Trust and Inventory Replenishment Decision Under Continuous Review System

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Dedication

To all those who remind me the worth of

peace and unconditional love

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Abstract

This thesis examines the impact of inventory manager' trust on their replenishment decision. We conduct this study in the experimental environment and design an experiment with unknown market demand, local information, and under continuous replenishment review. We also develop a multi-round trust measurement procedure through questionnaires and administer it in the context of a laboratory experiment. To conduct the study, we take the three following steps: First we investigate inventory replenishment decision under continuous review in a decentralized supply chain. Our results show that order time intervals increase along the supply chain. Inventory managers' replenishment decisions affect their own and the other echelons' costs. Moreover, we find that wholesaler plays the smoothing role in the decentralized supply chain. Second, we develop a multi-round trust measurement procedure through questionnaires and conduct it in the context of a laboratory experiment. This design allows us to observe inventory managers' trust in customer and trust in supplier over time. Our results show that trust exist in a decentralized supply chain, with local information, no communication, and no access to the market demand, and trust level varies in a continuum of intensity in a decentralized supply chain. Also, we find that trust evolves and for some echelons it grows over time. We further examine trust in customer and trust in supplier along the supply chain. Our results suggest that trust in supplier is the lowest in the middle of supply chain and that trust in customer decreases while moving upstream along a decentralized supply chain. Finally, we study the impact of trust in inventory replenishment decision and analyze data at individual and echelon level. Our results show that low trust in customer is linked to high order quantity and long order time intervals at the individual levels. Also, results on the echelon level suggest that distributor exhibits the lowest trust, highest order quantity and largest order time intervals among echelons, and retailer is the only echelon that considers trust in supplier while placing order quantities to upstream supplier. We further explore the inventory holding behavior of managers and find that inventory managers hold higher inventory level when they have lower trust in customer and trust in their upstream supplier. This research fits within the behavioral operations field.

Keywords: Trust, Supply chain relationships, Inventory replenishment decision, Continuous review, laboratory experiment, behavioral operations.

Résumé

Cette thèse examine l'impact de la confiance entre entreprises partenaires dans une chaîne logistique sur le comportement des approvisionneurs, et notamment leurs décisions d'achat. L'étude est développée et réalisée dans un cadre expérimental représentant une chaîne logistique de quatre échelons s'approvisionnant en continu, sans communication entre échelons et avec une demande non divulguée. Nous développons dans ce cadre une procédure de mesure de l'évolution du niveau de confiance en fonction des transactions effectuées. Pour notre étude, nous avons procédé en trois étapes: D'abord nous investiguons la décision d'approvisionnement dans une chaîne logistique décentralisée où les fréquences de passage d'ordres sont laissées au libre choix du décideur. Nos résultats démontrent que les intervalles de temps entre commandes augmentent de l'aval de la chaîne vers l'amont, affectant les coûts à chaque échelon. De plus, nous constatons que les maillons du centre de la chaîne jouent des rôles de régulateur. En second lieu, nous développons une procédure de mesure de la confiance sous forme de questionnaires dans un contexte expérimental composé de plusieurs étapes, permettant d'évaluer la confiance du gestionnaire aussi bien en son client qu'en son fournisseur. Nos résultats montrent que dans une chaîne logistique décentralisée sans communication et sans accès à l'information sur la demande du marché, la confiance existe et son degré varie selon l'intensité de la relation entre les partenaires. Nous avons trouvé que la confiance peut changer et évoluer dans le temps pour certains échelons. De plus, nous avons examiné la confiance en le client et la confiance en le fournisseur. Nos résultats démontrent que la confiance en le client diminue d'aval vers l'amont de la chaîne. Finalement, nous étudions l'impact de la confiance sur les décisions d'approvisionnement et nous analysons les données au niveau individuel et au niveau des échelons. Notre résultat implique que la diminution de la confiance en un client est liée à la grande taille des commandes passées et aux longs intervalles de temps entre commandes. Au niveau de l'échelon, les résultats suggèrent que le distributeur affiche la confiance la plus basse, la plus grande taille moyenne de commande et les commandes les plus espacées dans le temps, alors que le détaillant est le seul échelon qui prend en considération la confiance en son fournisseur quand il place ses commandes. Nous explorons le comportement du gestionnaire du stock et concluons qu'il constitue davantage de stocks quand sa confiance en son client et sa confiance en son fournisseur sont faibles.

Mots-clés : Confiance, relations dans les chaînes logistiques, décision d'approvisionnement de stocks, gestion comportementale, expérimentation.

Contents

List of Figures

List of Tables

List of Symbols

M	Market
R	Retailer
W	Wholesaler
D	Distributor
OQ	Order quantity
OT	Order time intervals
CV_{OQ}	Variability of order quantity
CV_{OT}	Variability of order time intervals
OI	On-hand inventory
SL	Supply line
S	Shipment
HC	Holding cost
BC	Backorder cost
PC	Purchasing cost
TTC	Total cost
p	Price
π	Backorder cost per unit per day
h	Holding cost per unit per day
F	Fixed purchasing cost
T_c	Trust in customer
T_s	Trust in supplier
IR	Inventory replenishment decision
IB	Inventory holding behavior

Chapter 1

Introduction

The main goal of this chapter is to highlight the motivation and the objective of this research. The following issues will be addressed in this chapter;

1. Thesis motivation and objective
2. Research questions
3. Research methods
4. Research contribution
5. Thesis structure

Introduction

1. Thesis motivation and objective

Supply chain is "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Christopher, 2010). A supply chain has a dynamic nature that encompasses people, activities, information, and resources.

One way to reach this goal is to see the supply chain dynamic with a normative lens. By this way, we assume that people, hereafter inventory managers, are fully rational, make profit-maximizing decisions, and they are aware of the feedback of their decisions. Thus, inventory managers must "mind the gap!" between demand and supply and adjust to the prescribed normative models.

Various normative models to date have been proposed to assist inventory managers in filling the gap between demand and supply. The common behavioral assumptions used in normative models are as follows: people are; (1) not the core of operations, (2) not predictable, (3) independent, (4) observable, (5) emotionless, (6) stationary with no learning, fatigue, and problem solving, and (7) not part of product or service (Bourdreau et al., 2003). Nevertheless, the demand-supply mismatch still remains.

One might ask while satisfying downstream customer demand and minimizing total costs in supply chain, how do the inventory managers' decisions change over time along supply chains? The most obvious answer is that the inventory manager who makes decision, the customer who places orders, and the supplier who regulates the inventory level are all "human beings" and human decision-making is bounded to availability of information and their processes.

Research shows that decision makers have a cognitive limitation to formulate complex problems, in a finite time on the basis of available information, and fail to follow normative models. Furthermore, it appears that decision makers systematically deviate from the normative models (Kahneman et al., 1982). Evidence within the supply chain literature also confirms this breakdown (Bolton and Katok, 2005; Croson and Donohue, 2006; Sterman, 2006). This fact calls for a new way to look at supply chain dynamic and the basic assumptions of operations.

As an alternative lens, behavioral operations explore human behavior and cognition and the impact on operating systems and processes (Gino and Pisano, 2008). By this way, we treat human behavior as the core on operations and consider the decision maker at best boundedly rational.

Behavioral operations is a multidisciplinary branch of operations management. It offers insight to the problems in operations management with elements from all three components of behavior, operations, and management. Fundamental theories on cognitive psychology, social psychology, and sociology to date enormously offer insight to solve the operations problems (Bendoly et al., 2010). Therefore, there is a large range of research methods from experiment, survey, to mathematical modeling to utilize in behavioral operations research (Croson et al., 2012).

This thesis fits within the behavioral operations field and aims to identify whether the trust perception of the inventory manager affects her/his inventory replenishment decision. Within this context, the objectives of this thesis are three-fold.

1. To identify the ordering behavior of the inventory manager under continuous review in decentralized supply chain. This requires micro analysis of the inventory manager decisions on order quantity and order time intervals at individual and echelon levels.
2. To develop a procedure to measure the level of trust between inventory managers in different echelons over time. This involves a measurement that considers multiple observations of the inventory managers' trust perception in her/his customer and in her/his supplier.
3. To examine the effect of trust in customer and trust in supplier on the inventory manager's replenishment decision. This requires an appropriate research design to draw conclusion on causality between trust and inventory replenishment decisions.

2. Research questions

The following questions correspond to the main goal of this study:

1. How do inventory replenishment decisions in continuous review systems change along the supply chain; more specifically; how do order time intervals change along the supply chain?
2. Do all inventory managers behave similarly in different echelons?
3. How does the variability of order quantity and order time intervals influence costs within the supply chain?
4. Do inventory managers trust in their supplier or trust in their customer in a decentralized supply chain?
5. How does the level of trust in customer change among echelons?
6. How does the level of trust in supplier change among echelons?
7. How does trust (in customer and in supplier) change over time?
8. Does trust (in customer or in supplier) of the inventory manager affect her/his inventory replenishment decisions? If so, how?
9. Is there a link between the inventory manager's trust perception (in supplier or customer) and her/his inventory holding behavior?

3. Research methods

In order to cover research goals and provide suitable answers to the research questions, this study is conducted in an experimental environment. The experimental environment is selected for two main reasons. First, it is a stable and controlled environment. Thus, it allows one to control extraneous variables (Katok, 2011) and remove possible behavioral noises such as coalition and power. Second, it provides continuous data storage that assures the availability of a reliable database for later analysis.

We design an experimental setting where there are unknown market demands and local information availability. Communication is not possible, and in fact participants interact anonymously and never find out with whom they play. We implement a role-playing simulation platform developed by Montreuil et al. (2008) to mimic the decentralized supply chain. This allows us to untangle order quantity and order time intervals and examine their behavior along the supply chain.

To measure trust, a multi-round trust measurement procedure through questionnaires is administrated in the context of a laboratory experiment. We distinguish between trust in supplier and trust in customer and measure inventory managers' trust within a decentralized supply chain. Since the inventory manager's trust perception is measured over time, we examine the trend of trust development for each echelon. Moreover, using questionnaires in the context of a laboratory experiment provides repeatable and reliable observations for both trust perception and inventory replenishment decision. Analysis of the distribution of variables suggests that they do not have a normal-like distribution. We use nonparametric statistics to analyze data in Chapter 2 and implement Linear Mixed Effect Model (LMM) and Generalized Linear Mixed Model (GLMM) to assess the research questions of Chapter 3 and Chapter 4.

4. Thesis contribution

This research contributes to the extent literature in a number of ways.

First, it provides details on the ordering behavior of inventory managers in a continuous review system in a triadic supply chain context (Distributor, Wholesaler, Retailer) and it shows that (1) order time intervals increase along the supply chain, (2) wholesaler plays the smoothing role in the decentralized supply chain, (3) inventory managers' replenishment decisions affect their own and the other echelons' costs.

Second, this research develops a procedure to measure the level of trust among supply chain echelons over time. The findings show that (1) trust exist in a decentralized supply chain, with local information, no communication, and no access to the market demand, (2) trust level varies in a continuum of intensity in a decentralized supply chain, (3) trust evolves and for some echelons it grows over time, and (4) trust in supplier is the lowest in the middle of supply chain and that trust in customer decreases while moving upstream along a decentralized supply chain.

Third, this study shows that inventory managers' trust perception affects their inventory replenishment decision and inventory behavior at the individual and echelon levels. The findings show that (1) low trust in customer is linked to high order quantity and long order time intervals at the individual levels, (2) distributor exhibits the lowest trust, highest order quantity and largest order time intervals among echelons, (3) retailer is the only echelon that considers trust in supplier while placing order quantities to upstream supplier, (3) inventory managers hold higher inventory level when they have lower trust in customer and trust in their upstream supplier. Lower level of trust in customer lead inventory managers to hold higher inventory levels. These findings propose that trust in customer and trust in supplier under demand and supply uncertainties lead inventory managers to hold higher inventory levels.

5. Thesis structure

The thesis is organized as follows; Chapter 2 examines the inventory replenishment decision under continuous review system in decentralized supply chain. Chapter 3 proposes a procedure to measure the level of trust among supply chain echelons and evaluates trust in customer and trust in supplier over time in a decentralized supply chain. Chapter 4 studies the effect of trust on inventory managers' replenishment decision and their inventory holding behavior. Chapter 5 concludes the thesis, highlights the findings, limitations of this research, and provides recommendation for future research.

References

Bendoly, E., Croson, R., Gonçalves, P., Schultz, K. 2010. Bodies of knowledge for research in behavioral operations. *Production and Operations Management*, *19*(4), 434-452.

Bolton, G. E. Katok, E. 2005. Learning-by-doing in the newsvendor problem. Discussion paper, Penn State University.

Boudreau, J., Hopp, W., McClain, J. O., Thomas, L. J. 2003. On the interface between operations and human resources management. *Manufacturing & Service Operations Management*, *5*(3), 179-202.

Christopher, M. 2010. *Logistics and supply chain management*. Financial Times/Prentice Hall.

Croson, R., Donohue, K. 2006. Behavioral causes of the bullwhip effect and the observed value of inventory information. Management Science, 52, 323–336.

Croson, R., Schultz, K., Siemsen, E., Yeo, M. L. 2012. Behavioral operations: The state of the field. *Journal of Operations Management*.

Gino, F., Pisano, G. 2008. Toward a Theory of Behavioral Operations. Manufacturing & Service Operations Management, 10(4), 676-752.

Kahneman, D., Slovic, P., Tversky, A. (Eds.). 1982. *Judgment under uncertainty: Heuristics and biases*. Cambridge University Press.

Montreuil, B., Brotherton, E., Glardon, R., Yoo, M, J., Elamiri, Y,. Borter, A., Morneau, A., Naciri, S. Jermann, P. 2008. Experiences in Using XBeer Game Virtual Gaming for Learning Supply Chain Management, 2nd European Conference on Games Based Learning, Spain, 16-17 October.

Sterman, J. D. 2006. Operational and behavioral causes of supply chain instability. *The Bullwhip Effect in Supply Chains: A Review of Methods, Components and Cases*.

Katok, E. 2011. Using laboratory experiments to build better operations management models. Foundations and Trends in Technology, Information, and Operations Management, 5 (1), 1–86.

Chapter 2

Inventory Replenishment Decisions Under Continuous Review System

The main goal of this research is to identify the ordering behavior of the inventory manager in a continuous review system within a decentralized supply chain. The following questions will be addressed in this chapter;

1. How do order time intervals change along the supply chain?
2. Do all inventory managers behave similarly in different echelons?
3. How does the variability of order quantity and order time intervals influences the costs within the supply chain?

Inventory Replenishment Decisions Under Continuous Review System

Abstract

Inventory managers mostly do not follow normative optimization models. At best they introduce a level of bounded rationality instead of full rationality in their inventory replenishment decisions. In this paper, we examine the behavior of inventory managers in a continuous review system within a decentralized supply chain. We implement an experimental approach with unknown market demand and local information availability. The analysis reveals that not only the magnitude and the variability of order quantity tend to be larger, but also the order time intervals is lengthen and highly variable while moving upstream along the supply chain. We also investigate how the inventory managers' replenishment decisions influence echelons holding, backorder, and total costs. Results show that the large order quantities and long order time intervals induced by the inventory managers increase their holding and backorder costs in the upstream supply chain. Results also suggest that reduction in the variability of customer order quantity significantly decreases the upstream supplier total cost.

Keywords: Behavioral operations management, Continuous Inventory replenishment, Supply chain, Laboratory experiment.

1. Introduction

Consider a decentralized supply chain in which products move through multiple serial echelons before they are finally shipped to the end customer. In such a serial multi-echelon inventory system, inventory managers make inventory replenishment decisions based on local information (Lee and Billington, 1993) to regulate the inventory levels, minimize costs, and satisfy downstream customer demand. The inventory replenishment decision is in response to two fundamental questions: how much to order (*order quantity*) and when to order (*order time*)?

The frequency of inventory replenishment decisions is determined by the inventory review process, which can be classified in periodic review systems and continuous review systems. In a periodic review system, inventory is monitored periodically and the inventory replenishment decision is made at a fixed time interval, whereas in a continuous review system, inventory is checked continuously and the order time interval is variable. This fact denotes that in a continuous review system both order quantity and order time intervals are variable.

Numerous periodic and continuous inventory review models have been proposed to optimize echelon's cost and profit and consequently to improve supply chain performance (Aviv, 2003; Clark and Scarf, 1960; De Bodt and Graves, 1985; Federgruen and Zipkin, 1984). However, the actual behavior shows that decision maker's mind has a restricted capacity to formulate complex problems in a finite time, on the basis of available information (Loch and Wu, 2007; Gino and Pisano, 2008; Simon, 1969).

There is considerable empirical and experimental evidence indicating that the actual behavior of an inventory manager tends to deviate from the optimal decisions proposed by the extant literature on operations management (Bolton and Katok, 2005; Croson and Donohue, 2006; Schweitzer and Cachon, 2000; Sterman, 2000). One of well-acknowledged operations management problem is the mismatch arising between demand and supply processes. To match demand and supply, inventory managers place orders and regulate inventory levels to avoid backlog. Yet, their efforts are not always successful and most often result in the demand–supply mismatch. The demand-supply mismatch could further exacerbate order quantity and/or order frequency amplification along the chain. In spite of the vast amount of literature on order quantity oscillation and amplification, there is scarce evidence of the order time interval variation along the supply chain. Given that, interesting questions arise, namely, (*i*) How do order time intervals change along the supply chain? (*ii*) Do all inventory managers behave similarly in different echelons? (*iii*) How does the variability of order quantity and order time intervals influence costs within the supply chain?

The main goal of this research is to understand the ordering behavior of an inventory manager in a continuous review system within a decentralized supply chain. Toward this end, the experiment designed in this work shows that not only does the magnitude and variability of order quantity increase, but also the order time intervals lengthen and their variability increases along the supply chain from retailer and wholesaler to distributor.

The next section provides the literature related to the work. Section 3 describes the problem. Section 4 details the proposed method. Section 5 deals with the statistical analyses and results. Section 6 discusses the results and highlights the findings. Finally, section 7 concludes the paper, presents the limitations, and proposes the future research directions. All experimental materials are provided in appendixes.

2. Literature review

From pivotal studies of 1960s to the recent studies, researchers have long recognized the importance of order amplification in supply chains. The literature in inventory replenishment can be divided into two streams: Normative and behavioral. In the former literature stream, researchers model inventory replenishment and prescribe optimized policies while in the latter literature stream, researchers assess inventory replenishment decisions and in different experimental settings describe the causes of its amplification along the supply chain. The following subsections review the most relevant body of the literature to our work.

2.1. Normative literature stream on inventory replenishment

Simon (1952) utilizes control theory to analyze simple production-inventory systems. In his work, he highlights pure delays in production-inventory systems that are hard to deal with. To approximate pure delays, he uses exponential delays by smoothing the output signal over time. Vassian (1955) extends Simon's continuous-time theory to discrete time models. In one of the early operations research models addressing multi-echelon inventory, Clark and Scarf (1960) propose optimal policies for a multi-echelon inventory problem under periodic review, when the demand is unknown and uncertain.

Schmidt and Nahmias (1985) extend the Clark-Scarf approach by characterizing the optimal inventory policy for a simple assembly system. Federgruen and Zipkin (1984) also extend the Clark-Scarf approach from the finite horizon to the infinite horizon. De Bodt and Graves (1985) extend the Clark-Scarf approach from periodic review to continuous review. Badinelli (1992) constructs a model for continuous-review policies in multi-echelon supply chain. Grubbström and Wikner (1996) study inventory replenishment systems with the aid of control theory. They show that inventory trigger control policies can be mathematically described by differential equations involving Heaviside and Dirac impulse functions. Chen (1999) considers information delays in decentralized supply chains. He also verifies the optimality of implementing a base stock policy under a centralized team.

There is no doubt of the importance of models in inventory management as well as their contribution to finding optimal inventory replenishment decision indicators and improving the performance of supply chain. However, these normative models assume that people are fully rational, make profit-maximizing decisions, and they are aware of the feedback of their decisions. The actual human behavior shows significant deviations from optimal policies and prescriptive models (Bendoly at al., 2006; Bendoly et al., 2010; Gino and Pisano, 2008).

2.2. Behavioral literature stream on inventory replenishment

Forrester (1961) introduces a nonlinear model of supply chain using exponential delays. He designs a role-playing supply chain simulation game called 'Beer distribution game' and shows demand amplification in upstream supply chain. He underlines that structure, policies, and decision makers' interactions in supply chain are the main reasons for order amplification. Towill (1991) and Wikner et al. (1991)

extend Forrester's work to two-echelon and three-echelon supply chain contexts and conclude that the lack of coordination in supply chain leads to variability in order quantity across the supply chain. In an analytical study, Lee et al. (1997) highlight four structural reasons for order quantity amplification: demand signal processing, order batching, price variation, and inventory rationing.

Sterman (1989) presents a generic model of stock management. He proposes an ordering decision model based on locally rational heuristics in decentralized supply chain. In fact, by characterizing decision maker mental processes, he bases the decision process on an anchor and adjustment policy and identifies underweighting the supply line (units of product ordered but not yet received) as the cause of order quantity amplification. Dogan and Sterman (2005, 2006) study phantom ordering in order quantity decision-making processes. Phantom orders arise in supply chains when an upstream supplier is unable to fulfill orders on-time. Thus, the customer responds to backlogs by placing larger order quantities. In a similar work, Oliva and Gonçalves (2007) study overreaction in order quantity decision-making processes. As in previous studies, they find that decision makers ignore the supply line and in case of shortage, they saturate order quantity adjustment at a maximum value instead of overreacting.

In experimental studies, researchers show that shorter ordering and shipment lead-times improve decentralized supply chain performance under periodic review (Kaminsky and Simchi-Levi, 1998; Kimbrough et al., 2002; Steckel et al., 2004). Also, sharing point of sale information (Croson and Donohue, 2003; Gupta et al., 2001; Steckel et al., 2004), using electronic data interchange (Machuca and Barajas, 2004), and communication (Wu and Katok, 2006) can significantly improve decentralized supply chain performance under periodic review. Croson and Donohue (2006) show that order quantity amplification remains even when the market demand is known and when all four structural causes of order quantity amplification are removed. Rong et al. (2008) consider the reactions to supply and demand uncertainty and introduce reverse order quantity amplification. Croson et al. (2012) investigate the role of coordination stock on supply chain stability and show that uncertainty of individual decisions is one of the behavioral causes of order quantity amplification.

