order lead time reduction and have adopted various measures pertinent to their own situations to strive for lead time reduction (and hence moving towards QR) (see Table 3.1). For instance, Magenta is sharing their product styles with selected suppliers through a sophisticated information system so that they can communicate more efficiently with these suppliers. Without the use of advanced technology, PG Limited, on the other hand, would order fabric in advance upon receipt of client's initial commitment on the aggregated total order quantity to shorten the waiting time for the material. MOQ imposition is another important issue in the apparel industry as it concerns both the profits of the manufacturer and the retailer. From the case studies, we learnt about some of the reasons why the manufacturer needs to impose MOQ as well as the various factors affecting her determination of the MOQ (see Table 3.2). We found that the main purpose for the manufacturer to impose MOQ is to satisfy the various material MOQs imposed by the upstream suppliers and to justify the production cost to process an order. To obtain a mutually-agreed MOQ usually involves negotiation between the channel agents, which in turn depends on how well the relationship is between the two parties.

The case studies have prepared us to further investigate the relationship between QR and MOQ in two dimensions, namely: (1) empirically through a questionnaire survey, and (2) analytically through formulating various QR-MOQ systems and evaluating the respective performance of channel members and that of supply chain.

From the questionnaire survey, we observed that a high proportion of respondents are imposing MOQ on their clients or being imposed with MOQ by their business partners. From the comparison of the scores on individual QR-related practice, the buyer respondents are in general involving in QR practice in a more comprehensive way than the supplier respondents. Besides, we obtained statistically significant evidence that QR adoption can bring about positive impact on a supplier's performance. We note that this finding is different from what we have learnt from the literature about the impact of QR to the supplier. A possible explanation of this may be as follows. By enhancing the level of QR, the supplier has gained the competitive advantage over her peer groups in the sense that more buyers are willing to have business with her since she can help them to be more responsive. On the other hand, our survey result suggested that high-sale buyer respondents with MOQ imposition had a significantly higher level of QR adoption than those without MOQ. These findings provide empirical evidence to justify why the suppliers would consider QR adoption, and for the buyer to consider acceptance of MOQ as a token for their suppliers to adopt QR.

Mathematically, we have formulated different scenarios of the QR-MOQ systems and derived the corresponding optimal ordering policies from the retailer's perspective. Afterwards we have explored analytically the properties of the functions of the retailer expected profit function (REP), the manufacturer expected profit (MEP), and the supply chain expected profit (SCEP). We summarize our key findings in Tables 11.1 below.

Table 11.1. Summary of the key analytical findings.

	QRS-MOQ	**QRD-MOQ-I**	**QRD-MOQ-II**
Optimal order quantities	-- different quantities at different thresholds -- thresholds depend on updated demand mean (μ_1) & MOQ (and retailer reservation expected profit for QRS-MOQ)		Algorithm devised
Retailer Expected Profit (REP)	-- horizontal for small M_1 -- decreasing afterwards	-- horizontal for small M_0 -- decreasing for medium M_0 -- horizontal for large M_0	Depends on $\{M_0, M_1\}$ and cost-revenue parameters
Manufacturer Expected Profit (MEP)	-- no neat properties	-- horizontal for small M_0 and very large M_0 -- increasing for medium M_0 -- in some cases, MEP at medium M_0 may exceed that at very large M_0	
Optimal MOQ for Retailer	The range of MOQ that is no larger than the optimal order quantity		
Optimal MOQ for Manufacturer	Not able to be derived	Depends on production margin	

We noticed that the presence of MOQ complicates the optimal ordering policies. When there is no consideration of MOQ, both the REP and MEP functions possess nice properties (e.g., the REP is concave). On the contrary, with the presence of MOQ, even under the simple single-stage QR system, the analytical expression of the MEP function makes it difficult to conduct direct analytical inference for many results. Nevertheless, we have been able to derive the optimal ordering policies for the retailer under the QRS-MOQ and the QRD-MOQ-I systems. Specifically, the retailer's optimal order quantity differs at different thresholds which depend on the updated demand mean at Stage 1 and the MOQ at Stage 1 or 0 (For the QRS-MOQ system, the thresholds also depend on the reservation expected profit of the retailer) . Besides, our findings also indicate that the REP function is non-increasing in M_1 and M_0 for the QRS-MOQ and the QRD-MOQ-I systems, respectively. In other words, the retailer in general performs poorer with the presence of MOQ under these two systems. On the other hand, the MEP function under the QRD-MOQ-I system is a piece-wise function which is horizontal with small and very large M_0, and is increasing with the medium value of M_0. In particular, depending on the production margins of the manufacturer at the two stages, there are cases that the MEP under a medium value of M_0 exceeds that under a very large M_0. This suggests that the manufacturer may not always be benefited from imposing a large MOQ and she needs to take careful consideration in order to be better off. For the QRD-MOQ-II system, we have shown that finite multiple local maxima may exist in the REP function, and therefore we have devised an optimal ordering decision algorithm that can be easily implemented in nowadays' corporate information systems to facilitate the retailer's decision making of the optimal order quantity.

In addition to the above mathematical analysis, we have also explored the impacts of MOQ on the channel members' performance under the three QR-MOQ systems with different sets of cost-revenue parameters and MOQ(s) via extensive numerical analysis with reference to real company data. We summarize the main findings from the numerical analysis in Table 11.2 below.

Owing to the difficulty to cover all the combination of the Stage-0 and Stage-1 MOQs for the QRD-MOQ-II system in our numerical analysis, we cannot compare the expected profits of the channel members under this system with those under the other two. But between the two systems with single MOQ only, we observe that the manufacturer earns more expectedly under the QRS-MOQ system whereas the retailer can get a greater expected profit under the QRD-MOQ-I system. From the perspective of the whole supply chain, SCEP is also greater under the QRD-MOQ-I system.

Table 11.2. Comparison of the performance of the channel members and the supply chain under the three QR-MOQ systems – Numerical Analysis.

	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II	Remark
Greatest REP?		Greater	No direct comparison (limited cases explored)	
Greatest MEP?	Greater			
Greatest SCEP?		Greater		
Pareto improvement?	Possible in some cases	More possible cases than QRS-MOQ	Possible for those M_1 under study	For QRS-MOQ and QRD-MOQ-I: Sensitive to MR and CR
Able to attain same SCEP under the centralized system ?	NO	NO	NO	
Greater SCEP than the system without MOQ?	NO	YES in some cases (when CR>MR)	NO	

Regarding the issue of channel coordination, our numerical analysis suggested that QR systems with MOQ in general fail to achieve the maximum SCEP. However, under the decentralized setting, Pareto improvement is feasible in most scenarios we have explored. The supply chain efficiency in general decreases as the MOQ(s) increases in all the QR-MOQ systems. In particular, the supply chain efficiency of QR systems with MOQ is always poorer than that without MOQ except for some cases in the QRD-MOQ-I system. To be specific, under a moderate sized Stage-0 MOQ and under the case with “a lower purchase cost ratio than the production ratio” (i.e. MR<CR), SCEP under the QRD-MOQ-I system can be greater than the "no-MOQ" one.

In order to compare the performance of the three systems under similar value of MOQ(s), as well as to explore the risk aspect of the QR-MOQ systems, we simulated 1000 runs of the updated demand at Stage 1 and calculate the average profits and the variance of profits for the channel members under the three systems (see Table 11.3).

We found that both the retailer and the supply chain would prefer the QRD-MOQ-I system as it gives them greater average profits. Though the variance of profit under the QRD-MOQ-I system is the smallest when compared with the QRS system (i.e. single ordering without MOQ), it generally gives the smallest variance of profit under all three systems with MOQ. For the manufacturer, by contrast, QRS-MOQ system appears to be the most desirable QR-MOQ system for her adoption as it provides her with the greatest average profits in most cases whilst the variance of profits is the smallest amongst the three systems.

Table 11.3. Comparison of the performance of the channel members and the supply chain under the three QR-MOQ systems - Simulation Experiment.

	QRS-MOQ	**QRD-MOQ-I**	**QRD-MOQ-II**	**Remark**
Retailer				
Greatest Avg. Profit?		Greatest		In some cases avg. profit under QRD-MOQ-I is smaller than that without MOQ
Smallest Variance of Profit?		Smallest		Not smaller than that under QRS
Manufacturer				
Greatest Avg. Profit?	Greatest in most cases			In some cases, maybe greatest under QRD-MOQ-I or QRD-MOQ-II, but such cases always smaller than those under old system
Smallest Variance of Profit?	Smallest			Not smaller than those under old system (Variance = zero)
Supply Chain				
Greatest Avg. Profit?		Greatest		
Smallest Variance of Profit?		Smallest in some cases	Smallest in some cases	Not smaller than that under QRS

Basing on the speculation that the static nature of the Stage-1 MOQ agreed in Stage 0 may hinder the full use of the updated market information brought about by QR adoption, we propose the use of the "dynamic MOQ" in which the specific MOQ value depends on the updated information (posterior demand mean). We have derived the optimal value of production cost and the purchase cost that can maximize the SCEP for the single-ordering system and stated the sufficient condition that enables channel coordination. Our numerical analysis verified that such dynamic MOQ policy can achieve channel coordination in almost all the scenarios under study. For the dual-ordering system, we have proposed the use of the dynamic MOQ with subsidy to coordinate the supply chain. Our numerical analysis reflected that such measure might not be able to achieve coordination in some scenarios under study. However, we found that the supply chain efficiency for these non-coordinating cases are very high, thus verifying its effectiveness to optimize the supply chain.

11.2.Managerial Insights

The above analysis of the various QR-MOQ systems has enriched our understanding of the impacts of MOQ imposition on the performance of channel members and the QR supply chain. It has also provided references for the supply chain agents to decide on the optimal type of the QR-MOQ system one should adopt as well as the optimal settings of the MOQ and the cost-revenue parameters that can help them achieve the best possible performance. We will discuss these two aspects in details as follows.

From the comparison of the performance of the channel members under the three QR-MOQ systems, we noticed that different channel members would have different preferences on the type of QR-MOQ systems to be adopted. Specifically, the retailer would normally prefer to have dual ordering flexibility with MOQ imposed at Stage 0 only (i.e. the QRD-MOQ-I system) as he can enjoy the greatest profit expectedly whilst the manufacturer would opt for allowing postponed single ordering from the retailer but with MOQ imposition (i.e. the QRS-MOQ system).

After the type of the QR-MOQ system has been confirmed, channel members have to determine the optimal size of the MOQ and/or the cost-revenue parameters.

Propositions 6.2 (b) and 7.4 has suggested the optimal ranges of the MOQ that the retailer should accept under the QRS-MOQ and QRD-MOQ-I systems, respectively, should not exceed the optimal order quantity under the no-MOQ case. Therefore, the retailer can refer to the two propositions in negotiating the size of the MOQ he is willing to accept. Once the size of the MOQ(s) and the cost-revenue parameters have been finalized, the retailer can then follow Proposition 6.1(a), Algorithms 7.1 and 8.1 to determine his optimal order quantity (quantities) under the QRS-MOQ, QRD-MOQ-I and the QRD-MOQ-II systems, respectively.

Reflected from the analysis in the previous chapters, determination of the MOQs requires thorough consideration and the manufacturer needs to set her

MOQ(s) carefully. To be specific, she may not always enjoy a greater profit by imposing a larger MOQ. Apparently, the manufacturer would prefer adoption of the QRS-MOQ system as she would enjoy a greater expected profit. However, an over-aggressive MOQ may hinder the retailer from ordering anything, resulting in a reduction in the manufacturer expected profit. From the perspective of the whole supply chain, even though a large MOQ in some cases does provide a greater income to the manufacturer, the efficiency of the whole supply chain is nonetheless damaged. In the QRD-MOQ-I system, on the other hand, by wisely setting a medium value of the Stage-0 MOQ with some suitable cost-revenue parameters, the manufacturer may be able to enjoy the maximum expected profit whilst at the same time enhancing the overall supply chain efficiency (even greater than that in the no-MOQ system).

We demonstrate the applicability of the above recommendations by taking PG Limited (one of the companies in our case studies) as an example. Upon request, the company provides dual ordering flexibility to Brand X, one of her branded buyers that have both wholesale and retail operations. For each season, Brand X would normally place the first order shortly after their launch of the trade show. At that time Brand X has only obtained few confirmed orders and therefore they can only have rough estimate about the demand for their ordering decision. In around two and a half months' time, having gathered most of the trade show orders, Brand X would submit their second order based on the updated information from the trade show response. Having a shorter lead time, this second order will be delivered around a month after the season launch, which is acceptable for Brand X.

As we have learnt from this thesis study, the QRD-MOQ-I system may not be the most desirable system for PG Limited. Yet from the numerical studies, we learnt that if the company can control her production margin at Stage 1 to be smaller than that at Stage 0, then she can set a medium size of the Stage-0 MOQ that can maximize her expected profit. By doing so, the expected profit of the decentralized supply chain can also be maximized (and exceed that under the no-MOQ case). In the case that her production margin at Stage 1 is greater than that at Stage 0, PG Limited can still follow Proposition 7.3 to set her Stage-0 MOQ to gain the possible maximum expected profit.

It should be noted that the above discussion on the optimal MOQ(s) is based on the perspectives of individual channel members. We have also learnt from the case studies that negotiation between supply chain agents is usually needed in order to arrive at a mutually-agreed value of the MOQ(s) and other contract terms. Therefore, a strong buyer-supplier relationship is always beneficial to individual channel members as well as the whole supply chain and it is always desirable to take the benefits of both channel members into consideration when determining any contract terms. In light of this, we encourage the supply chain agents to employ the use of dynamic MOQ(s) and our suggested mechanisms to achieve channel coordination.

11.3. Contributions of this Research

We believe that this research has achieved the following contributions:

(1) To the best of our knowledge, this research is the first one that addresses the QR supply chain management issues with the consideration of MOQ and we have contributed by generating new insights on this under-explored problem.

(2) Through the questionnaire survey, we have acquired a deeper understanding of the practice of MOQ in the apparel industry. Our findings have provided the empirically grounded evidence about the prevalence of MOQ imposition in the apparel industry, the factors affecting suppliers' settings of MOQ, as well as the perceptions of different channel members regarding MOQ imposition and QR. Being the first empirical study on the topic, we hope that our work may arouse interests of other researchers to further pursue empirical research on exploring the relationship between QR and MOQ imposition in the apparel supply chains.

(3) Through the mathematical approach, we have acquired a deeper understanding of the performance of the channel members and that of the supply chain under the various QR-MOQ systems under study. By deriving the optimal ordering policies

/ algorithms and numerically investigating the performance of the supply chain agents under these systems, we believe that our work can help apparel companies to better assess their business environment and devise appropriate QR-MOQ strategies that help improving their business performance.

(4) The proposed dynamic MOQ policy is an innovative scheme for achieving supply chain coordination. We believe that it can be implemented in practice for the case when the manufacturer and the retailer are working closely together with information sharing measures such as forecast sharing, and the popular collaborative planning, forecasting and replenishment (CPFR) scheme.

11.4. Limitations and Future Research Directions

In this section, several limitations in this research work are identified with possible extensions. Directions for future works are also listed as below:

(1) Collection of more sample data for the survey statistical analysis:

As discussed in Chapter 4, owing to the time and resource constraints, only relatively few sample data were collected for the empirical studies. As a result, we failed to employ some sophisticated tool such as structural equation modelling (SEM) to verify our proposed model regarding the relationship between QR and MOQ. We suggest the continuation of the questionnaire survey to collect more data, so that a more statistically sound analysis can be conducted.

(2) Employment of general distribution for the demand distribution:

In our mathematical model formulation, we chose to use the normal distribution as the demand probability distribution for two reasons. Firstly it is one of the most commonly known probability distributions and it has been widely used in literature which includes both recent and classical papers published in leading journals such as *Management Science* (e.g. Eppen and Iyer, 1997; Iyer and Bergen, 1997; and Taylor and Xiao, 2010). Secondly under the Bayesian Theory for information updating, the use of normal distribution for the prior demand distribution results in the posterior demand distribution also being a normal distribution. This will facilitate the derivation of the various optimal ordering policies and other analytical inference.

However, one may argue that in reality the demand distribution may not follow a normal distribution. A future direction is hence to make use of other form of demand distribution to obtain a more generalized result.

(3) The issue of information asymmetry:

In formulating the various QR-MOQ mathematical systems, we consider all information, including the demand distribution parameter estimates and cost-revenue parameters are equally shared between the retailer and the manufacturer. However, in reality it is common that the retailer would keep their forecast of the consumer demand private. The manufacturer would also treat the production cost as sensitive data and normally would not disclose this cost-revenue parameter to the other party. In the future, one may consider the scenarios that either one or both of these data are kept as private information and explore the impacts of information asymmetry on the QR-MOQ supply chains.

(4) The effect of bargaining powers between channel members:

In the part of the mathematical modelling research, we did not consider that different bargaining powers exist between the channel members. When discussing our findings, it happens frequently that the optimal action for one party may not be beneficial to the other. Some good examples include the type of QR-MOQ systems to be adopted and the optimal values of the MOQ(s) in individual stages. For instance, the retailer generally gains a greater expected profit under the QRD-MOQ-I system and prefers to have MOQ smaller than his optimal order quantity in the no-MOQ case. By contrast, the manufacturer would consider the QRS-MOQ system the most desirable and be more profitable in many situations by having an MOQ greater than the retailer's optimal quantity in the no-MOQ case. As a result, the two parties would need to resolve to negotiation to obtain a mutually-agreed decision. Since difference in the bargaining powers would definitely affect the final result of the negotiation process, a possible extension to the current research would be to investigate the impact of such imbalance in the bargaining powers on the value of the MOQ(s) and the subsequent ordering decisions in these QR-MOQ systems.

(5) Other means of coordinating mechanism for QR-MOQ supply chains:

In this thesis study, we have proposed the use of the dynamic MOQ as a mechanism to achieve channel coordination. Such idea is based on speculation of the static nature of the Stage-1 MOQ that may hinder the full use of the information updating process. With respect to this, a future direction may concern the use of other types of contracts, such as dynamic buyback or two-part tariff contract, to achieve coordination.

11.5.Summary

Being the last chapter of the report, we summarized the major findings of this thesis study and discussed the managerial insights we had obtained from these findings. We concluded by stating the contributions of this thesis study to the current literature and limitations of this research, as well as proposing suggestions for future research.

APPENDIX A

-- Summary of Case Studies

Table 3.1 Various lead-time-reduction measures adopted by the two companies under interviews.

Scope			Details
1.	Information Sharing	a.	Access to POS system of the retailer (under progress - Magenta)
		b.	Sharing style information with suppliers (Magenta)
		c.	Buyer’s sharing of seasonal production forecast (PG)
2.	Process Streamlining	a.	Integrated information system across the company (under development - Magenta)
		b.	Advanced ordering of fabrics, yarns and other materials (PG)
3.	Buyer-Supplier Relationship	a.	Develop “focus suppliers’ for strategic partnership (Magenta)
		b.	Prompt communication between buyer and designer/supplier regarding order changes (PG)

Table 3.2 Practice of MOQ imposition in the apparel industry (advised by PG Limited)

Scope			Details
1.	Factors affecting MOQ determination	a.	Materials MOQ(s) imposed by upstream suppliers
		b.	Material transportation cost
		c.	Factory productivity
		d.	Production complexity of individual styles
2.	Reasons for MOQ imposition	a.	To satisfy material MOQs imposed by upstream suppliers
		b.	To justify production cost
		c.	To increase profit
		d.	Use of large MOQ to decline order
3.	Resolution when buyer’s desirable order falls below MOQ	a.	Negotiation
		b.	Surcharge

APPENDIX B

-- Conceptual Model and Questionnaire for Survey Analysis

Fig. 4.1. Conceptual QR-MOQ model to be explored in this study.

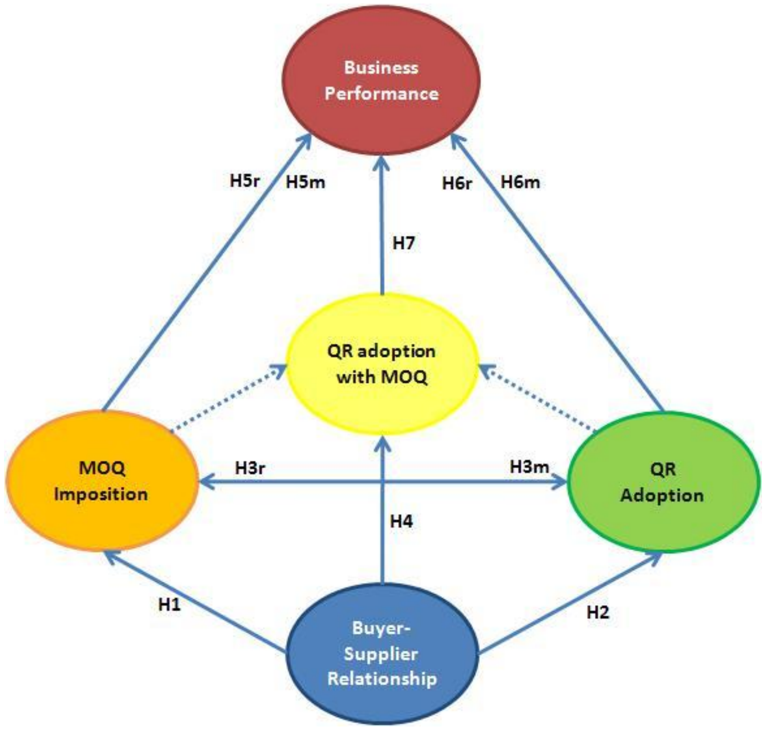

Table 4.1. A summary of the hypotheses proposed with the corresponding theoretical perspectives and references.

Hypothesis		Theory Perspective		Illustrative Reference(s)
		Theory	**Rationale**	
H1:	Good buyer-supplier relationship facilitates MOQ imposition.	Network Theory	Mutual dependence and trust between channel members facilitate supply chain management practices.	Dickson & Zhang (2004); Ketchen & Hult (2007)
H2:	Good buyer-supplier relationship has a direct positive impact on QR adoption.	Network Theory	A strong tie between channel members is required to facilitate QR adoption for supply chain performance optimization.	Frazier et al (1994); Fairbairn (1997); Perry et al (1999); Shin et al (2000); Handfield & Bechtel (2002)
H3m:	MOQ imposition encourages supplier's adoption of QR.	Agency Theory	MOQ acts as a reward for the supplier so that align members' interests are aligned.	Narayanan & Raman (2004); Ketchen & Hult (2007)
H3r:	QR adoption facilitates buyer's acceptance of MOQ imposition.	Transaction Cost Economics	Buyer focuses on the ultimate benefits (e.g., those brought about by QR) and the short-term cost (e.g., owing to MOQ imposition) plays a secondary role.	Williamson (1975); Ketchen & Hult (2007);
H4:	Good buyer-supplier relationship serves as a mediating factor between MOQ imposition and QR adoption.		Strong ties between channel members facilitate alignment of interests (which may be opposing to each other).	
H5m:	MOQ imposition has a positive effect on supplier's business performance.		To the extent acceptable by the buyer, MOQ imposition provides profit guarantee to the supplier.	

[To be continued on the next page]

[Continued from previous page]

Hypothesis		Theory Perspective		Illustrative Reference(s)
		Theory	**Rationale**	
H5r:	MOQ imposition has an adverse effect on buyer's business performance.		MOQ imposition hinders buyer's ordering flexibility.	
H6m:	QR adoption has an adverse effect on supplier's business performance.			Iyer & Bergen (1997); Birtwistle et al (2003, 2006); Choi & Chow (2008)
H6r:	QR adoption has a positive effect on buyer's business performance.			Iyer & Bergen (1997); Fairbairn (1997); Perry et al (1999); Birtwistle et al 2003; Choi & Chow (2008)
H7:	QR adoption with MOQ imposition has a positive impact on an apparel company's performance.	Game Theory	For supplier, manufacturing strategy (i.e., MOQ imposition) mediates the relationship between competitive strategy (i.e., QR adoption) and performance. For buyer, the benefits of QR adoption outweigh the adverse effects of MOQ imposition on its performance. By accepting QR adoption with MOQ imposition, both channel members can be benefited.	

Exhibit 4.1. The Questionnaire employed for data collection.

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

INSTITUTE OF TEXTILES & CLOTHING
紡織及製衣學系

MOQ Imposition and Quick Response Adoption in Hong Kong's Apparel Industry: Questionnaire Survey

Section A: Role in Supply Chain

A1. What is the business nature of your company?

☐ Retailer ☐ Wholesaler ☐ Distributor ☐ Buying Office
☐ Trading Firm ☐ Manufacturer ☐ Other (please specify): ___________________

A2. Respondent's Job Position:

☐ Director/Owner ☐ Manager ☐ Executive/Officer Grade
☐ Other (please specify): ________________________________

A3. My job responsibilities require me to represent my company as a:

☐ Buyer →Please go to Section B
☐ Supplier →Please go to Section C

Section B: <u>To be completed by the buyer only</u>

B1. Imposition of Minimum Order Quantity (MOQ)

1.1	Are there any of your suppliers impose MOQ on your order placing?	☐ YES	☐ NO (→Please go to Question 1.8)
1.2	Do you have different MOQs for different products?	☐ YES	☐ NO
1.3	With the same supplier for the same product, do you have the same MOQ every time?	☐ YES	☐ NO

1.4 In general, the setting of MOQ is:

☐ determined by suppliers ☐ through negotiation between you and suppliers
☐ others (please specify): ____

1.5 What is the % of product styles having the MOQ requirement? ______ %

1.6 *On average*, for every single product style, its MOQ is around ______% of the order quantity.

1.7 Please rate the frequency of not ordering a product style owing to MOQ requirement:

Never <--- 1 2 3 4 5 6 7 ---> Every time

Please rate the degree of your agreement with the following statements:

		Strongly disagree						*Strongly agree*
1.8	We do not object MOQ imposition.	1	2	3	4	5	6	7
1.9	MOQ imposition adversely affects our relationship with the supplier.	1	2	3	4	5	6	7
1.10	MOQ imposition worsens our profit.	1	2	3	4	5	6	7
1.11	We are willing to accept MOQ if the supplier can reduce the order lead time.	1	2	3	4	5	6	7

In the following sections, please consider one particular supplier with whom you most frequently have business contacts.

B2. Quick Response (QR)* Adoption

**Quick Response (QR) strategy consists of a set of actions that aims at <u>reducing the lead time</u> in a supply chain.*

Please indicate the level of implementation of the following systems/practices in your company:

		No adoption						High-level adoption
2.1	Internet is used to communicate with the supplier.	1	2	3	4	5	6	7
2.2	Electronic data interchange (EDI) is used for placing orders to the supplier.	1	2	3	4	5	6	7
2.3	Stock is fully labelled including bar codes by the supplier.	1	2	3	4	5	6	7
2.4	Automatic replenishment processes.	1	2	3	4	5	6	7
2.5	On-line electronic communications are used between head office and stores.	1	2	3	4	5	6	7

QR-MOQ_v2 p.1

		No adoption						High-level adoption
2.6	On-line electronic communications are used between head office and distribution centres/warehouses.	1	2	3	4	5	6	7
2.7	Purchases are made in small lots.	1	2	3	4	5	6	7
2.8	Advanced delivery notices are used.	1	2	3	4	5	6	7
2.9	Stock is made floor-ready in the distribution centres / warehouses.	1	2	3	4	5	6	7
2.10	Cross-stocking[#] is part of the operations.	1	2	3	4	5	6	7
2.11	Small amounts of inventory are kept in the system.	1	2	3	4	5	6	7
2.12	Delivery containers (e.g. carton boxes) marked with barcode for quick cross reference and confirmation receipt.	1	2	3	4	5	6	7
2.13	We have close relationships with the supplier.	1	2	3	4	5	6	7
2.14	The supplier has facilities for of short-cycle manufacturing.	1	2	3	4	5	6	7
2.15	We have QR teams to meet with the supplier.	1	2	3	4	5	6	7
2.16	The supplier receives stock-out data from us.	1	2	3	4	5	6	7
2.17	The supplier receives sales data from us.	1	2	3	4	5	6	7
2.18	Bar code scanning for SKU.	1	2	3	4	5	6	7
2.19	Daily small shipments from distribution centres / warehouses to stores.	1	2	3	4	5	6	7
2.20	On-line electronic communications are used between distribution centres / warehouses to stores.	1	2	3	4	5	6	7

[#] *Cross-docking refers to the arrangement that products are moved directly from the inbound loading docks to the outbound loading docks without being placed in storage.*

B3. Buyer-Supplier Relationship

3.1 How many years of experience do you have in buying merchandises from this supplier? __________ years

3.2 What percentage of the volume of your merchandises is purchased from this supplier? ______ %

3.3 Does this supplier impose MOQ on your order? ☐ YES ☐ NO(→Please go to Question 3.5)

3.4 What percentage of the product styles from this supplier have MOQ requirement? ______ %

Please describe your feelings with respect to the outcomes with this supplier in the past one year.

