Demand disruption and coordination of a service supply chain

Tianyi Wei, Jin Qin (qjin@ustc.edu.cn)
School of Management, University of Science and Technology of China, Hefei, Anhui, China

Abstract

In this paper, we study demand disruption in service supply chain with a client and a vendor. We find the positive demand disruption worse off the double marginalization under wholesale contracts. To address the challenge, we propose a two-part tariff contract under which, the client pays the vendor a fixed fee besides the wholesale price if the service rate was met. The results show the channel coordination can be achieved under dynamic service rate agreements and it is possible to apply a disruption only (the vendor will only increase the staffing level after the disruption) contract with commitments.

Keywords: service supply chain; demand disruption; two-part tariffs

Introduction

An increasing number of companies are providing specialized service such as call centers and logistic supports. Ren and Zhou (2008) refer the call center outsourcing system as a service supply chain. In a typical outsourcing system, the company (the client) hires the service specialist (the vendor) to staff sufficiently to serve the client's customers (Hasija et al. 2008). The reason not all companies benefit from outsourcing the service operations may be attributed to the inefficiency of the service supply chain. Motivated by the traditional supply chain management, this paper examines the financial performance of each party and the system (the channel) as the result of the capacity investment decisions of the vendor. See Hasija et al. (2008) for comparisons between the service supply chain and the traditional supply chain.

In this paper, we model the vendor as a newsvendor. The vendor decides the capacity investment (the staffing level) to maximize its respective profits given a contract. Commonly, the client designs the contract and the vendor can accept or reject the offer. A wholesale contract is widely observed in practice. Under a wholesale contract, the client pays the vendor a wholesale price for each served customer. A called wholesale contract in this paper is on service outputs rather than inputs like an hourly wage. The vendor's output associates with its input (the staffing level), the customer arrival rate, and the customer abandonment. Bearing a resemblance to the Markovian queuing system with exponential abandonment in Hasija et al. (2008), we assume the customer abandonment decreases in the staffing level to simplify the analysis.

It is well known that under a wholesale contract, the risk of uncertain demand is imposed upon the party interacting directly with the customer. In our environment, the vendor as a newsvendor should prefer a particular (suboptimal) staffing level which is lower than the channel optimal (profit-maximizing) staffing level. In general, coordinating the service supply chain is to make the vendor staff the channel optimal level. We show the wholesale contract fails to yield the channel optimal staffing level. With high customer abandonment, the client suffers. Additionally, we show the situation becomes even worse after the demand increases (captures a positive disruption). Demand burst (positive demand disruption) risk has received increasing attention in the last few years (Kleindorfer and Saad 2005). Natural hazards and festivals present good samples. During planning horizon in service supply chain management, a disruption may induce considerable inefficiency.

Hasija et al. (2008) show the channel coordination can be achieved with a wholesale contract adding penalty for not meeting the service-level agreement and the client can maximize its profits. But in the perspective of the vendor, the profit isn't always greater than its reservation value, the profit earned under the original contract. Is it possible both of the parties better off along with the channel coordination?

To address the service supply chain challenge, we propose a two-part tariff contract. Tirole (1990) points out in a deterministic environment, the two-part tariff does as well as more complex contracts. A two-part tariff is a price schedule with a fixed fee and a marginal wholesale price. In traditional supply chain with a manufacturer and a retailer, the manufacturer "sells the firm" to the retailer at the fixed fee and offers a relatively low wholesale price (Anand et al. 2008). It's obvious a two-part tariff with the marginal wholesale price equal to manufacturer's producing cost can coordinate the supply chain and any reasonable fixed fee induces a division of the channel profits. As for a service supply chain in practice, a two-part tariff contract is close to the service-level agreement shown by Hasija et al. (2008). In our environment with a two-part tariff, the client pays a bonus (fixed fee) if the vendor meets the service-level agreement. Once the vendor level up his capacity to meet the agreement, it is possible to better off both the parties.