In spite of the vast amount of literature on *order quantity amplification*, there is scarce evidence of the order time behavior. Given the evidence about the order quantity amplification along the supply chain, an interesting question arises, namely, how do order time intervals change along the supply chain? In order to answer this question, we design and run experiments in a decentralized linear supply chain under continuous inventory replenishment.

3. Problem description

Let i be the echelon index (i = [R, W, D]; R: retailer, W: wholesaler, D: distributor) in a supply chain and $i = M$ for the market index. Each inventory manager fulfills the orders received from the downstream customer if sufficient on-hand inventory is available, otherwise he accumulates backlogs. S/he decides on *how much* and *when* to order with the upstream supplier and places an order OQ^{ij} at time $j \in [0, T]$, where T is the length of the relationship. We define order time intervals at the echelon i as the time durations between two consecutive placed orders denoted by OT^{ij}.

Market demand is unknown and customer orders are transferred in the form of information flows from market to factory, trigging material flows from upstream to downstream. Both information and material flows are subject to delays: Order lead-time ($L_o = 1\ day$), and shipment lead-time ($L_s \geq 2\ days$). Note that the shipment lead-time is potentially variable and depends on the availability of on-hand inventory at the upstream supplier. This represents the time required to receive and to ship orders, which is not less than 2 days. Therefore, on-hand inventory must be regulated with respect to the shipment delays.

Inventory managers make inventory replenishment decisions with *local information*. Local information for inventory manager of echelon i at time j includes the received orders from downstream customer the on-hand inventory, the placed orders to the upstream supplier, the shipments of upstream supplier, and the shipments to downstream customer. Moreover, inventory manager of echelon i does not know the orders from the downstream customer that are currently being processed, on-hand inventory level of her/his upstream supplier, and the time at which s/he receives the upstream supplier shipments. The inventory manager's goal is to maximize his profit. The profit that a manager earns at the echelon i is;

$$Profit^i = Income^i - Costs^i \tag{1}$$

$$Income^i = Sales^i + supplier\ backorder\ cost^i \tag{2}$$

$$Sales^i = p^i . \sum_{j=0}^{[T]} S^{ij} \tag{3}$$

where $p^i$is the price per unit at the echelon *i* and S^{ij} is shipment of *i* at *j*.

$$Supplier\ backorder\ cost^i = \pi^{i+1} . \sum_{j=0}^{[t]} OO^{(i+1)j} \tag{4}$$

where π^{i+1} is the backorder cost per unit per day and $OO^{(i+1)j}$ is the outstanding order or the unfilled order of *(i+1)*th echelon at time *j*. Also, the cost components that the inventory manager incurs in the echelon i are

$$Costs^i = Backorder\ cost^i + holding\ cost^i + purchasing\ cost^i \tag{5}$$

Backorder cost (BC) is the cost that the subjects incur for unfilled orders, that is

$$BC^i = \pi^i . \sum_{j=0}^{[T]} OO^{ij} \tag{6}$$

where π^i is the backorder cost per unit per day and OO^{ij} is the outstanding order or the unfilled order of *i*th echelon at time *j*.

Holding cost (HC) is the cost that the inventory manager incurs for holding inventory, that is

$$HC^i = h^i . \sum_{j=0}^{[T]} OI^{ij} \tag{7}$$

where h^i is the holding cost per unit per day and OI^{ij} is the on-hand inventory of the echelon i at time *j*.

Purchasing cost, the cost that the inventory managers incur for placing orders to their upstream supplier, has fixed and variable components. Purchasing cost is

$$PC^i = \sum_{j=0}^{[T]} (F^j + p^i . OQ^{ij}) \tag{8}$$

where F is the fixed order cost, p^i is the price per unit for the echelon i, and OQ^{ij} is the order quantity of the echelon i at time j. The price per unit, p^i depends on the echelon. It increases from the upstream supplier to the downstream customer, due to the added value to the finished product across the chain. There is no transportation cost.

Under a continuous review system, each inventory manager makes a decision on *how much to order* and *when to order* with local information. Inventory managers must keep enough inventory to fulfill their customer needs and to avoid backlogs. To hold enough on-hand inventory, orders must be placed at the right quantity and at the right time. Nevertheless, customer on-hand inventory depends on the supplier shipments and on-hand inventory at the upstream suppliers. Variable time lags and impacts of previous decisions on the future ones add complexity to the continuous replenishment decision.

4. Method

Continuous replenishment decision-making has a dynamic and complex nature. This decision includes order quantity and order time, and is characterized by time lags and impacts of previous decisions on future ones. A laboratory experiment is a suitable research tool to uncover the dynamic and complex nature of continuous replenishment decisions and address decision makers' cognitive limitations (Chatfield et al., 2004; Croson and Donohue, 2002). A laboratory experiment provides a stable and controlled environment, which eliminates possible noises and external perturbations (Katok, 2011). Moreover, it provides the opportunity to observe a decision maker's behavior over time and ensures multiple, repeatable, and reliable observations. To run the laboratory experiment, an appropriate platform is needed.

4.1. Experimental platform

We implement a role-playing platform developed by Montreuil et al. (2008). In this platform, continuous inventory replenishment is considered, which means that both *order quantity* and *order time* are variable. This is the major difference with respect to the well-known beer distribution game in which variable order quantities are placed within a fixed time interval between orders.

The platform mimics the inventory replenishment dynamics in a decentralized linear supply chain. The platform consists of four echelons representing the roles of retailer, wholesaler, distributor, and factory. Market does not fill orders and demands from the retailer. The retailer delivers the requested item orders out of his on-hand inventory and, if necessary, he orders the same items from the wholesaler. Likewise, the wholesaler delivers the requested items out of his on-hand inventory, orders items, and receives the items from the distributor, who in turn orders and receives items from the factory. The factory produces the items. There is no inventory capacity limitation. Figure 1 shows the structure supply chain in the experiment. Dotted lines indicate orders and solid lines indicate shipments. Filled rectangles represent echelons with human participants while empty rectangles represent echelons with computer agents. Human participants, thereafter subjects, play the roles of the retailer, wholesaler and distributor, and computer agents play the factory and the market roles. None of the subjects are aware of the fact that factory role is simulated by a computer.

Figure 1: Structure of the supply chain used in the experiment

The market demand is stable. It follows a normal distribution with a mean of 3000 units/day, and a standard deviation of 500 units/day, truncated at zero. This daily demand is randomly split in two orders per day. The demand information is unknown to the subjects.

4.2. Experimental procedure

The experiment proceeds as follows; a subject enters the laboratory at an appointed time and is randomly assigned to a team and a role. Before starting the experiment, we provide a 4-5 page handout explaining the instructions of the experiment and a summary of the role information to each subject. After that the subjects read the instructions of the experiment, their questions are answered, and the experiment interface is then presented.

Subjects are asked to play the simulation for 30 days (20 minutes) as a warm-up exercise to become familiar with the interface. After the warm-up session, we examine the subjects understanding of the experiment and their decision task in a short quiz to assure they acquired a sufficient knowledge. To avoid an end of the experiment behavior, the duration of the simulation is not announced in advance. The experiment lasts for 120 days (55 minutes) followed by a debriefing session. After the debriefing session, the subjects are asked to fill in a post-experiment questionnaire to reflect on their replenishment policies during the experiment. The subjects are paid based on their performance during the experiment as follows.

$$Earning = Min\ \{50,\ Show\text{-}up\ fee\ (10\ CHF) + 40\ CHF * (\frac{Your\ profit}{Average\ of\ the\ role\ profit})\} \qquad (9)$$

The subjects could earn 10 CHF for showing up to the experiment. In addition to this amount, they could earn up to 50 CHF, on the basis of their profit with respect to the role average profit. The maximum earning is approximately equivalent to two-hour wages for a student job.

4.3. Experimental settings

To examine the dynamics of inventory replenishment in a decentralized supply chain, the information availability is set as local (Lee and Billington, 1993). Thus, subjects are not allowed to communicate with anyone during the experiments and have visibility only of their own echelon dynamics. A given subject has access to the following local information; the received order quantity and order time from downstream customer, their own on-hand inventory, the placed order quantity and order time with the upstream supplier, incoming shipments of the upstream supplier, out bound shipments to the downstream customer, and their performance measures (i.e. cost and profit levels, supplier and customer service levels). The holding cost is set at 0.75$/unit/day and the backorder cost at 1.5$/unit/day for all echelons (see appendix A for more detail).

4.4. Subjects

48 undergraduate and graduate students from two Swiss universities, EPFL and UNIL, with engineering and business majors, participated in this experiment, for payoff contingent on their performance. The subjects consisted of 39% women and 61% men, with 24% of undergraduate, 54% master, and 22% PhD students. The experiment was conducted in the spring semester of 2011.

5. Statistical analyses and results

The data set consists of 16 supply chain teams. The exploratory graphs propose the elimination of four supply chains from the data sample, as the related subjects did not make properly use of the experimental platform. Therefore, we report on the results of 12 supply chains. Statistical analysis is carried out using the SPSS version 21. Results of the experiment are analyzed on two levels; the individual and the echelon levels. The individual level analysis refers to the obtained data for each subject, while the echelon level analysis refers to the aggregation of individual results for a considered role.

5*.1. Inventory replenishment*

5*.1.1 Mean replenishment decision indicators*

Table 1 summarizes the mean of order quantity and order time intervals for all individuals and echelons. Results reveal that for 100% of the teams, the replenishment decision indicators increase while moving from retailer to wholesaler. However, only

58% of the distributors increase their replenishment decision indicators compared to wholesalers. Thus, the analysis of the results in Table 1 leads us to two main observations.

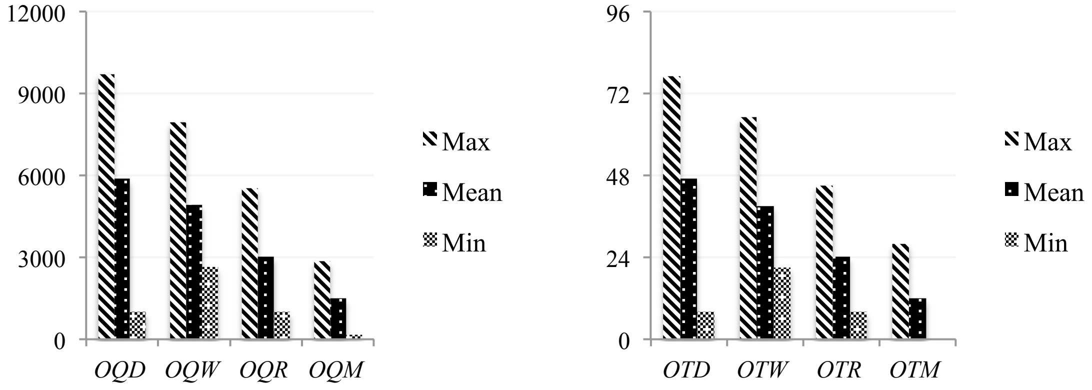
Table 1. Mean order quantity (OQ) and order time intervals (OT) for each individual and echelon

Team	D		W		R		M	
	OQ	*OT*	*OQ*	*OT*	*OQ*	*OT*	*OQ*	*OT*
1	7348	61	3137	25	1022	8	1508	12
2	7875	56	6911	48	5433	43	1508	12
3	4890	40	7140	59	1872	15	1508	12
4	3529	29	3802	31	3381	27	1508	12
5	7039	58	2813	22	1798	15	1508	12
6	9711	77	4751	38	3781	30	1508	12
7	5786	47	7957	65	5530	45	1508	12
8	6566	56	5839	48	5304	43	1508	12
9	3733	31	6992	57	2627	21	1508	12
10	1000	8	4000	31	3512	27	1508	12
11	3415	28	2645	21	1003	8	1508	12
12	9634	73	3236	24	1000	8	1508	12
Mean of each echelon	5877	47	4935	39	3022	24	1508	12

Observation 1: *The mean order quantity and mean order time intervals tend to increase while moving upstream along the supply chain under continuous review.*

Fig 2 displays the minimum, the maximum, and the mean of the replenishment decision indicators for each role over the game. The mean of order quantity and order time intervals are (1508, 12), (3022, 24), (4935, 39), (5877, 47) for market (M), retailer (R), wholesaler (W) and distributor (D) respectively. The Wilcoxon test generates a z-statistic (z) and associates significance level (p) based on the rank-order of the data in the two samples (sample size; $n = m = 12$), which are pairs of (OQ_R, OQ_W), (OQ_W, OQ_D), (OT_R, OT_W), and (OT_W, OT_D). Results show that for 100% of the cases mean order quantity and mean order time intervals increase while moving from retailer to wholesaler (z = -3.062, p < 0.002). Though, 58% of distributors increase their replenishment decision indicators compared with wholesalers, the result of the Wilcoxon signed-rank test does not support this hypothesis for distributors (z = -0.941,

$p < 0.347$). However, a review of the post-experiment questionnaire indicates that most of upstream suppliers tend to place larger quantities in longer time intervals.



(a) Order quantity (in items) (b) Order time intervals (in hours)

Fig 2. (a) Order quantity and (b) order time intervals for each echelon

Observation 2: *Retailer and wholesaler replenishment decision indicators are positively correlated, whereas distributor replenishment indicators have no significant correlation with its immediate customer.*

Table 2 shows the Spearman rank correlation (Spearman, 1904) among the replenishment decision indicators of each echelon. Spearman rank correlation is a nonparametric correlation. Because the current datasets are not normally distributed, using nonparametric test is of particular importance in data analysis.

*Table 2. Spearman rank correlation coefficient matrix among replenishment decision indicators of each echelon, ***, and ** significant at $p < 0.01$ and 0.05 levels, respectively. (N =12)*

	OQ^D	OQ^W	OQ^R	OT^D	OT^W	OT^R
OQ^D	1					
OQ^W	0	1				
OQ^R	0.035	0.699**	1			
OT^D	0.970***	-0.095	-0.079	1		
OT^W	-0.018	0.989***	0.709**	-0.095	1	
OT^R	0.057	0.676**	0.988***	-0.046	0.679**	1

Results reveal a strong positive correlation between mean order quantity and mean order time interval for each echelon. Moreover, results show that wholesaler's replenishment decision indicators are positively correlated with the immediate customer, whereas distributor's replenishment decision indicators are not.

5.1.2. Variability of replenishment decision indicators

The coefficient of variation (CV) is used to study the variability of the replenishment decision indicators. The coefficient of variation is a relative variation measure and is a way to interpret the relative magnitude of the standard deviation by dividing it by the mean. Table 3 provides an overview of the replenishment decision indicators variability. We classify the variability into low, medium, and high categories based on the following conditions:

- Low variability: $0 \leq CV_{OQ} < 0.5$ and $0 \leq CV_{OT} < 0.5$,
- Medium variability: $0.5 \leq CV_{OQ} < 1$, and/or $0.5 \leq CV_{OT} < 1$,
- High variability: $CV_{OQ} \geq 1$, and/or $CV_{OT} \geq 1$.

The analysis of the results presented in table 3 shows that:

- 6% of the subjects (2 out of 36) have low variability for both order quantity and order time intervals,
- 53% of the subjects (19 out of 36) have medium variability for at least one of the two replenishment indicators,
- 41% of the subjects (15 out of 36) have high variability for at least one of the two replenishment indicators.

Furthermore, among all the subjects, one retailer (R12), one wholesaler (W10), and one distributor (D10) have fixed order quantity ($CV_{OQ} = 0$) and variable order time intervals policy. All the other subjects (91.5%) follow a variable order quantity and variable order time intervals policy. Thus, the analysis of the results in Table 3 leads us to the following two main observations.

Table 3. Variability on order quantity and order time intervals for each individual

Variability of order quantity (CV_{OQ}) \ Variability of order time intervals (CV_{OT})	*Low*	*Medium*	*High*
High			R_2 W_1, W_2, W_6 D_6, D_7, D_9
Medium		R_6, R_8, R_{10} W_9, W_{11} D_2, D_3, D_{11}	W_{12} D_1, D_8
Low	W_3, W_7	R_3, R_4, R_5, R_7, R_9, R_{11} W_4, W_5, W_{10} D_4, D_5	R_1, R_{12} W_8 $D_{10,}$ D_{12}

Observation 3*: The relative number of subjects with high variability of their replenishment decision indicators tends to increase while moving upstream from market along the supply chain under continuous review*

Table 4 summarizes the numbers of individuals for each variability level. Results for the low variability condition, $0 \leq CV_{OQ} < 0.5$ and $0 \leq CV_{OT} < 0.5$, show that only 17% wholesalers place orders with low variability, where no retailer or distributor belongs to that variability range.

Table 4. The number of individuals on low, medium, high variability conditions

Variability level	*Condition*	*D*	*W*	*R*	*Team # with this condition*	*Team # with 2 echelons following this condition*
Low	$0 \leq CV_{OQ} < 0.5$ $0 \leq CV_{OT} < 0.5$	0	17%	0	-	-
Medium	$0.5 \leq CV_{OQ} < 1$ $0.5 \leq CV_{OT} < 1$	25%	33%	67%	4, 5	12
High	$CV_{OQ} \geq 1$ $CV_{OT} \geq 1$	75%	50%	33%	-	6, 11, 12

Results of the medium variability condition, $0.5 \leq CV_{OQ}$ or $CV_{OT} < 1$, show that the tendency of the subjects with the medium variability decreases from retailers (67%), wholesalers (33%), to distributors (25%). For the high variability, results reveal that the variability of the replenishment decision indicators tends to be higher on the upstream echelons. Therefore, subjects in upstream echelons place more variable order quantities at more variable time intervals.

Table 4 reports that there is no team with low variability condition. There are only 2 teams out of 12, with all three players, showing medium variability of their replenishment decision indicators. Table 4 also shows that there is at least one subject in a team, dominantly among the upstream echelons, who introduces the medium or high variability on her/his inventory replenishment decision.

Observation 4*: The variability of replenishment decision indicators for each echelon tends to increase while moving upstream from market along the supply chain under continuous review.*

Figure 3 illustrates the variability of the replenishment decision indicators for each echelon. The aggregated results at the echelon level show that retailers place orders with higher variability of the order quantity and order time interval than the market demand (CV_{OQ}^{R}= 0.43, CV_{OT}^{R} = 0.89). Wholesaler receives these fluctuating orders from retailer and increases the variability of order quantity, while the variability of order time intervals stays almost unchanged (CV_{OQ}^{W}= 0.62, CV_{OT}^{W} = 0.88). Finally, results show that distributor increases the variability of both order quantity and order time (CV_{OQ}^{D}= 0.69, CV_{OT}^{D} = 1.27). Thus, there is an increase of the variability of order quantity and order time interval while moving upstream from market along the supply chain.

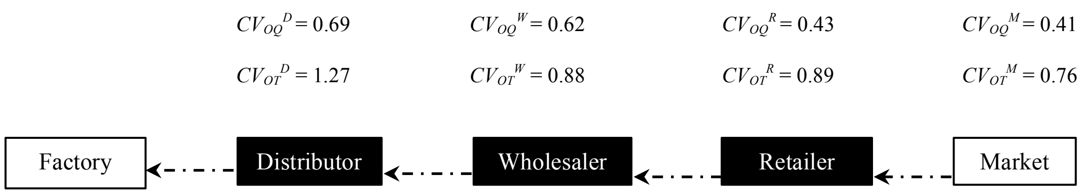


Figure 3: Variability of order quantity and order time intervals at the echelon level

5.2. Costs

Table 5 shows the mean of backorder cost (*BC*), holding cost (*HC*), and total cost (*TTC*) for each echelon. The cost components that a subject incurred over the experiment in the participatory simulation platform consists of backorder cost, holding cost, and purchasing cost. Owing the fact that purchasing cost is highly correlated with order quantity and order time intervals of each player, we exclude it from our analysis and mainly focused on backorder and holding cost. Thus, the total cost is their sum.

Table 5. Mean of backorder (BC), holding cost (HC), and total cost (TTC)

	BC	*HC*	*TTC*
Retailer	503,991	217,019	721,009
Wholesaler	497,937	486,766	984,703
Distributor	574,494	687,763	1,262,197

Note that the unit cost components are similar across the echelons (see appendix A). Results show that the total costs (*TTC*) increase from retailer to distributor. The holding cost (*HC*) column shows an increase from retailer to distributor and the backorder cost (*BC*) column shows wholesaler incurs less backorder cost compared to retailer and distributor. To investigate the relationship between the replenishment decision indicators with incurred costs, we perform Spearman rank correlation. Table 6 displays the link between replenishment decision indicators, backorder cost and holding cost.

Results show that the backorder cost of distributor is positively correlated with its order quantity. Her/his holding cost is also positively correlated with the order quantity as well as the order time intervals. Moreover, the same positive correlation is observed between wholesaler's backorder cost and both distributor's order quantity and order time intervals. No significant correlation is identified for any of the retailer's cost, nor for the wholesaler's holding cost.

*Table 6. Spearman rank correlation coefficient between replenishment decision indicators, holding and backorder costs, ***, and ** significant at $p < 0.01$ and 0.05 levels, respectively. (N =12)*

	Bc^D	Hc^D	Bc^W	Hc^W	Bc^R	Hc^R
OQ^D	0.538**	0.587***	0.706***	0.182	0.357	0.531
OQ^W	0.133	0.308	0.154	441	-0.336	0.175
OQ^R	0.028	0.091	0.339	0.385	-0.168	0.147
OT^D	0.417	0.644***	0.623***	0.053	0.406	0.41
OT^W	0.112	0.295	0.088	0.442	-0.372	0.123
OT^R	0.007	0.117	0.411	0.315	-0.159	0.209

Table 7 reports the correlation between replenishment decision indicators and total costs (*TTC*) of each echelon. Results show a strong positive correlation between distributor total cost and distributor's order quantity, order time intervals. Similarly, the retailer total cost is positively correlated with the distributor's order quantity and order time interval. Total cost of wholesaler is also positively correlated with wholesaler's order quantity, but no significant correlation is found with the wholesaler's order time intervals.