3.5	Pleased	<---	1	2	3	4	5	6	7	--->	Displeased
3.6	Sad	<---	1	2	3	4	5	6	7	--->	Happy
3.7	Contented	<---	1	2	3	4	5	6	7	--->	Disgusted
3.8	Dissatisfied	<---	1	2	3	4	5	6	7	--->	Satisfied

Please rate your degree of agreement with the following statements:

		Strongly disagree						Strongly agree
3.9	If our relationship was discontinued with this supplier, we would have difficulty in making up the sales volume in our trading area.	1	2	3	4	5	6	7
3.10	This supplier is crucial to our future performance.	1	2	3	4	5	6	7
3.11	It would be difficult for us to replace this supplier.	1	2	3	4	5	6	7
3.12	We are dependent on this supplier's resource.	1	2	3	4	5	6	7
3.13	We do not have a good alternative to this supplier.	1	2	3	4	5	6	7
3.14	This supplier is important to our business.	1	2	3	4	5	6	7
3.15	We are important to this supplier.	1	2	3	4	5	6	7
3.16	We are a major outlet for this supplier in our trading area.	1	2	3	4	5	6	7
3.17	If we discontinued buying from this supplier, this supplier would have difficulty making up the sales volume in our trading area.	1	2	3	4	5	6	7

Please consider one representative from this supplier with whom you most frequently contact in rating your agreement to the following statements:

		Strongly disagree						Strongly agree
3.18	This representative has been frank in dealing with us.	1	2	3	4	5	6	7
3.19	Promises made by this representative are reliable.	1	2	3	4	5	6	7
3.20	This representative is knowledgeable about his/her products.	1	2	3	4	5	6	7
3.21	If problems (such as shipment delays) arise, this representative is honest about the problems.	1	2	3	4	5	6	7
3.22	This representative has problems answering our questions.	1	2	3	4	5	6	7

B4. Performance

Compared with your company's competitors (those with the similar business scales and scopes as your company), please indicate your company's position on the following dimensions:

		Significantly lower			Equal			Significantly higher
4.1	Market share	1	2	3	4	5	6	7
4.2	Sales growth	1	2	3	4	5	6	7

4.3 The annual earnings growth from last year:
- ☐ Decreased by more than 20% ☐ Decreased by 11-20% ☐ Decreased by 6-10%
- ☐ Decreased by 1-5% ☐ No change ☐ Increased by 1-5%
- ☐ Increased by 6-10% ☐ Increased by 11-20% ☐ Increased by more than 20%

4.4 Does your company have any large-scaled lead-time reduction programme implemented over the past 10 years? ☐ YES ☐ NO (→Please go to B5)

4.5 Please rate the impact of this programme to your company's profit:

Significant decrease in profit <--- 1 2 3 4 5 6 7 ---> Significant increase in profit

B5. Respondent's company profile

5.1 Company name: ____ (for record only)

5.2 No. of employees: ☐ Less than 100 ☐ 100-500 ☐ 501-1000 ☐ 1,001-3,000 ☐ More than 3,000

5.3 Annual sales revenue: ☐ Less than HK$100M ☐ HK$101M – 500M ☐ HK$501M-1,000M ☐ HK$1,001M-3,000M ☐ More than HK$3,000M

5.4 % of merchandises that are bought from the largest supplier _____%

Section C: <u>To be completed by the supplier only</u>

C1. Imposition of Minimum Order Quantity (MOQ)

1.1 Do you impose any MOQ on your buyers' orders? ☐ YES ☐ NO (→Please go to Question 1.8)

1.2 Do you have different MOQs for different products? ☐ YES ☐ NO

1.3 With the same buyer for the same product, do you have the same MOQ every time? ☐ YES ☐ NO

1.4 In general, the setting of MOQ is:
- ☐ determined by you ☐ through negotiation between you and buyers
- ☐ others (please specify): ____

1.5 What is the % of product styles having the MOQ requirement? ______%

1.6 *On average*, for every single product style, its MOQ is around ______% of the production quantity.

1.7 Please indicate the factors that you consider when setting the MOQ for a product style (you may choose more than one option):
- ☐ Production capacity ☐ MOQ for material ordering ☐ Bulk order discount for materials
- ☐ Production cost ☐ Following industrial norm ☐ Economy of scale in transportation
- ☐ others (please specify): ____

Please rate the degree of your agreement with the following statements:

		Strongly disagree						Strongly agree
1.8	We prefer imposing MOQ on all buyers.	1	2	3	4	5	6	7
1.9	MOQ imposition adversely affects our relationship with the buyer.	1	2	3	4	5	6	7
1.10	MOQ imposition worsens our profit.	1	2	3	4	5	6	7
1.11	We are willing to adopt QR strategy if the buyer accepts our MOQ imposition.	1	2	3	4	5	6	7

In the following sections, please consider one particular buyer with whom you most frequently have business contacts.

C2. Quick Response (QR)* Adoption

**Quick Response (QR) strategy consists of a set of actions that aims at reducing the lead time in a supply chain.*

Please indicate the level of implementation of the following systems/practices in your company:

		No adoption						High-level adoption
2.1	Internet is used to communicate with the buyer.	1	2	3	4	5	6	7
2.2	Electronic data interchange (EDI) is used for receiving orders from the buyer.	1	2	3	4	5	6	7
2.3	We provide full labels including bar codes.	1	2	3	4	5	6	7
2.4	Automatic replenishment processes.	1	2	3	4	5	6	7
2.5	On-line electronic communications are used between head office and factories.	1	2	3	4	5	6	7
2.6	On-line electronic communications are used between head office and distribution centres / warehouses.	1	2	3	4	5	6	7
2.7	We accept the buyer to purchase in small lots.	1	2	3	4	5	6	7
2.8	Advanced delivery notices are used.	1	2	3	4	5	6	7
2.9	Stock is made floor-ready in the distribution centres / warehouses.	1	2	3	4	5	6	7
2.10	Cross-stocking[#] is part of the operations.	1	2	3	4	5	6	7
2.11	Small amounts of inventory are kept in the system.	1	2	3	4	5	6	7
2.12	Delivery containers (e.g. carton boxes) marked with barcode for quick cross reference and confirmation receipt.	1	2	3	4	5	6	7
2.13	We have close relationships with the buyer.	1	2	3	4	5	6	7
2.14	We have facilities for of short-cycle manufacturing.	1	2	3	4	5	6	7
2.15	We have QR teams to meet with the buyer.	1	2	3	4	5	6	7
2.16	We receive stock-out data from the buyer.	1	2	3	4	5	6	7
2.17	We receive sales data from the buyer.	1	2	3	4	5	6	7

[#] *Cross-docking refers to the arrangement that products are moved directly from the inbound loading docks to the outbound loading docks without being placed in storage.*

C3. Buyer-Supplier Relationship

3.1	How many years of experience do you have in selling merchandises to this buyer?	__________ years
3.2	What percentage of the volume of your merchandises is sold to this buyer?	______ %
3.3	Do you impose MOQ on this buyer's orders?	☐ YES ☐ NO(→Please go to Question 3.5)
3.4	What percentage of the product styles that you offer to this buyer have MOQ requirement?	______ %

Please describe your feelings with respect to the outcomes with this buyer in the past one year.

3.5	Pleased	<---	1	2	3	4	5	6	7	--->	Displeased
3.6	Sad	<---	1	2	3	4	5	6	7	--->	Happy
3.7	Contented	<---	1	2	3	4	5	6	7	--->	Disgusted
3.8	Dissatisfied	<---	1	2	3	4	5	6	7	--->	Satisfied

Please rate your degree of agreement with the following statements:

		Strongly disagree						Strongly agree
3.9	If our relationship was discontinued with this buyer, we would have difficulty in making up the sales volume in the concerned product category.	1	2	3	4	5	6	7
3.10	This buyer is crucial to our future performance.	1	2	3	4	5	6	7
3.11	It would be difficult for us to replace this buyer.	1	2	3	4	5	6	7
3.12	We are dependent on this buyer's order for sales in the concerned product category.	1	2	3	4	5	6	7
3.13	We do not have a good alternative to this buyer.	1	2	3	4	5	6	7
3.14	This buyer is important to our business.	1	2	3	4	5	6	7
3.15	We are important to this buyer.	1	2	3	4	5	6	7
3.16	We are a major source for this buyer in the concerned product category.	1	2	3	4	5	6	7
3.17	If we discontinued supplying to this buyer, this buyer would have difficulty making up the sales volume in the concerned product category.	1	2	3	4	5	6	7

Please consider one representative from this buyer with whom you most frequently contact in rating your agreement to the following statements:

		Strongly disagree						Strongly agree
3.18	This representative has been frank in dealing with us.	1	2	3	4	5	6	7
3.19	Promises made by this representative are reliable.	1	2	3	4	5	6	7
3.20	This representative is knowledgeable about his/her products.	1	2	3	4	5	6	7
3.21	This representative does not make false claims.	1	2	3	4	5	6	7
3.22	This representative has problems understanding our positions.	1	2	3	4	5	6	7

C4. Company Performance

Compared with your company's competitors (those with the similar business scales and scopes as your company), please indicate your company's position on the following dimensions:

		Significantly lower			Equal			Significantly higher
4.1	Market share	1	2	3	4	5	6	7
4.2	Sales growth	1	2	3	4	5	6	7

4.3 The annual earnings growth from last year:

☐ Decreased by more than 20% ☐ Decreased by 11-20% ☐ Decreased by 6-10%
☐ Decreased by 1-5% ☐ No change ☐ Increased by 1-5%
☐ Increased by 6-10% ☐ Increased by 11-20% ☐ Increased by more than 20%

4.4 Does your company have any large-scaled lead-time reduction programme implemented over the past 10 years? ☐ YES ☐ NO (→Please go to C5)

4.5 Please rate the impact of this programme to your company's profit:

Significant decrease in profit <--- 1 2 3 4 5 6 7 ---> Significant increase in profit

C5. Respondent's company profile

5.1 Company name: ____ (for record only)

5.2 No. of employees: ☐ Less than 100 ☐ 100-500 ☐ 501-1000 ☐ 1,001-3,000 ☐ More than 3,000

5.3 Annual sales revenue: ☐ Less than HK$100M ☐ HK$101M – 500M ☐ HK$501M-1,000M ☐ HK$1,001M-3,000M ☐ More than HK$3,000M

5.4 % of merchandises sold to the largest buyer _______%

~ ***End of questionnaire. Thank you!*** ~

APPENDIX C

-- Tables and Figures for Survey Analysis

Fig. 4.5.1. Result structure of the second-order latent variable, Relationship – Supplier respondents [Goodness-of-fit under concern].

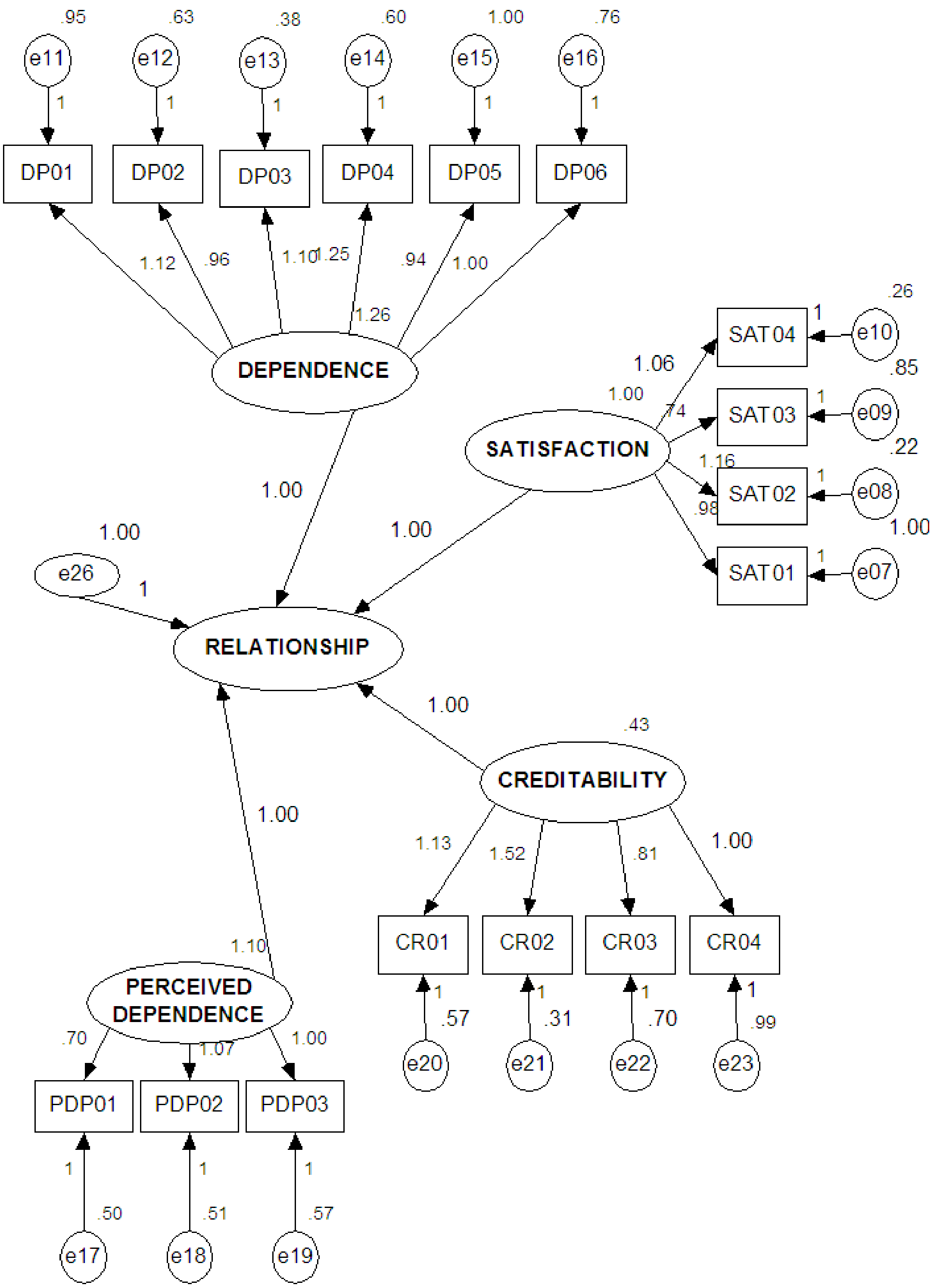

Fig. 4.5.2. Result structure of the QR-MOQ model – Supplier respondents [Poor goodness-of-fit results].

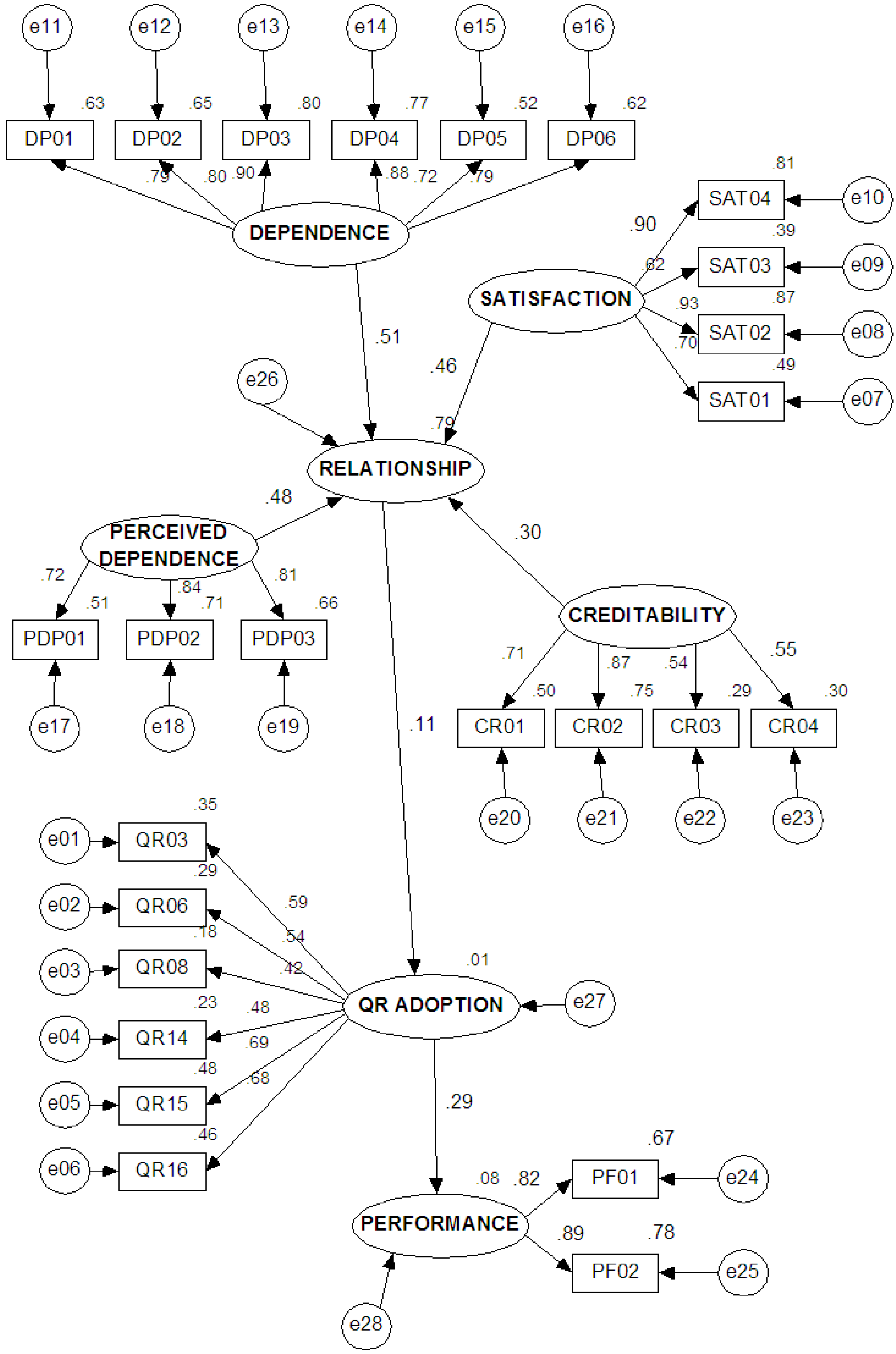

Table 4.5.1. Profile of survey respondents.

Metric	Buyer		Supplier		Total	
	No.	%	No.	%	No.	%
Business nature*:						
Retailer	35	47%	4	7%	39	29%
Wholesaler	12	16%	3	5%	15	11%
Distributor	3	4%	2	3%	5	4%
Buying office	16	22%	3	5%	19	14%
Trading firm	4	5%	10	16%	14	10%
Manufacturer	2	3%	37	61%	39	29%
Others	2	3%	2	3%	4	3%
Respondent's job position:						
Director/Owner	5	9%	9	16%	14	12%
Manager	17	29%	32	57%	49	43%
Executive/Officer	29	49%	8	14%	37	32%
Others/Not provided	8	14%	7	13%	15	13%
Number of employees:						
Less than 100	17	29%	18	32%	35	30%
100-500	21	36%	13	23%	34	30%
501-1000	8	14%	6	11%	14	12%
1000-3000	5	9%	11	20%	16	14%
More than 3000	8	14%	7	13%	15	13%
Not provided	0	0%	1	2%	1	1%
Annual sales revenue:						
Less than HK$100 million	5	8%	8	14%	13	11%
HK$101-500 million	7	12%	14	25%	21	18%
HK$501-1000 million	7	12%	12	21%	19	17%
HK$1001-3000 million	10	17%	11	20%	21	18%
More than HK$3000 million	17	29%	7	13%	24	21%
Not provided	13	22%	4	7%	17	15%

** Respondents may have multiple business natures.*

Table 4.5.2. Practice of MOQ imposition in respondents' companies.

	Buyer		Supplier		Total	
	Freq.	%	Freq.	%	Freq.	%
Have MOQ imposition?						
YES	52	88%	51	91%	103	90%
NO	7	12%	5	9%	12	10%
Different MOQs for different products?						
YES	50	96%	42	82%	92	89%
NO	1	2%	8	16%	9	9%
Not provided	1	2%	1	2%	2	2%
Same MOQ for same product every time?						
YES	31	60%	29	57%	60	58%
NO	20	38%	21	41%	41	40%
Not provided	1	2%	1	2%	2	2%
Who sets the MOQ?						
Determined by supplier	24	46%	20	39%	44	43%
Through negotiation	26	50%	24	47%	50	49%
Others/Not provided	2	4%	7	14%	9	9%
% of products having MOQ:						
<30%	9	17%	7	14%	16	16%
30-50%	9	17%	4	8%	13	13%
51-80%	8	16%	11	22%	19	18%
81-99%	6	12%	5	10%	11	11%
100%	17	33%	21	41%	38	37%
Not provided	3	6%	3	6%	6	6%
Average MOQ per style (compared with order qty / production qty)						
<30%	12	23%	17	33%	29	28%
30-50%	12	23%	7	14%	19	18%
51-80%	11	21%	10	20%	21	20%
81-99%	1	2%	3	6%	4	4%
100%	7	13%	5	10%	12	12%
Over 100%		0%	1	2%	1	1%
Not provided	9	17%	8	16%	17	17%

Table 4.5.3. Factors affecting supplier's setting of MOQ..*

	Freq.	%
Production capacity	25	49%
MOQ for material ordering	41	80%
Bulk order discount for materials	11	22%
Production cost	24	47%
Following industrial norm	14	27%
Economy of scale in transportation	20	39%
Others	4	8%

** Respondents may choose multiple factors at the same time.*

Table 4.5.4. Result of One-sample t-test on the mean score of the frequency a buyer respondent cannot order owing to MOQ requirement.

	Mean	s.d.	Test Value = 4					
			t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Frequency of not ordering owning to MOQ requirement	3.65	1.422	-1.726	47	.091	-.354	-.77	.06

Table 4.5.5. Result of independent t-tests on the mean scores for the opinions on MOQ imposition between buyer and supplier respondents.

Statement		Mean	s.d.	t	df	Sig. (2-tailed)
(Buyer) We do not object MOQ imposition. / (Supplier) We prefer imposing MOQ on all buyers.	Buyer	4.25	1.24	-3.348	113	0.001**
	Supplier	5.18	1.696			
MOQ imposition adversely affects our relationship with the supplier/buyer.	Buyer	3.9	1.185	-0.43	113	0.668
	Supplier	4	1.348			
MOQ imposition worsens our profits.	Buyer	4.46	1.236	2.817	113	0.006**
	Supplier	3.71	1.581			
(Buyer) We are willing to accept MOQ if the supplier can reduce the order lead time. / (Supplier) We are willing to adopt QR strategy if the buyer accepts our MOW imposition.	Buyer	4.36	1.31	0.762	113	0.448
	Supplier	4.16	1.437			

*** Significant at 0.01 level.*

Table 4.5.6. Result of independent t-tests on the mean scores for the opinions on MOQ imposition between supplier respondents with MOQ imposition and those without MOQ..

Statement	MOQ imposition?	Mean	s.d.	t	df	Sig. (2-tailed)
We prefer imposing MOQ on all buyers.	Yes	5.33	1.633	2.261	54	0.028*
	No	3.6	1.673			
MOQ imposition adversely affects our relationship with the supplier/buyer.	Yes	3.98	1.378	-0.345	54	0.732
	No	4.2	1.095			
MOQ imposition worsens our profits.	Yes	3.71	1.628	-0.126	54	0.9
	No	3.8	1.095			
We are willing to adopt QR strategy if the buyer accepts our MOW imposition.	Yes	4.2	1.47	0.585	54	0.561
	No	3.8	1.095			

** Significant at 0.05 level*

Table 4.5.7. Classification of respondents with respective to annual sales revenue.

	Buyer		Supplier		Total	
	Freq.	%	Freq.	%	Freq.	%
High (> HK$1000 M)	27	47%	18	32%	45	39%
Low (≦ HK$1000 M)	18	31%	34	61%	52	46%
Unclassified (Not provided)	13	22%	4	7%	17	15%
Total	**58**	**100%**	**56**	**100%**	**114**	**100%**

Table 4.5.8(a). Mean and standard deviation (s.d.) of the scores of individual items - Supplier.

Item	High-sale Supplier		Low-sale Supplier		Unclassified Supplier	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
QR01	5.83	1.72	5.91	1.44	3.75	3.20
QR02	4.89	2.25	3.26	2.06	2.75	1.50
QR03	4.44	2.20	4.12	2.21	4.00	2.94
QR04	5.06	1.92	2.82	1.98	4.00	2.94
QR05	5.00	2.11	4.26	2.30	4.25	2.50
QR06	4.94	1.83	4.29	2.13	3.00	1.83
QR07	4.06	1.55	4.56	1.62	5.00	2.00
QR08	4.44	1.76	4.29	2.05	4.00	2.45
QR09	4.89	1.68	3.91	1.90	3.00	1.83
QR10	4.61	2.15	3.50	2.00	3.25	1.71
QR11	4.78	1.63	4.06	1.97	4.75	1.89
QR12	5.39	2.06	4.03	2.11	2.25	1.26
QR13	5.89	1.41	5.26	1.58	5.75	1.50
QR14	4.67	1.72	4.91	1.29	4.00	1.41
QR15	4.50	1.89	3.62	1.86	2.25	0.96
QR16	4.44	1.92	3.21	1.97	4.00	2.58
QR17	4.61	1.94	3.18	1.83	4.50	2.52
SAT01*	4.44	1.25	4.88	1.53	5.25	0.96
SAT02	4.89	1.02	5.03	1.43	5.00	0.82
SAT03*	4.50	1.20	4.79	1.23	4.75	0.96
SAT04	5.11	1.08	5.09	1.29	5.25	0.96
DP01	4.50	1.58	4.91	1.66	4.75	1.50
DP02	5.00	1.28	5.06	1.46	5.25	0.96
DP03	4.72	1.13	4.56	1.52	5.25	1.50
DP04	4.28	1.32	4.76	1.71	5.00	2.16

DP05	4.06	1.39	3.85	1.46	5.00	1.83
DP06	5.22	1.44	5.18	1.49	6.25	0.50
PDP01	4.89	1.13	5.00	0.95	5.50	1.29
PDP02	4.78	1.11	4.65	1.43	5.25	1.71
PDP03	4.44	1.25	4.32	1.27	4.75	2.06
CR01	4.67	1.03	4.71	1.06	5.50	1.29
CR02	4.83	1.10	5.12	1.18	5.50	1.29
CR03	4.94	0.80	4.82	1.06	5.25	1.50
CR04	4.50	1.20	4.65	1.25	4.00	0.82
CR05*	4.06	1.63	3.94	1.46	4.00	0.82
PF01	4.72	1.02	4.12	1.13	3.75	1.26
PF02	4.72	0.67	4.03	1.22	4.25	0.50
PF03	6.29	2.23	6.21	2.27	5.00	4.24

** The score is reversed owing to reversed wordings.*

Table 4.5.8(b). Mean and standard deviation (s.d.) of the scores of individual items - Buyer.