This paper makes two mainly contributions. First of all, we examine the inefficiency of the service supply chain under wholesale contracts with and without demand disruptions. Second, we promote a two-part tariff contract to improve the channel performance. We show the two-part tariff contract can coordinate the service supply chain and discuss the channel performance with positive demand disruptions under a commitment two-part contract.

The rest of the paper is organized as follows. In the next section, we review three directions in the literature concerning our study. After that, we analyze wholesale contracts without demand disruptions. Then, we discuss the impact of a positive demand disruption on the capacity decision. To deal with the problems, we propose a two-part tariff contract to improve the channel performance and focus on a commitment agreement with positive demand disruptions. Conclusions and possible future research are drawn in the last section.

Relevant Literature

There are three mainly directions in the literature closely concerning our study including service supply chain management, managing demand disruptions and supply chain contracts.

First, there have been not much academic researches on service supply chain management. Ren and Zhou (2008) study the call center outsourcing in the perspective of service supply chain coordination. They analyze wholesale and pay-per-call-resolved contracts and suggest two nonlinear contracts to coordinate the staffing level and the service quality. Hasija et al. (2008) also model a call center outsourcing system as a service supply chain to examine contracts including pay-per-time, pay-per-call, service level agreement, and constraints on service rates and abandonment. Aksin et al. (2008) study the optimal capacity investment and pricing decisions under a volume-based and a capacity-based contract. They show operating environments and cost-revenue structures have impacts on the contract performance. More recently, Bhattacharya et al. (2013) model a similar problem as a sequential game with double-sided moral hazard in a client principal framework. They analyze a linear gain-share contract and cost-plus contract when efforts are observable and unobservable. Our work is closely related to the work of Hasija et al. (2008). Applying a two-part tariff contract, we extend the model to any capacity-flexible service supply chain, not only call center area.

Second, this paper derives motivations from demand disruption introduced by Qi et al. (2004). They show a demand disruption may impose considerable deviation costs throughout the supply chain. While Qi et al. (2004) model a one-supplier-one-retailer supply chain, Xiao et al. (2005), Xiao et al. (2007), and Zhang et al. (2012) study the supply chain with one supplier and two competing retailer and investigate contracts under demand disruptions. Chen and Xiao (2009) extend that to a supply chain consisting of one supplier, one dominant retailer and multiple fringe retailers to examine how to coordinate the supply chain after demand disruption. Tavakoli and Mirzaee (2014) examine the coordination of a supply chain with one supplier, one distributer, and on retailer under demand disruptions applying revenue-sharing and return policy contracts. Most of the works focus on the supply chain structure and apply a price-depend demand function. We examine a one-vendor-one-client supply chain and the customer demand is stochastic variable independent of the unit revenue (the price).

Coordinating the newsvendor in manufacturing supply chains is another related research area. An variety of contracts have been identified to improve the channel performance including quantity-flexibility (Tsay 1999), sales-rebate (Taylor 2002), revenue-sharing (Cachon and Lariviere 2005), buy-back (Pasternack 2008) contracts. See Cachon (2003) for details. These are different from contracts in service supply chain. As a form of quantity discounting, two-part tariffs are studied in the perspective of economics and business (Jeuland and Shugan 2008; Weng 1995). In this paper, we study several kinds of two-part tariffs and find how to coordinate the newsvendor in the service supply chain.

Model under wholesale contracts

We consider a service supply chain with a client and a vendor. When the proposed contract is accepted, the vendor provides service for the client's customer and incurs a cost c for each unit staffing level (the input). Each served customer generates revenues R and each abandoned customer incurs costs P for the client. Under a wholesale contract, the client pays the vendor a wholesale price r for each served customer (the output). We assume customers arriving rate is λ and the customers served probability is $F(N)$ given the vendor's staffing level N. In this paper, λ is exogenous which can be observed before the capacity investment. Garnett et al. (2002) propose a diffusion approximation method to simplify the analysis of $F(N)$. Our model doesn't address the customer abandon rate and escalation behavior. In our model, the customers served probability $F(N)$ is continuously differentiable (first-order and second-order) and we note $F'(N) = f(N)$ for simplicity. $F(N)$ increases in N and $0 \le F(N) \le 1$. Additionally, the cost parameters c, R, P, r are all exogenous. Diminishing marginal return indicates the following assumption.