*Table 7. Spearman rank correlation coefficient correlation between replenishment decision indicators and total costs, ***, and ** significant at $p < 0.01$ and 0.05 levels, respectively. (N =12)*

	TTC^D	TTC^W	TTC^R
OQ^D	0.727***	0.608**	0.580**
OQ^W	0.364	0.336	-0.301
OQ^R	0.168	0.357	-0.105
OT^D	0.658**	0.49	0.592**
OT^W	0.34	0.27	-0.358
OT^R	0.156	0.336	-0.071

Table 8 demonstrates the Spearman rank correlation coefficients between the variability of the replenishment decision indicators and holding and backorder costs. Results show that the distributor backorder cost is positively correlated with the variability of the distributor's order quantity, wholesaler's order quantity, and order time intervals. The distributor holding cost appears to be significantly positively correlated with variability of the distributor's order quantity. No significant correlation is found for wholesaler backorder cost, retailer's backorder, and holding costs.

*Table 8. Spearman rank correlation coefficient correlation between replenishment decision indicators and total costs, ***, and ** significant at p < 0.01 and 0.05 levels, respectively. (N =12)*

	Bc^D	Hc^D	Bc^W	Hc^W	Bc^R	Hc^R
CV_{OQD}	0.601**	0.678**	0.315	0.469	-0.196	0.343
CV_{OQW}	0.860***	0.483	0.371	0.503*	0.014	0.476
CV_{OQR}	0.091	-0.021	0.413	0.636**	0.224	-0.021
CV_{OTD}	0.196	0.406	0.497	0.315	0.175	0.021
CV_{OTW}	0.613**	0.165	0.305	0.2	0.242	0.406
CV_{OTR}	0.329	-0.333	0.098	0.238	-0.137	0.378

Table 9 depicts the Spearman correlation among variability of the replenishment decision indicators and the total cost for each echelon. Results show a strong correlation between the distributor's total cost and the wholesaler's and distributor's its variability of order quantity. Moreover, results reveal a positive correlation between wholesaler's and retailer's variability of order quantity and their supplier total costs (i.e. distributor and Wholesaler respectively). No significant correlation is observed between the variability of order time intervals and the total cost of any echelon.

*Table 9. Spearman rank correlation coefficient correlation between the variability of replenishment decision indicators and total costs, ***, and ** significant at p < 0.01 and 0.05 levels, respectively. (N =12)*

	TTC^D	TTC^W	TTC^R
CV_{OQD}	0.846***	0.28	-0.201
CV_{OQW}	0.867***	0.427	0.193
CV_{OQR}	0.119	0.580**	0.217
CV_{OTD}	0.371	0.545	0.147
CV_{OTW}	0.452	0.375	0.392
CV_{OTR}	0.063	0.494	-0.032

6. Discussion

Prior explanations for the order quantity amplification in decentralized supply chains revolve around decisions on order quantity. The experiment design and tool allow us to shed light on the both order quantity and order time intervals. Our results for both the individual and echelon levels show that order quantity tends to be larger and order time intervals tend to be lengthened while moving upstream along the supply chain from the market. The main question to answer is: What are the reasons for this amplification?

Order amplification is caused by both structural and behavioral reasons. Demand signal processing, order batching, price variation, and inventory rationing are structured characteristics that cause demand amplification (Lee et al., 1997). Decision maker bounded rationality to account for time lags and previous decisions feedbacks (Sterman, 1989), and uncertainty of individual decisions for the other supply chain members (Croson et al., 2012) are behavioral characteristics that amplify order. In this study, unknown market demand leads the subjects to uncertain forecasts that cause demand signal processing. Along with this structural cause, both above-mentioned behavioral causes play a role in the order amplification at each level of supply chain as one moves upstream from the market to distributor.

The analysis of the results of variability of order quantity and order time intervals suggests that there is a range of low, medium, and high variability on the subjects' decision indicators. Based on the observations in Table 4, the majority of retailers (67%) have medium variability of their replenishment decision indicators. Wholesalers behave differently. 17% of wholesalers have low variability of their replenishment indicators, while 33% of them introduce medium variability in their ordering behavior. Some of the distributors (25%) exhibit a medium variability, while the majority of them introduce high variability in their replenishment decision indicators. Although there are three subjects (R12, W10, D10) who follow the fixed order quantity and variable order time intervals ordering behavior, the majority of the subjects (91%) have variable order quantity and variable order time intervals ordering behavior. Furthermore, on the echelon level, results show that retailer has low variability on order quantity and medium variability on order time intervals. Wholesaler shows medium variability on both order quantity and order time intervals. Distributor has a medium variability on order quantity and high variability on order time intervals. Hence, results from the both individual and echelon levels confirm that the variability of order quantity and order time intervals tends to increase while moving upstream from the market along the supply chain.

One interesting point remains to be discussed further; why do wholesaler behave differently? Prior work (Baganha and Cohen, 1998; Blinder 1981; Cachon et al., 2007; Rong et al., 2008; West, 1986) has highlighted that the variability of order quantity increases from retailer to wholesaler and decreases from wholesaler to manufacturer. This study confirms the difference in wholesaler ordering behavior, but it distinguishes form previous works since we observe a constant increase in the variability of order quantity, but a decrease in the variability of the wholesaler order time intervals at the echelon level. Moreover, at the individual level analysis, half of wholesalers (50%) in Table 3 and Table 4 are placed on the low and medium variability classification. These evidences, in connection with the previous discussion, reveal that wholesaler injects variability in order quantity and smoothen order time intervals under continuous review. Therefore, wholesalers perform a smoothing role in the middle of supply chain.

Subjects hold on-hand inventory to guard against unknown customer orders and unreliable supplier shipment. Since there is no price variation in our study, the main reason to hold on-hand inventory is to avoid stock-out and incurring backorder costs. The higher variability of the order quantity and order time intervals may lead to higher costs for both inventory manager and his/her supplier. Inventory managers' on-hand inventory depends on on-hand inventory availability at the upstream supplier, and time delays for ordering and shipment. As shown in Table 7, larger order quantities and longer order time intervals increase inventory manager holding and backorder costs. The other important point is that replenishment policy of the most upstream echelon is decisive regarding the total cost of supply chain (see Table 5 and Table 6). The larger order quantity of distributor, the larger total costs of wholesaler and retailer. This observation also holds for distributor's lengthened order time intervals.

Results in Table 8 suggest that a reduction in the variability of order quantity specifically for upstream echelons could help the distributor to cut unnecessary backorder and holding costs. Costs are more correlated to upstream echelons due to the higher variations of replenishment decision indicators. Result in Table 9 shows that the high variability of wholesaler replenishment decision indicators increases distributor backorder cost. Also, high variability of retailer order quantity increases wholesaler holding cost. Therefore, results suggest that reduction in the variability of customer order quantity significantly decreases the supplier total cost.

7. Conclusion

We conduct this research to examine the behavior of inventory managers under continuous review in decentralized supply chain. We design an experiment to control the environment. The experimental setting is characterized by unknown market demand and local information availability. This research makes a new contribution to inventory replenishment literature by revealing (*i*) the change in order time intervals along the supply chain, (*ii*) the smoothing role of wholesaler in the decentralized supply chain, (*iii*) the influence of inventory managers' replenishment decisions on their own and the other echelons' costs.

This work purposely focuses on individual and echelon levels. This focus restricts the possible conclusions concerning the supply chain ordering behavior and its global performance. Therefore, one possible extension would be team level analysis. The use of student subjects can be other limitation of this study. Although significant difference between student and professional subjects has not been reported (Croson and Donohue, 2006; Holweg and Bicheno, 2002), the authors have experienced situations in which professional do tend to behave differently than students. Thus investigating potential deviations between these two categories is still worth investigation. Future research in this area may examine the robustness of our results in different supply chain contexts. Different experimental settings such as known demand to remove demand signal processing from structural causes of order amplification could help understanding the behavioral factors under continuous review.

References

Aviv, Y. 2003. A Time Series Framework for Supply Chain Inventory Management. Operations Research, 51, 210-227.

Badinelli, R., D. 1992. A Model for Continuous-Review Pull Policies in Serial Inventory Systems Operations Research, 40, 142-156.

Baganha, M. P., Cohen, M. A. 1998. The stabilizing effect of inventory in supply chains. Operations Research, 46 (3), S72-S83.

Bendoly, E., Croson, R., Gonçalves, P., Schultz, K. 2010. Bodies of Knowledge for Research in Behavioral Operations. Production and Operations Management. 1-19.

Bendoly, E., Donohue, K., Schultz, K. 2006. Behavior in Operations Management: Assessing recent findings and revisiting old assumptions. Journal of Operations Management. 24, 737-752.

Blinder, A.S. 1981. Retail inventory behavior and business fluctuations, Brooking Papers on Economic Activity, 2, 443-520.

Bolton, G. E. Katok, E. 2005. Learning-by-doing in the newsvendor problem. Discussion paper, Penn State University.

Cachon, G. P., Randall, T., Schmidt, G. M. 2007. In search of the bullwhip effect. Manufacturing & Service Operations Management, 9(4), 457-479.

Chatfield, D. C., Kim, J. G., Harrison, T. P., Hayya, J. C. 2004. The bullwhip effect—impact of stochastic lead time, information quality, and information sharing: A simulation study. Production and Operations Management, 13(4), 340-353.

Chen, F. 1999. Decentralized supply chains subject to information delays. Management Science, 45, 8, 1076-1090.

Clark, A. Scarf, H. 1960, Optimal Policies for a Multi-Echelon Inventory Problem, Management Science, 6, 475- 490.

Croson, R., Donohue, K. 2002. Experimental Economics in Supply Chain Management: An Experimental Study, Interfaces. 32, 74-82.

Croson, R., Donohue, K. 2003. Impact of POS data sharing on supply chain management: an experimental study. Production and Operations Management, 12 , pp. 1–11.

Croson, R., Donohue, K. 2006. Behavioral causes of the bullwhip effect and the observed value of inventory information. Management Science, 52, 323–336.

Croson, R., Donohue, K., Katok, E., Sterman, L.D. 2012. Order Stability in Supply Chains: Coordination Risk and the Role of Coordination Stock. In Working Paper, Smeal College of Business, Penn State. State College, PA.

De Bodt, M. A., Graves. S. C. 1985. Continuous-Review Policies for a Multi-Echelon Inventory Problem with Stochastic Demand. Management Science, 31. 1286-1299.

Dogan, G. Sterman, J.D. 2005. When less leads to more: Phantom ordering in the beer game. Proceedings of the 2005 International System Dynamics Conference, Boston, MA.

Dogan, G. Sterman, J.D. 2006. I'm not hoarding, I'm just stocking up before the hoarders get here Behavioral causes of phantom ordering in supply chains, MIT Working paper.

Federgruen, A., Zipkin, P. 1984. An efficient algorithm for computing optimal (s, S) policies. Operations Research, 32(6), 1268-1285.

Forrester, J. W. 1961. Industrial dynamics (Vol. 2). Cambridge, MA: MIT press.

Gino, F., Pisano, G. 2008. Toward a Theory of Behavioral Operations. Manufacturing & Service Operations Management, 10(4), 676-752.

Grubbström, R. W., Wikner, J. 1996. Inventory trigger control policies developed in terms of control theory. International Journal of Production Economics, 45(1), 397-406.

Gupta, S., Steckel, J. and Banerji, A. 2001. Dynamic decision making in marketing channels: An experimental study of cycle time, shared information and customer demand patterns. A. Rapoport, R.Zwick, eds. Experimental Business Research. Kluwer Academic Publishers, Boston, MA.

Holweg, M., Bicheno, J. 2002. Supply chain simulation–a tool for education, enhancement and endeavor. International journal of production economics, 78(2), 163-175.

Kaminsky, P., Simchi-Levi, D. 1998. A new computerized beer game: A tool for teaching the value of integrated supply chain management. Global Supply Chain and Technology Management. Hau Lee and Shu Ming Ng, eds., POMS Series in Technology and Operations Management, 216-225.

Katok, E., 2011. Using laboratory experiments to build better operations management models. Foundations and Trends in Technology, Information, and Operations Management, 5 (1), 1–86.

Kimbrough, S. O., Wu, D. J., Zhong, F. 2002. Computers play the beer game: can artificial agents manage supply chains?. Decision support systems, 33(3), 323-333.

Lee, H. L., Billington, C. 1993. Material management in decentralized supply chains. Operations research, 41(5), 835-847.

Lee, H. L., Padmanabhan, V., Whang, S. 1997. Information distortion in a supply chain: the bullwhip effect. Management science, 43(4), 546-558.

Loch, C. H., Wu, Y. 2007. Behavioral operations management (Vol. 1, No. 3). Now Pub.

Machuca, J.A.D., Barajas, R.P. 2004. The impact of electronic data interchange on reducing the bullwhip effect and supply chain inventory costs. Transportation Research Part E, 40, 209–228.

Montreuil, B., Brotherton, E., Glardon, R., Yoo, M, J., Elamiri, Y,. Borter, A., Morneau, A., Naciri, S. Jermann, P. 2008. Experiences in Using XBeer Game Virtual Gaming for Learning Supply Chain Management, 2nd European Conference on Games Based Learning, Spain, 16-17 October.

Oliva, R., Gonçalves, P. 2007. Behavioral Causes of the Bullwhip Effect:"Satisficing" Policies with Limited Information Cues. Under revision for resubmission to Journal of Operations Management.

Rong, Y., Shen, Z., J., M., Snyder, L., V. 2008. The Impact of Ordering Behavior on Order-quantity. Variability: A Study of Forward and Reverse. Bullwhip Effects. Flexible Services and Manufacturing Journal, 20, 95-124.

Schmidt, C. P., Nahmias, S. 1985. Optimal policy for a two-stage assembly system under random demand. Operations Research, 33(5), 1130-1145.

Schweitzer, M. E., Cachon, G. P. 2000. Decision bias in the newsvendor problem with a known demand distribution: Experimental evidence. Management Science, 46(3), 404-420.

Simon, H. A. 1952. On the application of servomechanism theory in the study of production control. Econometrica: Journal of the Econometric Society, 247-268.

Simon, H. A. 1969. The Sciences of the Artificial. The MIT Press, Cambridge.

Spearman, C. 1904. The proof and measurement of association between two things. The American journal of psychology, 15(1), 72-101.

Steckel, J.H., Gupta, S., Banerji, A. 2004. Supply chain decision making: will shorter cycle times and shared point-of sale information necessarily help. Management Science, 50, 458–464.

Sterman, J. D. 2000. Business dynamics: systems thinking and modeling for a complex world (Vol. 19). New York: Irwin/McGraw-Hill.

Sterman, J.D. 1989. Modeling of Managerial Behavior: misperceptions of feedback in a dynamic decision making experiment. Management Science. 35, 321-339.

Towill, D. R. 1991. Supply chain dynamics. International Journal of Computer Intergrated manufacturing, 4.197-208.

Vassian, H. J.1955. Application of discrete variable servo theory to inventory control. Journal of the Operations Research Society of America 3, 272–282.

West, K. D. 1986. A Variance Bound Test of the Linear Quadratic Inventory Model. Journal of Political Economics, 94 (2), 374- 401.

Wikner, J. Towill, D.R. Naim. M. 1991. Smoothing supply chain dynamics. International Journal of Production Economics, 22. 231–248.

Wu, D.,Y. Katok, E. 2006. Learning, communication, and the bullwhip effect. Journal of Operations Management. 24, 839–850.

Appendix A: experiment detailed set-up information

Table A1. Detail set-up information of the experiment

	Factory	Distributor	Wholesaler	Retailer
Initial On-hand inventory (unit)	9000	9000	9000	9000
Holding cost ($/unit/day)	0.75	0.75	0.75	0.75
Backorder cost ($/unit/day)	1.5	1.5	1.5	1.5
Ordering fixed cost ($)	15	15	15	15
Item price ($)	4	6	8	10
Benefit ($)	2	2	2	2

Chapter 3

Measuring Trust in Decentralized Supply Chain

The main goal of this chapter is to develop a procedure to measure the level of trust among supply chain echelons over time. The following questions will be addressed in this chapter;

1. Do inventory managers trust in their supplier or in their customer in a decentralized supply chain?
2. How does the level of trust in customer change among echelons?
3. How does the level of trust in supplier change among echelons?
4. How does trust (in customer and in supplier) change over time?

The findings of this chapter is partially presented at:

Kaboli, A. Cheikhrouhou, N. Glardon, R., Measuring Trust in Supply Chain, *7the annual conference on Behavioral Research in Operations Management, June 9-11, 2012, Washington, USA.*

Measuring Trust in Decentralized Supply Chain

Abstract

Trust is a significant role-playing factor in supplier-customer relationship and is known as a fundamental ingredient in supply chain. In this research, a multi-round trust measurement through questionnaires is administrated in the context of a laboratory experiment. We distinguish between trust in supplier and trust in customer and measure them in a serial multi-echelon inventory system. The validity and reliability of the proposed trust measurement are analyzed and its applicability demonstrated. Results show that trust does develop in decentralized supply chains, even in the absence of communication and with no access to market demand. It is found that trust level varies in a continuum of intensity and that trust evolves over time. Furthermore, we observe that trust in supplier is the lowest in the middle of the supply chain and that trust in customer decreases while moving upstream along a decentralized supply chain.

Keywords: Trust perception, trust in supplier, trust in customer, decentralized supply chain

1. Introduction

Trust has received a great deal of attention in supply chain management and has been extensively investigated. Studies suggest that trust is linked to information sharing (Clark and Fujimoto, 1991; Özer et al., 2011; Ebrahim-Khanjari et al., 2012), maintaining cooperation and avoiding conflicts (Kumar, 1996; Bachmann 2001, Spekman et al., 1998), as well as to transaction costs (Sako, 1994; Zaheer et al., 1998).

The level of trust among supply chain echelons plays an essential role (Sterman, 2006). It has been proposed that a certain level of trust is needed in supply chain to increase predictability (Sako, 1994) and to develop cooperation (Dibben, 2000). Trust also guards supply chains against high inventories, order quantity amplification, and poor customer services (Croson et al., 2012; Sterman, 2006). Echelons that trust each other generate greater profits and are more adaptable (Kumar, 1996). As a result, trust contributes to the long-term stability of a supply chain (Handfield and Bechtel, 2002).

Despite the acknowledged role of trust in supply chains, to the best of our knowledge, theoretical and/or empirical coherent attempts to measure trust across a decentralized supply chain have not been reported in the literature. The general objective of this work is the development of a procedure to measure the level of trust among supply chain echelons. Toward this end, a multi-round trust measurement procedure through questionnaires is administrated in the context of a laboratory experiment. We distinguish between trust in supplier and trust in customer and measure inventory managers' trust in a decentralized supply chain. Since trust perception is measured over time, trend of trust development can be examined for each echelon.

The next section provides the literature related to trust measurement in supply chain. Section 3 describes the proposed method. Section 4 highlights the validity and reliability of the trust measurement. Section 5 deals with the results of the trust measurement in supply chain context. Section 6 discusses the results, underlines the findings, presents the limitations, and proposes future research directions.

2. Research background

2.1. Trust definition

A review of the literature shows a number of different trust definitions in organizational sciences. Table 1 summarizes the most-quoted definitions of trust that present three main common points. The first point is the focus on the psychological state of the trustor. The second is the uncertainty of the outcome of trust that refers to the expectation of the trustor in future trustee's action(s). The third communality of trust definitions is the context dependability of trust. Indeed, trust is a context-dependent construct and may therefore change from one situation to another.

Table 1. Trust definitions

Definition	Author(s)
The extent to which one is willing to ascribe good intentions to and have confidence in the words and actions of other people	Cook and Wall (1980)
One party's belief that its needs will be fulfilled in the future by actions undertaken by the other party	Anderson and Weitz (1989)
Trust is a cognitive judgment about another's competence or reliability and an emotional bond of an individual towards the other person	McAllister (1995)
Trust is an individuals' behavioral reliance on another person under a condition of risk	Currall and Judge (1995)
Trust is an individual's belief or a common belief among a group of individuals that another individual or group	Cumming and Bromiley (1996)
Trust is an expectancy of positive (non negative) outcomes that one can receive based on the expected action of another party in an interaction characterized by uncertainty	Bhattacharya et al. (1998)
Trust is a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another	Rousseau et al. (1998)
Trust reflects an expectation or belief that the other party will act benevolently	Whitener et al. (1998)
Trust is confident positive expectations regarding another's conduct in a context of risk	Lewicki et al. (1998)
Trust is willingness of a party based on the expectations that the other party will perform a particular action important to the trustor, irrespective of the ability to monitor or control the party	Mayer and Davis (1999)
Trust is a consumer's confident belief that he or she can rely on the sellers to deliver promised services	Agustin and Singh (2005)

The forms of trust that researchers have mostly theorized and implemented are belief, decision, and action (McEvily et al., 2003). Belief is the trustor expectation or the belief about trustee; thus, it is perceptual. Decision to trust refers the willingness to be vulnerable (Rousseau et al. 1998); thus, it is intentional. This means that if a decision maker considers her/his trustee to be trustworthy, (s)he decides to take the risk to be vulnerable toward trustee's decisions and actions. The last form of trust, action, refers to the trustor's action or behavior.

While trust literature has made significant advances in recent years, it is still not well integrated and lacks coherence (McEvily et al., 2003). Lack of integration and coherency in trust literature may be due to the inconsistency between the chosen definition and the form of trust.

2.2. Trust measurement

Studies involving trust measurements have implemented different tools, depending on differences in the definitions and forms of trust, (McEvily and Tortoriello, 2011; Seppänen et al., 2007). In operations management, the predominant research tools to measure trust forms (belief, decision, action) are interviews, field data analysis, and psychometric tests. Experimental economists also examine trust. They mostly adopt Coleman's definition[1] for rational action of individuals in social situations (Coleman, 1994) and implement trust in laboratory environments by using trust game (Berg et al., 1995) and binary games (Güth et al., 1997). More details about trust and investment games can be found in Camerer (2011). Hereafter, we focus on trust measurement in operations management and marketing.