Item	High-sale Buyer		Low-sale Buyer		Unclassified Buyer	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
QR01	5.33	2.02	5.83	1.51	5.85	0.90
QR02	4.07	2.04	3.72	1.90	4.00	1.63
QR03	4.89	1.97	3.56	2.18	5.69	1.75
QR04	3.44	2.06	3.22	1.77	3.15	1.99
QR05	5.00	1.73	4.50	1.62	5.08	1.55
QR06	5.00	1.71	4.83	1.51	4.62	1.85
QR07	3.89	1.25	4.44	1.34	4.08	1.04
QR08	4.59	1.47	4.83	1.76	4.69	1.38
QR09	4.89	1.25	4.50	1.76	5.08	1.19
QR10	4.33	2.13	3.89	2.11	3.00	1.68
QR11	4.22	1.45	4.44	1.46	4.23	1.54
QR12	5.04	1.99	4.11	1.75	4.46	1.66
QR13	5.41	1.47	5.72	0.90	5.23	1.48
QR14	4.74	1.23	4.44	1.29	3.85	1.46
QR15	3.70	2.04	3.33	1.50	3.69	1.84
QR16	3.26	1.93	3.06	2.01	3.54	1.76
QR17	2.81	1.94	3.17	1.89	3.15	1.73
QR18	5.93	1.33	5.83	1.62	6.23	0.73
QR19	4.19	2.13	4.72	1.13	4.54	1.76

QR20	4.74	1.97	5.06	1.59	5.15	1.52
SAT01*	4.67	1.49	4.33	0.97	4.46	1.13
SAT02	4.93	1.24	4.39	1.04	4.54	1.13
SAT03*	4.59	1.45	4.56	0.78	4.54	0.97
SAT04	4.81	1.30	4.22	1.06	4.46	1.13
DP01	4.74	1.32	4.39	1.20	4.31	1.44
DP02	5.19	1.15	5.00	1.09	4.92	0.95
DP03	5.00	1.27	4.33	1.41	4.08	1.19
DP04	4.89	0.93	4.39	1.58	4.15	1.07
DP05	4.07	1.30	4.28	1.49	3.54	0.97
DP06	5.30	1.03	4.94	1.35	4.69	0.63
PDP01	5.56	0.89	4.83	1.20	4.69	1.18
PDP02	5.07	1.17	4.33	1.50	4.69	1.18
PDP03	4.74	1.29	4.50	1.38	4.23	1.42
CR01	4.89	0.97	4.17	0.92	3.92	1.04
CR02	4.96	0.98	4.44	0.78	4.08	0.95
CR03	5.15	1.10	4.89	0.90	4.62	0.65
CR04	5.00	1.33	4.61	0.92	4.15	0.99
CR05*	3.74	1.35	3.67	1.03	4.00	1.35
PF01	4.81	1.04	3.72	0.96	4.08	1.38
PF02	4.74	1.16	3.94	1.11	4.23	1.09
PF03	6.33	2.48	6.31	1.66	7.00	1.18

** The score is reversed owing to reversed wordings.*

Table 4.5.9(a). Mean and standard deviation of scores on QR items – Buyer respondents.

			Test Value = 4		
	Mean	s.d.	t	df	Sig. (2-tailed)
QR01	5.61	1.651	7.493	58	0.000 *
QR02	3.97	1.875	-0.139	58	0.890
QR04	3.36	1.945	-2.543	58	0.014
QR05	4.88	1.641	4.126	58	0.000 *
QR06	4.88	1.651	4.099	58	0.000 *
QR07	4.14	1.252	0.832	58	0.409
QR08	4.69	1.511	3.531	58	0.001 *
QR09	4.81	1.395	4.478	58	0.000 *
QR10	3.92	2.053	-0.317	58	0.752
QR11	4.31	1.441	1.626	58	0.109
QR12	4.64	1.855	2.667	58	0.010 *
QR13	5.47	1.305	8.682	58	0.000 *
QR14	4.46	1.317	2.668	58	0.010 *
QR15	3.58	1.802	-1.806	58	0.076
QR16	3.25	1.881	-3.046	58	0.003
QR17	3.00	1.838	-4.178	58	0.000
QR18	5.93	1.324	11.207	58	0.000 *
QR19	4.44	1.764	1.919	58	0.060 *
QR20	4.93	1.731	4.137	58	0.000 *

** Mean scores significantly greater than 4 (at 0.05 level).*

Table 4.5.9(b). Mean and standard deviation of scores on QR items – Supplier respondents.

			Test Value = 4		
	Mean	s.d.	t	df	Sig. (2-tailed)
QR01	5.73	1.742	7.439	55	0.000 *
QR03	4.21	2.222	0.722	55	0.473
QR05	4.5	2.24	1.67	55	0.101
QR06	4.41	2.043	1.504	55	0.138
QR07	4.43	1.616	1.984	55	0.052
QR08	4.32	1.955	1.23	55	0.224
QR09	4.16	1.876	0.641	55	0.524
QR10	3.84	2.069	-0.581	55	0.564
QR11	4.34	1.861	1.364	55	0.178
QR13	5.5	1.526	7.358	55	0.000 *
QR14	4.77	1.44	3.992	55	0.000 *
QR15	3.8	1.892	-0.777	55	0.440
QR16	3.66	2.039	-1.246	55	0.218

** Mean scores significantly greater than 4 (at 0.05 level).*

Table 4.5.10. Level of QR Adoption for retailer respondents - our survey v.s. Birtwistle et al. (2003).

Stage		Item	Our Survey (2010) 39 retailers		Birtwistle et al. (2003) All retailers (30)	Birtwistle et al. (2003) Multiple retailers (16)
			Mean*	s.d.	Mean*	Mean*
1	QR18	Bar code scanning for SKU.	6.00	1.31	4.68	4.67
1	QR01	Internet is used to communicate with the supplier/buyer.	5.90	1.31	2.71	3.47
1	QR02	Electronic data interchange (EDI) is used for order placing.	3.72	1.89	2.45	3.33
2	QR03	Stock is fully labelled including bar codes by the supplier	4.28	2.33	4.28	4.67
2	QR04	Automatic replenishment processes	3.49	2.05	4.03	4.27
2	QR05	On-line electronic communications are used between head office and store.	4.85	1.77	3.90	4.27
2	QR06	On-line electronic communications are used between head office and distribution centres.	4.95	1.70	3.68	4.20
2	QR07	Purchases are made in small lots.	4.54	1.17	3.48	3.93
2	QR08	Advanced delivery notices are used.	4.74	1.57	3.10	2.93
2	QR19	Daily small shipments from distribution centres to stores.	4.89	1.57	2.93	3.40
2	QR09	Stock is made floor-ready in the distribution centres	4.62	1.70	2.81	2.47
2	QR20	On-line electronic communications are used between distribution centres to stores.	5.23	1.50	2.77	3.07
2	QR10	Cross-stocking is part of the operations.	3.69	2.02	2.77	2.87
2	QR11	Small amounts of inventory are kept in the system.	4.44	1.60	2.70	3.13
2	QR12	Delivery containers (e.g. carton boxes) marked with barcode for quick cross reference and confirmation receipt.	3.95	1.82	2.37	2.87
3	QR13	We have close relationships with the supplier.	5.31	1.52	4.00	4.07
3	QR14	The supplier has facilities for of short-cycle manufacturing.	4.41	1.37	2.80	3.30
3	QR15	We have QR teams to meet with the supplier/buyer.	3.85	1.63	2.78	2.54
3	QR16	We provide stock-out data to the supplier.	3.21	1.92	2.52	2.46
3	QR17	We provide sales data to the supplier.	3.13	1.87	2.21	2.29

** The measurement scale adopted in our survey is based on the 7-point Likert scale whereas that for Birtwistle et al. (2003) is based on the 5-point Likert scale.*

Table 4.5.11(a). Items employed for various constructs – Supplier.

Construct	Cronbach's alpha		Item
QR Adoption (QR)	0.874	QR03	We provide full labels including bar codes
		QR06	On-line electronic communications are used between head office and distribution centres/warehouses.
		QR08	Advanced delivery notices are used.
		QR14	We have facilities for of short-cycle manufacturing.
		QR15	We have QR teams to meet with the buyer.
		QR16	We receive stock-out data from the buyer.
Satisfaction (SAT)	0.874	SAT01	Satisfaction to Past Outcome - Pleased to Displeased (reversed)
		SAT02	Satisfaction to Past Outcome - Sad to Happy
		SAT03	Satisfaction to Past Outcome - Contented to Disgusted (reversed)
		SAT04	Satisfaction to Past Outcome - Dissatisfied to Satisfied
Dependence (DP)	0.920	DP01	We would have difficulty in making up the sales volume if our relationship was discontinued with this buyer.
		DP02	This buyer is crucial to our future performance.
		DP03	It would be difficult for us to replace this buyer.
		DP04	We are dependent on this buyer's orders.
		DP05	We do not have a good alternative to this buyer.
		DP06	This buyer is important to our business.
Perceived Dependence (PDP)	0.830	PDP01	We are important to this buyer.
		PDP02	We are a major source for this buyer in the concerned product category.
		PDP03	This buyer would have difficulty making up the sales volume if we discontinued supplying to this buyer.
Creditability (CR)	0.752	CR01	This representative has been frank in dealing with us.
		CR02	Promises made by this representative are reliable.
		CR03	This representative is knowledgeable about his/her products.
		CR04	This representative does not make false claims.
Performance (PF)	0.845	PF01	Performance - perceived market share
		PF02	Performance - perceived sales growth

Table 4.5.11(b). Items employed for various constructs – High-sale Buyer.

Construct	Cronbach's alpha		Item
QR Adoption (QR)	0.863	QR02	Electronic data interchange (EDI) is used for order placing.
		QR04	Automatic replenishment processes
		QR06	On-line electronic communications are used between head office and distribution centres/warehouses.
		QR07	Purchases are made in small lots.
		QR08	Advanced delivery notices are used.
		QR10	Cross-stocking is part of the operations.
		QR11	Small amounts of inventory are kept in the system.
		QR15	We have QR teams to meet with the supplier.
		QR16	We provide stock-out data to the supplier.
		QR17	We provide sales data to the supplier.
		QR20	(Buyer only) On-line electronic communications are used between distribution centres / warehouses to stores.
Satisfaction (SAT)	0.877	SAT01	Satisfaction to Past Outcome - Pleased to Displeased (reversed)
		SAT02	Satisfaction to Past Outcome - Sad to Happy
		SAT03	Satisfaction to Past Outcome - Contented to Disgusted (reversed)
		SAT04	Satisfaction to Past Outcome - Dissatisfied to Satisfied
Dependence (DP)	0.874	DP01	We would have difficulty in making up the sales volume if our relationship was discontinued with this supplier.
		DP02	This supplier is crucial to our future performance.
		DP03	It would be difficult for us to replace this supplier.
		DP04	We are dependent on this supplier’s resource.
		DP05	We do not have a good alternative to this supplier.
		DP06	This supplier is important to our business.
Perceived Dependence (PDP)	0.815	PDP01	We are important to this supplier
		PDP02	We are a major outlet for this supplier in our trading area
		PDP03	This supplier would have difficulty making up the sales volume if we discontinued buying from this supplier.
Creditability (CR)	0.720	CR01	This representative has been frank in dealing with us.
		CR02	Promises made by this representative are reliable.
		CR03	This representative is knowledgeable about his/her products.
		CR04	If problems (such as shipment delays) arise, this representative is honest about the problem.
Performance (PF)	0.845	PF01	Performance - perceived market share
		PF02	Performance - perceived sales growth

Table. 4.5.12. Evaluation of goodness-of-fit of various constructs – Supplier respondents.

Construct	Items	χ^2 Test		RMSEA	GFI	CFI
		d.f.	Minimum fit p-value			
QR Adoption (QR)	6	9	0.003	0.177	0.876	0.770
Satisfaction (SAT)	4	2	0.001	0.321	0.914	0.913
Dependence (DP)	6	9	0.156	0.091	0.933	0.982
Perceived Dependence (PDP)	3	0	N/A	N/A	1.000	1.000
Creditability (CR)	4	2	0.613	0.000	0.991	1.000
Performance (PF)	2	0	N/A	N/A	1.000	1.000

Table 4.5.13. Estimates of regression weights on the fitted structural model – Supplier respondents [Poor goodness-of-fit test results]

			Estimate	S.E.	C.R.	P	Standard Estimate
REL	<---	DP	1.000				.510
REL	<---	SAT	1.000				.457
REL	<---	PDP	1.000				.481
REL	<---	CRE	1.000				.300
QR	<---	REL	.053	.085	.624	.532	.115
PF	<---	QR	.271	.155	1.750	.080	.287
CR03	<---	CRE	.815	.267	3.049	.002	.539
CR02	<---	CRE	1.502	.411	3.658	***	.866
CR01	<---	CRE	1.140	.316	3.611	***	.709
CR04	<---	CRE	1.000				.551
SAT03	<---	SAT	.733	.148	4.964	***	.622
SAT02	<---	SAT	1.157	.133	8.707	***	.930
SAT01	<---	SAT	.983	.169	5.805	***	.702
SAT04	<---	SAT	1.054	.128	8.235	***	.898
PDP03	<---	PDP	1.000				.815
PDP02	<---	PDP	1.067	.191	5.576	***	.845
PDP01	<---	PDP	.692	.133	5.190	***	.716
DP01	<---	DP	1.130	.175	6.443	***	.792
DP02	<---	DP	.967	.147	6.571	***	.804
DP03	<---	DP	1.107	.146	7.571	***	.896
DP04	<---	DP	1.256	.171	7.359	***	.877
DP05	<---	DP	.942	.164	5.758	***	.724
DP06	<---	DP	1.000				.787
QR16	<---	QR	1.358	.277	4.907	***	.678
QR15	<---	QR	1.286	.256	5.024	***	.691
QR14	<---	QR	.685	.206	3.330	***	.483
QR08	<---	QR	.814	.283	2.874	.004	.423
QR06	<---	QR	1.078	.288	3.747	***	.537
QR03	<---	QR	1.286	.309	4.168	***	.589
PF01	<---	PF	1.000				.816
PF02	<---	PF	1.000				.885

Table 4.5.14. Result of regression analysis for the relationship between QR adoption and various Relationship-related independent variables – Supplier respondents

	Un-standardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	2.827	1.338		2.113	0.040*
Satisfaction	0.156	0.179	0.13	0.868	0.389
Dependence	-0.022	0.143	-0.021	-0.152	0.880
Perceived Dependence	0.089	0.174	0.074	0.515	0.609
Creditability	0.06	0.239	0.039	0.252	0.802

Note: $R^2 = 0.031$ *; p-value for F change =0.803.; *: significant at 0.05 level*

Table 4.5.15. Result of regression analysis for the relationship between Performance and QR adoption – Supplier respondents

	Un-standardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	3.208	0.474		6.765	0.000*
QR adoption	0.221	0.108	0.267	2.04	0.046*

Note: $R^2 = 0.072$ *; p-value for F change =0.046.; * significant at 0.05 level.*

Table 4.5.16. Results of t-tests of the difference in various mean scores between supplier respondents with MOQ imposition and those without MOQ.

	MOQ imposition?	Mean	s.d.	t	df	Sig. (2-tailed)
QR (Supplier)	Yes	4.35	1.235	1.918	52	0.061
	No	3.53	1.404			
Satisfaction	Yes	4.93	1.085	-0.262	52	0.794
	No	5.02	0.855			
Dependence	Yes	4.78	1.238	0.286	52	0.776
	No	4.65	1.446			
Perceived Dependence	Yes	4.70	1.088	-0.245	52	0.807
	No	4.79	1.088			
Creditability	Yes	4.84	0.890	0.243	52	0.809
	No	4.77	0.693			
Performance	Yes	4.12	1.034	0.597	52	0.553
	No	3.91	0.995			

Table 4.5.17. Result of regression analysis for the relationship between QR adoption and various Relationship-related independent variables – High-sale buyer respondents

	Un-standardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	4.465	1.92		2.325	0.030*
Satisfaction	0.275	0.217	0.272	1.271	0.217
Dependence	-0.363	0.269	-0.281	-1.35	0.191
Perceived Dependence	-0.079	0.263	-0.064	-0.3	0.767
Creditability	0.066	0.288	0.05	0.228	0.822

Note: $R^2 = 0.148$ *; p-value for F change =0.450; *: significant at 0.05 level*

Table 4.5.18. Result of regression analysis for the relationship between Performance and QR adoption – High-sale buyer respondents

	Un-standardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	5.538	0.707		7.829	0.000*
QR adoption	-0.193	0.172	-0.219	-1.121	0.273

Note: $R^2 = 0.048$ *; p-value for F change =0.273.; * significant at 0.05 level.*

Table 4.5.19. Results of t-tests of the difference in various mean scores between high-sale buyer respondents with MOQ imposition and those without MOQ.

	MOQ imposition?	Mean	s.d.	t	df	Sig. (2-tailed)
QR (High-sale Buyer)	Yes	4.24	1.231	2.247	21.95	0.035*
	No	3.32	0.860			
Satisfaction	Yes	4.88	0.853	0.121	25	0.905
	No	4.83	1.096			
Dependence	Yes	5.20	0.984	0.603	25	0.552
	No	4.96	0.964			
Perceived Dependence	Yes	5.17	0.891	1.378	25	0.18
	No	4.67	0.884			
Creditability	Yes	5.17	0.891	1.378	25	0.18
	No	4.67	0.884			
Performance	Yes	4.56	1.013	-1.601	25	0.122
	No	5.22	1.034			

** Significant at 0.05 level*

Table 4.6.1 Summary of Hypothses Testing Result.

Hypothesis		Supplier	High-Sale Buyer
H1:	Good buyer-seller relationship facilitates MOQ imposition.	Not supported	Not supported
H2:	Good buyer-seller relationship has a direct positive impact on QR adoption.	Not supported	Not supported
H3m:	MOQ imposition encourages supplier's adoption of QR.	Not supported	N/A
H3r:	**QR adoption facilitates buyer's acceptance of MOQ imposition.**	N/A	**Supported**
H4:	Good buyer-seller relationship serves as a mediating factor between MOQ imposition and QR adoption.	Not supported	Not supported
H5m:	MOQ imposition has a positive effect on supplier's business performance.	Not supported	N/A
H5r:	MOQ imposition has an adverse effect on buyer's business performance.	N/A	Not supported
H6m:	**QR adoption has an adverse effect on supplier's business performance.**	**Not supported***	N/A
H6r:	QR adoption has a positive effect on buyer's business performance.	N/A	Not supported
H7:	QR adoption with MOQ imposition has a positive impact on an apparel company's performance.	Not supported	Not supported

* *Hypothesis H6m is not supported in the sense that there is statistically significant evidence to show that QR adoption has* ***positive*** *effect on a supplier's business performance.*

APPENDIX D

-- Mathematical Proofs

Proposition 6.1:

(a) $0 < \hat{\mu}_1^{QRS} < M_1 - \sigma_1 \Phi^{-1}(s_1)$;

(b) The optimal ordering quantity for the retailer under QRS-MOQ is given by:

(i) If $M_1 \le \sigma_1 \Phi^{-1}(s_1)$, $Q_1^{QRS} * = \hat{Q}_1^{QRS}$;

(ii) If $M_1 > \sigma_1 \Phi^{-1}(s_1)$,

$$Q_1^{QRS} * = \begin{cases} \hat{Q}_1^{QRS} = \mu_1 + \sigma_1 \Phi^{-1}(s_1) & \text{if } \mu_1 \ge M_1 - \sigma_1 \Phi^{-1}(s_1) \\ M_1 & \text{if } \hat{\mu}_1^{QRS} < \mu_1 < M_1 - \sigma_1 \Phi^{-1}(s_1) \\ 0 & \text{if } \mu_1 \le \hat{\mu}_1^{QRS} \end{cases} . \quad (6.6)$$

Proof of Proposition 6.1:

Differentiating $ER_1^{QRS}(M_1 | \mu_1) = J_R$ w.r.t. μ_1 shows that $ER_1^{QRS}(M_1 | \mu_1)$ is a strictly increasing function in μ_1.

(a) By simple manipulation we have: $ER_1^{QRS}(M_1 | \mu_1 = 0) < 0$ and $ER_1^{QRS}[M_1 | \mu_1 = M_1 - \sigma_1 \Phi^{-1}(s_1)] = ER_1^{QRS} * [M_1 - \sigma_1 \Phi^{-1}(s_1)] > J_R$. By the definition of $\hat{\mu}_1$, we have $0 < \hat{\mu}_1^{QRS} < M_1 - \sigma_1 \Phi^{-1}(s_1)$.

(b) With the monotonic property of $ER_1^{QRS}(M_1 | \mu_1)$ and the definition of $\hat{\mu}_1^{QRS}$, we have $ER_1^{QRS}(M_1 | \mu_1) \ge J_R$ for $\hat{\mu}_1^{QRS} \le \mu_1 < M_1 - \sigma_1 \Phi^{-1}(s_1)$, so the retailer is willing to order up to M_1 in this case. If $0 \le \mu_1 < \hat{\mu}_1^{QRS}$, then $ER_1^{QRS}(M_1 | \mu_1) < J_R$; therefore the retailer will not order anything in this case. (Q.E.D.)

Proposition 6.2:

(a) The expected profit that the retailer anticipates at Stage 0 under the QRS-MOQ system is a non-increasing function in M_1*;*

(b) The optimal MOQ for the retailer is given by: $0 \le M_1^{QRS,R*} \le \sigma_1 \Phi^{-1}(s_1)$.

Proof of Proposition 6.2:

(a) For $0 \le M_1 \le \sigma_1 \Phi^{-1}(s_1)$, the MOQ imposition would have no effect on the retailer's ordering decision [as $\mu_1 \ge 0 \ge M_1 - \sigma_1 \Phi^{-1}(s_1)$]. Thus the expected profit he anticipates at Stage 0 for this range of M_1 is always equal to $ER^{QRS}(\hat{Q}_1^{QRS})$. For $M_1 > \sigma_1 \Phi^{-1}(s_1)$, according to (6.6), the expected profit of the retailer that he anticipates at Stage 0 with the MOQ, M_1, is given by:

$$ER^{QRS-MOQ}(M_1)$$

$$= \int_{\hat{\mu}_1^{QRS}}^{M_1 - \sigma_1 \Phi^{-1}(s_1)} ER_1^{QRS}(M_1 | \mu_1) f(\mu_1) d\mu_1 + \int_{M_1 - \sigma_1 \Phi^{-1}(s_1)}^{\infty} ER_1^{QRS}(\hat{Q}_1^{QRS} | \mu_1) f(\mu_1) d\mu_1 .$$

Differentiate $ER^{QRS-MOQ}(M_1)$ w.r.t. M_1 gives:

$$dER^{QRS-MOQ} / dM_1$$

$$= (r - c_1)[\Phi(\xi_1) - \Phi(\rho_1)] - (r + h)\int_{\rho_1}^{\xi_1} \Phi[(M_1 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz ,$$

where $\rho_1 = (\hat{\mu}_1^{QRS} - \mu_0)/\sigma_\mu$, and $\xi_1 = [M_1 - \sigma_1 \Phi^{-1}(s_1) - \mu_0]/\sigma_\mu$.

For $z \in (-\infty, \xi_1)$, we have $\Phi[(M_1 - \mu_0 - \sigma_\mu z)/\sigma_1] > s_1$. So

$$\int_{\rho_1}^{\xi_1} \Phi[(M_1 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz > s_1[\Phi(\xi_1) - \Phi(\rho_1)].$$

Then,

$$dER^{QRS-MOQ} / dM_1 < (r - c_1)[\Phi(\xi_1) - \Phi(\rho_1)] - (r - c_1)[\Phi(\xi_1) - \Phi(\rho_1)] = 0$$

In other words, $ER^{QRS-MOQ}$ is strictly decreasing in M_1 for $M_1 > \sigma_1 \Phi^{-1}(s_1)$. Hence we have non-increasing property for the retailer's expected function under QR-MOQ system.

(b) The retailer would want to have M_1 as small as possible owing to the result in (a). On the other hand, notice that for $0 \leq M_1 \leq \sigma_1 \Phi^{-1}(s_1)$, the retailer can always order at his optimal quantity (because $\mu_1 > M_1 - \sigma_1 \Phi^{-1}(s_1)$ for all $\mu_1 \geq 0$ for this range of M_1). Hence it is most desirable for the retailer to have $0 \leq M_1^{QRS,,R} * \leq \sigma_1 \Phi^{-1}(s_1)$. (Q.E.D.)

Proposition 7.1:

Given $\hat{Q}_0^{QRD} < M_0$. We have:

(a) $EQ^{QRD-MOQ-I} > EQ^{QRD}$ for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$; and

(b) $EQ^{QRD-MOQ-I} \leq EQ^{QRD}$ for $\hat{Q}_0^{QRD} < \overline{Q}_0^{QRD} \leq M_0$.

Proof of Proposition 7.1:

(a) Suppose $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$.

Let $g(Q) = Q + \sigma_\mu \psi[\xi_2(Q)]$. Then, $g'(Q) = \Phi[(Q - \sigma_1 \Phi^{-1}(s_1) - \mu_0)/\sigma_\mu] > 0$.

Therefore, $g(Q)$ is an increasing function in Q.

Since $M_0 > \hat{Q}_0$, we have $EQ^{QRD-MOQ-I}(M_0) = g(M_0) > g(\hat{Q}_0^{QRD}) = EQ^{QRD}$.

(b) For $\hat{Q}_0^{QRD} < \overline{Q}_0^{QRD} \leq M_0$, consider:

$$EQ^{QRD-MOQ-I}(M_0) - EQ^{QRD}$$

$$= \quad -\sigma_\mu \{\xi_2(\hat{Q}_0^{QRD}) + \psi[\xi_2(\hat{Q}_0^{QRD})]\}.$$

Let $h(x) = x + \psi(x)$. Then we have:

i/ $h(x)$ is a non-decreasing function as $h'(x) = \Phi(x) \geq 0$ for all x.

ii/ $\lim\limits_{x\to-\infty} h(x) = \lim\limits_{x\to-\infty}[x + \Psi(x)] = \lim\limits_{x\to-\infty}\{x + \phi(x) - x \cdot [1 - \Phi(x)]\} = 0$; also,

$\lim\limits_{x\to\infty} h(x) = \lim\limits_{x\to\infty}[\phi(x) + x \cdot \Phi(x)] = \infty$.