Assumption 1 $\forall N \in [0, \infty),\ f^{'}(N) < 0.$

Following Hasija et al. (2008), we can obtain under wholesale contracts, the profit per unit time for the client (π_c) and for the vendor (π_v)

$$\pi_c = R\lambda F(N) - P\lambda\big(1 - F(N)\big) - r\lambda F(N) \tag{1}$$

$$\pi_v = r\lambda F(N) - cN. \tag{2}$$

The profit per unit time for the service supply chain is

$$\pi_s = \mathrm{R\lambda F(N) - P\lambda\big(1 - F(N)\big) - cN}. \tag{3}$$

Under a wholesale contract with fixed cost parameters, the only decision variable is the staffing level N and the vendor's decision problem is to $\max_N \pi_v$. As mentioned, the channel coordination refers to the channel profits maximizing staffing level. We obtain the following proposition.

Proposition 1 Under a wholesale contract, the channel coordination cannot be achieved. And the vendor will staff a suboptimal level $N_v = f^{-1}\left(\frac{c}{r\lambda}\right)$ which is lower than the channel optimal level $N_s = f^{-1}(\frac{c}{R\lambda+P\lambda})$.

Proof Examine the first order condition for $\pi_v(N)$ and $\pi_s(N)$,

$$\frac{\partial \pi_v}{\partial N} = r\lambda f(N) - c = 0$$

$$\frac{\partial \pi_s}{\partial N} = R\lambda f(N) + P\lambda f(N) - c = 0$$

and the second order derivative,

$$\frac{\partial^2 \pi_v}{\partial N^2} = r\lambda f'(N) < 0$$

$$\frac{\partial^2 \pi_s}{\partial N^2} = (R\lambda + P\lambda) f'(N) < 0.$$

The vendor's optimal staffing level is $N_v = f^{-1}\left(\frac{c}{r\lambda}\right)$ and the channel's optimal staffing level is $N_s = f^{-1}(\frac{c}{R\lambda+P\lambda})$. Because the client earns a positive profits as introduced by equation (1), we have $r < R$. Additionally, $f(\cdot)$ and $f^{-1}(\cdot)$ are both decreasing function (by assumption 1). Therefore,

$$N_v = f^{-1}\left(\frac{c}{r\lambda}\right) < N_s = f^{-1}\left(\frac{c}{R\lambda + P\lambda}\right).$$

The vendor will staff a suboptimal level which is lower than the channel optimal level. □

Demand disruptions

In this section, we describe a demand disruption in the planning horizon of a service supply chain. To simplify our analysis, we focus on positive demand disruptions, i.e., demand burst. We consider a positive demand disruption where the arrival rate increases from λ_1 to λ_2 $(\lambda_1 < \lambda_2)$ with relatively customers served probability function $F_1(\cdot)$ and $F_2(\cdot)$. It's obvious $F_1(N) \geq F_2(N) \forall N$. Similarly, we note $F_1^{'}(\cdot) = f_1(\cdot)$ and $F_2^{'}(\cdot) = f_2(\cdot)$. Under wholesale contracts, define the vendor's decision $N_{v,i} = f_i^{-1}(\frac{c}{r\lambda_i})$ for $i = 1,2$. This paper focus on how the vendor acts with demand disruptions. It's complicated to check $N_{v,2}$ against $N_{v,1}$. To make the analysis more tractable, we promote $f_1^{-1}(\frac{c}{r\lambda_2})$ as a temporary variable and refer to the impact of the arrival rate increasing on the staffing decisions (from $N_{v,1}$ to $f_1^{-1}(\frac{c}{r\lambda_2})$) as the arrival effect and the impact of the changed customers served probability function on the staffing decisions (from $f_1^{-1}(\frac{c}{r\lambda_2})$ to $N_{v,2}$) as the probability effect. With demand increases, diminishing marginal return becomes moderate. Therefore, we have following assumption.