Anderson and Weitz (1989) investigate the trust perception of sellers in their manufacturers. They find that the level of communication in seller-manufacturer dyad has a strong influence on trust. Anderson and Narus (1990) examine trust perception of distributors in manufacturers and manufacturers in distributors. They find that cooperation and trust are closely linked. Crosby et al. (1990) study the belief of insurance policy buyers in sales agent. They find that the customer's perception of the seller's level of expertise has a significant impact on trust. Mohr and Spekman (1994) analyze dealers' trust perception in their manufacturers. They find that greater level of trust guarantees successful partnership and alliance. McAllister (1995) investigates managers' trust perception in their peers. He identifies that interpersonal trust has two principle dimensions; cognition-based and affect-base. Zaheer and Venkatraman (1995) examine trust perception of insurance agencies in their carriers. They show that the performance of inter-organizational exchange improves in the presence of trust. Doney and Cannon (1997) study trust perception in supplier-customer relationships. They argue that customer trust perception in buyer is related to supplier characteristics and the length of the relationship. Costa (2003) explores trust in work

[1] "Trust is an action that involves the voluntary placement of resources such as; physical, financial, intellectual, or temporal at the disposal of the trustee with no real commitment from the trustee" (Coleman, 1994).

teams and proposes that team member's attitude towards the organization is strongly related to work team trust.

Mayer et al. (1995) propose a model for the relationship between trust and interpersonal behavior. They show that trustor's belief about trustee's ability, benevolence, and integrity result in a willingness to take risk. Mayer and Davis (1999) examine top management-employee relationships and empirically test the model proposed by Mayer et al. (1995). They suggest that implementing an acceptable performance appraisal system increases employee's trust level in the management board. Gillespie (2003) identifies reliance and disclosure as salient forms of trusting behavior in working relationships. Özer et al. (2011) measure trusting behavior in an experimental setting and show that contrary to the mathematical prediction, human subjects show deviations from being self-interested in repeated interactions. In particular, they find that human subjects behave altruistically in revealing information, even when there are some incentives to keep and hide demand forecast information. Ebrahim-Khanjari et al. (2012) model the trusting behavior of a retailer and wholesaler. They show that retailer tends to trust wholesaler in long-term relationships and that benevolent and honest wholesaler improves supply chain performance.

Previous studies mostly focus on single or dyadic relationships and there is little research on measuring trust across a multi-echelon supply chain. Moreover, researchers mainly focus on measuring trust at a single period of time, as a static concept, and less attention has been paid to considering trust over time. In this paper, we consider inventory manager's trust perception within a decentralized supply chain. We measure their trust over time to examine the trust level ranges and changes over time. Measuring inventory managers' trust allows a better understanding of the behavior of trust in customer and trust in supplier along the supply chain.

3. Method

3.1. Decentralized supply chain

We consider a linear supply chain as schematically represented in Figure 1. Inventory is managed in each echelon with local information under continuous inventory review. Local information means each inventory manager is provided with the following information; received orders from downstream customer, on-hand inventory, placed orders to upstream supplier, shipments of upstream supplier, and shipments to downstream customer. Continuous inventory review means that inventory is monitored continuously and orders can be placed at any time. This implies that, in a continuous review system, both order quantity and order time intervals are variable.

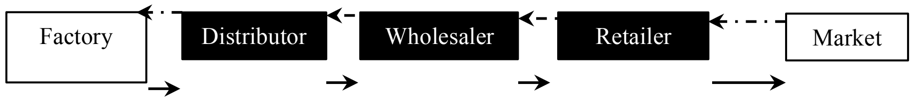


Figure 1. The structure of the supply chain

Each echelon operates as follows:

- The inventory managers receives customer orders from its downstream customer
- If on-hand inventory is sufficient; the customer order is filled and shipped; otherwise, the customer order is backlogged.
- A replenishment order of any size can be sent at any time to the upstream supplier.

There is no partial delivery; i.e. delivery of the exact ordered quantity is required.

The Retailer receives costumer orders from the market. Factory replenishment orders are sent to production, which delivers the orders after a fixed production lead-time (2 days).

There are two types of lead-times for retailer, wholesaler, and distributor echelons:

- an ordering lead-time: 1 day delay between order placement by the customer and order receipt by the supplier.
- a shipment lead-time: 2 days delay between order shipment by the supplier and order receipt by the customer.

Each echelon has to deal with the following cost and earning elements:

- Purchasing cost paid to supplier after material receipt, proportional to the received quantity.

- Holding cost proportional to stored quantity and time.
- Backorder cost paid to customer for backlogged orders, proportional to quantity and time.
- Sales revenue received from costumer for delivered material, proportional to delivered quantity.
- Backorder income paid by supplier for backlogged orders, proportional to quantity and time.

The echelon profit is equal to the difference between the sum of the earnings and the sum of the costs. The subjects' goal is to maximize their local profit.

We implement a role-playing simulation platform developed by Montreuil et al. (2008) to mimic the decentralized supply chain. Figure 1 illustrates the structure of the supply chain. Dotted lines indicate orders, solid lines indicate shipments, filled rectangles represent echelons operated by human participants and empty rectangles represent echelons run by computer agents. Human participants, thereafter called subjects, play the roles of the retailer, wholesaler and distributor and computer agents are used for factory and market. None of the subjects are aware of this fact. Moreover, the market demand is characterized by a normally distributed daily demand rate with a mean of 3000 units/day and a standard deviation of 500 units/day, truncated at zero. Each daily demand quantity is stochastically divided into two single orders.

3.2. Trust measurement approach

We draw on prior literature in defining trust as *"one party's belief that its needs will be fulfilled in the future by actions undertaken by the other party "* Anderson and Weitz, 1989). In the considered supply chain context, the features of trust in a supplier and trust in a customer are different. Therefore, we specify trust in supplier as *inventory manager's belief that her/his needs will be fulfilled in the future by actions undertaken by the supplier* and trust in customer as *inventory manager's belief that her/his needs will be fulfilled in the future by actions undertaken by the customer*.

Therefore, two questionnaires are developed to capture the inventory manager trust in his/her supplier (T_s) and customer (T_c).

Trust is a context-dependent construct (Hardin, 2002; Rousseau et al., 1998) and measures of trust might vary in different settings (McEvily and Tortoriello, 2011). Considering our experimental setting characterized by decentralized supply chain with local information availability, trust items were pooled[2] and adapted to the context of the study from a number of sources (Table 2).

Table 2. Selected items and wordings used for the trust construct

#	Item	Item wording	Source
1	Intention	My supplier (customer) will not use opportunities that arise to take advantage at my expense	Crosby et al. 1990; Kennedy et al. 2001
2	Competence	My supplier (customer) knows how to efficiently manage his/her company	Boles et al. 1996
3	Commitment	My supplier (customer) is committed to on-time delivery (stable ordering behavior)	Crosby et al. 1990; Zaheer and Venkatramon 1995; Cummings and Bromiley 1996
4	Reputation	My supplier (customer) has reputation for on-time delivery (stable ordering behavior)	Ganesan 1994; Plank et al. 1999; Doney and Cannon 1997

The trust construct is based on four items: intention, competence, commitment, and reputation. The number of considered items is voluntarily kept small to avoid any problem with response biases (Hinkin, 1995; Schmitt and Stults, 1985; Schriesheim and Eisenbach, 1990), to reduce the respondent fatigue (Anastasi and Urbina, 1997), and to decrease the development and implementation time (Carmines and Zeller 1979).

The chosen item wordings are the result of previous pilot experiments (Kaboli et al. 2012). The subjects are asked to evaluate the items on a seven-point Likert scale (from 1 = strongly disagree to 7 = strongly agree). Reverse-scored items, negatively worded items, are not employed because of the two following reasons. First, reverse-

[2] We refer the reader for the details on scale development to Hinkin (1995) and DeVellis (2003).

scored trust items may lead to mistrust (Cordery and Sevastos, 1993; Wrightsman, 1991), which is out of the scope of this study. Second, it may reduce the items validity (Schriesheim and Hill, 1981), the reliability and accuracy (Schriesheim et al., 1991), and cause systematic error to a scale (Jackson et al., 1993).

3.3. Procedure

Data for the study are collected through questionnaires administrated in the context of the laboratory experiment. In the experiment, three subjects play the roles of inventory managers of the distributor, wholesaler and retailer. Therefore, six trust levels are measured (three levels for the trust in customer, T_c and three levels for the trust in supplier, T_s) as shown in Figure 2.

The experiment proceeds as follows: Subjects enter to the laboratory at an appointed time and are randomly assigned to their team and their role. Before starting the experiment, each subject is provided with a handout (4-5 pages) explaining the experimental procedure and presenting the simulation platform features. After reading the instructions, subjects' questions are answered, and the simulation platform interface is presented. Then, subjects are asked to participate in two initial rounds of the experiment as a warm-up exercise. After warm-up, the subjects are asked to answer a short quiz in order to assure a sufficient level of understanding about the experiment.

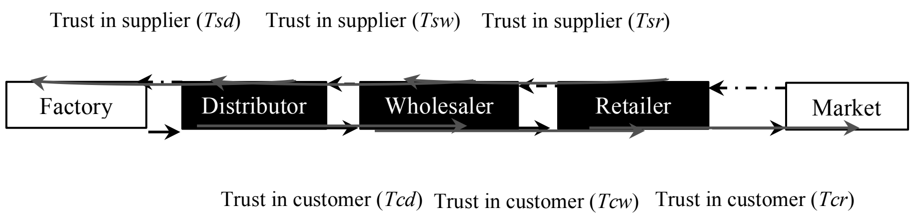


Figure 2. Trust measurements in the supply chain

Being assured that the subjects understand the questionnaires, the simulation platform, and the experiment procedure, the main experiment is started (see Figure 3).

To evaluate the evolution of trust during the game, the experiment is divided into eight rounds of approximately seven minutes, providing 16 trust measurements for each inventory manager; eight measures for trust in supplier and eight measures for trust in customer. The experiment is stopped at the beginning of each round and subjects are asked to fill form A (customer trust in her/ his supplier) and form B (supplier trust in her/ his customer).

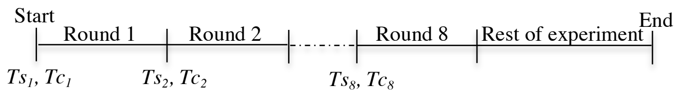


Figure 3. The procedure of trust measurement in the main experiment

To reduce the risk of response bias, the item statements order in both questionnaires changes at each round. At the end of the experiment, subjects are asked to fill a post-experiment questionnaire to explain their replenishment decision strategy (-ies) and finally they are paid based on the attained performance. The duration of the experiment is not announced in advance in order to avoid end behavior.

3.4. Subjects

Forty-eight undergraduate and graduate students from two Swiss Universities EPFL and UNIL (engineering and business majors) participate in this experiment for payoff contingent on performance. The subjects consist of 39% women and 61% men, with 24% of students in their bachelor, 54% in their master, and 22% in their PhD. As shown in Equation (1), in addition to a fix payment of 10 CHF for showing up to the experiment, the subjects could earn, on the basis of their performance, up to 50 CHF.

$$Earning = \min \{\text{Show-up fee (10 CHF)} + 40 \text{ CHF} * \left(\frac{Your\ profit}{Average\ of\ the\ role\ profit}\right), 50 \text{ CHF}\} \quad (1)$$

4. Validity and reliability analysis

The analysis is conducted at the echelon level. The data set consists of 16 supply chains. We eliminate four supply chains from our sample since the examination of the post-experiment questionnaire shows that there is at least one subject in these four supply chains who misunderstand the experiment and the decision task. Therefore, we report on the results of 12 supply chains, 36 subjects, over 8 rounds, building 96 observations for each echelon or 288 total observations. Statistical analysis is carried out using the SPSS version 21.

The Kaiser-Meyer-Olkin (KMO) measure of the sampling adequacy and Barttlett test of sphericity are used to indicate whether the obtained data on trust in supplier and trust in customer are suitable for factor analysis or not (Dziuban and Shirkey, 1974; Kaiser, 1974). Factor analysis allows an investigator to assess the validity of measurement test. It helps to determine smaller number of factors among a set of inter-related items (DeVellis, 2003).

Results (see Table 3) show that KMO measures are between 0.712 to 0.778 for trust in supplier; for trust in customer they range between 0.660 to 0.779. KMO measure for sampling adequacy should be located between 0.6 and 1 for satisfactory factor analysis (Kaiser, 1974).

Table 3. Sample adequacy and sphericity tests

Tests	Measures	*Trust in supplier (T_s)*			*Trust in customer (T_c)*		
		D	W	R	D	W	R
KMO Sample adequacy	KMO	0.712	0.778	0.753	0.660	0.779	0.670
Barttlett 's test of sphericity	$\chi^2(df=6)$	211.22	210.9	196.65	194.16	270.59	139.12
	P-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Barttlett test of sphericity is a Chi-squre (χ^2) test that examine whether there is correlation among the items. Therefore, if there is no relationship among the items, the correlation matrix should be an identity matrix. The critical value of the χ^2 with $df=6$ is 12.59. Results of Barttlett test of sphericity (see Table 4) show that $\chi^2(df=6)$ range between 139.12 to 270.59 and four-item correlation matrixes are highly significant (p < .001).. Acceptable values of KMO measure and Barttlett's test demonstrate that sample data are appropriate for conducting factor analysis (Hair et al., 1998, p.619).

To demonstrate the validity of the measurement, we conduct the explanatory factor analysis with a varimax rotation on the four items (see Table 3). Results show that all four items have eigenvalue greater than one, explaining total variance ranging from 60% to 75% (Kaiser, 1960, p.145; Sharma, 1996, p.120; Hair et al., 1995, p.385). Moreover, the scree test (Cattell, 1966) is applied to further check the number of factors that should be considered. The scree test results also suggest only one factor for each of trust in supplier and trust in customer at each echelon. Considering the item factor loading above 0.30, all items are retained to measure trust in supplier and trust in customer.

Table 4. Factor loading

	Ts			*Tc*		
Items	D	W	R	D	W	R
1. Intention	0.319	0.552	0.431	0.378	0.819	0.526
2. Competence	0.843	0.875	0.893	0.756	0.772	0.771
3. Commitment	0.934	0.922	0.935	0.921	0.931	0.897
4. Reputation	0.940	0.919	0.89	0.937	0.94	0.864
Variation explained (%)	64.22	69.13	66.23	61.04	75.40	60.54

One might ask what is the acceptable cut-off for an item factor loading to be retained? It seems there is no answer for the lower and higher bound of an item factor loading (Comrey and Lee, 1992) and scholars utilize factor loading thresholds based on their experiences. However, in the social and behavioral sciences, 0.30 is the minimum acceptable threshold (Merenda, 1997; Hair et al., 1998, p.111).

To check the reliability of the measurement, we assess corrected item-total correlations, and internal consistency reliability (Churchill, 1979; DeVellis, 2003). Corrected item-total correlation tests the consistency of each item with the average behavior of the other items and internal consistency reliability deals with the homogeneity of the items within a scale (here trust) and is measured with Cronbach's coefficient alpha (Cronbach, 1951; DeVellis, 2003, p.27).

Table 5 and Table 6 list the measurement items, means, standard deviation, corrected item-total correlations, and Cronbach's coefficient alphas for trust in supplier and trust in customer, respectively. The minimum corrected item-total correlation belongs to intention and is 0.20 for trust in supplier (Table 4) and 0.23 for trust in customer (Table 5). Recommended minimum for corrected item-total correlation is 0.30 (Ferketich, 1991). However, a minimum of 0.20 is justifiable since deleting intention from the trust scale does not lead to a substantial increase in Cronbach's coefficient alphas. Therefore, it is retained in the trust scale.

Table 5. Reliability evaluation for measurement of trust in supplier

Echelon	Items	Mean	Std. Deviation	Corrected item-total correlation	Cronbach's Alpha
Retailer	Intention	4.98	1.322	0.285	0.823
	Competence	4.16	1.761	0.756	
	Commitment	4.45	1.794	0.833	
	Reputation	4.27	1.701	0.752	
Wholesaler	Intention	4.5	1.692	0.39	0.84
	Competence	4.08	1.646	0.728	
	Commitment	3.93	1.784	0.815	
	Reputation	3.73	1.767	0.802	
Distributor	Intention	4.4	1.454	0.202	0.784
	Competence	4.63	1.371	0.648	
	Commitment	4.85	1.661	0.795	
	Reputation	4.69	1.605	0.801	

Cronbach's coefficient alpha (α) ranges between 0 to 1. Ranges for research scales are as follows: $\alpha < 0.6$, unacceptable; $0.60 < \alpha < 0.65$ are undesirable; $0.65 < \alpha < 0.70$, minimally acceptable; $0.70 < \alpha < 0.80$, respectable; $0.80 < \alpha < 0.90$, very good; $0.90 < \alpha$, one should consider shortening the scale (DeVellis, 2003, p.95). Increase of Cronbach's coefficient alpha is partially dependent upon the extent of covariation among the items, the number of items (DeVellis, 2003, p.97), and Likert-type scales (using five-point Likert scale increases Cronbach's coefficient alpha (Hinkin, 1995). All Cronbach's coefficient alphas are within the acceptance range. Consequently, results of Table 5 and Table 6 indicate a high degree of reliability of the trust measurements.

Note that in 7-point Likert scale 1 represents strongly disagree; 7 represents strongly agree; and 4 is the midpoint. Though the inclusion of the midpoint is necessary in the scale measurement to provide a neutral option to the subjects (Matell and Jacoby, 1971), one might argue that considering the midpoint on Likert scale which refers to “neither agree and nor disagree” *may* increase the positive rating (Worcester and Burns, 1975), distort the results and consequently affect the research findings (Garland, 1991).

Table 6. Reliability evaluation for measurement of trust in customer

Echelon	Items	Mean	Std. Deviation	Corrected item-total correlation	Cronbach's Alpha
Retailer	Intention	4.73	1.418	0.339	0.77
	Competence	4.94	1.177	0.574	
	Commitment	4.17	1.633	0.724	
	Reputation	4.44	1.471	0.699	
Wholesaler	Intention	4.05	1.997	0.69	0.889
	Competence	4.68	1.599	0.627	
	Commitment	3.68	1.922	0.86	
	Reputation	3.65	1.963	0.873	
Distributor	Intention	4.19	1.669	0.234	0.763
	Competence	3.67	1.574	0.534	
	Commitment	3.36	1.898	0.756	
	Reputation	3.54	1.771	0.793	

To further validate the findings and evaluate whether or not the midpoint should be included on trust in supplier and trust in customer scales, we separately check the effect of exclusion of the midpoint on the trust measurement validity and reliability. Since the exclusion of the midpoint increases slightly the reliability without a significant change on the validity of the measurement, we decide to include the midpoint (for more detail please refer to Change, 1994; Cronbach, 1950, p. 22).

5. Results

So far, we checked the sampling adequacy, the suitability for conducting factor analysis, and the validity and reliability of the trust measurement. In this section we review the applicability of the proposed trust measurement process. To this end, we provide results of an experiment and seek to explain the observations related to trust in supplier and trust in customer across echelons. Table 7 provides the descriptive statistics, as well as the percentage of scoring above and below the scale midpoint over the 8 rounds for all three echelons.

Table 7: Descriptive statistics over 8 rounds (N=96 for each echelon)

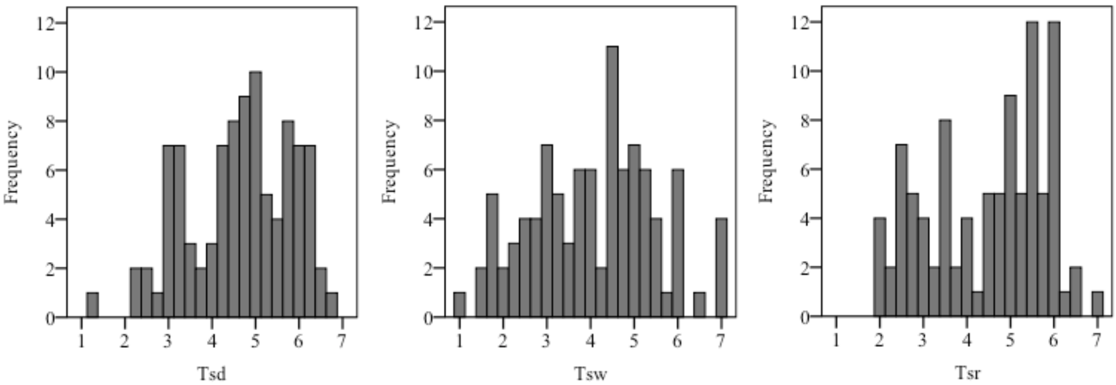
		Trust in supplier (T_s)			Trust in customer (T_c)		
Status	Measures	D	W	R	D	W	R
With midpoint	Mean	4.64	4.06	4.46	3.69	4.01	4.57
	SD	1.19	1.41	1.34	1.32	1.63	1.1
	Median	4.75	4.12	4.75	3.75	4	4.75
	Above midpoint	70.80%	50%	60.40%	41.70%	46.90%	62.50%
	Below midpoint	26%	43.80%	35%	54.20%	47.90%	29.20%
Without midpoint	Mean	4.71	4.03	4.46	3.64	3.98	4.61
	SD	1.42	1.54	1.45	1.51	1.73	1.33
	Median	5	4.25	5	3.67	4	5
	Above midpoint	70.20%	50.50%	59.40%	31.60%	50.50%	57.40%
	Below midpoint	26.6%	44.20%	35.40%	45.30%	44.20%	23.40%

The first part of Table 7 shows results with midpoint, and the second part illustrates results without midpoint. Recall that Likert scale falls within the ordinal level of measurement and that for ordinal data it has been recommended to employ the median as the measure of central tendency (Clegg, 1998). Though there is a debate among methodologists that a Likert scale (and not Likert item) can be considered as grouped form of a continuous scale, we prefer to employ median as a core measure to represent results and to draw conclusions.