By i/ and ii/, we can conclude that $h(x) \geq 0$ for all x. Therefore, we have

$$EQ^{QRD-MOQ-I}(M_0) - EQ^{QRD} = -\sigma_\mu h[\xi_2(\hat{Q}_0^{QRD})] < 0. \qquad \text{(Q.E.D.)}$$

Proposition 7.2:

(a) If $M_0 < \overline{Q}_0^{QRD}$ and $(c_1 - m_1) \le (c_0 - m_0)$, then

$$EM^{QRD-MOQ-I}(M_0) \ge EM^{QRD}(\hat{Q}_0^{QRD});$$

(b) If $M_0 \ge \overline{Q}_0^{QRD}$ and $(c_1 - m_1) \le (c_0 - m_0)$, then

$$EM^{QRD-MOQ-I}(M_0) < EM^{QRD}(\hat{Q}_0^{QRD}).$$

Proof of Proposition 7.2:

(a) Suppose $M_0 < \overline{Q}_0^{QRD}$ and $(c_1 - m_1) \le (c_0 - m_0)$. By Equation (7.16), consider

$$EM_{MOQ,I} - EM_{NIL}$$

$$= (c_0 - m_0)(M_0 - \hat{Q}_0^{QRD}) - \sigma_\mu (c_1 - m_1)\{\psi[\xi_2(\hat{Q}_0^{QRD})] - \psi[\xi_2(M_0)]\}$$

$$\ge (c_0 - m_0)(M_0 - \hat{Q}_0^{QRD}) - \sigma_\mu (c_0 - m_0)\{\psi[\xi_2(\hat{Q}_0^{QRD})] - \psi[\xi_2(M_0)]\}$$

$$= (c_0 - m_0)\{EQ^{QRD-MOQ-I}(M_0) - EQ^{QRD}\} \qquad \text{[by (7.12) and (7.13)]}$$

$$> 0. \qquad \text{[by Proposition 7.1 (a)]}$$

(b) For $M_0 \ge \overline{Q}_0^{QRD}$, by Proposition 7.1(b), we have $EQ^{QRD-MOQ-I}(M_0) < EQ^{QRD}$.

This implies $\mu_0 + \sigma_1 \Phi^{-1}(s_1) < \hat{Q}_0^{QRD} + \sigma_\mu \psi[\xi_2(\hat{Q}_0^{QRD})]$

$$\Rightarrow EM^{QRD-MOQ-I}(M_0) = (c_1 - m_1)[\mu_0 + \sigma_1 \Phi^{-1}(s_1)]$$

$$< (c_1 - m_1)\{\hat{Q}_0^{QRD} + \sigma_\mu \psi[\xi_2(\hat{Q}_0^{QRD})]\}.$$

Suppose we have $c_1 - m_1 \le c_0 - m_0$. Then,

$$EM^{QRD-MOQ-I}(M_0) < (c_1 - m_0)\hat{Q}_0^{QRD} + \sigma_\mu (c_1 - m_1)\psi[\xi_2(\hat{Q}_0^{QRD})]$$

$$= EM_0^{QRD}(\hat{Q}_0^{QRD}). \qquad \text{(Q.E.D.)}$$

Proposition 7.3:

Under the QRD-MOQ-I system:

(a) For $(c_0 - m_0) \geq (c_1 - m_1)$, the MEP function is strictly increasing in M_0 for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. The manufacturer obtains a greater expected profit as M_0 is closer to $\overline{Q}_0^{QRD}$ and the greatest possible MEP is close to $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$.

(b) For $(c_0 - m_0) < (c_1 - m_1)$. Let $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ be the limit of $EM^{QRD-MOQ-I}(M_0)$ when M_0 approaches to the left-hand side of $\overline{Q}_0^{QRD}$.

(i) If $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ is the largest compared with $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$ and $EM^{QRD-MOQ-I}(0)$, then the manufacturer obtains a greater expected profit as M_0 is closer to $\overline{Q}_0^{QRD}$ and the greatest possible MEP is close to $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$.

(ii) If $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ is not greater than either $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$ or $EM^{QRD-MOQ-I}(0)$, then the maximum value of $EM^{QRD-MOQ-I}$ is either $EM^{QRD-MOQ-I}(\hat{Q}_0^{QRD})$ or $EM^{QRD-MOQ-I}(0)$, whichever is greater.

Proof of Proposition 7.3:

(a) Suppose $(c_0 - m_0) \geq (c_1 - m_1)$. Direct observation shows that $dEM^{QRD-MOQ-I} / dM_0 > 0$ for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. In other words,

$EM^{QRD-MOQ-I}$ is strictly increasing in this range of M_0. Together with Proposition 7.2 which states that $EM^{QRD-MOQ-I}$ attains a greater value for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$, the manufacturer obtains a greater expected profit as M_0 is closer to $\overline{Q}_0^{QRD}$. However, since MEP is discontinuous at $M_0 = \overline{Q}_0^{QRD}$, its greatest possible value would be close to $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$.

(b) Suppose $(c_0 - m_0) < (c_1 - m_1)$. Then, for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$, $EM^{QRD-MOQ-I}(M_0) = EM^{QRD}(M_0)$. The second derivative of EM^{QRD} w.r.t. M_0, which is given by: $d^2 EM^{QRD} / dM_0{}^2 = (c_1 - m_1)\phi[\xi_2(M_0)]$, is greater than zero. In other words, $EM^{QRD-MOQ-I}$ is a strictly convex function in this range of M_0. Let $M_{0,M}^{QRD,\min}$ be the value of M_0 at which $EM^{QRD}(M_0)$ attains its global minimum. Solving the first-order condition shows that $M_{0,M}^{QRD,\min} = \mu_0 + \sigma_1\Phi^{-1}(s_1) + \sigma_\mu\Phi^{-1}[1-(c_0 - m_0)/(c_1 - m_1)]$. Depending on the value of $M_{0,M}^{QRD,\min}$, there are three different cases to be discussed as below.

Case (1) - $M_{0,M}^{QRD,\min} \geq \overline{Q}_0^{QRD}$:

$EM^{QRD-MOQ-I}$ [and $EM^{QRD}(M_0)$] is strictly decreasing for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. Since $EM^{QRD-MOQ-I}$ is continuous at $M_0 = \hat{Q}_0^{QRD}$, it is non-increasing for $M_0 \leq \overline{Q}_0^{QRD}$ and the local maximum expected profit equals $EM^{QRD}(\hat{Q}_0^{QRD})$. Then we need to further compare between $EM^{QRD}(\hat{Q}_0^{QRD})$ and $EM^{QRD}(0)$ to determine the global maximum MEP.

Case (2) - $\overline{Q}_0^{QRD} < M_{0,M}^{QRD,\min} < \overline{Q}_0^{QRD}$:

The local maximum appears at one of the boundary points. Globally, we need to compare amongst $EM^{QRD}(\hat{Q}_0^{QRD})$, $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$, and $EM^{QRD}(0)$ to determine the global maximum MEP.

Case (3) - $M_{0,M}^{QRD,\min} \le \overline{Q}_0^{QRD}$:

$EM^{QRD-MOQ-I}$ [and $EM^{QRD}(M_0)$] is strictly increasing for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. Since $EM^{QRD-MOQ-I}$ is continuous at $M_0 = \hat{Q}_0^{QRD}$, we have $EM^{QRD-MOQ-I}$ is non-decreasing for $M_0 < \overline{Q}_0^{QRD}$. The greatest possible MEP in this range would be very close to $\lim_{M_0 \to \overline{Q}_0^{QRD}} EM^{QRD-MOQ-I}(M_0)$. It remains to compare between $\lim_{M_0 \to \overline{Q}_0^{QRD}} EM^{QRD-MOQ-I}(M_0)$ and $EM^{QRD}(0)$ to determine the global maximum MEP.

From all the above three cases, the maximum MEP, if exists, is equal to either $EM^{QRD}(\hat{Q}_0^{QRD})$ or $EM^{QRD}(0)$. In particular, if $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ is the greatest amongst the three values, then the greatest possible value for $EM^{QRD-MOQ-I}$ would be close to $\lim_{M_0 \to \overline{Q}_0^{QRD-}} EM^{QRD-MOQ-I}(M_0)$ as M_0 is close to $\overline{Q}_0^{QRD}$. (Q.E.D.)

Proposition 7.4:

The optimal value of M_0 from the retailer's perspective is: $0 \le M_{0,R}^{QRD-MOQ-I} * \le \hat{Q}_0^{QRD}$.

Proof of Proposition 7.4:

Note that from (7.15), $ER^{QRD-MOQ-I}$ is a continuous function in M_0 but not differentiable at $M_0 = \overline{Q}_0^{QRD}$. Also, $ER^{QRD-MOQ-I}$ is constant for $0 \le M_0 \le \hat{Q}_0^{QRD}$ and $M_0 \ge \overline{Q}_0^{QRD}$ whereas it is strictly decreasing for $\hat{Q}_0^{QRD} < M_0 < \overline{Q}_0^{QRD}$. As a result, the retailer attains his maximum expected profit for $0 \le M_0 \le \hat{Q}_0^{QRD}$. Moreover, from the perspective of the retailer, the optimal values of the Stage-0 MOQ lies within the range of $0 \le M_0 \le \hat{Q}_0^{QRD}$. (Q.E.D.)

Lemma 8.1: (a) $\eta(\mu_1; M_1, Q_0)$ is an increasing function in μ_1;

(b) $\lim_{\mu_1 \to -\infty} \eta(\mu_1; M_1, Q_0) < 0$ and $\lim_{\mu_1 \to \infty} \eta(\mu_1; M_1, Q_0) > 0$.

Proof of Lemma 8.1:

(a) Differentiating $\eta(\mu_1; M_1, Q_0)$ w.r.t. μ_1 gives:

$$\partial\eta / \partial\mu_1 = (r+h)\{\Phi[(M_1 + Q_0 - \mu_1)/\sigma_1] - \Phi[(Q_0 - \mu_1)/\sigma_1]\} > 0$$

(b) η can be rewritten as follows:

$$\eta(\mu_1; M_1, Q_0)$$

$$= (r+h)\sigma_1 \left\{ \frac{M_1}{\sigma_1}\left[1 - \Phi\left(\frac{M_1 + Q_0 - \mu_1}{\sigma_1}\right)\right] + \phi\left(\frac{Q_0 - \mu_1}{\sigma_1}\right) - \phi\left(\frac{M_1 + Q_0 - \mu_1}{\sigma_1}\right) \right.$$

$$\left. - \left(\frac{Q_0 - \mu_1}{\sigma_1}\right)\left[\Phi\left(\frac{M_1 + Q_0 - \mu_1}{\sigma_1}\right) - \Phi\left(\frac{Q_0 - \mu_1}{\sigma_1}\right)\right]\right\} - (h + c_1)M_1$$

By direct manipulation one can check that $\lim_{\mu_1 \to -\infty} \eta(\mu_1; M_1, Q_0) = -\infty < 0$ and

$\lim_{\mu_1 \to \infty} \eta(\mu_1; M_1, Q_0) = (r - c_1)M_1 > 0$. (Q.E.D.)

Lemma 8.2:

(a) $Q_0 - \sigma_1 \Phi^{-1}(s_1) < \hat{\mu}_1^{QRD} < M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1)$;

(b) $\hat{\mu}_1^{QRD} = Q_0 + g(M_1)$ for some function g that is purely in M_1.

Proof of Lemma 8.2:

(a) First, as $\eta(\mu_1)$ is an increasing function in μ_1, by the definition of $\hat{\mu}_1^{QRD}$, we have $\eta(\mu_1; M_1, Q_0) < 0$ for all $\mu_1 < \hat{\mu}_1^{QRD}$ and $\eta(\mu_1; M_1, Q_0) > 0$ for all $\mu_1 > \hat{\mu}_1^{QRD}$. Next, observe that $\eta[Q_0 - \sigma_1 \Phi^{-1}(s_1); M_1, Q_0] < 0$ and $\eta[M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1); M_1, Q_0] > 0$. Thus Lemma 8.1(a) results.

(b) By (8.5), we have:

$$(r+h)\sigma_1[\psi\left(\frac{Q_0 - \hat{\mu}_1^{QRD}}{\sigma_1}\right) - \psi\left(\frac{M_1 + Q_0 - \hat{\mu}_1^{QRD}}{\sigma_1}\right)] - (h + c_1)M_1 = 0$$

Differentiating the above equation w.r.t. Q_0 yields:

$$\left[1 - \frac{\partial \hat{\mu}_1^{QRD}}{\partial Q_0}\right]\left[\Phi\left(\frac{M_1 + Q_0 - \mu_1}{\sigma_1}\right) - \Phi\left(\frac{Q_0 - \mu_1}{\sigma_1}\right)\right] = 0$$

As $M_1 > 0$, $\Phi\left(\frac{M_1 + Q_0 - \mu_1}{\sigma_1}\right) > \Phi\left(\frac{Q_0 - \mu_1}{\sigma_1}\right)$. So we must have $\partial \hat{\mu}_1^{QRD} / \partial Q_0 = 1$. Then by the principle of calculus, $\hat{\mu}_1^{QRD}$ can be written as: $\hat{\mu}_1^{QRD} = Q_0 + c$, where c is some constant independent of Q_0. But (8.5) suggests that $\hat{\mu}_1^{QRD}$ also depends on M_1. Thus we have $\hat{\mu}_1^{QRD} = Q_0 + g(M_1)$ for some function g which solely takes M_1 as its argument. (Q.E.D.)

Lemma 8.3:

(a) $\lim_{Q_0 \to -\infty} \{ \partial ER^{QRD-MOQ-II} / \partial Q_0 \} > 0$ and $\lim_{Q_0 \to \infty} \{ \partial ER^{QRD-MOQ-II} / \partial Q_0 \} < 0$;

(b) There exists at least one value of Q_0 such that $\partial ER^{QRD-MOQ-II} / \partial Q_0 = 0$;

(c) $ER^{QRD-MOQ-II}$ is strictly concave for $Q_0 > \overline{Q}_0 = M_1 + \mu_0 + \sigma_1 \Phi^{-1}(s_1)$.

Proof of Lemma 8.3:

As stated in Chapter 8, the first derivative of $ER^{QRD-MOQ-II}(Q_0, M_1)$ w.r.t. Q_0 is given by:

$$\partial ER^{QRD-MOQ-II}(Q_0, M_1) / \partial Q_0$$

$$= (c_1 - c_0) + (r - c_1)\Phi[\xi_2(M_1, Q_0)]$$

$$-(r+h)\{\int_{-\infty}^{\rho_2(M_1,Q_0)} \Phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$+\int_{\rho_2(M_1,Q_0)}^{\xi_2(M_1,Q_0)} \Phi[(M_1 + Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz\}, \quad (8.10)$$

where $\xi_2(M_1, Q_0) = [M_1 + Q_0 - \sigma_1 \Phi^{-1}(s_1) - \mu_0]/\sigma_\mu$, (8.11)

$$\rho_2(M_1, Q_0) = (\hat{\mu}_1^{QRD} - \mu_0)/\sigma_\mu. \quad (8.12)$$

(a) From Lemma 8.2(b), $\lim_{Q_0 \to -\infty} \hat{\mu}_1^{QRD} = -\infty$; so $\lim_{Q_0 \to -\infty} \rho_2 = \lim_{Q_0 \to -\infty} \xi_2 = -\infty$.

Therefore, $\lim_{Q_0 \to -\infty} \partial ER^{QRD-MOQ-II} / \partial Q_0 = (c_1 - c_0) > 0$. Similarly, $\lim_{Q_0 \to \infty} \hat{\mu}_1^{QRD} = \infty$, so $\lim_{Q_0 \to \infty} \rho_2 = \lim_{Q_0 \to \infty} \xi_2 = \infty$. Thus $\lim_{Q_0 \to \infty} \partial ER^{QRD-MOQ-II} / \partial Q_0 = -(h + c_0) < 0$.

(b) For an infinitely large N, we have

$$\partial ER^{QRD-MOQ-II} / \partial Q_0 \big|_{-N}$$

$$\approx (c_1 - c_0) + (r - c_1)\Phi(-N) - (r+h)\int_{-\infty}^{-N} \Phi[(-N - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$> (c_1 - c_0) + (r - c_1)\Phi(-N) - (r+h)\Phi(-N)$$

$$= (c_1 - c_0) - (h + c_1)\Phi(-N) \approx (c_1 - c_0) > 0$$

Similarly, we have $\partial ER^{QRD-MOQ-II} / \partial Q_0 \big|_{N}$

$$\approx (c_1 - c_0) - (h + c_1)\Phi(N) \approx (c_1 - c_0) - (h + c_1) = -(h + c_0) < 0 .$$

Together with the fact that $\partial ER^{QRD-MOQ-II} / \partial Q_0$ is a continuous function over the whole the real number line, by Intermediate Value Theorem, we have $\exists\, Q_0 \in [-N, N]\, s.t.\, \partial ER^{QRD-MOQ-II} / \partial Q_0 = 0$.

(c) The second derivative of $ER^{QRD-MOQ-II}$ w.r.t. Q_0 is given by:

$$\partial^2 ER^{QRD-MOQ-II} / \partial Q_0^{\,2}$$

$$= \frac{(r+h)}{\sigma_\mu}\left\{\int_{-\infty}^{\rho_2(M_1,Q_0)} \Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz + s_1\phi[\xi_2(M_1, Q_0)]\right.$$

$$\left. + \int_{\rho_2(M_1,Q_0)}^{\xi_2(M_1,Q_0)} \Phi\left(\frac{M_1 + Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz \right\}. \qquad \text{(A8.1)}$$

Suppose $Q_0 > \overline{Q}_0 = M_1 + \mu_0 + \sigma_1 \Phi^{-1}(s_1)$. Then, we have $\hat{\mu}_1^{QRD} > \mu_1$ and $\rho_2(M_1, Q_0) > 0_\mu$. Also, $\Phi[(M_1 + Q_0 - \hat{\mu}_1^{QRD})/\sigma_1] > s_1$ and $\Phi[(Q_0 - \mu_0)/\sigma_1] > s_1$. Therefore,

$$\int_{-\infty}^{\rho_2(M_1,Q_0)} \Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz$$

$$= \int_{-\infty}^{0} \Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz + \int_{0}^{\rho_2(M_1, Q_0)} \Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz$$

Now $\int_{-\infty}^{0} \Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz$

$$\leq \underset{z\in(-\infty,0]}{Min}\left\{\Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right)\right\}\int_{-\infty}^{0} z\phi(z)dz \quad [\because\ z\phi(z) < 0 \text{ for } \ \forall z \in (-\infty,0)\ ]$$

$$= -\Phi\left(\frac{Q_0 - \mu_0}{\sigma_1}\right)\phi(0) < -s_1\,\phi(0)$$

Similarly,

$$\int_{0}^{\rho_2(M_1, Q_0)} \Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz$$

$$\leq \underset{z\in(0,\,\rho_2(M_1, Q_0))}{Max}\left\{\Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right)\right\}\int_{0}^{\rho_2(M_1, Q_0)} z\phi(z)dz \quad [\quad \because \quad z\phi(z) > 0 \quad \text{for}$$

$\forall z \in (-\infty,0)$]

$$= \Phi\left(\frac{Q_0 - \mu_0}{\sigma_1}\right)\{\,\phi(0) - \phi[\rho_2(M_1, Q_0)]\} < s_1\,\{\,\phi(0) - \phi[\rho_2(M_1, Q_0)]\}$$

Thus we have

$$\int_{-\infty}^{\rho_2(M_1, Q_0)} \Phi\left(\frac{Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz \leq -\, s_1\phi[\rho_2(M_1, Q_0)]$$

On the other hand,

$$\int_{\rho_2(M_1,Q_0)}^{\xi_2(M_1,Q_0)} \Phi\left(\frac{M_1 + Q_0 - \mu_0 - \sigma_\mu z}{\sigma_1}\right) z\phi(z)dz$$

$$\leq \Phi\left(\frac{M_1 + Q_0 - \hat{\mu}_1^{QRD}}{\sigma_1}\right)\{\phi[\rho_2(M_1,Q_0)] - \phi[\xi_2(M_1,Q_0)]\}$$

$< s_1\{\phi[\rho_2(M_1,Q_0)] - \phi[\xi_2(M_1,Q_0)]\}$. Hence,

$$\partial^2 ER^{QRD-MOQ-II} / \partial Q_0^{\ 2}$$

$$< \ [(r+h)/\sigma_\mu]\{-s_1\phi[\rho_2(M_1,Q_0)] + s_1\phi[\xi_2(M_1,Q_0)]$$

$$+ s_1\{\phi[\rho_2(M_1,Q_0)] - \phi[\xi_2(M_1,Q_0)]\}$$

$= \ 0$. (Q.E.D.)

Lemma 8.4: $ER^{QRD-MOQ-II}$ is strictly decreasing for a sufficiently large Q_0.

Proof of Lemma 8.4:

By Lemma 8.3(b), there exists at least one stationary point of $ER^{QRD-MOQ-II}$. If all of them are smaller than $\overline{Q}_0$ (defined in Lemma 8.3 (c)), since $ER^{QRD-MOQ-II}$ is strictly concave for $Q_0 \geq \overline{Q}_0$ and $\lim_{Q_0 \to \infty} \partial ER^{QRD} / \partial Q_0 = -(h + c_0) < 0$ (Lemmas 8.3 (c) and (a), respectively), we know that $ER^{QRD-MOQ-II}$ is strictly decreasing for $Q_0 \geq \overline{Q}_0$. On the other hand, suppose that there exists a stationary point $\hat{Q}_0$ of $ER^{QRD-MOQ-II}$ that is larger than $\overline{Q}_0$. Then the strict concavity of $ER^{QRD-MOQ-II}$ over the range of

$Q_0 \geq \overline{Q}_0$ implies that $\hat{Q}_0$ is the only local maximum in the range and $ER^{QRD-MOQ-II}$ is strictly decreasing for $Q_0 \geq \hat{Q}_0$. (Q.E.D.)

Lemma 8.5: There exists at least one local maximum for $ER^{QRD-MOQ-II}$.

Proof of Lemma 8.5:

By Lemma 8.3(b), there exists at least one stationary point for $ER^{QRD-MOQ-II}$. Suppose there is only one stationary point. Then by Lemma 8.3(a), it must be the global maximum for the function. Suppose, on the other hand, that there are two or more stationary points for $ER^{QRD-MOQ-II}$. Since $\lim_{Q_0 \to -\infty} \partial ER^{QRD-MOQ-II} / \partial Q_0 > 0$, the two smallest stationary points must be either: (i) a local maximum; or (ii) an inflection point with positive gradient on an open interval extending right from it. For the latter case, we can keep classifying the next smallest stationary point into either a local maximum or an inflection point with positive gradient on an open interval extending right from it. In the case that we have checked all the stationary points except the last one and found that all of them are inflection points with positive gradient on its right-hand side, since the function is strictly decreasing for a sufficiently large Q_0 (Lemma 8.4), we must have the last stationary point being a local maximum. (Q.E.D.)

Proposition 10.1:

The SCEP under QRS-DMP is the same as that under the centralized system.

Proof of Proposition 10.1:

The maximum SCEP under the centralized system is achieved when the supply chain order quantity is equal to $\hat{Q}_{0,SC}^{QRD}* = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ and the maximum SCEP anticipated at Stage 0 is given by:

$$ECSC* = (r - m_1)\mu_0 - (h + m_1)\Phi^{-1}(s_1^{SC}) - (r + h)\sigma_1 \psi[\Phi^{-1}(s_1^{SC})]$$

At Stage 1, REP and MEP with $\widetilde{M}_1^{QRS}$ are given by below respectively:

$$ER_1(\widetilde{M}_1^{QRS} \mid \mu_1) = (r - c_1)\mu_1 - (h + c_1)\sigma_1 \Phi^{-1}(s_1^{sc}) - (r + h)\sigma_1 \psi[\Phi^{-1}(s_1^{sc})],$$

$$EM_1(\widetilde{M}_1^{QRS} \mid \mu_1) = (c_1 - m_1)[\mu_1 + \sigma_1 \Phi^{-1}(s_1^{sc})].$$

Correspondingly, their expected profits anticipated at Stage 0 are respectively:

$$ER(\widetilde{M}_1^{QRS}) = (r - c_1)\mu_0 - (h + c_1)\sigma_1 \Phi^{-1}(s_1^{sc}) - (r + h)\sigma_1 \psi[\Phi^{-1}(s_1^{sc})],$$

$$EM(\widetilde{M}_1^{QRS}) = (c_1 - m_1)[\mu_0 + \sigma_1 \Phi^{-1}(s_1^{sc})].$$

Summation of the two equations yields:

$$ER(\widetilde{M}_1^{QRS}) + EM(\widetilde{M}_1^{QRS}) = ECSC*. \qquad \text{(Q.E.D.)}$$

Proposition 10.2:

With QRS-DMP: (a) the manufacturer is not worse off under QR with MOQ if and only if $c_1 \geq c_1^M$ *; (b) the retailer is not worse off under QR with MOQ if and only if* $c_1 \leq c_1^R$.

Proof of Proposition 10.2:

(a) The MEP under the old system and QRS-DMP are, respectively:

$$EM^{Old} = (c_0 - m_0)[\mu_0 + \sigma_1 \Phi^{-1}(s_0)],$$

$$EM^{QRS-DMP} = (c_1 - m_1)[\mu_0 + \sigma_1 \Phi^{-1}(s_1^{sc})].$$

The difference in MEP after adopting QRS-DMP is given by:

$$\begin{aligned} \Delta EM &= EM^{QRS-DMP} - EM^{Old} \\ &= (c_1 - m_1)[\mu_0 + \sigma_1 \Phi^{-1}(s_1^{sc})] - (c_0 - m_0)[\mu_0 + \sigma_1 \Phi^{-1}(s_0)]. \end{aligned}$$

After some manipulation, one can show that $\Delta EM \geq 0 \Leftrightarrow c_1 \geq c_1^M$.

(b) The difference in REP after adopting DMP is given by:

$$\begin{aligned} \Delta ER = {} & ER^{QRS-DMP} - ER^{Old} \\ & = c_0[\mu_0 + \sigma_0 \Phi^{-1}(s_0)] - c_1[\mu_0 + \sigma_1 \Phi^{-1}(s_1^{sc})] + h[\sigma_0 \Phi^{-1}(s_0) - \sigma_1 \Phi^{-1}(s_1^{sc})]. \\ & \quad -(r+h)\{\sigma_0 \psi[\Phi^{-1}(s_0)] - \sigma_1 \psi[\Phi^{-1}(s_1^{sc})]\}. \end{aligned}$$

Then, with some manipulation we have $\Delta ER \geq 0 \Leftrightarrow c_1 \leq c_1^R$. (Q.E.D.)

Corollary 10.1:

Channel coordination can be achieved by QRS-DMP with $\widetilde{M}_1^{QRS}(\mu_1) = \mu_1 + \sigma_1 \Phi^{-1}(s_1^{sc})$ *for any* $c_1^M < c_1 < c_1^R$ *if and only if* $m_1 \in \{m_1 : g(m_1) < 0\}$.

Proof of Corollary 10.1:

For Pareto improvement to be feasible under QRS-DMP, we need to have $c_1^M < c_1^R$. By direct manipulation, we have $c_1^R - c_1^M > 0 \Leftrightarrow g(m_1) < 0$ and thus Corollary 10.1 is resulted. (Q.E.D.)

Lemma 10.1:

(a) $\tilde{\eta}(\mu_1, Q_0)$ *is a strictly increasing function in* μ_1 *for* $\mu_1 > Q_0 - \sigma_1 \Phi^{-1}(s_1)$ *;*

(b) $\lim_{\mu_1 \to Q_0 - \sigma_1 \Phi^{-1}(s_1)} \tilde{\eta}(\mu_1, Q_0) < 0$ *and* $\lim_{\mu_1 \to \infty} \tilde{\eta}(\mu_1, Q_0) > 0$ *; and*

(c) $d\hat{\mu}_1^{QRD-DMP} / dQ_0 = 1$.

Proof of Lemma 10.1:

(a) The first and second derivatives of $\tilde{\eta}(\mu_1, Q_0)$ w.r.t. μ_1 are given by:

$$\partial \tilde{\eta} / \partial \mu_1 = (r - c_1) - (r + h)\Phi[(Q_0 - \mu_1)/\sigma_1], \tag{A10.1}$$

$$\partial^2 \tilde{\eta} / \partial {\mu_1}^2 = (r + h)\phi[(Q_0 - \mu_1)/\sigma_1]/\sigma_1. \tag{A10.2}$$

A direct observation of (A10.2) indicates that $\partial^2 \tilde{\eta} / \partial {\mu_1}^2 > 0$ for all μ_1. Thus $\tilde{\eta}(\mu_1, Q_0)$ is strictly convex in μ_1. Solving the first-order condition yields $\mu_1 = Q_0 - \sigma_1 \Phi^{-1}(s_1)$, which is the global minimum of the function. By the strict convexity of the function, we have that $\tilde{\eta}(\mu_1, Q_0)$ is strictly increasing for $\mu_1 > Q_0 - \sigma_1 \Phi^{-1}(s_1)$.