Assumption 2 $\forall N \in [0,\infty)$, $f_1'(N) \le f_2'(N)$.

Under wholesale contracts, the vendor's staffing decision varies after demand disruption. The following proposition describes the change of the staffing level with positive demand disruption.

Proposition 2 With positive demand disruptions, the probability effect doesn't always increase the staffing level, i.e., $N_{v,2}$ isn't always bigger than $f_1^{-1}(\frac{c}{r\lambda_2})$.

Proof

Step 1 Let $G(N) = F_1(N) - F_2(N)$. We have $g(N) = f_1(N) - f_2(N)$ and $g'(N) = f_1'(N) - f_2'(N) \le 0$ (by assumption 2). Additionally, $G(0) = \lim_{N\to\infty} G(N) = 0$. Therefore, there exists a unique $N_0 \in (0,\infty)$, $g(N_0) = 0$. $\forall N \le N_0$, $f_1(N) \ge f_2(N)$, and $\forall N > N_0$, $f_1(N) < f_2(N)$. Meanwhile, there exists a unique $M_0 \in (0,\infty)$, $\forall M \le M_0$, $f_1^{-1}(M) \le f_2^{-1}(M)$, and $\forall M > M_0$, $f_1^{-1}(M) > f_2^{-1}(M)$.

Step 2 $N_{v,1} = f_1^{-1}\left(\frac{c}{r\lambda_1}\right) < f_1^{-1}\left(\frac{c}{r\lambda_2}\right) \le f_2^{-1}\left(\frac{c}{r\lambda_2}\right) = N_{v,2}$ when $\frac{c}{r\lambda_2} \le M_0$. Meanwhile, when $\frac{c}{r\lambda_2} > M_0$, $N_{v,1} = f_1^{-1}\left(\frac{c}{r\lambda_1}\right) < f_1^{-1}\left(\frac{c}{r\lambda_2}\right)$ and $N_{v,2} = f_2^{-1}\left(\frac{c}{r\lambda_2}\right) < f_1^{-1}\left(\frac{c}{r\lambda_2}\right)$. □

From the proof of proposition 2, it's interesting that the exogenous wholesale price r has an impact on the probability effect. A relatively small wholesale price r more likely results in $N_{v,2} < N_{v,1}$. Next define the channel optimal staffing level $N_{s,i} = f_i^{-1}(\frac{c}{R\lambda_i + P\lambda_i})$ for $i = 1,2$. The following proposition shows the channel optimal staffing level shares a similar property as the vendor's optimal staffing level with positive demand disruption.

Proposition 3 With positive demand disruptions, $N_{s,2}$ can be smaller than $N_{s,1}$ when wholesale price $R + P$ is relatively small.

Proof See proof of proposition 2. □

With proposition 2 and proposition 3, we obtain the following corollary.

Corollary 1 With positive demand disruptions,

(i) The vendor will decrease the staffing level if the channel optimal staffing level decreases.

(ii) The vendor may decrease the staffing level even though the channel optimal staffing level increases

Proof It's straightforward by $R + P > r$. □

The immediate implication of corollary 1 is surprising for a possible staffing level decreasing with a positive demand disruption. We consider a consideration that may induce the negative probability effect big enough. For the service supply chain, any increased staffing level may have little help to increase the customers served probability. A marginal staffing cost incurs while the possible revenue is generated. It's even worse for the vendor in the service supply chain who generates a less unit revenue on output.

Two-Part Tariffs

A two-part tariff is characterized as a price schedule $(T,\ r)$. In our environment, r is exogenous. In other words, based on wholesale contracts with fixed wholesale price, we consider a conditional bonus T for the vendor. If the agreement $F(N) \geq \alpha$ is met, the perspective profits become

$$\pi_c = R\lambda F(N) - P\lambda\big(1 - F(N)\big) - r\lambda F(N) - T \tag{4}$$

$$\pi_v = r\lambda F(N) - cN + T \tag{5}$$

We assume the client always offers a two-part tariff contract. If the vendor's profit is bigger than that under the original wholesale contract, the agreement will be met. Otherwise, the two-part tariff reverts to the original wholesale contract. The following proposition describes the coordinated two-part contracts.