Analyses of the obtained lead to the following observations:

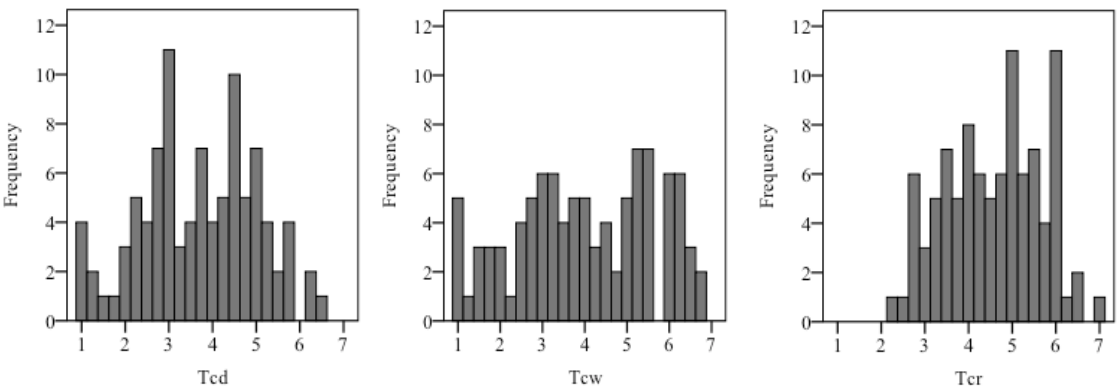
Observation 1: *The level of trust among echelons varies along a continuum of intensity.*

Figure 4 displays the histogram of trust in supplier and Figure 5 shows the histogram of trust in customer for each echelon. Results reveal that trust in supplier and trust in customer exist in decentralized supply chain with local information, unknown supplier and customer, and unknown market demand. They further indicate that trust can vary from 1 (low trust) to 7 (high trust) on the trust-scale values. Thus trust can be considered as a continuum in a decentralized supply chain instead of no-trust and full-trust levels.



(a) *(b)* *(c)*

Figure 4: (a) histogram of trust in supplier for distributor, (b) wholesaler, and (c) retailer



(a) *(b)* *(c)*

Figure 5: (a) histogram of trust in customer for distributor, (b) wholesaler, and (c) retailer

Note that ordinary statistical tests assume independent and identically distributed observations, our experimental data however fails to satisfy the independence assumption. In other words, our data include several trust measures made on the same individual over time, thus we implement linear mixed effect model to compare the trust level among echelons. In this occasion and everywhere from now on, to fit a linear mixed effect model, a random intercept is injected into the model for each individual to take the interdependence of observations, corresponding to the same individual, into account (Diggle et al. 2013, p.126). Furthermore, fit adequacy is assessed for all fitted models using graphical tools.

Observation 2: *Wholesaler has the lowest trust in supplier in a decentralized supply chain.*

Results in Table 7 show that wholesaler has the lowest mean and median trust in supplier. To check whether this observation is statistically significant, we implement the linear mixed effect model. The test results confirm that trust in supplier is significantly the lowest in a decentralized supply chain (F=5.449, p= 0.005). In particular, the level of trust in supplier is higher for retailer than for wholesaler (Estimate=0.401, t=2.235, p=0.05) and trust in supplier is significantly higher for distributor than for wholesaler (Estimate=0.578, t=3.222, p=0.001). Figure 6 illustrates observation 2.

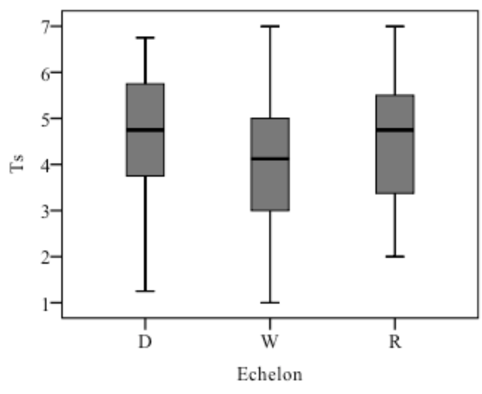


Figure 6: Trust in supplier

Observation 3: *Trust in customer decreases while moving upstream along a decentralized supply chain.*

Results in Table 7 indicate that mean and median of retailer's trust in customer are the highest and that mean and median of trust in customer decrease from retailer to distributor. To test whether this difference is significant, we use the linear mixed effect model. Results show that trust in customer significantly decreases while moving from retailer, wholesaler to distributor (F=12.909, p= 0.0001). In particular, the level of trust in customer is higher for retailer than for wholesaler (Estimate=0.554, t=3.175, p=0.005) and trust in customer is significantly lower for distributor than for wholesaler (Estimate=-0.322, t=-1.848, p=0.1). Figure 7 illustrates the observation 3.

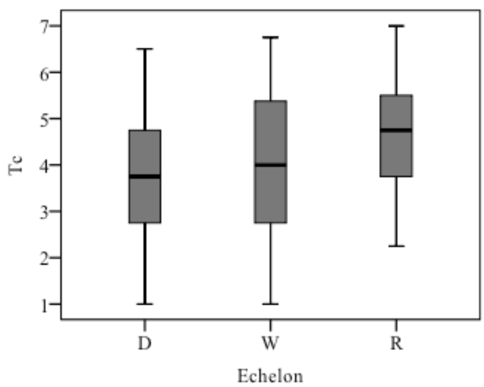


Figure 7: Trust in customer

Observation 4: *Trust evolves over time in a decentralized supply chain.*

Figure 8 and Figure 9 display the median of trust in supplier and trust in customer over each round of the experiment. Figure 8 indicates that the median of trust in supplier starts from (3.75, 4.63, 4.25) and ends up at (4.88, 4.13, 5.00) for distributor, wholesaler and retailer respectively. As shown in Figure 9, the median of trust in customer starts from (3.13, 3.38, 4.38) and ends up at (3.63, 4.76, 5.00) for distributor, wholesaler, and retailer respectively. Figure 8 and Figure 9 clearly show that trust evolves over time.

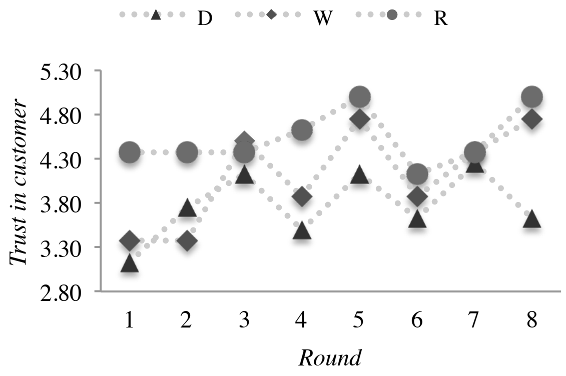


Figure 8: Median of trust in customer over each round of the experiment

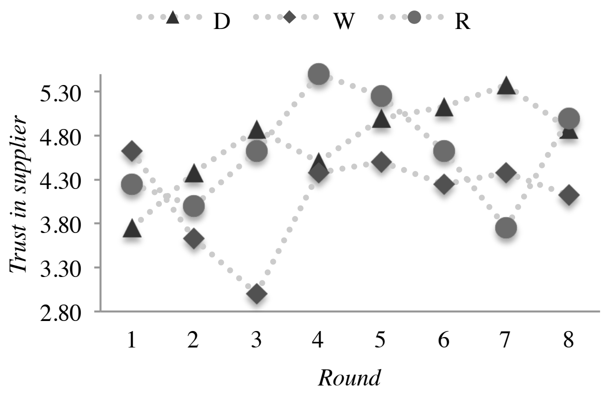


Figure 9: Median of trust in supplier over each round of the experiment

The linear mixed Effect model is used to examine the trust trend over time. The results of this analysis are summarized in Table 8. They indicate that distributor's trust in supplier and wholesaler's trust in customer significantly grows over time, whereas the other four trust measures do not show a significant variation over time.

Table 8: Trust trend analysis of trust measures over 8 rounds (N=96)

	Trust in supplier (T_s)			*Trust in customer (T_c)*		
Parameter	D	W	R	D	W	R
Round	0.135	0.039	0.0456	0.0126	0.121	0.015
P-value	0.0012	*n.s.*	*n.s.*	*n.s.*	0.0015	*n.s.*

6. Discussion and conclusion

The present study examines trust in a decentralized supply chain. The study provides several noteworthy methodological and theoretical issues. The research is designed to measure trust in the context of a laboratory experiment. The main reasons for using a laboratory experiment are that it is a stable and controlled environment and that it provides repeatable and reliable observations. In particular, in the research design, it allows us to control the level of communication among the subjects and eliminate possible noises such as asymmetric power regime among the echelons. For instance, we set equal backorder and holding costs for each echelon to avoid this possible noise on examining trust.

We measure trust in supplier and trust in customer over time through questionnaires. Results suggest that trust exists in a serial supply chain, with local information, no communication, and no access to the market demand. They also suggest that trust level varies in a continuum of intensity in a decentralized supply chain. We find trust evolves and for some echelons it grows over time. Furthermore, we observe that trust in supplier is the lowest in the middle of supply chain and that trust in customer decreases while moving upstream along a decentralized supply chain.

6.1. Methodological issues

We disentangle trust in supplier and trust in customer and measure them through questionnaires. Trust items are pooled, selected, and accordingly worded from previous research to build the trust construct regarding the research design and context. The choice of scale length is guided by two main considerations: response biases and subject fatigue over the experiment. Particularly among the impatience student subjects it necessitated the use of small items. KMO measure of the sample adequacy, Barttlett test of sphericity, and adequate internal consistency reliability of the scale assure that we minimize the risk of the response biases and the subject fatigue.

The 7-point Likert scale is used to present and format items. It is a widely used scale to measure beliefs and opinions ranging from strong disagreement to strong agreement with a natural midpoint. In this study, inclusion and exclusion of the midpoint on Likert scale which refers to “neither agree and nor disagree” is analyzed and statistical tests prove the validity and reliability of the proposed trust measurement. Though the results suggest that the exclusion of the midpoint does not increase the reliability and the validity of the measurement at the same time, we propose for future studies to include a “no option” answer for the subjects to obtain a more clear view of the neutrality case.

6.2. Theoretical issues

In economics and sociology, it is usually assumed that subjects are rational, self-interested and they do not trust if there is no way to communicate, reciprocate, and penalize their counterpart’s odd behaviors (Camerer, 2011). Therefore, based on this reasoning, inventory managers neither trust in their customer nor in their supplier in decentralized supply chain. The proportion of strong and weak views about trust in supplier and trust in customer on Table 6 shows that contrarily to the standard assumption in game theory, subjects trust in decentralized supply chain, and not all subjects are self-interested, nor are they reluctant to trust even if there is no way to communicate and access to market demand.

The obtained results show that inventory managers’ trust levels vary within a continuum of intensity in a decentralized supply chain and there is no binary state of trust as no-trust and full-trust levels. Our research design allows us to study the levels of trust in supplier and trust in customer across the supply chain. We find that trust in customer decreases while moving upstream along a decentralized supply chain. Also, we find that wholesaler has the lowest trust in supplier in a decentralized supply chain.

Results also show that trust evolves over time. They further imply that trust for distributor (T_{sd}) and wholesaler (T_{cw}) grow in a decentralized supply chain. This finding shows that over time, interactions between supplier and customer allow subjects, in particular upstream echelons, to learn more about their customer ordering and their supplier delivery patterns and to gain more experience on regulating their inventory, even without communication. Thus it appears that the experience gained over time about supplier and customer influences the trust levels in a decentralized supply chain mostly in upstream supply chain.

This study has some limitations that provide several opportunities for future research. One potential limitation of our study is that we measure trust based on four items. Although it is a reasonable first step, other items for measuring trust in supply chain, depending on the context, decentralized or coordinated, are worth examining. The other limitation is that this study is based on experimental data from student subjects and not professional inventory managers. Although Croson (2007) reports some evidences of better performance of professional versus student subjects, we believe that this does not question the proposed methodological approach.

The findings of this study suggest that inventory replenishment decision-making may be more complex than previously assumed. Specially, this study provides evidence that trust levels change among the supply chain echelons and consequently that this might have a significant influence on the related replenishment decisions. To develop a more comprehensive understanding of the effect of trust in decentralized supply chain, further work is needed. It may examine the link between trust and inventory replenishment decision for each role. Another extension would be considering two different treatments in warm-up session; one in low trust and the other in high trust condition. Then examining how trust evolves in both groups. It would also be interesting to investigate how trust in supply chain breaks and how to measure mistrust. In this paper, we examine trust in decentralized supply chain. The proposed procedure can serve in further researches as a reliable measurement of trust to study the links between trust, replenishment policies and decisions, as well as supply chain performances and cost.

References

Agustin, C., Singh, J. 2005. Curvilinear effects of consumer loyalty determinants in relational exchanges. *Journal of Marketing Research*, 96-108.

Anastasi, A., Urbina, S. 1997. *Psychological testing* (7th ed.). Upper Saddle River, NJ: Prentice Hall.

Anderson, E., Weitz, B. 1989. Determinants of continuity in conventional industrial channel dyads. *Marketing Science*. 8, 31*0*-323.

Anderson, J. C., Narus, J. A. 1990. A model of distributor firm and manufacturer firm working partnerships. *the Journal of Marketing*, 42-58.

Bachmann, R. 2001. Trust, power and control in trans-organization relations. *Organization Studies*. 22, 337–365.

Berg, J., Dickhaut, J., McCabe, K. 1995. Trust, reciprocity, and social history. *Games and economic behavior*, *10*(1), 122-142.

Bhattacharya, R., Devinney, T. M., Pillutla, M. M. 1998. A formal model of trust based on outcomes. *Academy of management review*, *23*(3), 459-472.

Boles, J. S., Barksdale, H. C. 1996. What national account decision makers would tell salespeople about building relationships. *Journal of Business & Industrial Marketing*, *11*(2), 6-19.

Camerer, C. F. 2011. *Behavioral game theory: Experiments in strategic interaction*. Princeton University Press.

Carmines, E. G., Zeller, R. A. 1979. *Reliability and validity assessment* (Vol. 17). Sage Publications.

Cattell, R. B. 1966. The scree test for the number of factors. *Multivariate behavioral research*, *1*(2), 245-276.

Chang, L. 1994. A psychometric evaluation of 4-point and 6-point Likert-type scales in relation to reliability and validity. *Applied Psychological Measurement, 18(3),* 205-215.

Churchill, G.A. 1979. A paradigm for developing better measures of marketing constructs, Journal of Marketing Research, Vol. 16 No. 1, pp. 64-73.

Clark, K. B., Fujimoto, T. 1991. *Product development performance: Strategy, organization, and management in the world auto industry*. Harvard Business Press.

Clegg F. Simple Statistics. Cambridge: Cambridge University Press 1998.

Coleman, J. S. 1994. *Foundations of social theory*. Belknap Press.

Comrey, A. L., Lee, H. B. 1992. *A first course in factor analysis*. Lawrence Erlbaum.

Cook, J., Wall, T. 1980. New work attitude measures of trust, organizational commitment and personal need non‐fulfilment. *Journal of occupational psychology*, *53*(1), 39-52.

Cordery, J. L., Sevastos, P. P. 1993. Responses to the original and revised job diagnostic survey: is education a factor in responses to negatively worded items?. *Journal of Applied Psychology; Journal of Applied Psychology*, *78*(1), 141.

Costa, A. C. 2003. Work team trust and effectiveness. *Personnel Review*, *32*(5), 605-622.

Cronbach, L. J.1950. Further evidence on response sets and test design. *Educational and Psychological Measurement, 10(1),* 3-31.

Cronbach, L.J. 1951. Coefficient alpha and the internal structure of tests, Psychometrika, Vol. 16, pp. 297-334.

Crosby, L. A., Evans, K. R., Cowles, D. 1990. Relationship quality in services selling: an interpersonal influence perspective. *The journal of marketing*, 68-81.

Croson, R. 2007. *The use of students as participants in experimental research*. Working paper.

Croson, R., Donohue, K., Katok, E., Sterman, L.D. 2012. Order Stability in Supply Chains: Coordination Risk and the Role of Coordination Stock. In Working Paper, Smeal College of Business, Penn State. State College, PA.

Cummings, L. L., Bromiley, P. 1996. The organizational trust inventory (OTI). *Trust in organizations: Frontiers of theory and research*, *302*, 330.

Currall, S. C., Judge, T. A. 1995. Measuring trust between organizational boundary role persons. *Organizational behavior and Human Decision processes*, *64*(2), 151-170.

DeVellis, R. F. 2003. *Scale development: Theory and applications* (Vol. 26). Sage Publications, Incorporated.

Dibben, M. 2000. Exploring inter-personnel trust in the entrepreneurial venture. *Basingstoke: Macmillan Press*.

Diggle, P., Heagerty, P., Liang, K. Y., Zeger, S. 2013. *Analysis of longitudinal data* (No. 25). Oxford University Press.

Doney, PM, Cannon, J. 1997. An examination of the nature of trust in buyer-seller relationships, *the Journal of Marketing*, 35-51.

Dziuban, C. D., Shirkey, E. C. 1974. When is a correlation matrix appropriate for factor analysis? Some decision rules. *Psychological Bulletin*, *81*(6), 358.

Ebrahim‐Khanjari, N., Hopp, W., Iravani, S. M. 2012. Trust and Information Sharing in Supply Chains. *Production and Operations Management*.

Ferketich, S. 1991. Focus on psychometrics. Aspects of item analysis. Research in nursing & health, 14(2), 165-168.

Ganesan, S. 1994. Determinants of long-term orientation in buyer-seller relationships. *the Journal of Marketing*, 1-19.

Garland, R. 1991. The mid-point on a rating scale: Is it desirable? *Marketing Bulletin, 2,* 66-70.

Gillespie, N. 2003. Measuring trust in working relationships: the behavioral trust inventory. In *Proceedings of the Academy of Management Conference*.

Güth, W., Ockenfels, P., Wendel, M. 1997. Cooperation based on trust. An experimental investigation. *Journal of Economic Psychology*, *18*(1), 15-43.

Hair Jr, J. F., Anderson, R. E., Tatham, R. L., William, C. Black. 1995. Multivariate data analysis with readings. *New Jersey: Prentice Hall*.

Hair, Joseph F. Jr., Rolph E. Anderson, Ronald L. Tatham, William C. Black. 1998. Multivariate Data Analysis, 5th ed. Upper Saddle River, NJ: Prentice Hall.

Handfield, R.B., Bechtel, C. 2002. The roles of trust and relationship structure in improving supply chain responsiveness". *Industrial Marketing Management*. 31, 367–382.

Hardin, J. W. 2002. The robust variance estimator for two-stage models. *The Stata Journal*, *2*(3), 253-266.

Hinkin, T. R. 1995. A review of scale development practices in the study of organizations. *Journal of Management*, *21*(5), 967-988.

Jackson, P. R., Wall, T. D., Martin, R., Davids, K. 1993. New measures of job control, cognitive demand, and production responsibility. *Journal of applied psychology*, *78*(5), 753.

Kaboli, A., Cheikhrouhou, N., Glardon, R. 2012. Trust and Inventory Replenishment Decisions: An Experimental Investigation in Serial Supply Chains. *Working paper*. LGPP, EPFL.

Kaiser, H. F. 1960. The application of electronic computers to factor analysis. Educational and Psychological Measurement, 20, 141-151.

Kaiser, H. F. 1974. An index of factorial simplicity. *Psychometrika*, *39*(1), 31-36.

Kennedy, M. S., Ferrell, L. K., LeClair, D. T. 2001. Consumers' trust of salesperson and manufacturer: an empirical study. *Journal of Business Research*, *51*(1), 73-86.

Kumar, N. 1996. The power of trust in manufacturer-retailer relationships, *Harvard Business Review*, 92–106.

Lewicki, R. J., McAllister, D. J., Bies, R. J. 1998. Trust and distrust: New relationships and realities. *Academy of management Review*, *23*(3), 438-458.

Matell, M. S., Jacoby, J. 1971. Is there an optimal number of alternatives for Likert scale items? Study I: Reliability and validity. *Educational and psychological measurement*, *31*(3), 657-674.

Mayer, R. C., Davis, J. H. 1999. The effect of the performance appraisal system on trust for management: A field quasi-experiment. *Journal of applied psychology*, *84*(1), 123.

Mayer, R. C., Davis, J. H., Schoorman, F. D. 1995. An integrative model of organizational trust. *Academy of management review*, 709-734.

McAllister, D. J. 1995. Affect-and cognition-based trust as foundations for interpersonal cooperation in organizations. *Academy of management journal*, 24-59.

McEvily, B., Perrone, V., Zaheer, A. 2003. Trust as an organizing principle. *Organization science*, *14*(1), 91-103.

McEvily, B., Tortoriello, M. 2011. Measuring Trust in Organizational research: Review and Recommendations. *Journal of Trust Research*, 1, 23-63.

Merenda, P. F. 1997. A guide to the proper use of factor analysis in the conduct and reporting of research: Pitfalls to avoid. *Measurement and Evaluation in counseling and Development*.

Mohr, J., Spekman, R. 1994. Characteristics of partnership success: partnership attributes, communication behavior, and conflict resolution techniques. *Strategic management journal*, *15*(2), 135-152.

Özer, Ö., Zheng, Y., Chen, K. Y. 2011. Trust in forecast information sharing. *Management Science*, *57*(6), 1111-1137.

Plank, R. E., Reid, D. A., Pullins, E. B. 1999. Perceived trust in business-to-business sales: A new measure. *The Journal of Personal Selling and Sales Management*, 61-71.

Rousseau, D. M., Sitkin, S. B., Burt, R. S., Camerer, C. 1998. Not so different after all: A cross-discipline view of trust. *Academy of management review*, *23*(3), 393-404.

Sako, M. 1994. Supplier relationships and innovation. In: Dodgson, M., Rothwell, R., (Eds.), *The Handbook of Industrial Innovation (242-268)*. Edward Elgar, Aldershot, Hants, England and Brookfield, Vermont, USA.

Schmitt, N., Stults, D. M. 1986. Methodology review: Analysis of multitrait-multimethod matrices. *Applied Psychological Measurement*, *10*(1), 1-22.