(b) $\lim_{\mu_1 \to Q_0 - \sigma_1 \Phi^{-1}(s_1)} \tilde{\eta}(\mu_1, Q_0)$

$$= \lim_{\mu_1 \to Q_0 - \sigma_1 \Phi^{-1}(s_1)} \{ER_1^{QRD}(\tilde{M}_1^{QRD}; Q_0, \mu_1) - ER_1^{QRD}(0; Q_0, \mu_1)\}$$

$$= ER_1^{QRD}[\sigma_1 \Phi^{-1}(s_1^{SC}) - \sigma_1 \Phi^{-1}(s_1); Q_0, Q_0 - \sigma_1 \Phi^{-1}(s_1)]$$

$$- ER_1^{QRD}[0; Q_0, Q_0 - \sigma_1 \Phi^{-1}(s_1)]$$

$$= ER_1^{QRD}[\sigma_1 \Phi^{-1}(s_1^{SC}) - \sigma_1 \Phi^{-1}(s_1); Q_0, Q_0 - \sigma_1 \Phi^{-1}(s_1)]$$

$-ER_1^{QRD}[\hat{Q}_1^{\mathrm{QRD}}; Q_0, Q_0 - \sigma_1\Phi^{-1}(s_1)]$ [$\because \hat{Q}_1^{QRD} = 0$ for $\mu_1 = Q_0 - \sigma_1\Phi^{-1}(s_1)$]

$<$ 0 [as ER_1^{QRD} attains its global maximum at $\hat{Q}_1^{\mathrm{QRD}}$].

On the other hand, since $\psi(a) = \phi(a) - a\Phi(a)$, from (10.14), $\tilde{\eta}(\mu_1, Q_0)$ can be re-written as:

$$\tilde{\eta}(\mu_1, Q_0) = (h + c_1)\sigma_1[\phi(K) + K\Phi(K)] + (r - c_1)\sigma_1\psi(K) - (r + h)\sigma_1\psi[\Phi^{-1}(s_1^{SC})]$$

$$- (h + c_1)\sigma_1\Phi^{-1}(s_1^{SC}), \text{ where } K = (Q_0 - \mu_1)/\sigma_1.$$

Then, we have $\lim_{\mu_1 \to \infty} K = -\infty$ and so

$$\lim_{\mu_1 \to \infty} \tilde{\eta} = (h + c_1)\sigma_1(0 - 0) + \infty - (r + h)\sigma_1\psi[\Phi^{-1}(s_1^{SC})] = \infty > 0.$$

(c) Differentiating $\tilde{\eta}(\hat{\mu}_1^{QRD-DMP}, Q_0) = 0$ w.r.t. Q_0 yields:

$$(r + h)[(d\hat{\mu}_1^{QRD-DMP} / dQ_0) - 1][s_1 - \Phi[(Q_0 - \hat{\mu}_1^{QRD-DMP}) / \sigma_1] = 0.$$

As $\hat{\mu}_1^{QRD-DMP}$ is defined over the range of $\mu_1 > Q_0 - \sigma_1\Phi^{-1}(s_1)$, of course $\hat{\mu}_1^{QRD-DMP} > Q_0 - \sigma_1\Phi^{-1}(s_1)$, so we have $s_1 > \Phi[(Q_0 - \hat{\mu}_1^{QRD}) / \sigma_1]$. Since $s_1 - \Phi[(Q_0 - \hat{\mu}_1^{QRD-DMP}) / \sigma_1 \neq 0$, we must have $d\hat{\mu}_1^{QRD} / dQ_0 = 1$. (Q.E.D.)

Lemma 10.2:

(a) $\lim_{Q_0 \to -\infty} \{\partial ER^{QRD-DMP} / \partial Q_0\} > 0$ *and* $\lim_{Q_0 \to \infty} \{\partial ER^{QRD-DMP} / \partial Q_0\} < 0$*;*

(b) There exists at least one value of Q_0 *such that* $\partial ER^{QRD-DMP} / \partial Q_0 = 0$*;*

(c) $ER^{QRD-DMP}$ *is strictly concave for* $Q_0 > \tilde{Q}_0 = \mu_0 + \sigma_1 \Phi^{-1}(s_1)$.

Proof of Lemma 10.2:

(a) From Lemma 10.1(c), $\lim_{Q_0 \to -\infty} \hat{\mu}_1^{QRD-DMP} = -\infty$; so $\lim_{Q_0 \to -\infty} \rho_3 = -\infty$.

Therefore, $\lim_{Q_0 \to -\infty} \partial ER^{QRD-DMP} / \partial Q_0 = (c_1 - c_0) > 0$. Similarly, $\lim_{Q_0 \to \infty} \hat{\mu}_1^{QRD-DMP} = \infty$, so $\lim_{Q_0 \to \infty} \rho_3 = \infty$. Thus $\lim_{Q_0 \to \infty} \partial ER^{QRD-DMP} / \partial Q_0 = -(h + c_0) < 0$.

(b) For an infinitely large N, we have

$$\partial ER^{QRD-DMP} / \partial Q_0 \big|_{-N}$$

$$\approx (c_1 - c_0) + (r - c_1)\Phi(-N) - (r + h)\int_{-\infty}^{-N} \Phi[(-N - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$> (c_1 - c_0) + (r - c_1)\Phi(-N) - (r + h)\Phi(-N)$$

$$= (c_1 - c_0) - (h + c_1)\Phi(-N) \approx (c_1 - c_0) > 0.$$

Similarly, we have $\partial ER^{QRD-DMP} / \partial Q_0 \big|_N$

$$\approx (c_1 - c_0) - (h + c_1)\Phi(N) \approx (c_1 - c_0) - (h + c_1) = -(h + c_0) < 0.$$

Together with the fact that $\partial ER^{QRD-DMP} / \partial Q_0$ is a continuous function over the whole the real number line, by Intermediate Value Theorem, we have $\exists\, Q_0 \in [-N, N]$ *s.t.* $\partial ER^{QRD-DMP} / \partial Q_0 = 0$.

(c) The second derivative of $ER^{QRD-DMP}$ w.r.t. Q_0 is given by:

$$\partial^2 ER^{QRD-DMP} / \partial Q_0{}^2$$

$$= [(r+h)/\sigma_\mu]\phi[\rho_3(Q_0)]\{s_1 - \Phi[(Q_0 - \hat{\mu}_1^{QRD-DMP})/\sigma_1]\}$$

$$-[(r+h)/\sigma_1]\int_{-\infty}^{\rho_3(Q_0)} \phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz\,. \qquad \text{(A10.3)}$$

For $Q_0 \geq \widetilde{Q}_0 = \mu_0 + \sigma_1 \Phi^{-1}(s_1)$,

$\rho_3(Q_0) = \hat{\mu}_1^{QRD-DMP} - \mu_0 > \hat{\mu}_1^{QRD-DMP} - [Q_0 - \sigma_1 \Phi^{-1}(s_1)] > 0$. So,

$$\int_{-\infty}^{\rho_3(Q_0)} \phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$= \int_{-\infty}^{0} \phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz + \int_{0}^{\rho_3(Q_0)} \phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$> \int_{0}^{\rho_3(Q_0)} \phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$> \phi[\rho_3(Q_0)]\int_{0}^{\rho_3(Q_0)} \phi[(Q_0 - \mu_0 - \sigma_\mu z)/\sigma_1]dz$$

[$\because \phi[\rho_3(Q_0)] > \phi(z)$ for all $z \in (0, \rho_3(Q_0))$]

$$= \phi[\rho_3(Q_0)](\sigma_1/\sigma_\mu)\int_{(Q_0 - \hat{\mu}_1^{QRD-DMP})/\sigma_1}^{(Q_0-\mu_0)/\sigma_1} \phi(z)dz$$

$$= (\sigma_1/\sigma_\mu)\phi[\rho_3(Q_0)]\{\Phi[(Q_0 - \mu_0)/\sigma_1] - \Phi[(Q_0 - \hat{\mu}_1^{QRD-DMP})/\sigma_1]\}\,.$$

Therefore, we have

$$\partial^2 ER^{QRD-DMP} / \partial Q_0{}^2$$

$$< [(r+h)/\sigma_\mu]\phi[\rho_3(Q_0)]\{s_1 - \Phi[(Q_0 - \hat{\mu}_1^{QRD-DMP})/\sigma_1]\}$$

$$-[(r+h)/\sigma_\mu]\phi[\rho_3(Q_0)]\{\Phi[(Q_0 - \mu_0)/\sigma_1] - \Phi[(Q_0 - \hat{\mu}_1^{QRD-DMP})/\sigma_1]\}$$

$$= [(r+h)/\sigma_\mu]\phi[\rho_3(Q_0)]\{s_1 - \Phi[(Q_0 - \mu_0)/\sigma_1]\}$$

$$< 0 \qquad \text{(Q.E.D.)}$$

Lemma 10.3:

$ER^{QRD-DMP}$ is strictly decreasing for a sufficiently large Q_0.

Proof of Lemma 10.3:

By Lemma 10.2(b), there exists at least one stationary point of $ER^{QRD-DMP}$. If all of them are smaller than $\tilde{Q}_0$ (defined in Lemma 10.2 (c)), since $ER^{QRD-DMP}$ is strictly concave for $Q_0 \geq \tilde{Q}_0$ and $\lim_{Q_0 \to \infty} \partial ER^{QRD-DMP} / \partial Q_0 = -(h + c_0) < 0$ (Lemmas 10.2 (c) and (a), respectively), we know that $ER^{QRD-DMP}$ is strictly decreasing for $Q_0 \geq \tilde{Q}_0$. On the other hand, suppose that there exists a stationary point $\hat{Q}_0$ of $ER^{QRD-DMP}$ that is larger than $\tilde{Q}_0$. Then the strict concavity of $ER^{QRD-DMP}$ over the range of $Q_0 \geq \tilde{Q}_0$ implies that $\hat{Q}_0$ is the only local maximum in the range and $ER^{QRD-DMP}$ is strictly decreasing for $Q_0 \geq \hat{Q}_0$. (Q.E.D.)

Lemma 10.4:

There exists at least one local maximum for $ER^{QRD-DMP}$.

Proof of Lemma 10.4:

By Lemma 10.2(b), there exists at least one stationary point for $ER^{QRD-DMP}$. Suppose there is only one stationary point. Then by Lemma 10.2(a), it must be the global maximum for the function. Suppose, on the other hand, that there are two or more stationary points for $ER^{QRD-DMP}$. Since $\lim_{Q_0 \to -\infty} \partial ER^{QRD-DMP} / \partial Q_0 > 0$, the smallest stationary point must be either: (i) a local maximum; or (ii) an inflection point with positive gradient on an open interval extending right from it. For the latter case, we can keep classifying the next smallest stationary point into either a local maximum or an inflection point with positive gradient on an open interval extending right from it. In the case that we have checked all the stationary points except the last one and found that all of them are inflection points with positive gradient on its right-hand side, since the function is strictly decreasing for a sufficiently large Q_0 (Lemma 10.3), we must have the last stationary point being a local maximum.

(Q.E.D.)

Proposition 10.4:

A sufficient condition for $\hat{Q}_0^{QRD-DMP} < Q_{0,SC}^{QRD}*$ *is given by:*

$$(c_1 - c_0) < (m_1 - m_0) - (r - m_1)\{\Phi[\rho_3(\hat{Q}_0^{QRD-DMP}) - \Phi[\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})]\}.$$

Proof of Proposition 10.4:

Since $ECSC^{QRD}$ is strictly concave, to have $\hat{Q}_0^{QRD-DMP} < Q_{0,SC}^{QRD}*$ is equivalent to have $\partial ECSC^{QRD} / \partial Q_0\Big|_{\hat{Q}_0^{QRD-DMP}} > 0$. Now consider:

$$\partial ECSC^{QRD} / \partial Q_0\Big|_{\hat{Q}_0^{QRD-DMP}}$$

$$= \partial ECSC^{QRD} / \partial Q_0\Big|_{\hat{Q}_0^{QRD-DMP}} - \partial ER^{QRD-DMP} / \partial Q_0\Big|_{\hat{Q}_0^{QRD-DMP}}$$

[as the latter equals zero with $\hat{Q}_0^{QRD-DMP}$ being a local maximum of $ER^{QRD-DMP}$]

$$\begin{aligned}
= \quad & (m_1 - m_0) - (c_1 - c_0) + (r - m_1)\Phi[\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})] - (r - c_1)\Phi[\rho_3(\hat{Q}_0^{QRD-DMP})] \\
& - (r+h)\int_{-\infty}^{\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})} \Phi[(\hat{Q}_0^{QRD-DMP} - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz \\
& + (r+h)\int_{-\infty}^{\rho_3(\hat{Q}_0^{QRD-DMP})} \Phi[(\hat{Q}_0^{QRD-DMP} - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz \\
> \quad & (m_1 - m_0) - (c_1 - c_0) + (r - m_1)\Phi[\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})] - (r - m_1)\Phi[\rho_3(\hat{Q}_0^{QRD-DMP})] \\
& - (r+h)\int_{-\infty}^{\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})} \Phi[(\hat{Q}_0^{QRD-DMP} - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz \\
& + (r+h)\int_{-\infty}^{\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})} \Phi[(\hat{Q}_0^{QRD-DMP} - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz
\end{aligned}$$

[$\because$ $c_1 \geq m_1$ and $\rho_3 > \xi_3^{SC}$ as $\hat{\mu}_1^{QRD\text{-DMP}} > Q_0 - \sigma_1\Phi^{-1}(s_1) > Q_0 - \sigma_1\Phi^{-1}(s_1^{SC})$]

$$= \quad (m_1 - m_0) - (c_1 - c_0) - (r - m_1)\{\Phi[\rho_3(\hat{Q}_0^{QRD-DMP})] - \Phi[\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})]\}$$

Thus if we have

$(c_1 - c_0) < (m_1 - m_0) - (r - m_1)\{\Phi[\rho_3(\hat{Q}_0^{QRD-DMP})] - \Phi[\xi_3^{SC}(\hat{Q}_0^{QRD-DMP})]\}$, we can ensure that $\partial ECSC^{QRD} / \partial Q_0 \Big|_{\hat{Q}_0^{QRD-DMP}} > 0$. (Q.E.D.)

Proposition 10.5:

A sufficient condition for $\Delta ER^{QRD-DMP} > 0$ *is given by:*

$$(c_1 - c_0)\sigma_\mu \xi_3^{SC}(Q_{0,SC}^{QRD}*) + (h + c_0)[\sigma_0 \Phi^{-1}(s_0) - \sigma_1 \Phi^{-1}(s_1^{SC})]$$

$$+ (r + h)\{\sigma_0 \psi[\Phi^{-1}(s_0)] - \sigma_1 \psi[\Phi^{-1}(s_1^{SC})] - (h + c_1)\sigma_\mu \phi[\rho_3(Q_{0,SC}^{QRD}*)] > 0.$$

Proof of Proposition 10.5:

As $\psi[(Q_{0,SC}^{QRD} * - \mu_0 - \sigma_\mu z)/\sigma_1]$ is an increasing function in z, we have

$$\int_{-\infty}^{\rho_3(Q_{0,SC}^{QRD}*)} \psi[(Q_{0,SC}^{QRD} * - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$< \quad \psi[(Q_{0,SC}^{QRD} * - \hat{\mu}_1^{QRD-DMP})/\sigma_1]\int_{-\infty}^{\rho_3(Q_{0,SC}^{QRD}*)} \phi(z)dz$$

$$= \quad \psi[(Q_{0,SC}^{QRD} * - \hat{\mu}_1^{QRD-DMP})/\sigma_1]\Phi[\rho_3(Q_{0,SC}^{QRD}*)].$$

By (10.21), we have:

$$\Delta ER^{QRD-DMP}$$

$$> \quad (c_1 - c_0)(Q_{0,SC}^{QRD} * - \mu_0) - (h + c_1)\sigma_1 \Phi^{-1}(s_1^{SC}) + (h + c_0)\sigma_0 \Phi^{-1}(s_0)$$

$$+ (r + h)\{\sigma_0 \psi[\Phi^{-1}(s_0)] - \sigma_1 \psi[\Phi^{-1}(s_1^{SC})] - (h + c_1)\sigma_\mu \phi[\rho_3(Q_{0,SC}^{QRD}*)]$$

$$- \Phi[\rho_3(Q_{0,SC}^{QRD}*)]\{(h + c_1)\sigma_\mu \xi_3^{SC}(Q_{0,SC}^{QRD}*) - (r + h)\sigma_1 \psi[\Phi^{-1}(s_1^{SC})]\}$$

$$-(r+h)\sigma_1\psi[(Q_{0,SC}^{QRD}*-\hat{\mu}_1^{QRD-DMP})/\sigma_1]\Phi[\rho_3(Q_{0,SC}^{QRD}*)]$$

$$= \quad (c_1-c_0)(Q_{0,SC}^{QRD}*-\mu_0)-(h+c_1)\sigma_1\Phi^{-1}(s_1^{SC})+(h+c_0)\sigma_0\Phi^{-1}(s_0)$$

$$+(r+h)\{\sigma_0\psi[\Phi^{-1}(s_0)]-\sigma_1\psi[\Phi^{-1}(s_1^{SC})]-(h+c_1)\sigma_\mu\phi[\rho_3(Q_{0,SC}^{QRD}*)]$$

$$-(r+h)\Phi[\rho_3(Q_{0,SC}^{QRD}*)]\tilde{\eta}(\hat{\mu}_1^{QRD-DMP},Q_{0,SC}^{QRD}*)$$

where $\tilde{\eta}$ is defined in (10.14).

By the definition of $\hat{\mu}_1^{QRD-DMP}$ in (10.15), $\tilde{\eta}(\hat{\mu}_1^{QRD-DMP},Q_{0,SC}^{QRD}*)=0$. Also, rearranging the first three terms in the expression, we have

$$\Delta ER^{QRD-DMP}$$

$$> \quad (c_1-c_0)\sigma_\mu\xi_3^{SC}(Q_{0,SC}^{QRD}*)+(h+c_0)[\sigma_0\Phi^{-1}(s_0)-\sigma_1\Phi^{-1}(s_1^{SC})]$$

$$+(r+h)\{\sigma_0\psi[\Phi^{-1}(s_0)]-\sigma_1\psi[\Phi^{-1}(s_1^{SC})]-(h+c_1)\sigma_\mu\phi[\rho_3(Q_{0,SC}^{QRD}*)].$$

Thus if the above expression is greater than 0, we have $\Delta ER^{QRD-DMP}>0$. (Q.E.D.)

Proposition 10.6:

If (i) $\hat{\mu}_1^{QRD-DMP}(Q_{0,SC}^{QRD}*) < \mu_0$, *(ii)* $c_1 - m_1 < c_0 - m_0$, *and (iii)* $\sigma_1 \Phi^{-1}(s_1^{SC}) > \sigma_0 \Phi^{-1}(s_0)$, *then* $\Delta EM^{QRD-DMP} > 0$.

Proof of Proposition 10.6:

(i) If $\hat{\mu}_1^{QRD-DMP}(Q_{0,SC}^{QRD}*) < \mu_0$, we have $\xi_3^{SC}(Q_{0,SC}^{QRD}*) < \rho_3(Q_{0,SC}^{QRD}*) < 0$, which implies $\phi[\rho_3(Q_{0,SC}^{QRD}*)] > \phi[\xi_3^{SC}(Q_{0,SC}^{QRD}*)]$. Since $c_1 \geq m_1$, we have

$$(h+c_1)\sigma_\mu \phi[\rho_3(Q_{0,SC}^{QRD}*)] - (h+m_1)\sigma_\mu \phi[\xi_3^{SC}(Q_{0,SC}^{QRD}*)] > 0.$$

(ii) If $c_1 - m_1 < c_0 - m_0$, we have $\sigma_\mu \xi_3^{SC}(Q_{0,SC}^{QRD}*)[(m_1 - m_0) - (c_1 - c_0)] > 0$.

(iii) If $\sigma_1 \Phi^{-1}(s_1^{SC}) > \sigma_0 \Phi^{-1}(s_0)$, we have $(c_0 - m_0)[\sigma_1 \Phi(s_1^{SC}) - \sigma_0 \Phi^{-1}(s_0)] > 0$.

(iv) As $\psi[(Q_{0,SC}^{QRD} * - \mu_0 - \sigma_\mu z)/\sigma_1]$ is an increasing function in z, we have

$$\int_{\xi_3^{SC}(Q_{0,SC}^{QRD}*)}^{\rho_3(Q_{0,SC}^{QRD}*)} \psi[(Q_{0,SC}^{QRD} * - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$> \psi[\Phi^{-1}(s_1^{SC})] \int_{\xi_3^{SC}(Q_{0,SC}^{QRD}*)}^{\rho_3(Q_{0,SC}^{QRD}*)} \phi(z)dz$$

$= \psi[\Phi^{-1}(s_1^{SC})]\{\Phi[\rho_3(Q_{0,SC}^{QRD}*)] - \Phi[\xi_3^{SC}(Q_{0,SC}^{QRD}*)]\}$. So we have:

$$(r+h)\sigma_1 \{ \int_{\xi_3^{SC}(Q_{0,SC}^{QRD}*)}^{\rho_3(Q_{0,SC}^{QRD}*)} \psi[(Q_{0,SC}^{QRD} * - \mu_0 - \sigma_\mu z)/\sigma_1]\phi(z)dz$$

$$- \psi[\Phi^{-1}(s_1^{SC})]\{\Phi[\rho_3(Q_{0,SC}^{QRD}*)] - \Phi[\xi_3^{SC}(Q_{0,SC}^{QRD}*)]\}\} > 0.$$

Putting them into (10.22), we have $\Delta EM^{QRD-DMP} > 0$. (Q.E.D.)

APPENDIX E

-- Tables and Figures for Numerical Analysis

Fig.9.2.1. REP function under QRS-MOQ system

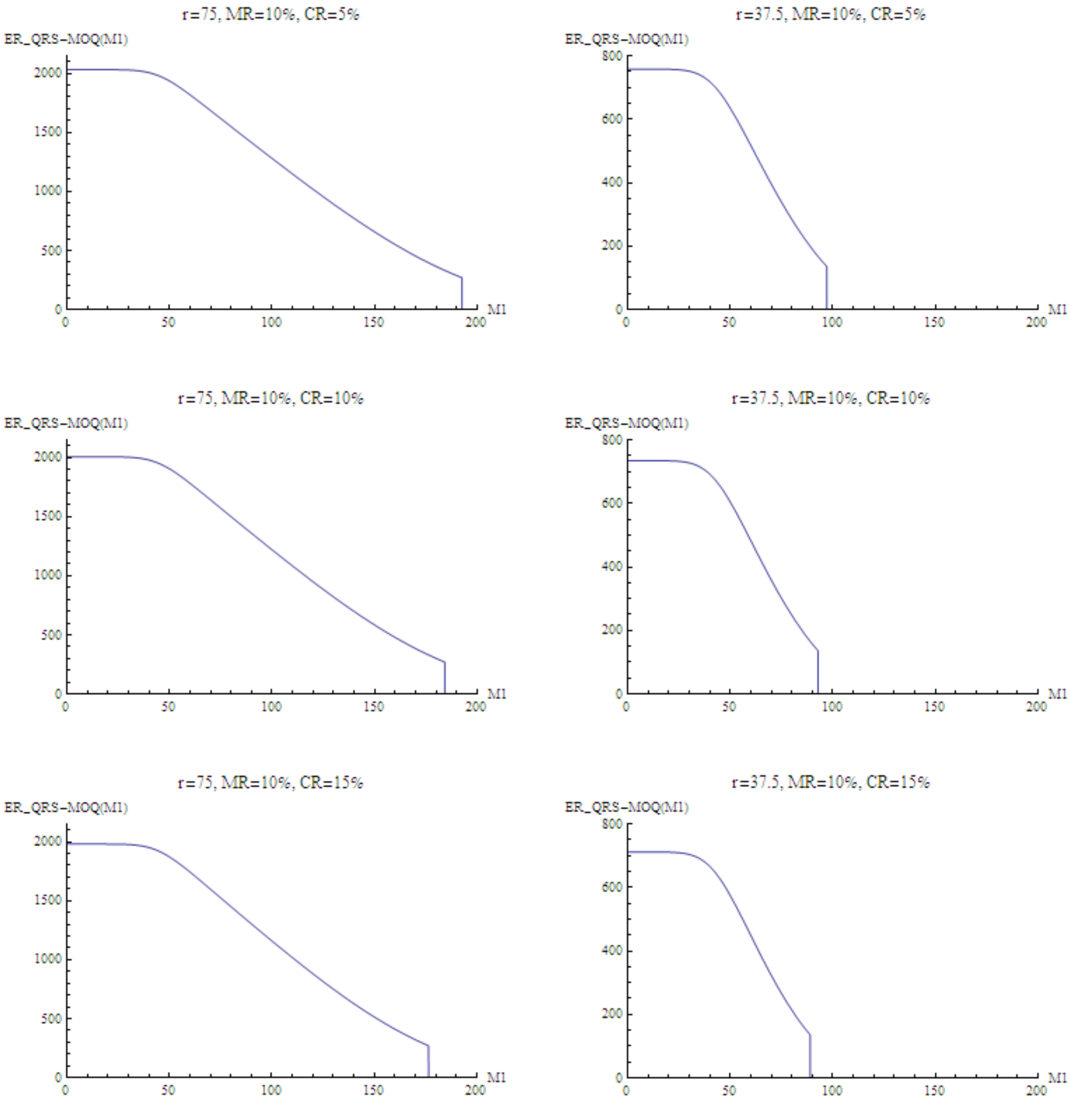

Fig.9.2.2(a). MEP function under QRS-MOQ system (r=75)

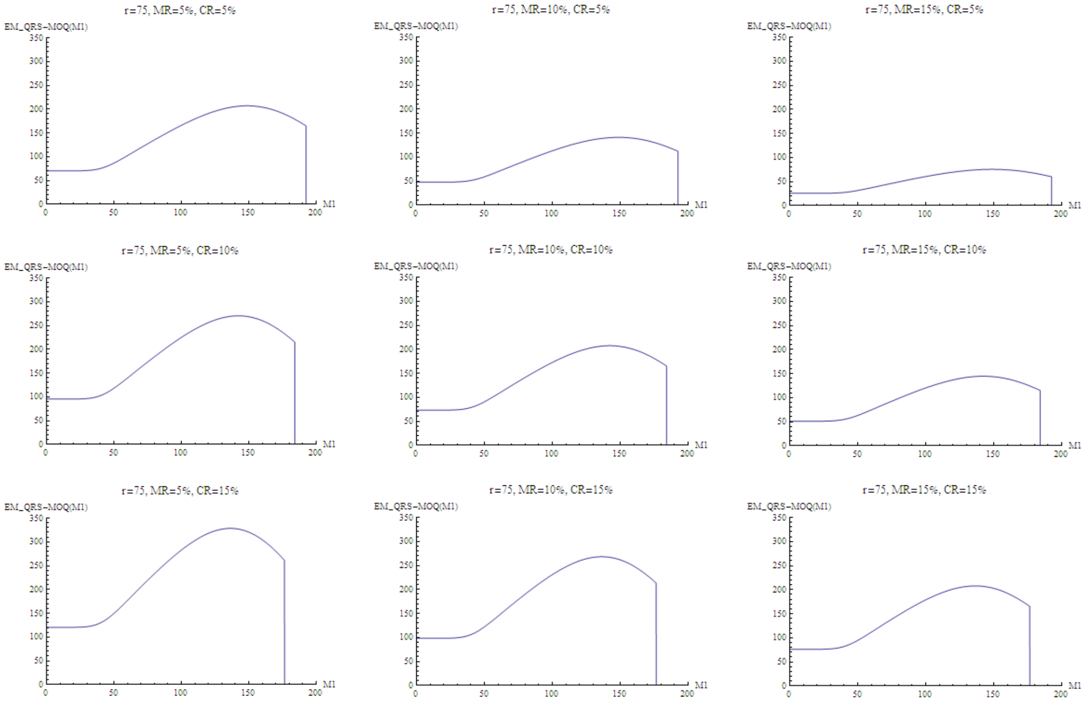

Fig.9.2.2(b). MEP function under QRS-MOQ system (r=37.5)

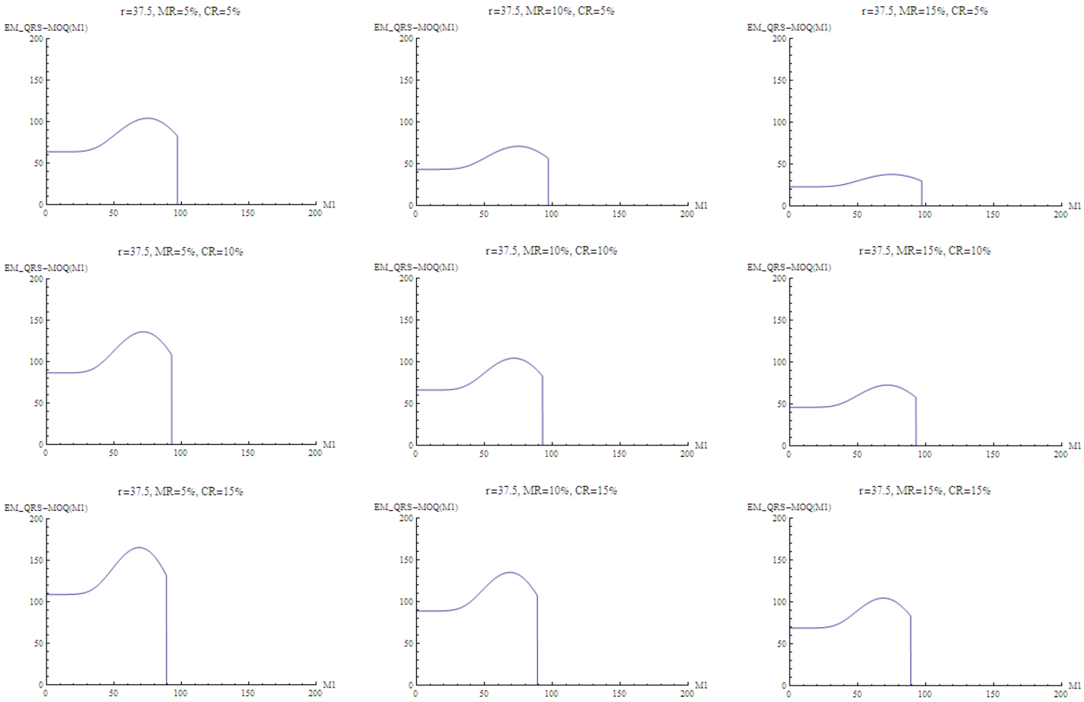

Fig.9.2.3. REP function under QRD-MOQ-I system.