Proposition 4 The service supply chain can be coordinated under two-part tariff contracts with $\alpha = F(N_s)$ and any $T > r\lambda[F(N_v) - F(N_s)] - c(N_v - N_s)$.

Proof Because $N_s > N_v$, the vendor will never apply a staffing level bigger than the agreement. If the agreement of the proposed contract is met, the vendor's staffing level equals to N_s, and the vendor's expected profits become $\pi_v = r\lambda F(N_s) - cN_s + T > r\lambda F(N_v) - cN_v$. Therefore, the vendor will increase the staffing level to meet the agreement. □

With positive demand disruptions (the arrival rate increases from λ_1 to λ_2 $(\lambda_1 < \lambda_2)$ with correlative $F_1(\cdot)$, $f_1(\cdot)$, $F_2(\cdot)$, $f_1(\cdot)$), the agreements of our contracts include dynamic agreements and commitment agreements. The dynamic agreement indicates the client can adjust the service level agreement just before the demand disruption. This case is similar to one period case and applies Proposition 4. We next discuss one of the commitment agreements with fixed $\alpha = F_1\big(N_{s,1}\big)$ and study how the vendor acts with positive demand disruption.

Now define

$$T_1 = r\lambda_1 F_1\big(N_{v,1}\big) - cN_{v,1} - r\lambda_1 F_1\big(N_{s,1}\big) + cN_{s,1} \tag{6}$$

$$T_2 = r\lambda_2 F_2\big(N_{v,2}\big) - cN_{v,2} - r\lambda_2 F_2(N_\alpha) + cN_\alpha \tag{7}$$

where $N_\alpha = F_2^{-1}(\alpha)$. We have $F_2(N_\alpha) = F_1(N_{s,1})$ and $N_\alpha > N_{s,1} > N_{v,1}$.

By proposition 4, any bonus which is bigger than T_1 will coordinate the service supply chain before the disruption. As mentioned above, we have not been able to check $N_{v,2}$ against $N_{v,1}$. The following proposition describes the vendor's decision after the disruption.

Proposition 5 If $N_{v,2} > N_\alpha$, the agreement will be met after the disruption and the vendor doesn't concern with the bonus. Else the agreement will be met with any $T > T_2$.

Proof See proof of proposition 4. □

Corollary 2 Suppose $T_1 > T_2$ and $N_\alpha > N_{v,2}$, any $T \in (T_2, T_1]$ makes the vendor increase the staffing level to get the bonus only after the disruption.

Proof It's straightforward by proposition 5. □

The immediate implication of corollary 2 describes a disruption-only two-part tariff contract. The vendor will increase the staffing level to win the bonus only with the demand disruption. It's instructive to operate the profits under demand burst with the commitment two-part tariff contract.

Discussion

This paper examines positive demand disruptions in a service supply chain with a client and a vendor. We show the inefficiency of the service supply chain under wholesale contracts with and without disruption. Different marginal revenue makes the double marginalization worse after the disruption. To deal with the challenge, we propose a two-part tariff contract to improve the channel performance. We focus on the fixed fee and the service agreement of the contract and discuss two different kinds of two-part tariff contracts. The dynamic two-part tariff contract coordinates the service supply chain and shares the same property with the one-period contract, i.e., without disruptions. The commitment two-part tariff contract is not able to coordinate the capacity but help deal with special capacity plan.

Our results provide guidance to clients. To motivate the vendor level up the staffing level, the client share part of the profits with conditional bonus. It's not complicate to apply channel profits-maximizing contract parameters without demand disruptions. In practice, disruption-only two-part tariff contracts provide flexibility for the service supply chain. With the typical nonlinear contract, the client is able to cope with the demand burst easily.

Further research is needed to formulate more tractable demand disruptions. It will be helpful to figure out when and how the staffing level decreases after disruption. Another interesting direction for future research is the impact of the wholesale price, i.e., a more complicated two-part tariff.

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