Schriesheim, C. A., Eisenbach, R. J. 1990. Item wording effects on exploratory factoranalytic results: An experimental investigation. In *Proceedings of the I990 Southem Management Association annual meetings* (pp. 396-398).

Schriesheim, C. A., Eisenbach, R. J., Hill, K. D. 1991. The effect of negation and polar opposite item reversals on questionnaire reliability and validity: An experimental investigation. *Educational and Psychological Measurement*, *51*(1), 67-78.

Schriesheim, C. A., Hill, K. D. 1981. Controlling acquiescence response bias by item reversals: The effect on questionnaire validity. *Educational and psychological measurement*, *41*(4), 1101-1114.

Seppänen, R., Blomqvist, K., Sundqvist, S. 2007. Measuring inter-organizational trust—a critical review of the empirical research in 1990–2003. *Industrial Marketing Management*, 36, 249-265.

Sharma, S., 1996. Applied Multivariate Techniques. John Wiley and Sons, New York.

Spekman, R. E., Kamauff Jr, J. W., Myhr, N. 1998. An empirical investigation into supply chain management: a perspective on partnerships. *Supply Chain Management: An International Journal*, *3*(2), 53-67.

Sterman, J. D. 2006. Operational and behavioral causes of supply chain instability. *The Bullwhip Effect in Supply Chains: A Review of Methods, Components and Cases*.

Whitener, E. M., Brodt, S. E., Korsgaard, M. A., Werner, J. M. 1998. Managers as initiators of trust: An exchange relationship framework for understanding managerial trustworthy behavior. *Academy of Management Review*, *23*(3), 513-530.

Worcester, R. M., Burns, T. R. 1975. A statistical examination of the relative precision of verbal scales. *Journal of the Market Research Society, 17(3),* 181-197.

Wrightsman, L. S. 1991. Interpersonal trust and attitudes toward human nature. *Measures of personality and social psychological attitudes*, *1*, 373-412.

Zaheer, A., McEvily, B., Perrone, V. 1998. Does trust matter? Exploring the effects of interorganizational and interpersonal trust on performance. *Organization science*, *9*(2), 141-159.

Zaheer, A., Venkatraman, N. 1995. Relational Governance as an Inter-organizational Strategy: An Empirical Test of the Role Trust in Economic Exchange. *Strategic Management Journal*, *19*(5), 373–392.

Chapter 4

The Impact of Trust on Inventory Replenishment Decision and Extended Inventory

The main goal of this research is to examine the link between trust in customer, trust in supplier, and the inventory manager's replenishment decision. The following questions will be addressed in this chapter;

1. Does trust (in customer or in supplier) of the inventory manager affect her/his inventory replenishment decisions? If so, how?
2. Is there any link between the inventory manager's trust perception (in supplier or customer) and her/his extended inventory?

The findings of this chapter is partially presented at:

Kaboli, A. Cheikhrouhou, N. Glardon, R. Darvish, M. 2012. *An Experimental Study of the Relationship between Trust and Inventory Replenishment in Triadic Supply Chain*. The 4th Production and Operations Management World Conference, July 1-5, Amsterdam, the Netherlands.

Kaboli, A. Cheikhrouhou, N. Glardon, R. 2012. *The Relationship between Trust and Inventory Replenishment in Supplier-Customer Dyad: An Experimental Study*. 4th International Conference on Information Systems, Logistics and Supply Chain, August 26-29, Quebec, Canada.

The Impact of Trust on Inventory Replenishment Decision and Extended Inventory

Abstract

Trust has a substantial impact in supply chain relationships. While the effect of trust on supply chain performance has been extensively studied, relatively little is known about the link between trust, inventory replenishment decision-making, and inventory behavior. This paper examines the impact of inventory manager' trust perception on their replenishment decision and their extended inventory. We design an experiment with unknown market demand, local information, and under continuous replenishment review. We analyze the experimental data on the individual and echelon levels. We find that lower trust in customer leads to higher order quantity, lengthen order time intervals, and higher extended inventory at the individual levels. Results at the echelon level also show some supports. Moreover, our results show that inventory managers prefer to hold higher inventory level when they have lower trust in their upstream supplier. We find that distributor exhibits the lowest trust in customer, highest order quantity and longest order time intervals among echelons. Furthermore, we find that retailer is the only echelon that considers trust in supplier while placing order quantities to upstream supplier.

Keywords: Trust, inventory replenishment decision, supply chain relationships, experiment, behavioral operations management.

1. Introduction

Trust has a substantial impact in supply chain relationships. Previous research findings in operations management have shown that trust is a fundamental ingredient in building and maintaining cooperation (Bachmann 2001) and a significant contributor to the long-term stability of a supply chain (Handfield and Bechtel 2002).

But, why should trust matter within a supply chain? The most obvious answer is that trust can reduce perceived relational risk between the supplier and customer (Das and Teng 1998). Trust also can increase confidence in the inventory manager that short-term disruptions will be resolved (Ganesan 1994). Hence, echelons that trust each other may generate greater profits and exhibit more adaptability (Kumar 1996).

While the effect of trust on supply chain performance has been extensively studied (Handfield and Bechtel 2002; Panayides and Venus 2009), relatively little is known about the link between inventory manager's trust perception, their replenishment decision and their extended inventory.

Recognition of the importance of inventory replenishment decision and its significant effect on supply chain performance has grown in recent years, evidenced by an abundance of published work attempting to understand the phenomenon from both normative and behavioral perspectives (Aviv 2003; Croson and Donohue 2003; Croson and Donohue 2006; Croson et al. 2012; Oliva and Gonçalves 2005; Sterman 1989; Wu and Katok 2006).

Various periodic and continuous inventory replenishment models have been proposed for optimal ordering policies (Aviv 2003; Clark and Scarf 1960; De Bodt and Graves 1985; Federgruen and Zipkin 1984). Nevertheless, the actual behavior of an inventory manager tends to deviate from optimal ordering policies (Loch and Wu 2005; Gino and Pisano 2008; Simon 1969).

If following optimal ordering policies satisfies downstream customer demand and minimizes total costs in supply chain, why do inventory managers' decisions deviate from the optimal policy? Evidence from supply chain laboratory experiments show that decision makers have a cognitive limitation to formulate inventory replenishment decision-making problems in a finite time on the basis of available information (Bolton and Katok 2005; Croson and Donohue 2006; Sterman 2006).

Research from several literature streams addresses inventory replenishment decision-making problem. It highlights that the mismatch arising between supply and demand at each echelon can exacerbate order quantity and order time at upstream echelons and lead to order quantity and order time interval amplifications (Blinder 1981; Chen 1999; Chen and Lee 2012; Croson and Donohue 2006, Kaboli et al. 2013a; Sterman 1989; Towill 1991).

Supply and demand mismatch (also known as order or demand amplification, Forrester effect, and bullwhip effect) is caused by structural and behavioral reasons. Lee et al. (1997) introduces the following characteristics that cause demand amplification; demand signal processing, order batching, price variation, and inventory rationing. These four reasons are structural causes of demand amplification. Decision maker bounded rationality to account for time lags and previous decisions feedbacks (Sterman 1989) and uncertainty of individual decisions for the other supply chain members (Croson et al. 2012) are behavioral characteristics that amplify order variability.

Moreover, Sterman (1989) identifies that inventory managers place orders to (1) fill customer orders, (2) reduce the gap between desired and actual on-hand inventory levels, and (3) maintain an adequate supply line of open orders. Therefore, the extended inventory can be attributed to the inventory manager's response to supply and demand mismatch with backlog avoidance (Kahn 1992). Given that, it can be expected that changes in the inventory managers' trust will influence her/his inventory replenishment decision, as inventory managers seek to hold enough inventory to reduce the cost of demand and supply uncertainties. Therefore, understanding how trust affects inventory replenishment decisions and extended inventory is pivotal for research and practice.

The purpose of this paper is thus to address the following two important issues. First, does trust (in customer or in supplier) of the inventory manager affect her/his inventory replenishment decisions? At this point, to the best of our knowledge, there is no evidence in the inventory management literature to substantiate the proposition that a higher level of trust in supplier or customer results in lower order quantities and shorter order time intervals. Second, this study seeks whether there is a link between the inventory manager's trust perception (in supplier or customer) and her/his extended inventory? A clear answer for this proposition advances prior research studies on inventory managers' tendency to hold higher or lower inventory.

In addressing these two important issues, this study contributes to the literature on the effect of trust on inventory decisions and extended inventory. Given the effect of demand and supply uncertainty on supply chain decisions (Lee et al. 1997; Tomlin 2009), understanding the role of trust perception on these decisions is particularly important for research and practice.

The next section provides the related literature. Section 3 describes the research method. Section 4 highlights the statistical analyses. Section 5 reports the results. Section 6 concludes the paper, underlines the findings, presents the limitations, and proposes future research directions.

2. Theory and hypotheses

In this section, we survey literature on the link between trust, inventory replenishment decisions, and extended inventory. Based on existing theory, we develop a model for relationships between these variables. The model and hypotheses are depicted in Figure 1.

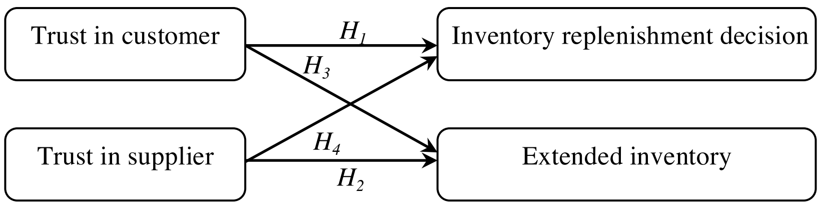


Figure 1: The hypothesized relationships.

2.1. Trust

Despite different trust definitions in the literature, researchers mostly conceptualize and measure trust as trustor's belief or perception on trustee's good intention and proper action (McAllister 1995; Whitener et al. 1998). Furthermore, most of the extant literature has focused on either trust in customer or trust in supplier, while studies that simultaneously examine both are scarce (Johnston et al. 2004).

In this study, we consider both trust in customer and trust in supplier and draw on prior literature in defining trust as *"one party's belief that its needs will be fulfilled in the future by actions undertaken by the other party "* Anderson and Weitz 1989). The focal referent of an inventory manager's trust is the downstream customer and upstream supplier. Thus, we specify trust in customer as *inventory manager's belief that her/his needs will be fulfilled in the future by actions undertaken by the customer* and trust in supplier as *inventory manager's belief that her/his needs will be fulfilled in the future by actions undertaken by the supplier*.

Trust in downstream customer and trust in upstream supplier are meaningful concepts in supply chain relationships. Since supply chain echelons are interconnected and an echelon profit is dependent on the demands of its downstream customer and supplies of its upstream supplier. Moreover, considering trust in customer and trust in supplier can provide more information on their intention and allow us to examine possible linkages of trust perception, inventory decision, and extended inventory (Dietz and Den Hartog 2006; Smith and Barclay 1997).

2.2. The effect of trust on inventory replenishment decision

In a decentralized supply chain, inventory managers make inventory replenishment decisions with local information. Local information means each inventory manager is provided with the following information; received orders from downstream customer, on-hand inventory, placed orders to upstream supplier, shipments of upstream supplier, and shipments to downstream customer. The inventory manager does not know the orders from the downstream customer. Thus, the inventory manager faces demand uncertainty from downstream customer that may result in forecasting errors (Chen et al. 2000).

Croson and Donohue (2003, 2006) hypothesize that demand amplification might be due to demand signal processing. They use stationary demand in their studies. However, retailer knows the customer demand and other echelons have no information about the realization of demand. To control that, Croson et al. (2012) keep the market demand stationary and known to all echelons. By this design, they remove all operational causes for demand uncertainty (Lee et al. 1997). Thus, decisions of the inventory managers in a chain remain the single source of uncertainty. They conclude that inventory managers have limited trust in their downstream customer orders. Hence, theory suggests:

HYPOTHESIS 1. *A higher trust in customer leads to lower order quantity and shorter order time intervals.*

In a decentralized supply chain, the inventory manager also does not know her/his upstream supplier's on-hand inventory level, and the time s/he receives the upstream supplier shipments. Moreover, there is no communication among the managers. Therefore, the inventory manager may face supply uncertainty.

The inventory manager must consider that the time required for the upstream supplier to receive and to ship orders is at least as large as the shipment lead-time. Therefore, s/he must regulate her/his inventory with respect to the shipment lead-time. Nevertheless, evidence shows that inventory managers typically underweight the supply line (Sterman 1989) and expect shorter shipment lead-time from suppliers (Christopher 2005); this consequently leads to instability in the supply chain.

According to the trust definition in Section 2.1, trust in supplier is the inventory manager's perception that the upstream supplier acts in a way to satisfy her/his needs. Given that trust is a psychological state of mind that can lead to a decision or a behavior (Rousseau et al. 1998), we expect trust in one's upstream supplier to influence the inventory manager's replenishment decision:

HYPOTHESIS 2. *A higher trust in supplier leads to lower order quantity and shorter order time intervals.*

2.3. The effect of trust on extended inventory

Numerous studies propose that shipment delay and supply uncertainty reduce customer purchases (Heim and Sinha 2001; Anderson et al. 2006) or lead customers to switch their supplier (Fitzsimons 2000). Graves (1999) demonstrates that in a multi-echelon supply chain, the needs for inventory to buffer stochastic demand is greater than the stationary demand. Baganha and Cohen (1998) highlight the stabilizing role of inventory to absorb demand uncertainty. Thus, inventory is influenced by shipment delays, demand uncertainty, and inventory costs (Lieberman et al. 1999; Zipkin 2000).

In a serial supply chain, however, the inventory manager cannot cancel downstream customer orders, or abandon placing orders to her/his upstream supplier and/or shift the supplier. Demand and supply uncertainty in this supply chain context can increase the likelihood of backlog (Fisher 1997). To mitigate this risk, the inventory manager must hold inventory (Able 1985; Kahn 1987).

Given that, the inventory manager perceives the situation, builds perception about the downstream customer and upstream supplier (Chen et al. 2010; Tomlin 2009; Scarf 1959; Wecker 1978), and then s/he may decide and/or act (Ajzen 2002; Rokeach 1960; Smith et al. 1956). Consequently, we expect a link between an inventory manager's trust levels and her/his extended inventory.

HYPOTHESIS 3. *A higher trust in customer leads to lower inventory levels.*

HYPOTHESIS 4. *A higher trust in supplier leads to lower inventory levels.*

3. Research method

3.1. Experimental setting

We conduct the experiment within the context of "XBeer Game". The "XBeer Game" is a role-playing simulation of a production and distribution system developed at Laval University (Montreuil et al. 2008). The experimental environment is selected for two main reasons. First, it is a stable and controlled environment. Thus, it allows us to control extraneous variables (Katok 2011) and to avoid undesirable effects such as coalition and power. Second, it provides continuous data storage that assures the availability of a reliable data set for later analysis.

The participatory simulation platform mimics the dynamics of a serial decentralized supply chain under continuous inventory review. The inventory managers decide how much to order for and when such an order should be placed? These decisions are made based on the available information to regulate inventory levels, to minimize total costs, and to satisfy downstream customer demand.

Figure 2 represents the structure of the supply chain in the experiment. A different subject manages each echelon. The market demand is stable and unknown to the subjects. The demand follows a normal distribution with a mean of 3000 units/day and a standard deviation of 500 units/day, truncated at zero. It is randomly split into two orders/day. The market demand arises at retailer; retailer fills customer orders out of on-hand inventory and places orders to wholesaler if necessary. Wholesaler, likewise, delivers required materials to retailer out of on-hand inventory and replenishes her/his inventory from distributor. Distributor delivers the orders to wholesaler, place orders and receives them from the factory. Factory is the producer who launches orders in production. Therefore, it exhibits a structural difference with respect to all other downstream levels. This structural difference is the main reason that factory role is played by computer agent. The subjects in distributor, wholesaler, and retailer roles are not aware of the fact that the most upstream supplier, factory, is simulated by a computer.

Each subject has access to the received orders from downstream customer, on-hand inventory, placed orders to the upstream supplier, the shipments of upstream supplier, and the shipments to downstream customer.

There are two types of lead-times for the roles played by the subjects; an ordering lead-time of 1 day between order placement by a customer and order receive by the supplier and shipment lead-time of 2 days between order shipment by a supplier and order delivery to the customer. When the customer order exceeds the on-hand inventory the excess is backlogged.

The cost components that a subject incurs over the experiment are backorder cost, inventory holding cost, and purchasing cost. The incomes are sales to downstream customer and backlog fees from the upstream supplier. Incomes minus costs constitute the subject's profit. Detailed set-up information is available in Appendix A.

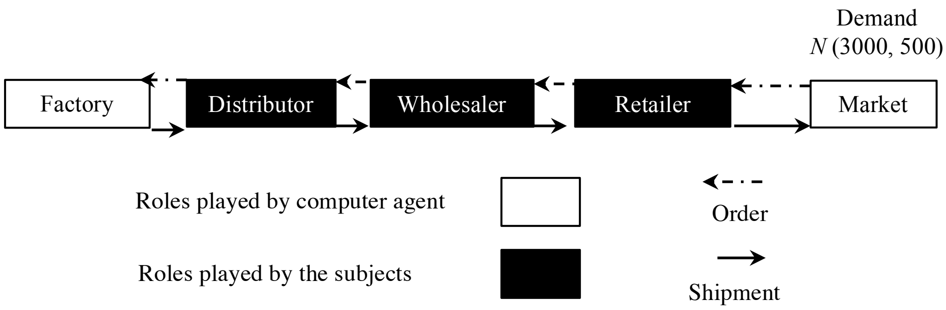


Figure 2: Structure of the supply chain.

3.2. Experiment protocol

The experiment proceeds as follows: Subjects enter the laboratory at an appointed time and are randomly assigned to their team and their role. We take four steps before starting the experiment to assure the subjects understand the experiment. First, each subject is provided with a handout (4-5 pages) explaining the experimental procedure and presenting the game interface. Second, after reading the instructions, subjects' questions are answered, and the interface is presented. Third, subjects are asked to participate in two initial rounds of the experiment as a warm-up exercise. These three steps should have allowed a relatively stable understanding of the experiment. As the last step and to make sure the subjects understand the experiment, we ask them to answer a short quiz after warm-up session. The evaluation of their answers convinces us to run the experiment.

In design of the experiment, we tried to make the timing of data collection appropriate. The experiment is divided into eight rounds of approximately seven minutes. We disentangle trust in supplier and trust in customer and measure them through questionnaires. Data on trust are collected at the beginning of each round. More specifically, the experiment is stopped at the beginning of each round and subjects are asked to fill out form A, the inventory manager trust in her/ his supplier, and form B, the inventory trust in her/ his customer (for more details about trust construct and trust measurement, see Kaboli at al. 2013 b).

To reduce the risk of response bias, the order of questions in both questionnaires is changed at each round. To avoid any phony behavior and to remove the potential for inflated statistical relationships, the duration of the experiment is not announced in advance. Hence, we gather data on the first 8 rounds of the experiment and data from the rest of the experiment is not considered in the data analysis. At the end of the experiment, subjects are asked to fill a post-experiment questionnaire to explain their replenishment decision strategy (-ies) and finally they are paid based on the attained performance.

3.3. Variables

Table 1 summarizes the variables and the symbols.

Trust. Trust is measured using a procedure of previous work (see Appendix B). The subjects respond to 4 items using a seven-point Likert-scale ranging from strongly disagree (1) to strongly agree (7). The mean of the 4 items is used as the measurement of trust; either trust in customer (T_c) or trust in supplier (T_s). Thus the experiment results in 16 trust measurements for each subject; eight for trust in supplier and eight for trust in customer. An exploratory factor analysis with varimax rotation on the four items indicated that all items loaded onto a single factor that accounted for 60% to 75% of the variance. Items loaded on the factor at values above .30 for trust in supplier and trust in customer. Cronbach's alpha coefficient for the trust in supplier and trust in customer ranges from .77 to .90 (Kaboli et al. 2013b).

Inventory replenishment decision (IR). In this study, we consider a continuous review system. This fact denotes that both order quantity and order time intervals are variable. To assess placed order quantity (*OQ*), we consider the indicated units of beer for each order sent to the immediate upstream supplier. The duration between two consecutive placed orders to the immediate upstream supplier is defined as placed order time intervals (*OT*).

Extended inventory (EI). To assess inventory managers buffering behavior, the following elements are used: on-hand inventory (*OI*), as the amount of beers available in stock for immediate shipment to customer and supply line (*SL*), as the amount of beers that have been ordered to the upstream supplier but not yet received. Therefore, *EI* is the sum of *OI* and *SL* at each round.

Table 1: Summary of the variables and symbols

Variable	Symbol
Trust	
Trust in customer	*Tc*
Trust in supplier	*Ts*
Inventory replenishment decision	*IR*
Placed order quantity	*OQ*
Placed order time intervals	*OT*
Extended inventory	*EI*
On-hand inventory	*OI*
Supply line	*SL*

Data on trust are collected at the beginning of each round, as mentioned earlier in section 3.2, and data on the inventory replenishment decision and extended inventory are gathered continuously over the experiment through the participatory simulation platform. Thus, the timing of data gathering provides the ability to draw conclusions of causality between trust, inventory replenishment decision-making, and inventory levels (see Figure 3).

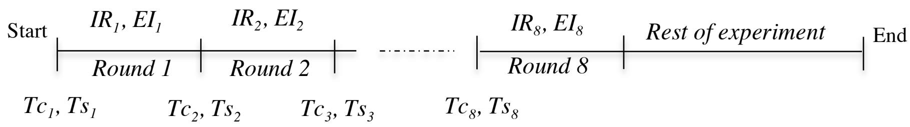


Figure 3: The process of measurement.