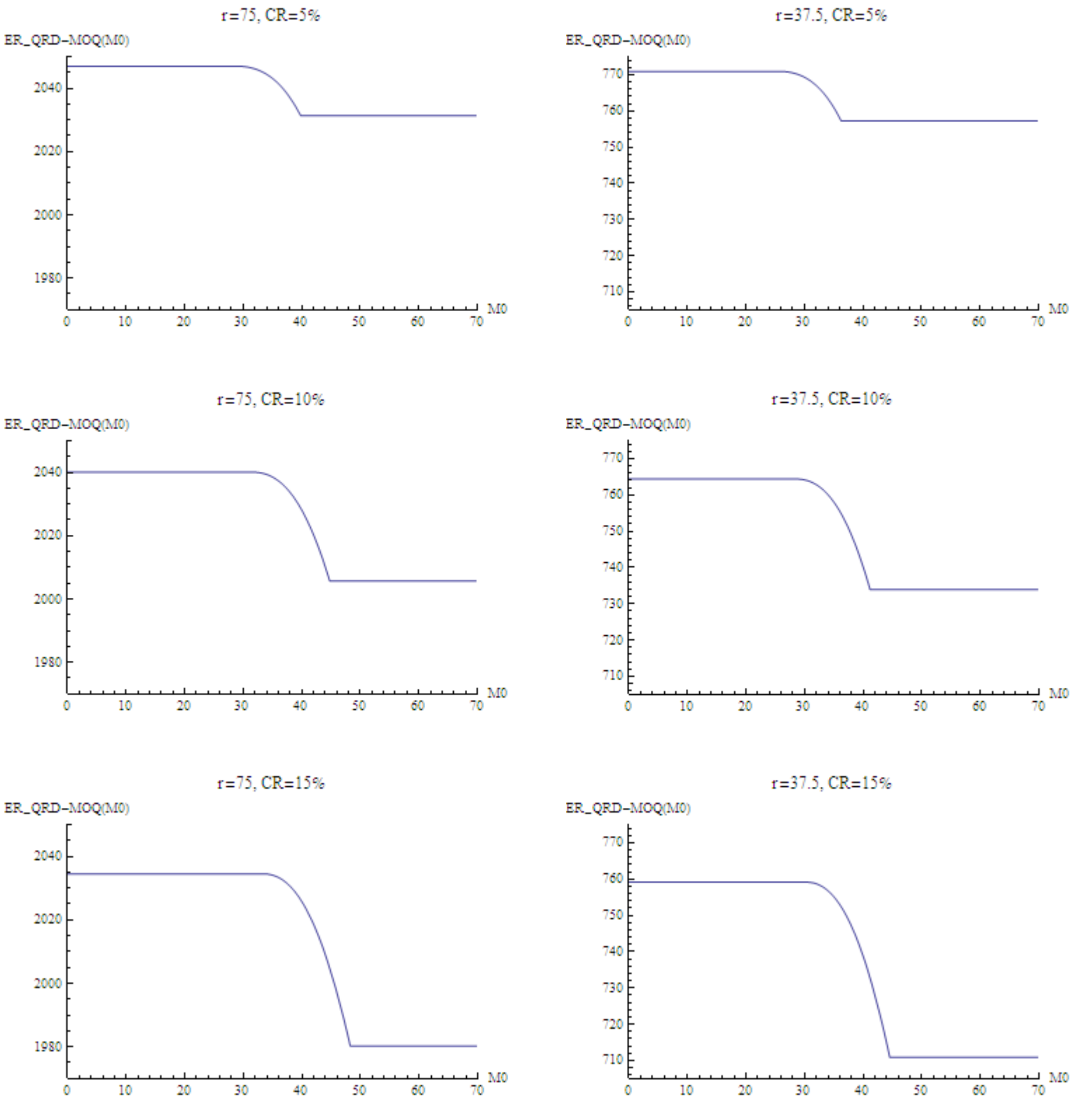

Fig.9.2.4(a). MEP function under QRD-MOQ-I system (r=75)

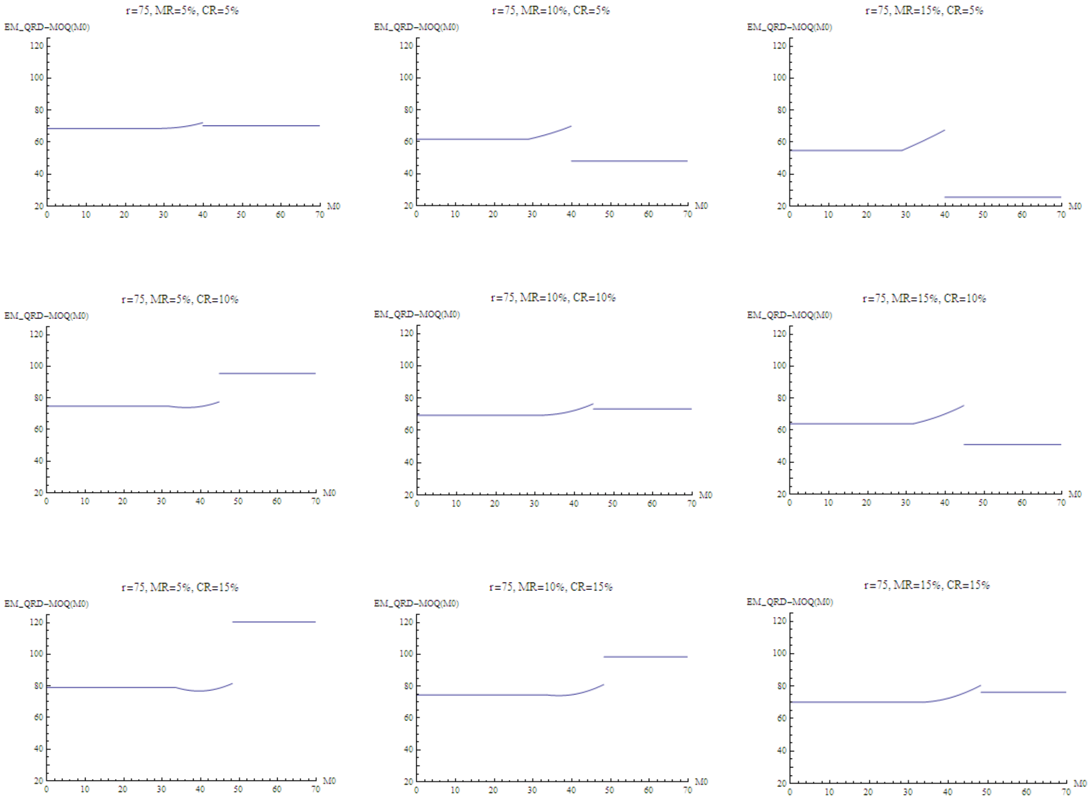

Fig.9.2.4(b). MEP function under QRD-MOQ-I system (r=37.5)

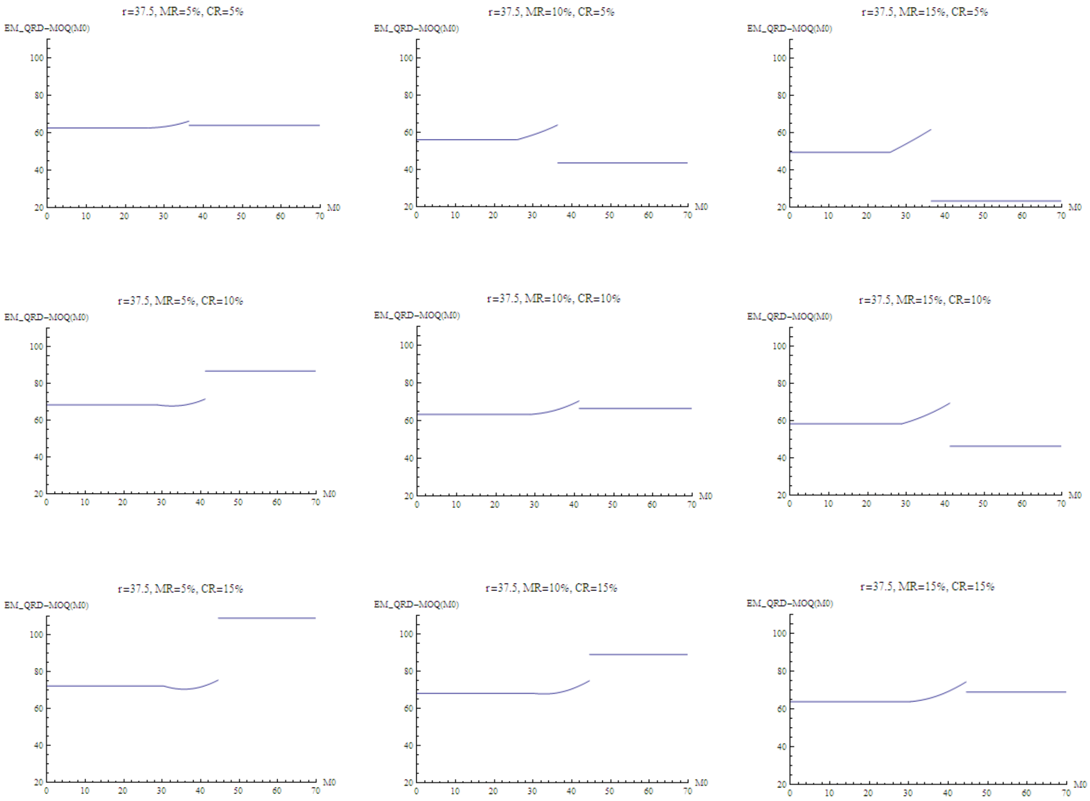

Fig.9.2.5. Retailer Expected Profit (REP) function under QRD-MOQ-II system

[r=75, CR=10%, M0=0, $M_1 = \alpha M^\wedge$ *where* $M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ *].*

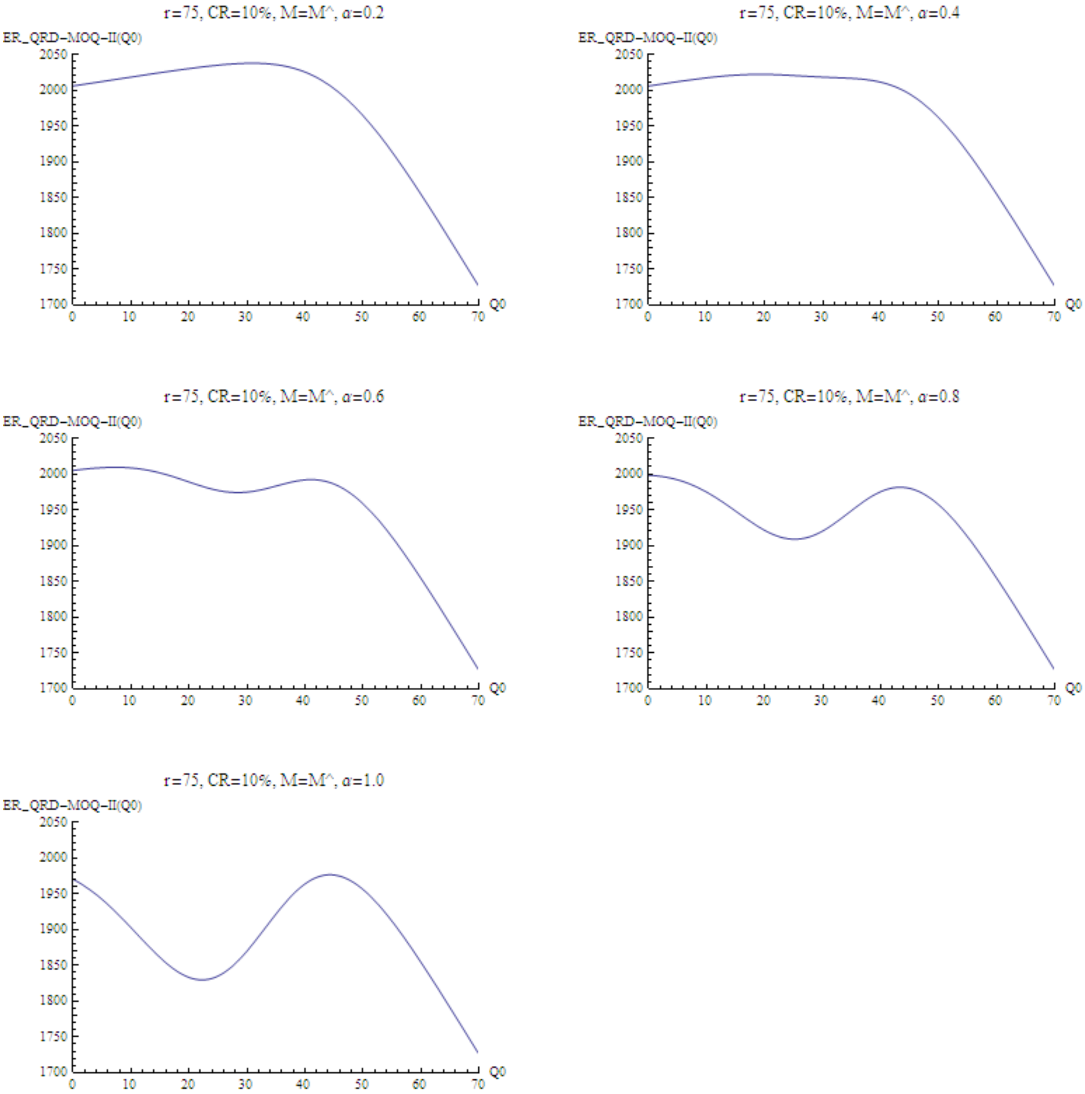

Fig.9.2.6. Manufacturer Expected Profit (MEP) function under QRD-MOQ-II system

[r=75, MR=5%,,CR=10%, M0=0, $M_1 = \alpha M^\wedge$ *where* $M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ *].*

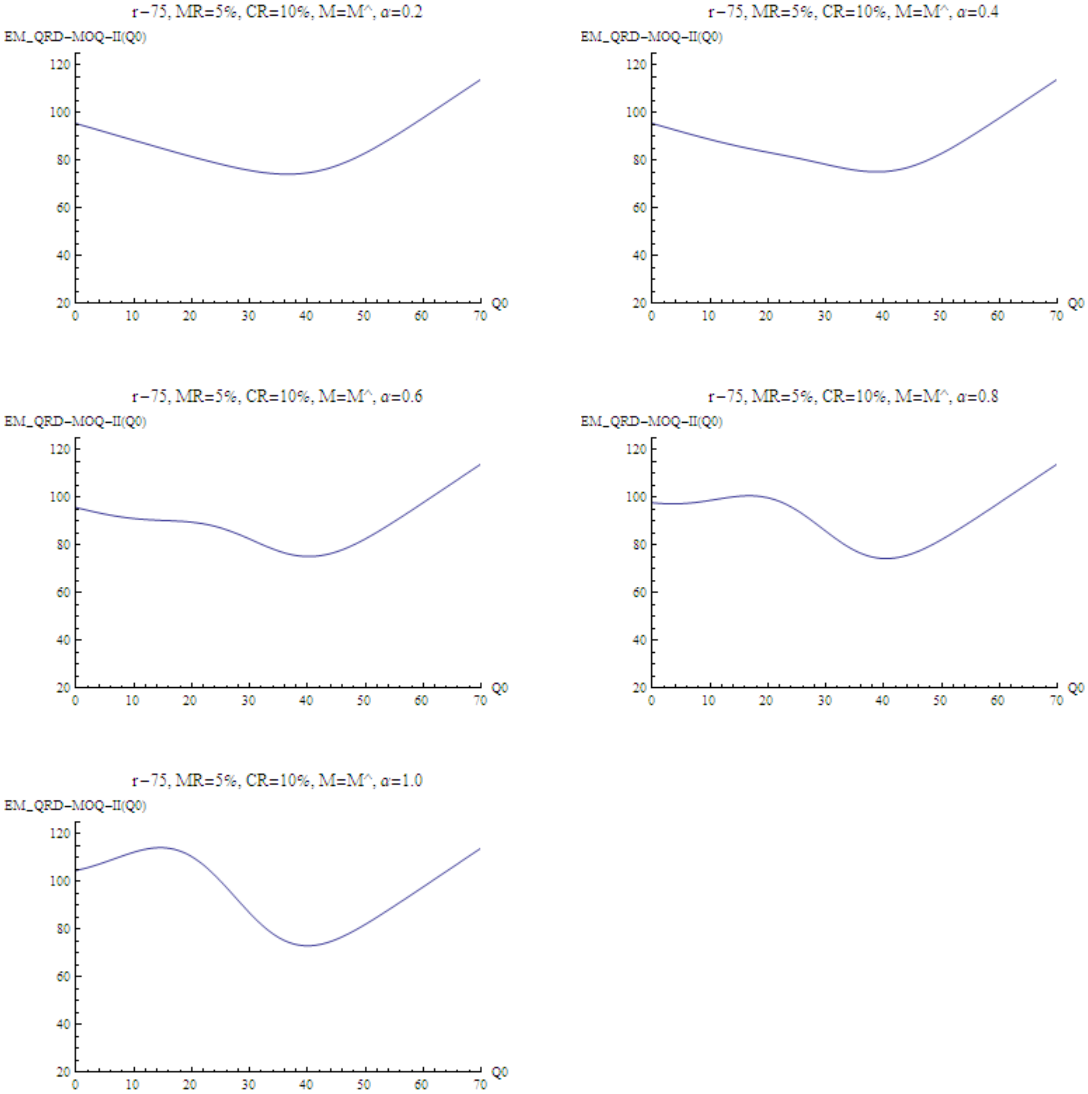

Fig. 9.2.7(a). REP function under QRD-MOQ-II system with constant total MOQ, $M^\wedge = \mu_0 + \sigma_1 \Phi^{-`}(s_1^{SC})$ *where* $M_1 = \alpha M^\wedge$ *and* $M_0 = (1-\alpha) M^\wedge$ *(r=75).*

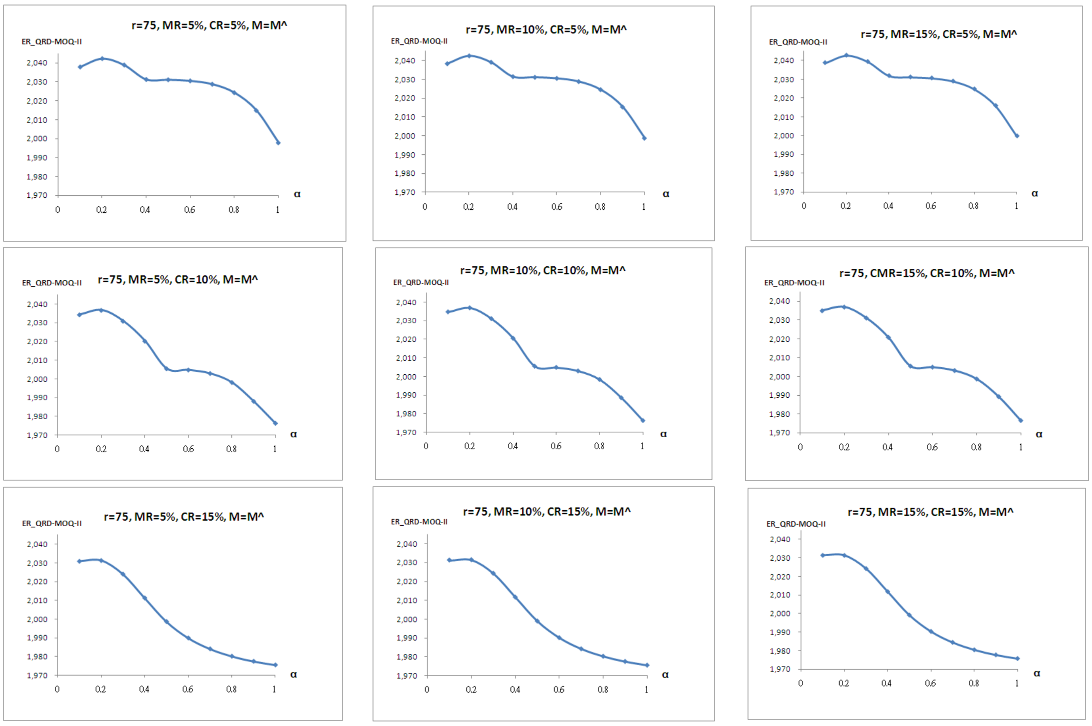

Fig. 9.2.7(b).REP function under QRD-MOQ-II system with constant total MOQ, $M^\wedge = \mu_0 + \sigma_1 \Phi^{-`}(s_1^{SC})$ *where* $M_1 = \alpha M^\wedge$ *and* $M_0 = (1-\alpha) M^\wedge$ *(r=37.5).*

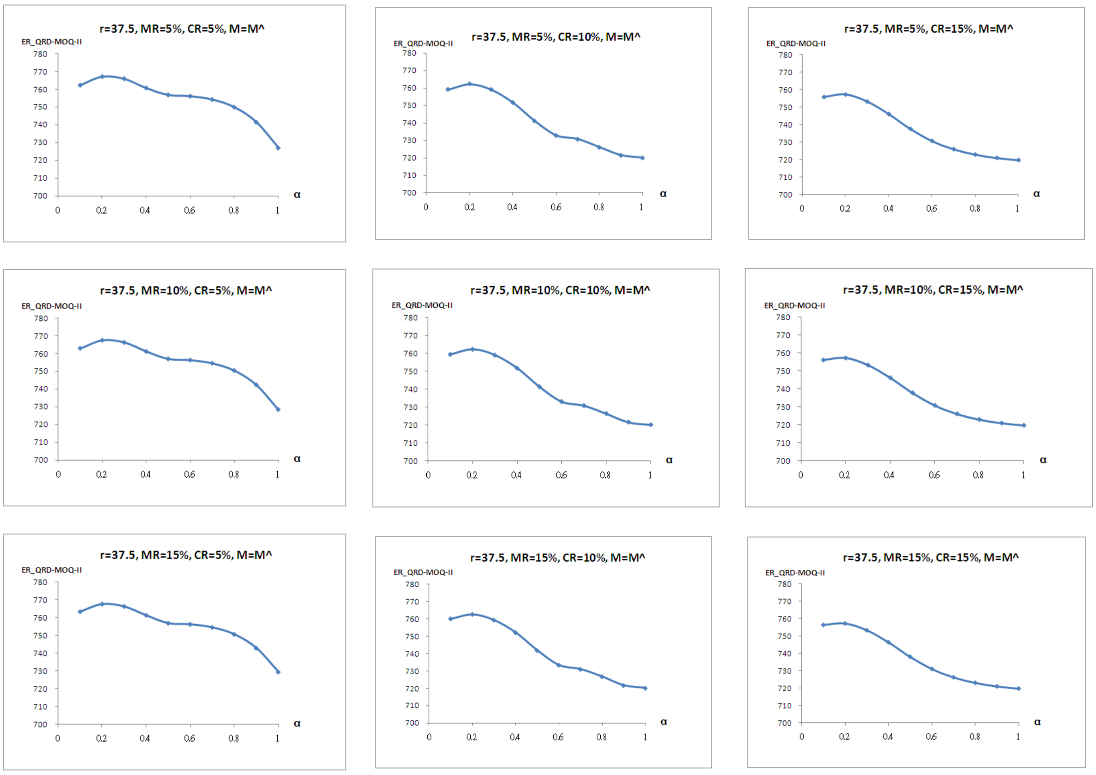

Fig. 9.2.8(a). MEP function under QRD-MOQ-II system with constant total MOQ, $M^{\wedge} = \mu_0 + \sigma_1 \Phi^{-`}(s_1^{SC})$ *where* $M_1 = \alpha M^{\wedge}$ *and* $M_0 = (1-\alpha)M^{\wedge}$ *(r=75)*

Fig. 9.2.8(b). MEP function under QRD-MOQ-II system with constant total MOQ, $M^{\wedge} = \mu_0 + \sigma_1 \Phi^{-`}(s_1^{SC})$ *where* $M_1 = \alpha M^{\wedge}$ *and* $M_0 = (1-\alpha)M^{\wedge}$ *(r=37.5)*

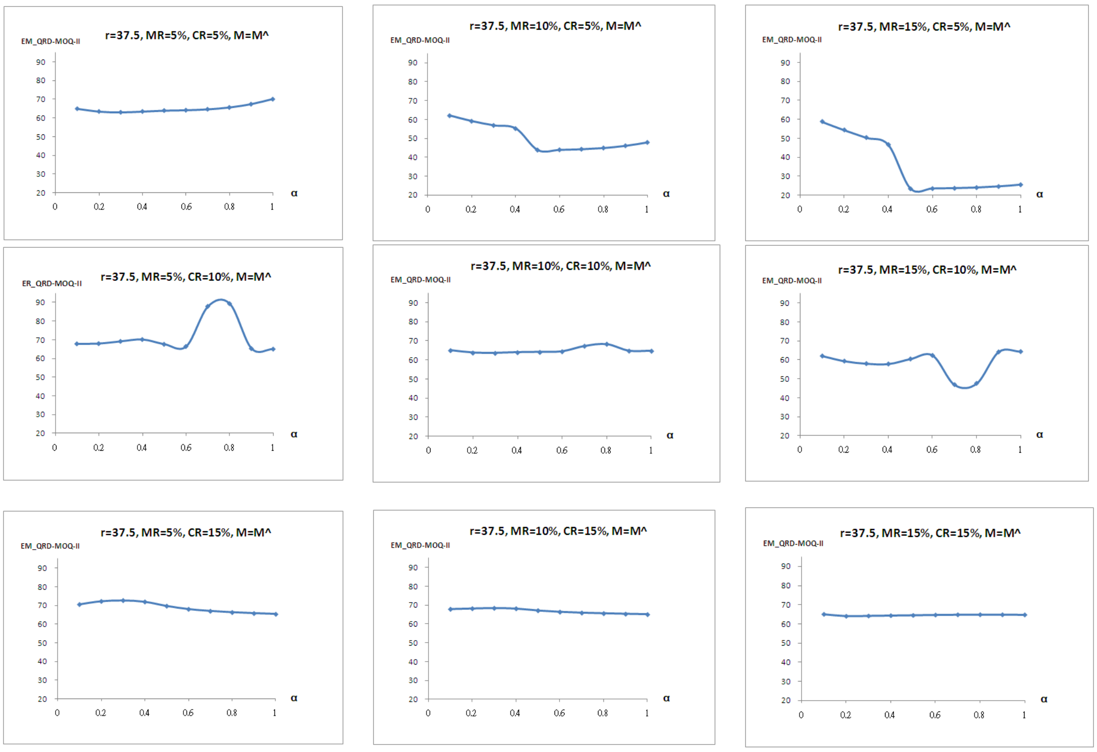

Fig. 9.3.1(a). Supply Chain Expected Profit (SCEP) function (dashed) under QRS-MOQ system, with comparison with the SCEP function under the centralized system (solid) (r=75).