3.4. Subjects

Forty-eight undergraduate and graduate students from two Swiss Universities EPFL and UNIL (engineering and business majors) participate in this experiment for payoff contingent on performance. The subjects consist of 39% women and 61% men, with 24% of students in their bachelor, 54% in their master, and 22% in their PhD. As shown in Equation (1), in addition to a fix payment of 10 CHF for showing up to the experiment, the subjects could earn, on the basis of their performance, up to 50 CHF. Therefore, the subject goal is to maximize her/his earning.

$$Earning = min\ \{Show\text{-}up\ fee\ (10\ CHF) + 40\ CHF * (\frac{Your\ income}{Average\ of\ the\ role\ income}),\ 50\ CHF\} \quad (1)$$

4. Statistical analysis

In this study, several measurements are made on the same subjects over time. This fact induces inter-correlations among the observations corresponding to the same subject. Also, further exploration of the distribution of dependent variables; inventory replenishment decision (order quantity, order time intervals) and extended inventory suggests that they do not have a normal-like distribution. Therefore, we propose the use of Generalized Linear Mixed Model (GLMM) to assess the validity of the main hypotheses. GLMMs extend Generalized Linear Models (GLMs) by incorporating common random effects for observations corresponding to the same individual in the linear predictors, using Gamma family distributions for non-normal response (dependent variable), and relating dependent variable with independent variables using link function (See Diggle et al. (2002) and Demidenko (2005) for further details).

The data set consists of 16 supply chains. The exploratory graphs propose the existence of outliers in four supply chains. Also further examination of the post-experiment questionnaire shows that there is (at least) one subject in these four supply chains who may have misunderstood the experiment and the decision task. Therefore, in order to have a sample corresponding to a homogeneous target population we decided to exclude these four supply chains from the sample and we report on the results of 12 supply chains, 36 subjects, over 8 rounds, building 96 observations for each echelon or 288 total observations. Proposed analyses are conducted both at the individual and echelon levels.

4.1. Model specification

Since our exploration on the distributions of inventory replenishment decision (order quantity and order time intervals) and extended inventory shows that they have positive values that are right-skewed, we select a Gamma distribution with a logarithmic link function. Moreover, a random intercept is injected into the model for each subject to take the interdependence of observations, corresponding to the same subject, into account (Diggle et al. 2002, p.126). The adequacy of the fit is assessed for all fitted models using graphical tools. Statistical analyses are carried out using SAS 9.2.

To avoid multicoliniarity (Belsley et al. 2005, p.85; Gujarati 2003) and to disentangle subjects' decisions on quantity and/or time intervals, we separate order quantity from customer's order time intervals and consider them in two separate models. To test how inventory managers trust in customer affect the order quantity (*OQ*) and order time intervals (*OT*), we propose to construct the following models:

H_{1a} : $Log\ (OQ_{ij}) = \beta_0 + \beta_1 Tc_{ij-1} + \beta_2 Tc_{ij} + \beta_3 Role_i(R) + \beta_4 Role_i(W) + \beta_5 Role_i(D)$ (2)

H_{1b}: $Log\ (OT_{ij}) = \beta_0 + \beta_1 Tc_{ij-1} + \beta_2 Tc_{ij} + \beta_3 Role_i(R) + \beta_4 Role_i(W) + \beta_5 Role_i(D)$ (3)

where *i* denote the subject and *j* represents the round. Given that the subjects' trust perception are history dependent (Kramer and Cook 2004) and trust is built over time through previous interactions and experiences (Boon and Holmes 1991; Gulati 1995; King-casas et al. 2005; Poppo et al. 2008), we consider "trust in customer" of previous round along with the "trust in customer" of the current round. Also, we take into account the effect of echelon differences (Kaboli et al. 2013a) on order quantity and order time intervals. Therefore, all three echelons; retailer (R), wholesaler (W), and distributor (D) are considered.

Following the same line of reasoning, to examine Hypothesis 2 we propose following models:

H_{2a} : $Log\ (OQ_{ij}) = \beta_0 + \beta_1 Ts_{ij-1} + \beta_2 Ts_{ij} + \beta_3 Role_i(R) + \beta_4 Role_i(W) + \beta_5 Role_i(D)$ (4)

H_{2b}: $Log\ (OT_{ij}) = \beta_0 + \beta_1 Ts_{ij-1} + \beta_2 Ts_{ij} + \beta_3 Role_i(R) + \beta_4 Role_i(W) + \beta_5 Role_i(D)$ (5)

Moreover, we consider the following models for H_3 and H_4 respectively:

H_3: $Log\ (EI_{ij}) = \beta_0 + \beta_1 Tc_{ij-1} + \beta_2 Tc_{ij} + \beta_3 Role_i(R) + \beta_4 Role_i(W) + \beta_5 Role_i(D)$ (6)

H_4: $Log\ (EI_{ij}) = \beta_0 + \beta_1 Ts_{ij-1} + \beta_2 Ts_{ij} + \beta_3 Role_i(R) + \beta_4 Role_i(W) + \beta_5 Role_i(D)$ (7)

where EI_{ij} denote the extended inventory of the i^{th} subject on j^{th} round.

5. Result and discussion

5.1. Descriptive statistics

Table 2 presents descriptive statistics for the variables. The table is divided into four sections and provides the descriptive statistics for both individual (pooled), and echelon (retailer, wholesaler, distributor) levels. Results show that the mean and median of trust in customer decrease from retailer to distributor. Concerning trust in supplier, the mean and median of wholesaler's trust in supplier is the lowest. Distributor and retailer mean and median of trust in supplier are in the same level. The mean, median, and standard deviation of order quantity and order time intervals increase from retailer to distributor. Likewise, mean, median, and standard deviation of extended inventory tend to increase while moving upstream along the supply chain from retailer to distributor.

Table 2: Descriptive statistics of the dependent and independent variables

	Mean	Median	SD	Min	Max
Pooled (*N*=288)					
Trust in customer (*Tc*)	4.09	4.25	1.41	1	7
Trust in supplier (*Ts*)	4.39	4.5	1.34	1	7
Placed order quantity (*OQ*)	5571	4095	5601	1000	43000
Placed order time intervals (*OT*)	46	34	47	5	432
Extended inventory (*EI*)	14825	12148	9438	4990	73295
Retailer (*N*=96)					
Trust in customer (*Tc*)	4.57	4.75	1.1	2.25	7
Trust in supplier (*Ts*)	4.46	4.75	1.34	2	7
Placed order quantity (*OQ*)	3797	2661	4931	1000	40000
Placed order time intervals (*OT*)	26	22	20	5	120
Extended inventory (*EI*)	12069	10541	5393	6152	41977
Wholesaler (*N*=96)					
Trust in customer (*Tc*)	4.01	4	1.63	1	6.75
Trust in supplier (*Ts*)	4.06	4.13	1.42	1	7
Placed order quantity (*OQ*)	5892	4755	5097	1483	43000
Placed order time intervals (*OT*)	52	36	53	12	432
Extended inventory (*EI*)	15563	12614	10387	5071	69229
Distributor (*N*=96)					
Trust in customer (*Tc*)	3.69	3.75	1.32	1	6.5
Trust in supplier (*Ts*)	4.64	4.75	1.19	1	7
Placed order quantity (*OQ*)	7088	5586	6270	1000	39000
Placed order time intervals (*OT*)	60	47	54	5	304
Extended inventory (*EI*)	16843	13710	10944	4990	73295

5.2. The effect of trust in customer on inventory replenishment decision (H_1)

Recall we consider inventory replenishment decision in a continuous review environment. This denotes that both order quantity and order time intervals are variable. Table 3 represents the results of Hypothesis 1 for the effect of trust in customer on order quantity (H_{1a}, Equation 2) and order time intervals (H_{1b}, Equation 3).

Results in Table 3 show that trust in customer has a negative effect on the inventory manager's order quantity at the individual level. At the echelon level, results show that only distributor's trust in customer at the current round has a negative effect on order quantity and there is a no significant effect of trust in customer on wholesaler's and retailer's order quantity.

Table 3: GLMM regression of trust in customer on inventory replenishment decision (H_1)

	Pooled	Distributor	Wholesaler	Retailer
Coefficient	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)
H_{1a}: $T_c \rightarrow OQ$				
Intercept	9.139*** (.236)	9.232*** (.284)	8.953*** (.306)	8.379*** (.402)
Trust at round *j*-1	-.066** (.031)	-.048 (.054)	-.055 (.054)	-.086 (.055)
Trust at round *j*	-.072** (.032)	-.116** (.055)	-.050 (.059)	-.015 (.055)
Retailer	-.585** (.269)			
Wholesaler	-.056 (.268)			
Distributor	†			
N	248	80	84	84
H_{1b}: $T_c \rightarrow OT$				
Intercept	4.354*** (.246)	4.367*** (.331)	4.375*** (.390)	3.384*** (.361)
Trust at round *j*-1	-.109*** (.039)	-.178** (.069)	-.054 (.075)	-.052 (.051)
Trust at round *j*	-.011 (.040)	.053 (.071)	-.091 (.080)	-.021 (.051)
Retailer	-.747*** (.257)			
Wholesaler	-.084 (.255)			
Distributor	†			
N	248	80	84	84

Note. Standard errors are reported in parentheses. * significant at p <.1, ** significant at p <.05, and *** significant at p <.01. † is considered as reference category.

Furthermore, results of H_{1b} show that trust in customer has a negative effect on order time intervals at the individual level in the previous round. Analysis at the echelon level reveals that trust in customer at the previous round has a negative effect on distributor's order time intervals and there is a no significant effect of trust in customer on wholesaler's and retailer's order time intervals.

The experimental results support Hypothesis 1 at the individual level as we find that low trust in customer is linked to high order quantity and the lengthen order time intervals at the individual levels. This outcome supports finding of Croson et al. (2012). However, at the echelon level, Hypothesis 1 is partially supported. This is in particular the case for distributor who exhibits the lowest trust in customer, highest order quantity and largest order time intervals among echelons. This finding shows that lower distributor's trust in customer is associated with a significant increase of her/his order quantity and order time intervals. We believe this may be due to the higher demand uncertainty for the most upstream supplier.

5.3. The effect of trust in supplier on inventory replenishment decision (H_2)

Table 4 represents the results of Hypothesis 2 for the effect of trust in supplier on order quantity (H_{2a}, Equation 4) and order time intervals (H_{2b}, Equation 5). Results in Table 4 for H_{2a} show that there is no significant effect of trust in supplier on order quantity at the individual level. However, on the echelon level, analysis shows that retailer is the only echelon that considers trust in supplier while placing order quantities to upstream supplier. This could be explained by the fact that supply uncertainty is higher for the downstream customer than for the most upstream supplier (Tomiln 2009; Rong et al. 2008) and that suppliers shipment delays can increase order quantities (Dada et al. 2007; Silver 1976).

Furthermore, results for H_{2b} show there is no significant effect of trust in supplier on the order time intervals at the individual level. At the echelon level, we only observe a positive association between wholesaler trust in supplier and order time intervals. Further inspections show that retailer coefficient of variation for order quantity and order time intervals are .43, .89, respectively, and wholesaler coefficient of variation for order quantity and order time intervals are .62, and .88, respectively (see Figure 3 of chap. 2). Thus, one possible explanation is that wholesaler filters retailer variable order quantity and transforms them into variable order time intervals. In other words, retailer implements a replenishment procedure close to a variable quantity, fixed order time policy, while the wholesaler uses a replenishment practice close to a fixed quantity, variable time policy. This fact gives a demand signal of large order quantities with variable time intervals to the distributor. Thanks to the computer agent on factory role, distributor could build up higher inventory levels with less shipment delays.

Table 4: GLMM regression of trust in supplier on inventory replenishment decision (H_2)

	Pooled	Distributor	Wholesaler	Retailer
Coefficient	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)
H_{2a}: $T_s \rightarrow OQ$				
Intercept	8.796*** (.269)	8.788*** (.475)	8.160*** (.325)	8.265*** (.303)
Trust at round *j*-1	-.028 (.029)	.022 (.068)	.042 (.056)	-.077** (.035)
Trust at round *j*	-.007 (.031)	-. 053 (.078)	.049 (.056)	-.002 (.036)
Retailer	-.723*** (.277)			
Wholesaler	-.126 (.278)			
Distributor	†			
N	248	80	84	84
H_{2b}: $T_s \rightarrow OT$				
Intercept	4.102*** (.282)	3.837*** (.540)	3.678*** (.401)	3.339*** (.265)
Trust at round *j*-1	-.059 (.036)	.029 (.083)	-.107 (.073)	-.043 (.032)
Trust at round *j*	-.018 (.037)	-. 011 (.093)	.135* (.074)	-.021 (.033)
Retailer	-.868*** (.258)			
Wholesaler	-.148 (.260)			
Distributor	†			
N	248	80	84	84

Note. Standard errors are reported in parentheses. * significant at p <.1, ** significant at p <.05, and *** significant at p <.01. † is considered as reference category.

5.4. The effect of trust in customer on extended inventory (H_3)

Hypothesis 3 suggests that there is a negative relationship between trust in supplier and extended inventory. This means, inventory managers tend to buffer higher inventory levels (on-hand and supply line) when their trust in customer is low.

Experimental results in Table 5 fully support Hypothesis 3 for the individual and echelon levels. More precisely, results show that at the individual level trust in customer negatively affects inventory behavior in the current round. Moreover, at the echelon level, distributor and retailer trust in the current round are negatively associated with inventory behavior while for wholesaler this relationship holds at the previous round.

Table 5: GLMM regression of trust in customer and trust in supplier on extended inventory (H_3 and H_4)

	Pooled	Distributor	Wholesaler	Retailer
Coefficient	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)
H_3: $T_c \rightarrow EI$				
Intercept	3.126*** (.150)	2.959*** (.237)	3.314*** (.230)	3.026*** (.256)
Trust at round *j*-1	-.028 (.029)	.040 (.056)	-0.004 (.005)	-.051 (.043)
Trust at round *j*	-.074** (.029)	-0.005 (.376)	-.077 (.048)	-0.003 (.139)
Retailer	-.198 (.138)			
Wholesaler	-.064 (.136)			
Distributor	†			
N	252	84	84	84
H_4: $T_s \rightarrow EI$				
Intercept	3.183*** (.183)	††	2.719*** (.281)	2.948*** (.173)
Trust at round *j*-1	-.027 (.026)		.062 (.048)	-.023 (.028)
Trust at round *j*	-.066** (.027)		-.079 (.050)	-.085*** (.028)
Retailer	-.304** (.146)			
Wholesaler	-.152 (.147)			
Distributor	†			
N	252	84	84	84

Note. Standard errors are reported in parentheses. * significant at p <.1, ** significant at p <.05, and *** significant at p <.01. † is considered as reference category. †† represents the model is not converged.

5.5. The effect of trust in supplier on extended inventory (H_4)

Table 5 also represents the results of Hypothesis 4 for the effect of trust in supplier on extended inventory (H_4, Equation 7). Results show that Hypothesis 4 is supported at the individual level analysis. At the echelon level, the model did not converge for distributor. However, retailer's trust in supplier at the current round has a negative effect on her/his extended inventory. Thus our results show that inventory managers prefer to hold higher inventory level when they have lower trust in their upstream supplier.

6. Conclusion

The main objective of this study is to examine the effect of inventory managers' trust perception on their inventory replenishment decision and extended inventory. We experimentally provide some supports that inventory managers' trust has a cognitive basis that effects their replenishment decision and extended inventory at the individual and echelon levels (see Table 6).

Table 6: Summary of the hypothesis testing

Hypothesis				Individual level	Echelon level
H_1	H_{1a}	$Tc \rightarrow OQ$	(-)	Fully supported	Partially supported
	H_{1b}	$Tc \rightarrow OT$	(-)	Fully supported	Partially supported
H_2	H_{2a}	$Ts \rightarrow OQ$	(-)	Not supported	Partially supported
	H_{2b}	$Ts \rightarrow OT$	(-)	Not supported	Not supported
H_3	H_3	$Tc \rightarrow EI$	(-)	Fully supported	Fully supported
H_4	H_4	$Ts \rightarrow EI$	(-)	Fully supported	Partially supported

More precisely, we find that low trust in customer is linked to high order quantity and long order time intervals at the individual levels. Moreover, at the echelon level we find that distributor exhibits the lowest trust, highest order quantity and largest order time intervals among echelons. For the effect of trust in supplier on the order quantity and order time intervals, there is no support on the individual level. However, we find that when the retailer has lower trust in her/his supplier (wholesaler), s/he places larger order quantities. Findings of Hypothesis 1 and Hypothesis 2 at the echelon level perfectly show how upstream supplier and downstream customer respectively react toward demand and supply uncertainty.

Moreover, we find that when inventory managers' trust in customer is low, they tend to hold higher inventory levels. This outcome supports finding of Baganha and Cohen (1998) on stabilizing effect of inventory in decentralized supply chain. Further, we find that inventory managers hold higher inventory level when they have lower trust in their upstream supplier. These findings provide more details to previous key influencers on extended inventory (Lieberman et al. 1999; Zipkin 2000), and propose that trust in customer and trust in supplier under demand and supply uncertainties lead inventory managers to hold higher inventory levels.

6.1. Limitations and extensions

There are several factors beyond the scope of our study that we leave for future studies. First, this study focuses on distributor-wholesaler-retailer triad. Future research should examine the robustness of our results in different supply chain contexts. Second, this study considers the effect of trust on inventory managers replenishment decision and extended inventory in a decentralized supply chain context. The level of trust in customer and trust in supplier is higher when there is communication between the subjects (Cummings and Bromiley, 1996). Also, information sharing has a positive effect on trust (Özer et al. 2011; Ebrahim-Khanjari et al. 2012). Thus, it would be interesting to extend this research to a centralized supply chain and compare the results. Third, we consider a conceptual model without feedback focusing on the inventory managers' replenishment decision and extended inventory. Hence, future studies should examine a dynamic model considering feedback loops and corrections. Fourth, it should be noted that using student subjects does not necessarily limit our findings due to the simplicity of the decision task. However, there is some evidence that professional subjects perform better than student subjects (Croson 2007). Thus, it would be worthwhile to run a similar experiment for professionals, analyze, and compare data from both types of subject.

References

Abel, A. B. 1985. Inventories, stock-outs and production smoothing. *The Review of Economic Studies*, *52*(2), 283-293.

Ajzen, I. 2002. Perceived Behavioral Control, Self-Efficacy, Locus of Control, and the Theory of Planned Behavior1. *Journal of applied social psychology*, *32*(4), 665-683.

Anderson, E. T., Fitzsimons, G. J., Simester, D. 2006. Measuring and mitigating the costs of stockouts. *Management Science*, *52*(11), 1751-1763.

Anderson, E., and Weitz, B. 1989. Determinants of continuity in conventional industrial channel dyads. *Marketing Science*. 8, 31*0*-323.

Aviv, Y. 2003. A time-series framework for supply-chain inventory management. *Operations Research*, *51*(2), 210-227.

Bachmann, R. 2001. Trust, power and control in trans-organizational relations. *Organization Studies*, *22*(2), 337-365.

Baganha, M. P., Cohen, M. A. 1998. The stabilizing effect of inventory in supply chains. *Operations Research*, *46*(3), S72-S83.

Belsley, D. A., Kuh, E., Welsch, R. E. 2005. *Regression diagnostics: Identifying influential data and sources of collinearity* (Vol. 571). John Wiley & Sons.

Blinder, A.S. 1981. Retail inventory behavior and business fluctuations, *Brooking Papers on Economic Activity*. 2, 443-520.

Boles, J. S., Barksdale, H. C. 1996. What national account decision makers would tell salespeople about building relationships. *Journal of Business & Industrial Marketing*, *11*(2), 6-19.

Bolton, G. E., Katok, E. 2005. *Learning-by-doing in the newsvendor problem*. Discussion paper, Penn State University.

Boon, S. D., Holmes, J. G. 1991. The dynamics of interpersonal trust: Resolving uncertainty in the face of risk. *Cooperation and prosocial behavior*, 190-211.

Chen, F. 1999. Decentralized supply chains subject to information delays. *Management Science*, *45*(8), 1076-1090.

Chen, F., Drezner, Z., Ryan, J. K., Simchi-Levi, D. 2000. Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead times, and information. *Management science*, *46*(3), 436-443.

Chen, L., Lee, H. L. 2012. Bullwhip effect measurement and its implications. *Operations Research*, *60*(4), 771-784.

Chen, M., Xia, Y., Wang, X. 2010. Managing supply uncertainties through Bayesian information update. *Automation Science and Engineering, IEEE Transactions on*, *7*(1), 24-36.

Christopher, M. 2005. *Logistics and Supply Chain Management: Creating Value-Adding Networks*, 3rd ed., FT Prentice-Hall, Harlow.

Clark, A. and Scarf, H. 1960. Optimal Policies for a Multi-Echelon Inventory Problem, *Management Science* 6, 475- 490.

Crosby, L. A., Evans, K. R., Cowles, D. 1990. Relationship quality in services selling: an interpersonal influence perspective. *The journal of marketing*, 68-81.

Croson, R. 2007. *The use of students as participants in experimental research*. Working paper.

Croson, R., Donohue, K. 2003. Impact of POS data sharing on supply chain management: An experimental study. *Production and Operations management*, *12*(1), 1-11.

Croson, R., Donohue, K. 2006. Behavioral causes of the bullwhip effect and the observed value of inventory information. *Management Science*, *52*(3), 323-336.

Croson, R., Donohue, K., Katok, E., Sterman, L.D. 2012. Order Stability in Supply Chains: Coordination Risk and the Role of Coordination Stock. In Working Paper, Smeal College of Business, Penn State. State College, PA.

Cummings, L. L., Bromiley, P. 1996. The organizational trust inventory (OTI). *Trust in organizations: Frontiers of theory and research*, *302*, 330.

Dada, M., Petruzzi, N. C., Schwarz, L. B. 2007. A newsvendor's procurement problem when suppliers are unreliable. *Manufacturing & Service Operations Management*, *9*(1), 9-32.

Das, T. K., Teng, B. S. 1998. Between trust and control: developing confidence in partner cooperation in alliances. *Academy of Management review*, *23*(3), 491-512.

De Bodt, M. A., Graves. S. C. 1985. Continuous-Review Policies for a Multi-Echelon Inventory Problem with Stochastic Demand. *Management Science*. 31. 1286-1299.

Demidenko, E. 2005. *Mixed models: theory and applications* (Vol. 518). John Wiley & Sons.