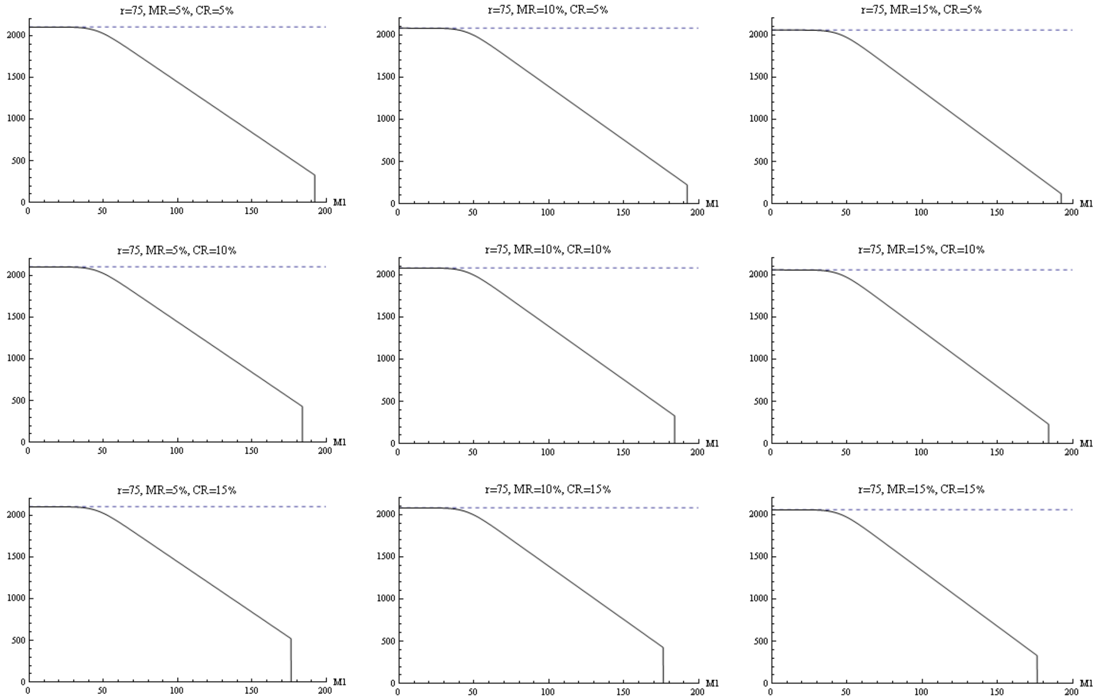

Fig. 9.3.1(b). Supply Chain Expected Profit (SCEP) function (dashed) under QRS-MOQ system, with comparison with the SCEP function under the centralized system (solid) (r=37.5).

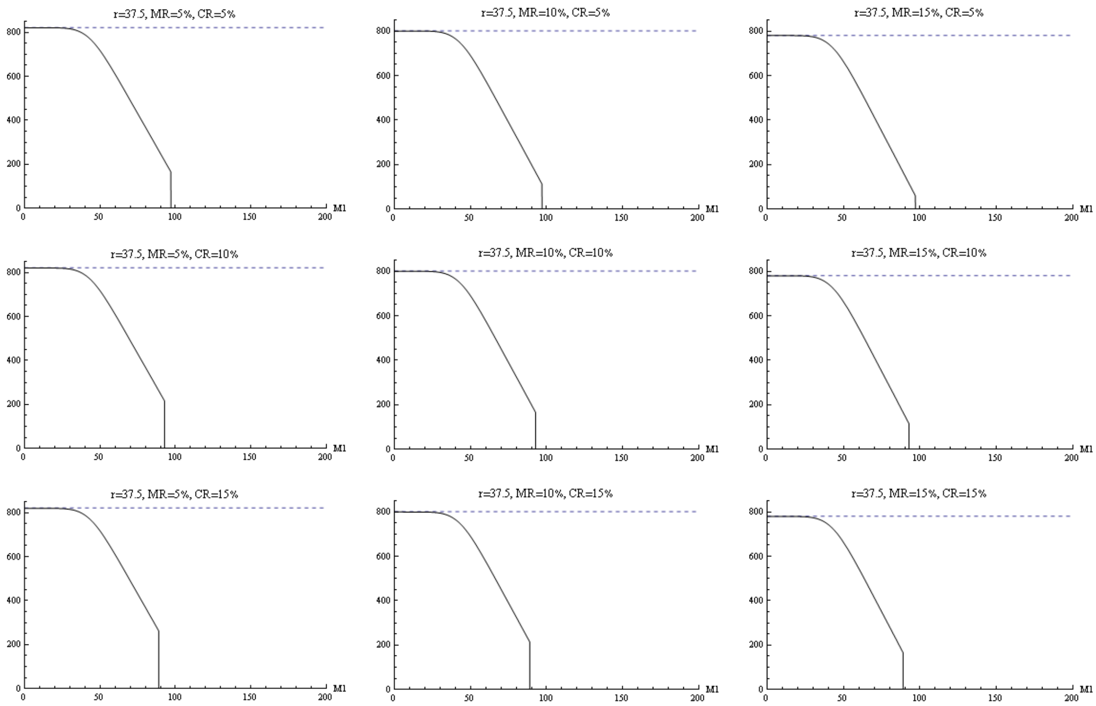

Fig. 9.3.2(a). Supply Chain Expected Profit (SCEP) function (dashed) under QRD-MOQ-I system, with comparison with the SCEP function under the centralized system (solid) (r=75).

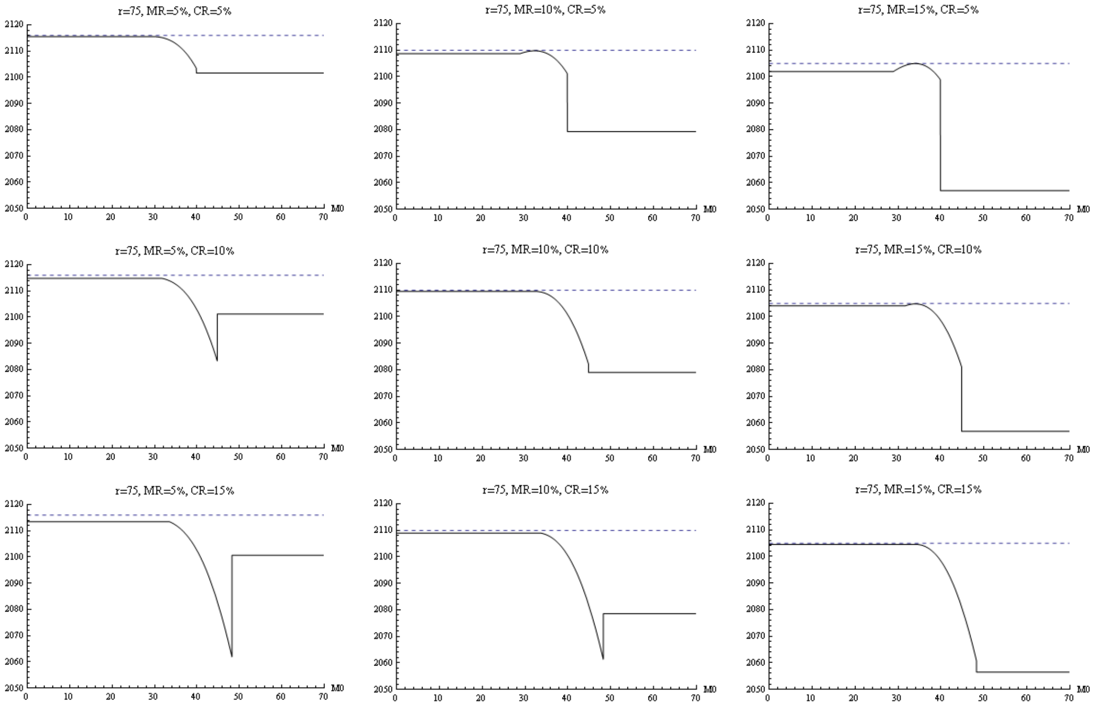

Fig. 9.3.2(b). Supply Chain Expected Profit (SCEP) function (dashed) under QRD-MOQ-I system, with comparison with the SCEP function under the centralized system (solid) (r=37.5).

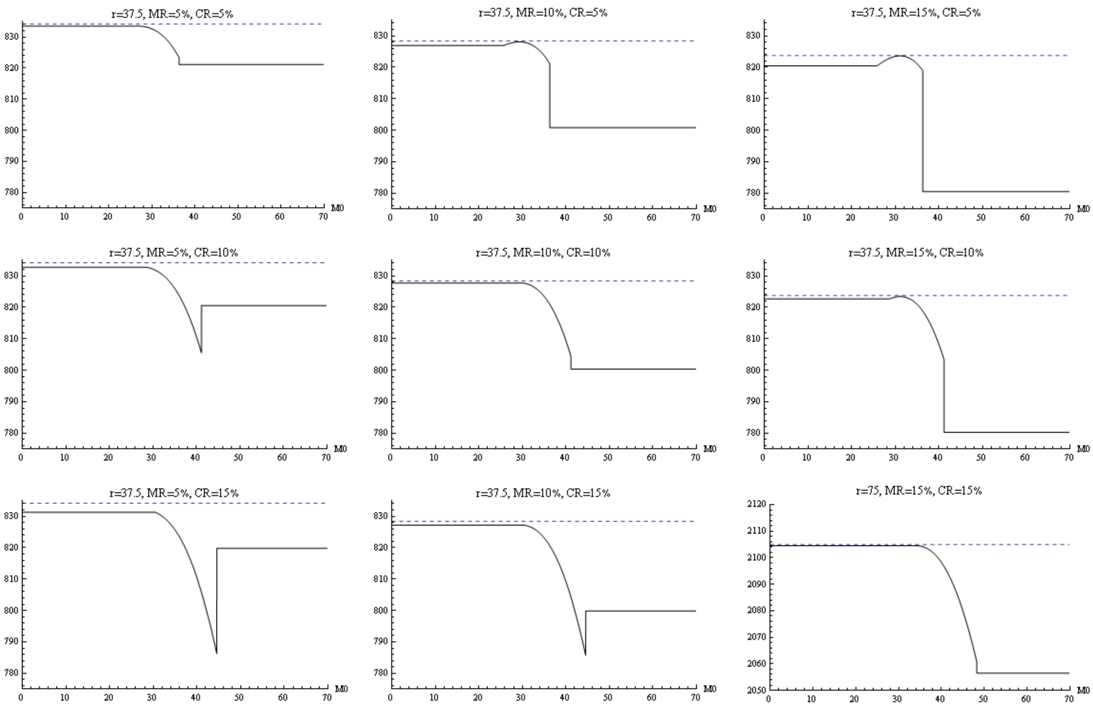

Fig. 9.3.3. Supply Chain Expected Profit (SCEP) function (dashed) under QRD-MOQ-II system, with comparison with the SCEP function under the centralized system (solid). [r=75, MR=5%,CR=10%, $M_0 = 0, M_1 = \alpha M\wedge$ *where* $M\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ *].*

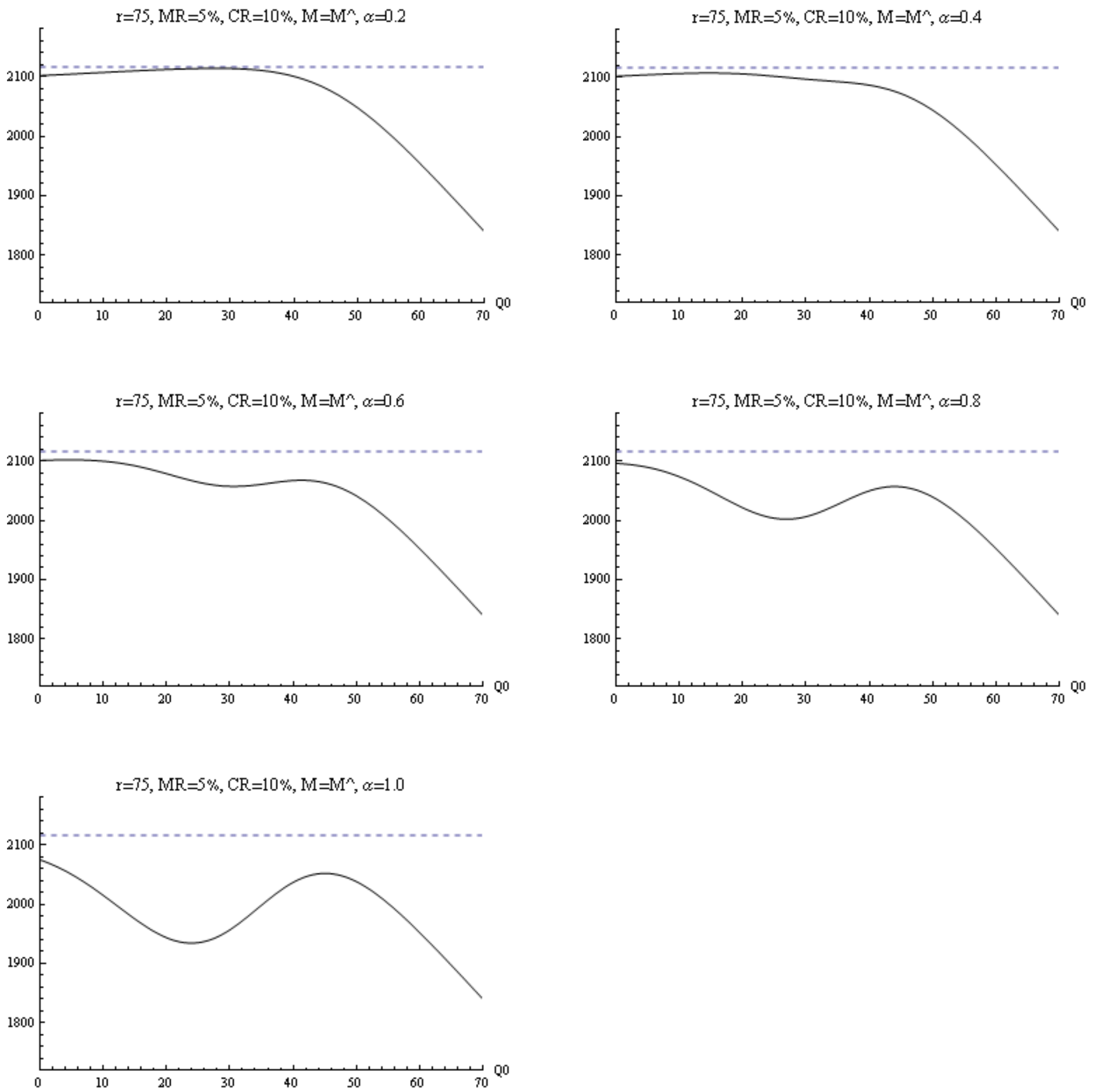

Table 9.1. Parameters adopted for this numerical study.

Parameter	Value(s)
r	$\{75, 37.5\}$
m_0	10.87
c_0	12.5
MR	$\{5\%, 10\%, 15\%\}$
CR	$\{5\%, 10\%, 15\%\}$
h	0.625
μ_0	35
σ_0	$\sqrt{125}$
d_0	100
δ	25

Table 9.3.1. Feasibility of Pareto improvement under various QR-MOQ systems.

MR	CR	r=75			r=37.5		
		QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II
5%	5%	Yes	No	Yes	Yes	Yes	Yes
	10%	Yes	Yes	Yes	Yes	Yes	Yes
	15%	Yes	Yes	Yes	No	Yes	Yes
10%	5%	No	No	Yes	No	No	Yes
	10%	Yes	Yes	Yes	Yes	Yes	Yes
	15%	Yes	Yes	Yes	No	Yes	Yes
15%	5%	No	No	Yes	No	No	Yes
	10%	No	Yes	Yes	No	Yes	Yes
	15%	Yes	Yes	Yes	No	Yes	Yes

Table 9.3.2(a). Range of M_1 for Pareto improvement under the QRS-MOQ system (r=75).

MR	CR	M1 for delta ER>=0	M1 for delta EM>=0	Pareto improvement possible?
5%	5%	0<=M1<=46.03	38.14<=M1<=236.99	Yes
	10%	0<=M1<=41.64	0<=M1<=236.16	Yes
	15%	0<=M1<=34.24	0<=M1<=232.29	Yes
10%	5%	0<=M1<=46.03	63.78<=M1<=219.89	No
	10%	0<=M1<=41.64	30.17<=M1<=226.76	Yes
	15%	0<=M1<=34.24	0<=M1<=225.05	Yes
15%	5%	0<=M1<=46.03	135.49<=M1<=161.58	No
	10%	0<=M1<=41.64	59.55<=M1<=211.45	No
	15%	0<=M1<=34.24	0<=M1<=217.38	Yes

Table 9.3.2(b). Range of M_1 for Pareto improvement under the QRS-MOQ system (r=37.5).

MR	CR	M1 for delta ER>=0	M1 for delta EM>=0	Pareto improvement possible?
5%	5%	0<=M1<=40.03	23.73<=M1<=106.37	Yes
	10%	0<=M1<=34.15	0<=M1<=108.55	Yes
	15%	N/A	0<=M1<=107.99	No
10%	5%	0<=M1<=40.03	58.63<=M1<=89.96	No
	10%	0<=M1<=34.15	0<=M1<=101.80	Yes
	15%	N/A	0<=M1<=103.84	No
15%	5%	0<=M1<=40.03	N/A	No
	10%	0<=M1<=34.15	54.22<=M1<=87.52	No
	15%	N/A	0<=M1<=97.61	No

Table 9.3.3(a). Range of M_0 for Pareto improvement under the QRD-MOQ-I system (r=75).

MR	CR	M1 for delta ER>=0	M1 for delta EM>=0	Pareto improvement possible?
5%	5%	M0>=0	N/A	No
	10%	M0>=0	0<=M0<=33.9495 or M0>=38.4453	Yes
	15%	M0>=0	M0>=0	Yes
10%	5%	M0>=0	N/A	No
	10%	M0>=0	42.2955<=M0<44.7782	Yes
	15%	M0>=0	0<=M0<=35.5491 or M0>=37.7038	Yes
15%	5%	M0>=0	N/A	No
	10%	M0>=0	43.7009<=M0<44.7782	Yes
	15%	M0>=0	M0>=42.2063	Yes

Table 9.3.3(b). Range of M_0 for Pareto improvement under the QRD-MOQ-I system (r=37.5).

MR	CR	M1 for delta ER>=0	M1 for delta EM>=0	Pareto improvement possible?
5%	5%	M0>=0	32.8933<=M0<36.2912	Yes
	10%	M0>=0	M0>=0	Yes
	15%	M0<=43.5789	M0>=0	Yes
10%	5%	M0>=0	N/A	No
	10%	M0>=0	M0>=32.5115	Yes
	15%	M0<=43.5789	M0>=0	Yes
15%	5%	M0>=0	N/A	No
	10%	M0>=0	36.4825<=M0<41.1624	Yes
	15%	M0<=43.5789	M0>=32.0795	Yes

Table 9.3.4(a). Range of M_0 for Pareto improvement under the QRD-MOQ-II system with different values of M_1 (r=75, MR=5%).

CR	M1	M0 for delta ER>=0	M0 for delta EM>=0	Pareto improvement?
5%	8.34	M0<=49.4271	M0>=42.2618	Yes
	16.68	M0<=48.9603	M0>=42.0287	Yes
	25.02	M0<=48.3967	18.0711<=M0<=29.9951 or M0>=42.3373	Yes
	33.35	M0<=14.7188 or 38.001<=M0<=47.8858	5.67206 <=M0<=33.1297 or M0>=43.1299	Yes
	41.69	M0<=4.7923 or 40.9349<=M0<=47.4504	M0<=32.9255 or M0>=43.8624	Yes
10%	8.34	M0<=49.3678	M0>=0	Yes
	16.68	M0<=48.8927	M0>=0	Yes
	25.02	M0<=48.3197	M0>=0	Yes
	33.35	M0<=10.9417 or 38.7481<=M0<=47.8012	M0>=0	Yes
	41.69	41.3503<=M0<=47.3613	M0<=37.2415 or M0>=43.0147	Yes
15%	8.34	M0<=49.3094	M0>=0	Yes
	16.68	M0<=48.8266	M0>=0	Yes
	25.02	M0<=21.5631 or 32.2218<=M0<=48.2446	M0>=0	Yes
	33.35	M0<=3.54135 or 39.3682<=M0<=47.7192	M0>=0	Yes
	41.69	41.714<=M0<=47.2755	M0>=0	Yes

Table 9.3.4(b). Range of M_0 for Pareto improvement under the QRD-MOQ-II system with different values of M_1 (r=37.5, MR=5%).

CR	M1	M0 for delta ER>=0	M0 for delta EM>=0	Pareto improvement?
5%	7.64	M0<=43.6621	M0>=32.6888	Yes
	15.29	M0<=43.1492	M0>=32.2359	Yes
	22.93	M0<=42.4207	2.97334<=M0<=27.0102 or M0>=34.6006	Yes
	30.57	M0<=12.2908 or 33.0426<=M0<=41.6884	M0<=25.8514 or M0>=37.1251	Yes
	38.22	M0<=2.14589 or 36.3177<=M0<=41.056	M0<=23.6483 or M0>=38.3323	Yes
10%	7.64	M0<=43.5546	M0>=0	Yes
	15.29	M0<=43.0341	M0>=0	Yes
	22.93	M0<=42.2971	M0>=0	Yes
	30.57	M0<=6.30929 or 33.9794<=M0<=41.5597	M0<=32.5966 or M0>=35.2922	Yes
	38.22	36.738<=M0<=40.9295	M0<=27.6387 or M0>=38.0602	Yes
15%	7.64	3.687<=M0<=43.448	M0>=0	Yes
	15.29	3.84614<=M0<=42.9205	M0>=0	Yes
	22.93	7.17188<=M0<=13.8643 or 26.5517<=M0<=42.1764	M0>=0	Yes
	30.57	34.7096<=M0<=41.4358	M0>=0	Yes
	38.22	37.0927<=M0<=40.8099	M0<=29.4881 orM0>=37.8905	Yes

Table 9.4.1. Average retailer profit under various systems at different levels of d_0 - based on simulation results (MR=10%).

			r=75			r=37.5		
	CR		d0=100	d0=95	d0=90	d0=100	d0=95	d0=90
Old	N/A	Mean	1,982.44	1,982.39	1,982.23	722.28	722.23	722.18
		s.d.	717.22	713.82	710.26	300.50	299.41	298.30
QRS	5%	Mean	2,040.26	2,040.24	2,040.23	759.05	759.05	759.06
		s.d.	699.96	699.80	699.62	281.35	281.31	281.27
	10%	Mean	2,014.21	2,014.20	2,014.19	735.65	735.66	735.66
		s.d.	693.10	692.94	692.77	274.91	274.88	274.84
	15%	Mean	1,988.30	1,988.29	1,988.28	712.43	712.44	712.44
		s.d.	686.30	686.15	685.98	268.46	268.43	268.39
QRD	5%	Mean	2,055.84	2,055.88	2,055.81	773.15	773.16	773.15
		s.d.	706.02	706.50	705.70	286.96	287.57	288.25
	10%	Mean	2,049.15	2,049.13	2,049.01	766.44	766.40	766.37
		s.d.	705.49	706.26	707.10	287.36	288.26	289.21
	15%	Mean	2,043.19	2,043.22	2,043.21	761.18	761.19	761.17
		s.d.	705.28	706.33	707.05	287.77	288.78	289.83
QRS-MOQ	5%	Mean	2,009.54	2,009.60	2,009.67	731.33	731.36	731.40
		s.d.	752.28	752.11	751.92	330.31	330.26	330.21
	10%	Mean	1,981.27	1,981.34	1,981.42	705.80	705.84	705.87
		s.d.	748.88	748.71	748.52	327.22	327.17	327.11
	15%	Mean	1,953.10	1,953.18	1,953.26	679.47	679.50	679.54
		s.d.	745.58	745.41	745.22	325.48	325.43	325.37
QRD-MOQ-I	5%	Mean	2,055.48	2,055.18	2,054.87	773.16	771.81	771.59
		s.d.	712.59	713.36	714.17	287.94	295.18	296.12
	10%	Mean	2,049.10	2,048.98	2,048.88	766.44	766.33	766.29
		s.d.	706.81	707.64	708.52	287.36	290.08	291.11
	15%	Mean	2,043.19	2,043.22	2,043.21	761.18	761.19	761.17
		s.d.	705.28	706.33	707.05	287.77	288.78	289.83
QRD-MOQ-II	5%	Mean	2,051.35	2,051.36	2,051.36	769.49	769.50	769.51
		s.d.	717.45	717.29	717.11	298.40	298.36	298.31
	10%	Mean	2,045.77	2,045.77	2,045.77	764.50	764.51	764.52
		s.d.	712.15	711.99	711.81	293.34	293.29	293.24
	15%	Mean	2,039.55	2,038.78	2,040.03	758.73	759.27	759.67
		s.d.	706.57	705.51	707.65	288.35	288.30	289.55

Table 9.4.2. Average manufacturer profit under various systems at different levels of d_0 *- based on simulation results (MR=10%).*

			r=75			r=37.5		
	CR		d0=100	d0=95	d0=90	d0=100	d0=95	d0=90
Old	N/A	Mean	74.18	73.84	73.48	64.36	64.21	64.06
		s.d.	0.00	0.00	0.00	0.00	0.00	-
QRS	5%	Mean	48.48	48.46	48.45	44.16	44.15	44.14
		s.d.	10.64	10.64	10.64	10.64	10.64	10.64
	10%	Mean	74.05	74.03	74.00	67.26	67.25	67.24
		s.d.	16.33	16.33	16.33	16.33	16.33	16.33
	15%	Mean	99.37	99.34	99.31	90.01	90.00	89.99
		s.d.	22.02	22.02	22.02	22.02	22.02	22.02
QRD	5%	Mean	62.21	62.44	62.18	63.29	63.31	63.34
		s.d.	9.88	9.81	9.88	14.33	14.23	14.12
	10%	Mean	70.11	70.13	70.15	69.27	69.15	69.05
		s.d.	14.30	14.18	14.05	18.31	18.14	17.97
	15%	Mean	75.46	75.34	75.25	73.28	73.08	72.89
		s.d.	18.28	18.09	17.95	21.85	21.65	21.43
QRS-MOQ	5%	Mean	52.67	52.65	52.63	48.08	48.07	48.07
		s.d.	6.28	6.28	6.28	7.57	7.57	7.57
	10%	Mean	80.67	80.64	80.61	73.49	73.48	73.46
		s.d.	9.52	9.52	9.52	11.69	11.69	11.69
	15%	Mean	108.55	108.51	108.48	98.31	98.30	98.28
		s.d.	12.68	12.68	12.68	17.05	17.05	17.05
QRD-MOQ-I	5%	Mean	63.34	63.86	63.93	64.22	64.43	64.64
		s.d.	14.18	13.17	13.03	9.26	9.18	9.09
	10%	Mean	69.27	68.98	68.88	70.17	70.19	70.22
		s.d.	18.31	17.82	17.64	14.14	14.01	13.87
	15%	Mean	73.28	73.08	72.89	75.46	75.34	75.25
		s.d.	21.85	21.65	21.43	18.28	18.09	17.95
QRD-MOQ-II	5%	Mean	65.13	65.10	65.08	59.57	59.56	59.55
		s.d.	9.13	9.13	9.13	8.93	8.93	8.93
	10%	Mean	70.72	70.69	70.67	64.50	64.49	64.48
		s.d.	13.95	13.95	13.94	13.64	13.64	13.64
	15%	Mean	76.15	75.90	75.82	69.10	68.93	68.92
		s.d.	18.70	18.84	18.52	18.29	18.25	18.06

Table 9.4.3. Average supply chain profit under various systems at different levels of d_0 - based on simulation results (MR=10%).

			r=75			r=37.5		
	CR		d0=100	d0=95	d0=90	d0=100	d0=95	d0=90
Old	N/A	Mean	2,056.63	2,056.23	2,055.71	786.63	786.44	786.23
		s.d.	717.22	713.82	710.26	300.50	299.41	298.30
QRS	5%	Mean	2,088.74	2,088.71	2,088.68	803.21	803.20	803.20
		s.d.	708.29	708.12	707.95	289.53	289.49	289.45
	10%	Mean	2,088.26	2,088.23	2,088.19	802.92	802.91	802.90
		s.d.	705.89	705.74	705.57	287.50	287.46	287.42
	15%	Mean	2,087.68	2,087.64	2,087.59	802.45	802.44	802.43
		s.d.	703.57	703.42	703.26	285.48	285.45	285.41
QRD	5%	Mean	2,118.06	2,118.32	2,118.00	836.44	836.48	836.50
		s.d.	713.68	714.10	713.37	297.86	298.37	298.94
	10%	Mean	2,119.27	2,119.25	2,119.16	835.70	835.55	835.41
		s.d.	716.40	717.05	717.75	300.96	301.69	302.46
	15%	Mean	2,118.65	2,118.55	2,118.46	834.46	834.27	834.07
		s.d.	718.97	719.83	720.41	303.61	304.39	305.21
QRS-MOQ	5%	Mean	2,062.21	2,062.25	2,062.30	779.41	779.44	779.47
		s.d.	756.35	756.18	755.99	334.91	334.86	334.80
	10%	Mean	2,061.94	2,061.98	2,062.03	779.29	779.31	779.34
		s.d.	755.01	754.84	754.65	334.24	334.19	334.14
	15%	Mean	2,061.65	2,061.69	2,061.74	777.78	777.80	777.83
		s.d.	753.69	753.52	753.33	335.69	335.65	335.59
QRD-MOQ-I	5%	Mean	2,119.70	2,119.61	2,119.51	836.50	835.66	835.52
		s.d.	719.63	720.32	721.04	298.68	304.87	305.67
	10%	Mean	2,119.27	2,119.17	2,119.10	835.70	835.31	835.17
		s.d.	717.54	718.25	718.99	300.96	303.18	304.01
	15%	Mean	2,118.65	2,118.55	2,118.46	834.46	834.27	834.07
		s.d.	718.97	719.83	720.41	303.61	304.39	305.21
QRD-MOQ-II	5%	Mean	2,116.48	2,116.46	2,116.44	829.06	829.06	829.06
		s.d.	724.26	724.10	723.92	304.84	304.79	304.74
	10%	Mean	2,116.49	2,116.47	2,116.44	829.00	829.00	828.99
		s.d.	722.52	722.36	722.19	303.14	303.10	303.05
	15%	Mean	2,115.69	2,114.69	2,115.86	827.83	828.20	828.58
		s.d.	720.48	719.50	721.33	301.44	301.38	302.42

Table 9.5.1(a). Comparison of average retailer profit under different systems – based on simulation result (r=75).

MR	CR		Old	QRS	QRD	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II
5%	5%	Mean	1,982.44	2,040.26	2,055.84	2,008.60	2,055.90	2,051.45
		s.d.	717.22	699.96	706.02	753.42	706.74	718.04
	10%	Mean	1,982.44	2,014.21	2,049.15	1,980.27	2,049.15	2,045.68
		s.d.	717.22	693.10	705.49	750.07	705.49	712.55
	15%	Mean	1,982.44	1,988.30	2,043.19	1,952.03	2,043.19	2,038.42
		s.d.	717.22	686.30	705.28	746.82	705.28	707.08
10%	5%	Mean	1,982.44	2,040.26	2,055.84	2,009.54	2,055.48	2,051.35
		s.d.	717.22	699.96	706.02	752.28	712.59	717.45
	10%	Mean	1,982.44	2,014.21	2,049.15	1,981.27	2,049.10	2,045.77
		s.d.	717.22	693.10	705.49	748.88	706.81	712.15
	15%	Mean	1,982.44	1,988.30	2,043.19	1,953.10	2,043.19	2,039.55
		s.d.	717.22	686.30	705.28	745.58	705.28	706.57
15%	5%	Mean	1,982.44	2,040.26	2,055.84	2,010.42	2,053.94	2,051.66
		s.d.	717.22	699.96	706.02	751.17	717.79	716.91
	10%	Mean	1,982.44	2,014.21	2,049.15	1,982.20	2,048.53	2,045.83
		s.d.	717.22	693.10	705.49	747.71	712.35	711.28
	15%	Mean	1,982.44	1,988.30	2,043.19	1,954.09	2,043.23	2,039.90
		s.d.	717.22	686.30	705.28	744.36	707.00	705.66

Remarks:

-- *For QRS-MOQ system:* $M_1 = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$

-- *For QRD-MOQ-I system:* $M_0 = \hat{Q}_{0,SC}^{QRD} *$

-- *For QRD-MOQ-II system:* $M_0 + M_1 = M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ *, where* $M_1 = 0.2M^\wedge$ *, and* $M_0 = 0.8M^\wedge$.

Table 9.5.1(b). Comparison of average retailer profit under different systems – based on simulation result (r=37.5).

MR	CR		Old	QRS	QRD	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II
5%	5%	Mean	722.28	759.05	773.15	730.16	773.16	769.35
		s.d.	300.50	281.35	286.96	331.73	287.94	298.87
	10%	Mean	722.28	735.65	766.44	704.35	766.44	763.70
		s.d.	300.50	274.91	287.36	329.09	287.36	294.16
	15%	Mean	722.28	712.43	761.18	678.33	761.18	759.46
		s.d.	300.50	268.46	287.77	326.55	287.77	288.32
10%	5%	Mean	722.28	759.05	773.15	731.33	772.03	769.49
		s.d.	300.50	281.35	286.96	330.31	294.29	298.40
	10%	Mean	722.28	735.65	766.44	705.80	766.37	764.50
		s.d.	300.50	274.91	287.36	327.22	289.12	293.34
	15%	Mean	722.28	712.43	761.18	679.47	761.18	758.73
		s.d.	300.50	268.46	287.77	325.48	287.77	288.35
15%	5%	Mean	722.28	759.05	773.15	732.44	770.68	769.47
		s.d.	300.50	281.35	286.96	328.92	299.57	298.11
	10%	Mean	722.28	735.65	766.44	706.98	765.85	764.66
		s.d.	300.50	274.91	287.36	325.77	294.82	292.60
	15%	Mean	722.28	712.43	761.18	680.72	761.16	758.95
		s.d.	300.50	268.46	287.77	323.99	290.14	288.13

. *Remarks:*

-- *For QRS-MOQ system:* $M_1 = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$

-- *For QRD-MOQ-I system:* $M_0 = \hat{Q}_{0,SC}^{QRD} *$

-- *For QRD-MOQ-II system:* $M_0 + M_1 = M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$, *where* $M_1 = 0.2M^\wedge$, *and* $M_0 = 0.8M^\wedge$.

Table 9.5.2(a). Comparison of average manufacturer profit under different systems – based on simulation result (r=75).

MR	CR		Old	QRS	QRD	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II
5%	5%	Mean	74.18	71.04	69.28	77.35	69.31	70.30
		s.d.	0.00	15.58	14.48	9.09	14.37	13.33
	10%	Mean	74.18	96.50	75.68	105.35	75.68	75.75
		s.d.	0.00	21.28	18.64	12.25	18.64	18.09
	15%	Mean	74.18	121.71	80.13	133.25	80.13	80.98
		s.d.	0.00	26.97	22.39	15.33	22.39	22.83
10%	5%	Mean	74.18	48.48	62.21	52.67	64.22	65.13
		s.d.	0.00	10.64	9.88	6.28	9.26	9.13
	10%	Mean	74.18	74.05	70.11	80.67	70.17	70.72
		s.d.	0.00	16.33	14.30	9.52	14.14	13.95
	15%	Mean	74.18	99.37	75.46	108.55	75.46	76.15
		s.d.	0.00	22.02	18.28	12.68	18.28	18.70
15%	5%	Mean	74.18	25.92	55.15	28.10	60.77	59.83
		s.d.	0.00	5.69	5.28	3.40	4.71	4.90
	10%	Mean	74.18	51.60	64.55	56.09	65.91	65.57
		s.d.	0.00	11.38	9.97	6.71	9.37	9.76
	15%	Mean	74.18	77.04	70.78	83.97	70.85	71.09
		s.d.	0.00	17.07	14.17	9.95	13.96	14.60

Remarks:

-- *For QRS-MOQ system:* $M_1 = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$

-- *For QRD-MOQ-I system:* $M_0 = \hat{Q}_{0,SC}^{QRD} *$

-- *For QRD-MOQ-II system:* $M_0 + M_1 = M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ *, where* $M_1 = 0.2M^\wedge$ *, and* $M_0 = 0.8M^\wedge$.

Table 9.5.2(b). Comparison of average manufacturer profit under different systems – based on simulation result (r=37.5).

MR	CR		Old	QRS	QRD	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II
5%	5%	Mean	64.36	64.70	63.29	70.68	63.34	64.28
		s.d.	0.00	15.58	14.33	10.97	14.18	13.05
	10%	Mean	64.36	87.65	69.27	95.90	69.27	68.96
		s.d.	0.00	21.28	18.31	15.68	18.31	17.70
	15%	Mean	64.36	110.24	73.28	120.71	73.28	73.23
		s.d.	0.00	26.97	21.85	21.07	21.85	22.35
10%	5%	Mean	64.36	44.16	56.54	48.08	58.70	59.57
		s.d.	0.00	10.64	9.78	7.57	9.07	8.93
	10%	Mean	64.36	67.26	64.03	73.49	64.12	64.50
		s.d.	0.00	16.33	14.05	11.69	13.81	13.64
	15%	Mean	64.36	90.01	68.93	98.31	68.93	69.10
		s.d.	0.00	22.02	17.84	17.05	17.84	18.29
15%	5%	Mean	64.36	23.61	49.80	25.63	55.60	54.66
		s.d.	0.00	5.69	5.23	4.09	4.60	4.79
	10%	Mean	64.36	46.87	58.79	51.05	60.29	59.83
		s.d.	0.00	11.38	9.79	8.22	9.11	9.54
	15%	Mean	64.36	69.78	64.59	75.96	64.71	64.67
		s.d.	0.00	17.07	13.83	13.31	13.53	14.22

. *Remarks:*

-- *For QRS-MOQ system:* $M_1 = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$

-- *For QRD-MOQ-I system:* $M_0 = \hat{Q}_{0,SC}^{QRD} *$

-- *For QRD-MOQ-II system:* $M_0 + M_1 = M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$ *, where* $M_1 = 0.2M^\wedge$ *, and* $M_0 = 0.8M^\wedge$.

Table 9.5.3(a). Comparison of average supply chain profit under different systems – based on simulation result (r=75).

MR	CR		Old	QRS	QRD	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II
5%	5%	Mean	2,056.63	2,111.30	2,125.12	2,085.94	2,125.21	2,121.75
		s.d.	717.22	712.18	717.27	759.29	717.88	727.98
	10%	Mean	2,056.63	2,110.71	2,124.83	2,085.62	2,124.83	2,121.43
		s.d.	717.22	709.80	719.73	757.93	719.73	726.04
	15%	Mean	2,056.63	2,110.01	2,123.32	2,085.28	2,123.32	2,119.41
		s.d.	717.22	707.49	722.08	756.59	722.08	724.00
10%	5%	Mean	2,056.63	2,088.74	2,118.06	2,062.21	2,119.70	2,116.48
		s.d.	717.22	708.29	713.68	756.35	719.63	724.26
	10%	Mean	2,056.63	2,088.26	2,119.27	2,061.94	2,119.27	2,116.49
		s.d.	717.22	705.89	716.40	755.01	717.54	722.52
	15%	Mean	2,056.63	2,087.68	2,118.65	2,061.65	2,118.65	2,115.69
		s.d.	717.22	703.57	718.97	753.69	718.97	720.48
15%	5%	Mean	2,056.63	2,066.18	2,110.99	2,038.52	2,114.71	2,111.49
		s.d.	717.22	704.41	710.11	753.38	721.31	720.56
	10%	Mean	2,056.63	2,065.81	2,113.70	2,038.30	2,114.44	2,111.40
		s.d.	717.22	702.00	713.08	752.05	719.33	718.56
	15%	Mean	2,056.63	2,065.34	2,113.97	2,038.06	2,114.08	2,110.99
		s.d.	717.22	699.67	715.88	750.75	717.39	716.52

Remarks:

-- *For QRS-MOQ system:* $M_1 = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$

-- *For QRD-MOQ-I system:* $M_0 = \hat{Q}_{0,SC}^{QRD}*$

-- *For QRD-MOQ-II system:* $M_0 + M_1 = M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$, *where* $M_1 = 0.2M^\wedge$, *and* $M_0 = 0.8M^\wedge$.

Table 9.5.3(b). Comparison of average supply chain profit under different systems – based on simulation result (r=37.5).

MR	CR		Old	QRS	QRD	QRS-MOQ	QRD-MOQ-I	QRD-MOQ-II
5%	5%	Mean	786.63	823.76	836.44	800.85	836.50	833.63
		s.d.	300.50	293.38	297.86	338.37	298.68	308.29
	10%	Mean	786.63	823.30	835.70	800.25	835.70	832.66
		s.d.	300.50	291.38	300.96	338.50	300.96	306.85
	15%	Mean	786.63	822.68	834.46	799.04	834.46	832.69
		s.d.	300.50	289.39	303.61	339.17	303.61	304.43
10%	5%	Mean	786.63	803.21	829.69	779.41	830.73	829.06
		s.d.	300.50	289.53	294.37	334.91	300.96	304.84
	10%	Mean	786.63	802.92	830.46	779.29	830.49	829.00
		s.d.	300.50	287.50	297.75	334.24	299.27	303.14
	15%	Mean	786.63	802.45	830.11	777.78	830.11	827.83
		s.d.	300.50	285.48	300.65	335.69	300.65	301.44
15%	5%	Mean	786.63	782.66	822.95	758.07	826.28	824.13
		s.d.	300.50	285.70	290.90	331.42	302.86	301.55
	10%	Mean	786.63	782.53	825.22	758.03	826.15	824.49
		s.d.	300.50	283.64	294.57	330.73	301.32	299.46
	15%	Mean	786.63	782.22	825.77	756.68	825.88	823.62
		s.d.	300.50	281.59	297.71	332.01	299.76	298.26

. *Remarks:*

-- *For QRS-MOQ system:* $M_1 = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$

-- *For QRD-MOQ-I system:* $M_0 = \hat{Q}_{0,SC}^{QRD} *$

-- *For QRD-MOQ-II system:* $M_0 + M_1 = M^\wedge = \mu_0 + \sigma_1 \Phi^{-1}(s_1^{SC})$*, where* $M_1 = 0.2M^\wedge$*, and* $M_0 = 0.8M^\wedge$.

Table 10.3.1. Feasibility of channel coordination under QRS-DMP with different production costs.

MR	$r = 75$			$r = 37.5$		
	c_1^M	c_1^R	Coordination feasible?	c_1^M	c_1^R	Coordination feasible?
-15%	10.983	14.490	YES	10.875	14.026	YES
-10%	11.536	14.516	YES	11.431	14.059	YES
-5%	12.088	14.539	YES	11.987	14.089	YES
0%	12.641	14.558	YES	12.542	14.114	YES
5%	13.193	14.575	YES	13.097	14.135	YES
10%	13.745	14.589	YES	13.653	14.152	YES
15%	14.296	14.599	YES	14.208	14.165	NO

Table 10.3.2(a). Expected profits of supply chain agents under QRS-DMP ($r = 75$).

MR	c_1	$ER^{QRS-DMP}$	$\Delta ER\%$*	$EM^{QRS-DMP}$	$\Delta EM\%$*	$ESC^{QRS-DMP}$
5%	13.00	2,036.36	3.33%	66.15	-10.83%	2,102.50
	13.193	2,028.32	2.92%	74.18	0.00%	2,102.50
	13.50	2,015.51	2.27%	86.99	17.27%	2,102.50
	14.00	1,994.66	1.22%	107.84	45.37%	2,102.50
	14.50	1,973.82	0.16%	128.69	73.47%	2,102.50
	14.575	1,970.69	0.00%	131.81	77.68%	2,102.50
	15.00	1,952.97	-0.90%	149.53	101.57%	2,102.50
10%	13.50	2,015.87	2.29%	64.03	-13.69%	2,079.90
	13.745	2,005.71	1.78%	74.18	0.00%	2,079.90
	14.00	1,995.12	1.24%	84.78	14.28%	2,079.90
	14.50	1,974.37	0.19%	105.53	42.25%	2,079.90
	14.589	1,970.69	0.00%	109.20	47.21%	2,079.90
	15.00	1,953.62	-0.87%	126.28	70.22%	2,079.90
15%	14.00	1,995.46	1.26%	61.94	-16.51%	2,057.40
	14.296	1,983.21	0.64%	74.18	0.00%	2,057.40
	14.50	1,974.80	0.21%	82.59	11.34%	2,057.40
	14.599	1,970.69	0.00%	86.70	16.87%	2,057.40
	15.00	1,954.15	-0.839%	103.25	39.18%	2,057.40

* $\Delta ER\% = (ER^{QRS-DMP} - ER^{Old}) / ER^{Old}$; $\Delta EM\% = (EM^{QRS-DMP} - EM^{Old}) / EM^{Old}$

Table 10.3.2(b). Expected profits of supply chain agents under QRS-DMP ($r = 37.5$).

MR	c_1	$ER^{QRS-DMP}$	$\Delta ER\%$*	$EM^{QRS-DMP}$	$\Delta EM\%$*	$ESC^{QRS-DMP}$
5%	13.00	761.45	6.04%	60.63	-5.79%	822.08
	13.097	757.73	5.52%	64.36	0.00%	822.08
	13.50	742.34	3.38%	79.74	23.91%	822.08
	14.00	723.23	0.72%	98.85	53.60%	822.08
	14.135	718.08	0.00%	104.00	61.61%	822.08
	14.50	704.12	-1.94%	117.96	83.29%	822.08
10%	13.50	742.83	3.45%	58.56	-9.01%	801.38
	13.653	737.03	2.64%	64.36	0.00%	801.38
	14.00	723.85	0.80%	77.53	20.48%	801.38
	14.152	718.08	0.00%	83.30	29.44%	801.38
	14.50	704.87	-1.84%	96.51	49.96%	801.38

* $\Delta ER\% = (ER^{QRS-DMP} - ER^{Old}) / ER^{Old}$; $\Delta EM\% = (EM^{QRS-DMP} - EM^{Old}) / EM^{Old}$

Table 10.3.3(a). Feasibility of SCEP maximization under the QRD-DMPS system (r=75).

MR	CR	$Q_{0,SC}^{QRD}$ *	$\hat{Q}_0^{QRD-DMPS}$	$Q_0^{QRD-DMPS}$ *	SCEP Maximization?
5%	5.0%	29.3335	28.9222	Q0_SC	YES
	5.5%	29.3335	29.3117	Q0_SC	YES
	6.0%	29.3335	29.6712	Q0_DMPS^	NO
	10.0%	29.3335	31.8580	Q0_DMPS^	NO
	15.0%	29.3335	33.6854	Q0_DMPS^	NO
10%	5.0%	32.2266	28.8845	Q0_SC	YES
	10.0%	32.2266	31.8106	Q0_SC	YES
	12.0%	32.2266	32.6191	Q0_DMPS^	NO
	15.0%	32.2266	33.6299	Q0_DMPS^	NO
15%	5.0%	34.0081	28.8624	Q0_SC	YES
	10.0%	34.0081	31.7774	Q0_SC	YES
	15.0%	34.0081	33.5874	Q0_SC	YES
	18.0%	34.0081	34.4253	Q0_DMPS^	NO
	19.0%	34.0081	34.6764	Q0_DMPS^	NO

Table 10.3.3(b). Feasibility of SCEP maximization under the QRD-DMPS system (r=37.5).

MR	CR	$Q_{0,SC}^{QRD}*$	$\hat{Q}_0^{QRD-DMPS}$	$Q_0^{QRD-DMPS}*$	SCEP Maximization?
5%	5.0%	26.4238	25.9012	$Q_{0,SC}^{QRD}*$	YES
	5.5%	26.4238	26.2922	$Q_{0,SC}^{QRD}*$	YES
	10.0%	26.4238	28.8443	$\hat{Q}_0^{QRD-DMPS}$	NO
	15.0%	26.4238	30.6705	$\hat{Q}_0^{QRD-DMPS}$	NO
10%	5.0%	29.3059	25.8428	$Q_{0,SC}^{QRD}*$	YES
	10.0%	29.3059	28.7721	$Q_{0,SC}^{QRD}*$	YES
	15.0%	29.3059	30.5874	$\hat{Q}_0^{QRD-DMPS}$	NO
15%	5.0%	31.0676	25.8084	$Q_{0,SC}^{QRD}*$	YES
	10.0%	31.0676	28.7212	$Q_{0,SC}^{QRD}*$	YES
	15.0%	31.0676	30.5233	$Q_{0,SC}^{QRD}*$	YES

Table 10.3.4(a). Feasibility of Pareto Improvement under the QRD-DMPS system (r=75).

MR	CR	$ER^{QRD-DMPS}$	$\Delta ER\%$	$EM^{QRD-DMPS}$	$\Delta EM\%$	$ESC^{QRD-DMPS}$	Efficiency	Pareto Improvement?
5%	5.0%	2046.50	3.9%	69.52	-6.2%	2116.02	100.00%	NO
	5.5%	2045.71	3.8%	70.31	-5.2%	2116.02	100.00%	NO
	6.0%	2044.93	3.8%	71.09	-4.1%	2116.02	100.00%	NO
	10.0%	2039.28	3.5%	76.29	2.9%	2115.57	99.98%	YES
	15.0%	2033.30	3.2%	81.20	9.5%	2114.50	99.93%	YES
10%	5.0%	2045.80	3.8%	64.15	-13.5%	2109.95	100.00%	NO
	10.0%	2039.59	3.5%	70.36	-5.1%	2109.95	100.00%	NO
	12.0%	2037.13	3.4%	72.81	-1.8%	2109.94	100.00%	NO
	15.0%	2033.70	3.2%	76.03	2.5%	2109.73	99.99%	YES
15%	5.0%	2044.38	3.8%	60.63	-18.2%	2105.01	100.00%	NO
	10.0%	2039.17	3.5%	65.84	-11.2%	2105.01	100.00%	NO
	15.0%	2033.98	3.2%	71.04	-4.2%	2105.02	100.00%	NO

18.0%	2030.90	3.1%	74.09	-0.1%	2104.99	100.00%	NO
19.0%	2029.91	3.0%	75.03	1.2%	2104.94	100.00%	YES

$* \Delta ER\% = (ER^{QRS-DMPS} - ER^{Old}) / ER^{Old}$; $\Delta EM\% = (EM^{QRS-DMPS} - EM^{Old}) / EM^{Old}$

Table 10.3.4(b). Feasibility of Pareto Improvement under the QRD-DMPS system (r=37.5).

MR	CR	$ER^{QRD-DMPS}$	$\Delta ER\%$	$EM^{QRD-DMPS}$	$\Delta EM\%$	$ESC^{QRD-DMPS}$	Efficiency	Pareto Improvement?
5%	5.0%	770.25	7.3%	63.88	-0.7%	834.13	100.00%	NO
	5.5%	769.49	7.2%	64.64	0.5%	834.13	100.00%	YES
	10.0%	763.31	6.4%	70.41	9.5%	833.72	99.95%	YES
	15.0%	757.60	5.6%	75.11	16.8%	832.71	99.83%	YES
10%	5.0%	769.58	7.2%	58.77	-8.6%	828.35	100.00%	NO
	10.0%	763.71	6.4%	64.64	0.5%	828.35	100.00%	YES
	15.0%	758.11	5.6%	70.05	8.9%	828.16	99.98%	YES
15%	5.0%	768.18	7.0%	55.51	-13.7%	823.70	100.00%	NO
	10.0%	763.32	6.4%	60.38	-6.1%	823.70	100.00%	NO
	15.0%	758.47	5.7%	65.23	1.4%	823.70	100.00%	YES

Table 10.3.5. Feasibility of channel coordination under the QRD-DMPS system.

r	MR	CR	SCEP Maximization?	Pareto Improvement?	Channel Coordination?
75	5%	5.0%	YES	NO	NO
		5.5%	YES	NO	NO
		6.0%	YES	NO	NO
		10.0%	NO	YES	NO
		15.0%	NO	YES	NO
	10%	5.0%	YES	NO	NO
		10.0%	YES	NO	NO
		12.0%	NO	NO	NO
		15.0%	NO	YES	NO
	15%	5.0%	YES	NO	NO
		10.0%	YES	NO	NO
		15.0%	NO	NO	NO
		18.0%	NO	NO	NO
		19.0%	NO	YES	NO
37.5	5%	5.0%	YES	NO	NO
		5.5%	**YES**	**YES**	**YES**
		10.0%	NO	YES	NO
		15.0%	NO	YES	NO
	10%	5.0%	YES	NO	NO
		10.0%	**YES**	**YES**	**YES**
		15.0%	NO	YES	NO
	15%	5.0%	YES	NO	NO
		10.0%	YES	NO	NO
		15.0%	**YES**	**YES**	**YES**

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