Dietz, G., Den Hartog, D. N. 2006. Measuring trust inside organisations. *Personnel Review*, *35*(5), 557-588.

Diggle, P. 2002. *Analysis of longitudinal data* (Vol. 25). Oxford University Press, USA.

Doney, PM, Cannon, J. 1997. An examination of the nature of trust in buyer-seller relationships, *the Journal of Marketing*, 35-51.

Ebrahim-Khanjari, N., Hopp, W., Iravani, S. M. 2012. Trust and Information Sharing in Supply Chains. *Production and Operations Management*.

Federgruen, A., Zipkin, P. 1984. An efficient algorithm for computing optimal (s, S) policies. *Operations Research*, *32*(6), 1268-1285.

Fisher, M. L. 1997. What is the right supply chain for your product?. *Harvard business review*, *75*, 105-117.

Fitzsimons, G. J. 2000. Consumer response to stockouts. *Journal of Consumer Research*, *27*(2), 249-266.

Ganesan, S. 1994. Determinants of long-term orientation in buyer-seller relationships. *the Journal of Marketing*, 1-19.

Gino, F., Pisano, G. 2008. Toward a Theory of Behavioral Operations. *Manufacturing & Service Operations Management*, pp. 676- 752.

Graves, S. C. 1999. A single-item inventory model for a nonstationary demand process. *Manufacturing & Service Operations Management*, *1*(1), 50-61.

Gujarati, D. N. 2003. Multicollinearity: What Happens if the Regressors are correlated'. *Basic Econometrics*, 341.

Gulati, R. 1995. Does familiarity breed trust? The implications of repeated ties for contractual choice in alliances. *Academy of management journal*, *38*(1), 85-112.

Handfield, R. B., Bechtel, C. 2002. The role of trust and relationship structure in improving supply chain responsiveness. *Industrial Marketing Management*, *31*(4), 367-382.

Heim, G. R., Sinha, K. K. 2001. Operational drivers of customer loyalty in electronic retailing: An empirical analysis of electronic food retailers. *Manufacturing & Service Operations Management*, *3*(3), 264-271.

Johnston, D. A., McCutcheon, D. M., Stuart, F. I., Kerwood, H. 2004. Effects of supplier trust on performance of cooperative supplier relationships. *Journal of operations Management*, *22*(1), 23-38.

Kaboli, A., Cheikhrouhou, N., Glardon, R. 2013a. Inventory Replenishment Decisions in Decentralized Supply Chain Under Continuous Review System. *Working paper*. LGPP, EPFL.

Kaboli, A., Cheikhrouhou, N., Glardon, R., Tucci, C, L.2013b. Measuring Trust in Decentralized Supply Chains. *Working paper*. LGPP, EPFL.

Kahn, J. A. 1987. Inventories and the volatility of production. *The American Economic Review*, 667-679.

Kahn, J. A. 1992. Why is production more volatile than sales? Theory and evidence on the stockout-avoidance motive for inventory-holding. *The Quarterly Journal of Economics*, *107*(2), 481-510.

Katok, E. 2011. Using laboratory experiments to build better operations management models. Foundations and Trends in Technology, Information, and Operations Management, 5 (1), 1–86.

Kennedy, M. S., Ferrell, L. K., LeClair, D. T. 2001. Consumers' trust of salesperson and manufacturer: an empirical study. *Journal of Business Research*, *51*(1), 73-86.

King-Casas, B., Tomlin, D., Anen, C., Camerer, C. F., Quartz, S. R., Montague, P. R. 2005. Getting to know you: reputation and trust in a two-person economic exchange. *Science*, *308*(5718), 78-83.

Kramer, R. M., & Cook, K. S. (Eds.). 2004. *Trust and distrust in organizations: Dilemmas and approaches* (Vol. 7). Russell Sage Foundation.

Kumar, N. 1996. The power of trust in manufacturer-retailer relationships, *Harvard Business Review*, 92–106.

Lee, H. L., Padmanabhan, V., Whang, S. 1997. Information distortion in a supply chain: the bullwhip effect. *Management science*, *43*(4), 546-558.

Lieberman, M. B., Helper, S., Demeester, L. 1999. The impact of determinants of inventory levels in high-volume manufacturing. *Production and Operations Management*, *8*(1), 44-55.

Loch, C. H., Wu, Y. 2007. *Behavioral operations management* (Vol. 1, No. 3). Now Pub.

McAllister, D. J. 1995. Affect-and cognition-based trust as foundations for interpersonal cooperation in organizations. *Academy of management journal*, 24-59.

Montreuil, B., Brotherton, E., Glardon, R., Yoo, M, J., Elamiri, Y,. Borter, A., Morneau, A., Naciri, S. Jermann, P. 2008. Experiences in Using XBeer Game Virtual Gaming for Learning Supply Chain Management, 2nd European Conference on Games Based Learning, Spain, 16-17 October.

Oliva, R., Gonçalves, P. 2007. Behavioral Causes of the Bullwhip Effect: Satisficing Policies with Limited Information Cues. *Under revision for resubmission to Journal of Operations Management*.

Özer, Ö., Zheng, Y., Chen, K. Y. 2011. Trust in forecast information sharing. *Management Science*, *57*(6), 1111-1137.

Panayides, P. M., Venus Lun, Y. H. 2009. The impact of trust on innovativeness and supply chain performance. *International Journal of Production Economics*, *122*(1), 35-46.

Plank, R. E., Reid, D. A., Pullins, E. B. 1999. Perceived trust in business-to-business sales: A new measure. *The Journal of Personal Selling and Sales Management*, 61-71.

Poppo, L., Zhou, K. Z., Ryu, S. 2008. Alternative origins to interorganizational trust: An interdependence perspective on the shadow of the past and the shadow of the future. *Organization Science*, *19*(1), 39-55.

Rokeach, M. 1960. *The open and closed mind*. New York: Basic.

Rong, Y., Shen, Z. J. M., Snyder, L. V. 2008. The impact of ordering behavior on order-quantity variability: a study of forward and reverse bullwhip effects. *Flexible services and manufacturing journal*, *20*(1-2), 95-124.

Rousseau, D. M., Sitkin, S. B., Burt, R. S., Camerer, C. 1998. Not so different after all: A cross-discipline view of trust. *Academy of management review*, *23*(3), 393-404.

Scarf, H. 1959. Bayes solutions of the statistical inventory problem. *The Annals of Mathematical Statistics*, *30*(2), 490-508.

Silver, E. A. 1976. Establishing the order quantity when the amount received is uncertain. *Infor*, *14*(1), 32-39.

Simon, H. A. 1969. The Sciences of the Artificial. The MIT Press, Cambridge.

Smith, J. B., Barclay, D. W. 1997. The effects of organizational differences and trust on the effectiveness of selling partner relationships. *Journal of Marketing*, 3-21.

Smith, M. B., Bruner, J. S., White, R. W. 1956. *Opinions and personality*. New York: John Wiley & Sons, Inc.

Sterman, J. D. 2006. Operational and behavioral causes of supply chain instability. *The Bullwhip Effect in Supply Chains: A Review of Methods, Components and Cases*.

Sterman, J.D. 1989. Modeling of Managerial Behavior: misperceptions of feedback in a dynamic decision making experiment. *Management Science*. 35, 321-339.

Tomlin, B. 2009. Impact of supply learning when suppliers are unreliable. *Manufacturing & Service Operations Management*, *11*(2), 192-209.

Towill, D. R. 1991. Supply chain dynamics. *International Journal of Computer Integrated Manufacturing*, *4*(4), 197-208.

Wecker, W. E. 1978. Predicting demand from sales data in the presence of stockouts. *Management Science*, *24*(10), 1043-1054.

Whitener, E. M., Brodt, S. E., Korsgaard, M. A., Werner, J. M. 1998. Managers as initiators of trust: An exchange relationship framework for understanding managerial trustworthy behavior. *Academy of Management Review*, *23*(3), 513-530.

Wu, D. Y., Katok, E. 2006. Learning, communication, and the bullwhip effect. *Journal of Operations Management*, *24*(6), 839-850.

Zaheer, A., Venkatraman, N. 1995. Relational Governance as an Inter-organizational Strategy: An Empirical Test of the Role Trust in Economic Exchange. *Strategic Management Journal*, *19*(5), 373–392.

Zipkin, P. 2000. *Foundations of inventory management*. McGraw-Hill, New York.

Appendix A: experiment detailed set-up information

Table A1. Detail set-up information of the experiment

	Factory	Distributor	Wholesaler	Retailer
On-hand inventory (unit)	9000	9000	9000	9000
Holding cost ($/unit/day)	0.75	0.75	0.75	0.75
Backorder cost ($/unit/day)	1.5	1.5	1.5	1.5
Ordering fixed cost ($)	15	15	15	15
Price of the beer ($)	4	6	8	10
Benefit ($)	2	2	2	2

Appendix B: trust items

Table B1. Selected items to operationalize trust

#		Item wording	Source
1	Intention	My supplier (customer) will not use opportunities that arise to take advantage at my expense	Crosby et al. 1990, Kennedy et al. 2001
2	Competence	My supplier (customer) knows how to efficiently manage his/her company	Boles et al. 1996
3	Commitment	My supplier (customer) is committed to on-time delivery (stable ordering behavior)	Crosby et al. 1990, Zaheer and Venkatramon 1995, Cumming and Bromiley 1996
4	Reputation	My supplier (customer) has reputation for on-time delivery (stable ordering behavior)	Ganesan 1994, Plank et al. 1999, Doney and Cannon 1997

Chapter 5

Conclusion

The main goal of this chapter is to review and to highlight the findings of this research. The following issues will be addressed in this chapter; thesis conclusion, contribution, research limitations, and recommendation for future research.

Conclusion

This study examines the impact of inventory managers' trust on their inventory replenishment decision under continuous review in a decentralized supply chain. To cover this research goal, we conduct our study in an experimental environment. The main reasons for using a laboratory experiment are that it is a stable and controlled environment and that it provides repeatable and reliable observations. Specifically, it allows us to control the demand function, level of communication, information availability, and operational settings. Thus, we design an experimental setting where there are unknown market demands, no possibility for communication, and local information availability. We also set equal backorder and holding costs for each echelon to avoid possible noise, such as echelon's power asymmetry, on examining trust. Moreover, to avoid framing effect (Tversky and Kahneman, 1981), we link the subjects' earing to their income and not the total costs.

The study has additional desirable feature. We study inventory replenishment decision under continuous review. This means both order quantity and order time intervals are variable for the inventory managers. Therefore, the inventory managers decide to regulate their inventory level based on quantity and/or time. Our analysis at the individual level shows that while moving upstream along the supply chain, the mean order quantity and the mean order time intervals tend to increase. Further analysis on the variability of order quantity and order time intervals along the supply chain reveals that the relative number of subjects with high variability of order quantity and order time intervals increases. On the echelon level also, we observe that the variability of order quantity increases while moving from retailer to distributor. However, our analysis shows that wholesaler plays a smoothing role in the middle of supply chain. More precisely, our study shows that wholesalers tend to implement fixed order quantity with variable time intervals policy. We consider echelon's costs as well. Results suggest that the inventory managers' replenishment decision has a significant influence on their own and the other echelons' costs.

We also consider the inventory managers' trust level. We disentangle trust in supplier and trust in customer and measure them through questionnaires within the laboratory experiment context. Trust items are pooled, selected, and accordingly worded from previous research to build the trust construct regarding to the research design and context. We conduct pilot studies to purify our questionnaires. The choice of trust scale length is guided by two main considerations. The response biases and the subject fatigue over the experiment. Reverse-scored items are not used. The subjects are asked to evaluate the questionnaires based on a seven point Likert scale. To observe the evolution of trust in supplier and trust in customer on the inventory managers, data are collected over time. We implement Kaiser-Meyer-Olkin (KMO) to check the sample adequacy and Barttlett test of sphericity to test the suitability of factor analysis. The factor analysis and an additional test, the scree test, suggest only one factor for each of trust in supplier and trust in customer. Moreover, the result of corrected item-total correlation and Cronbach's alpha analysis assure the validity and reliability of the trust measurement. Our analysis shows that contrary to the normative studies that assume subjects are rational, self-interested, and do not trust if there is no way to communicate (Camerer, 2011), the inventory managers do trust in their supplier and customer in a decentralized supply chain. Also, further analysis of the results reveal that they have a tendency to trust in a range of no trust to high trust and not in a binary state of no-trust and high-trust. Furthermore, we observe that trust in customer decreases while moving upstream along the supply chain and trust in supplier is equal for retailer and distributor, while wholesaler has the least trust in supplier. We further assess the robustness of the findings with and without midpoint in Likert scale. Results for the both ways report the same findings.

These observations suggest further investigations to find the relationship between trust in customer, trust in supplier, and inventory replenishment decision. Our analysis at the echelon level shows that distributor has the lowest trust in customer, the highest order quantity, and the longest order time intervals. Moreover, we observe trust in customer is linked to higher order quantity and longer order time intervals at the individual level. The echelon level analysis for the effect of trust in supplier reveals that lower trust in supplier causes higher order quantities for retailer. We also find that inventory managers hold higher inventory level when they have lower trust in customer and trust in their upstream supplier. Lower level of trust in customer lead inventory managers to hold higher inventory levels. These findings propose that trust in customer and trust in supplier under demand and supply uncertainties lead inventory managers to hold higher inventory levels.

It is important to highlight that the problem of trust in a decentralized supply chain is not only a matter of considerable theoretical interest; it is also one of the most practically attractive subjects. Sequential transactions that take place among unknown sellers and buyers on online auction platforms such as eBay (Ho and Weigelt, 2005), Amazon used books platform (Bolton et al., 2004; Resnick and Zeckhauser, 2002), peer-to-peer content distribution platforms such as BitTorrent and Flicker (Backes et al., 2010), and online virtual world platforms such as second life (Zhu and Mutka, 2005) are some of the real case examples.

This study focuses on the data analysis of the individual and echelon levels. This focus restricts the possible conclusions concerning the team trust level, supply chain ordering behavior, and its global performance. Therefore, one possible extension would be team level analysis.

The use of student subjects can be other limitation of this study. Although significant difference between student and professional subjects in supply chain has not been reported (Croson and Donohou, 2006; Holweg and Bicheno, 2002), the authors have experienced situations in which professional do tend to behave differently than students. Moreover, Croson (2007) reports some evidences from behavioral economics that professionals perform some subset of decision task better than students. Thus investigating potential deviations between these two categories is still worth investigation.

Future research in this area may examine the robustness of our results in different supply chain contexts. Different experimental settings such as known demand to remove demand signal processing from structural causes of order amplification could help understanding the behavioral factors under continuous review. Also, it increases the potential to draw conclusion on the fact that lack of trust is one of the behavioral causes of the bullwhip effect.

References

Backes, M., Lorenz, S., Maffei, M., Pecina, K. 2010. Anonymous webs of trust. In *Privacy Enhancing Technologies* (pp. 130-148). Springer Berlin Heidelberg.

Bolton, G. E., Katok, E., Ockenfels, A. 2004. Trust among internet traders: a behavioral economics approach. *Analyse und Kritik*, *26*(1), 185-202.

Croson, R. 2007. *The use of students as participants in experimental research*. Working paper.

Croson, R., Donohue, K. 2006. Behavioral causes of the bullwhip effect and the observed value of inventory information. Management Science, 52, 323–336.

Ho, T. H., Weigelt, K. 2005. Trust building among strangers. *Management Science*, *51*(4), 519-530.

Holweg, M., Bicheno, J. 2002. Supply chain simulation–a tool for education, enhancement and endeavor. International journal of production economics, 78(2), 163-175.

Resnick, P., Zeckhauser, R. 2002. Trust among strangers in Internet transactions: Empirical analysis of eBay's reputation system. *Advances in applied microeconomics*, *11*, 127-157.

Tversky, A., Kahneman, D., Choice, R. 1981. The framing of decisions. *Science*, *211*, 453-458.

Zhu, D., Mutka, M. 2005. Promoting cooperation among strangers to access internet services from an ad hoc network. *Pervasive and Mobile Computing*, *1*(2), 213-236.

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2009 -2013	EPFL *P.hD. in Manufacturing Systems & Robotics*	Lausanne, Switzerland
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Honors, scholarships, and awards

2009-2013	EPFL doctoral scholarship, Switzerland
2009-2011	Swiss National Science Foundation scholarship, EPFL, Switzerland
Apr-08	Graduated with high distinction (M.Sc.), IUST, Iran
Jun-Sep 2008	Selected for Arts et Métiers Paris Tech scholarship, Metz, France
2006-2008	Top rank student researcher for three consecutive academic years, IUST, Iran
Sep-05	Merit-based admission to M.Sc. program *without national entrance exam* among 5000 participants
Jun-05	Graduated with distinction (B.Sc.), IUST, Iran
1999	Won national award in fine art and calligraphy contest, Iran

Journal papers

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Kaboli, A. Cheikhrouhou, N. Glardon, R., Tucci, C. L , (2013). "Measuring Trust in Decentralized Supply Chain", *Working paper, LGPP, EPFL.*

Kaboli, A. Cheikhrouhou, N. Glardon, R. Gholam-Rezaee, M. (2013). "The Impact of Trust on Inventory Replenishment Decision and Inventory Behavior", *Submitted to journal of Operations Management.*

Tabari, M., **Kaboli, A.**, Aryanezhad, M. B., Shahanaghi, K., & Siadat, A. (2008). A new method for location selection: a hybrid analysis. *Applied Mathematics and Computation*, *206*(2), 598-606.

Kaboli, A., Aryanezhad, M. B., Shahanaghi, K., & Tavakkoli-Moghaddam, R. (2007). A holistic approach based on MCDM for solving location problems. International Journal of Engineering; Transactions A, Basics, , *20*(3), 251.

Conference papers (Selected)

Kaboli, A. Cheikhrouhou, N. Glardon, R., "The Relationship between Trust and Inventory Replenishment in Supplier-Customer Dyad: An Experimental study". , *4th International Conference on Information Systems, Logistics and Supply Chain, August 26-29, 2012, Quebec, Canada.*

Kaboli, A. Cheikhrouhou, N. Glardon, R., Darvish, M. , "An Experimental Study of the Relationships between Trust and Inventory Replenishment in Triadic Supply Chain.", *The 4th Production and Operations Management World Conference, July 1-5, 2012, Amsterdam, the Netherlands.*

Kaboli, A. Cheikhrouhou, N. Glardon, R., "Measuring Trust in Supply Chain", *7the annual conference on Behavioral Research in Operations Management, June 9-11, 2012, Washington, USA.*

Tavakkoli-Moghaddam, R, Siadat, A, **Kaboli**, **A.** "A Decision Framework for Location-Allocation Problems: A Case Study in Tea Industry". *Proceedings of the 4th IEEE International Conference on Management of Innovation and Technology, Bangkok, Thailand, Sep 2008.*

Kaboli, A, Aryanezhad, M, B, Shahanaghi, K, Niroomand, I. "A Mathematical Method for Location Problem: A Fuzzy-AHP Approach", *Proceedings of the IEEE International Conference Systems, Man, and Cybernetics, Canada, October, 2007*

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Experiences

2009-Sep 13 **PhD candidate, LGPP, EPFL** **Lausanne, Switzerland**

- Formulated methodology, designed experiments, and gathered data to analyze demand-supply mismatches on continuous review and to enhance decentralized supply chain responsiveness.
- Developed a trust measurement mechanism for supplier-customer relationships.
- Conducted projects on *supply chain management* to investigate the role of trust and power on inventory planners' ordering behavior and demand variability *resulting in more than five scientific publications and three speeches* in the international conferences on production and operations management in USA, Canada, and Netherlands.
- Taught, trained, and coached "Industrial Production Systems" and "Supply Chain Management" courses on *International Institute for Management of Logistics* (*IML*) to over 70 executive managers.
- Designed case studies and coached projects on *Value adding* network, *Forecasting, Production planning (MRP & MPS), Inventory Management, and Lean Manufacturing (Kanban)* for Master's degree students.
- Led, managed, and supervised 15 projects on supply chain management, production management, and inventory management.
- Wrote a proposal for Swiss National Science Foundation (SNSF) fellowship and *awarded 100,000 CHF* form 2009 to 2011 (with Naoufel Cheikhrouhou and Rémy Glardon).

Oct 08–Sep 09 **Risk and decision analyst, COMPUCO Switzerland international** **Tehran, Iran**

- Evaluated risk measures, model assumptions, information collection, and reporting processes of loan management.
- Analyzed credit scoring items for the local market *results into 20% accuracy in client scoring*.
- Managed and supported consulting projects on credit scoring and loan management.
- Developed a decision model to manage risk of banks and financial institutions based on Basel II.

Jun 08-Sep 08 **Research fellow, Arts et Métiers Paris Tech** **Metz, France**

- Created analytical model to allocate product demand using decision maker's priority metrics *resulting in 17% increase in optimal allocation rate and 28% cost reduction*.

2007 - 2008 **Team leader, Innovation and Entrepreneurship Center, IUST** **Tehran, Iran**

- Led a *team of 30 members with 100,000 CHF budget* to evaluate new business segment entry.
- Consulted clients in developing business plan resulting in 30% early stage cost savings.
- Managed and supported teams for interview with entrepreneurs and organizing innovation workshops
- Analyzed internet companies' trends for *National Radio resulting in 25% increase in audience satisfaction rate*.

2003 -2005 **Business analyst, Industrial Management Institute (IMI)** **Sari, Iran**

- Developed strategic recommendations for urban development and sport organizations, addressing gaps between business strategy, cost allocation model, and internal customer needs.
- Analyzed virtual teams and their needs and presented strategic and implementation recommendations to senior management.

Professional services

Ad hoc reviewer for: *European Journal of Operational Research (EJOR) and International Journal of Production Research (IJPR).*

Ad hoc referee and reviewer for numerous conferences.

Organizing committee member, The 5th International Conference on Industrial Engineering, 11-13 July, 2007, Tehran, Iran.

Language

Persian (Native), English (Fluent), French (Intermediate), Arabic (Intermediate), Russian (Beginner).