ESSEC

BAR-ILAN UNIVERSITY

Department of Operations Management

Topics in Supply Chain Management

Session 3

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OPTIMAL PRODUCT AVAILABILITY

AGENDA

- THE IMPORTANCE OF THE LEVEL OF PRODUCT AVAILABILITY
- FACTORS AFFECTING OPTIMAL LEVEL OF PRODUCT AVAILABILITY
- SEASONAL ITEMS WITH A SINGLE ORDER IN THE SEASON
- CONTINUOUSLY STOCKED ITEMS
- MANAGERIAL LEVERS TO IMPROVE SUPPLY CHAIN PROFITABILITY
- SUPPLY CHAIN CONTRACT AND THEIR IMPACT ON PROFITABILITY

THE IMPORTANCE OF THE LEVEL OF PRODUCT AVAILABILITY

The level of product availability is measured using the cycle service level of the fill rate, which correspond to the amount of customer demand satisfied from available inventory.

The level of product availability is a essential component of a supply chain's performance, because a high level of product availability improves the supply chain's responsiveness and attract customers, which thus increases the supply chain's revenue.

However, a high level of product availability requires large inventories, which tend to raise costs for the supply chain.

Therefore, a balance between the level of availability and the cost of inventory should be determined, in order to maximize the supply chain's profitability.

Every supply chain manager should be aware of the factors that influence the optimal level of product availability.

FACTORS AFFECTING OPTIMAL LEVEL OF PRODUCT AVAILABILITY

Consider the case of Tiger, a large mail order company selling apparel, among which ski jackets.

The selling season for ski jackets is from November to February.

Before the start of the selling season, the buyer at Tiger purchases the entire season's supply of ski jackets from the manufacturer.

⇒ The larger the number of jackets purchased, the higher the level of product availability.

⇒ Though a high level of product availability is likely to satisfy all demand that arises, it is also likely to result in large number of unsold jackets with Tiger loosing money with unsold jackets.

⇒ Conversely, a low level of product availability is likely to result in few unsold jackets, but it is also quite likely that potential customers will be turned away because of sold out jackets, with Tiger loosing potential profits.

When deciding the level of product availability, the manager at Tiger has to balance the loss from having too many unsold jackets (in case the number of jackets ordered is larger than demand) and the lost profit from turning away customers (in case the number of jackets ordered is less than demand).

FACTORS AFFECTING OPTIMAL LEVEL OF PRODUCT AVAILABILITY (Continued)

The cost of overstocking (C_o) is defined as the loss incurred by a firm for each unsold unit at the end of the selling season.

The cost of understocking (C_u) is defined as the margin lost by a firm for each lost sale because of stockout. This cost should include the margin lost from current as well as future sales if the customer does not return.

The relationship between the cost of overstocking and the cost of understocking determine the optimal level of product availability.

⇒ Deciding on the optimal level of product availability only makes sense in the context of demand uncertainty.

⇒ Traditionally, many firms have forecast a consensus estimate of demand without any measure of uncertainty. In this setting, firms do not make a decision regarding the level of product availability; they simply order the consensus forecast.

⇒ Over the last decade, firms have developed a better appreciation for uncertainty and have started developing forecasts that include a measure of uncertainty.

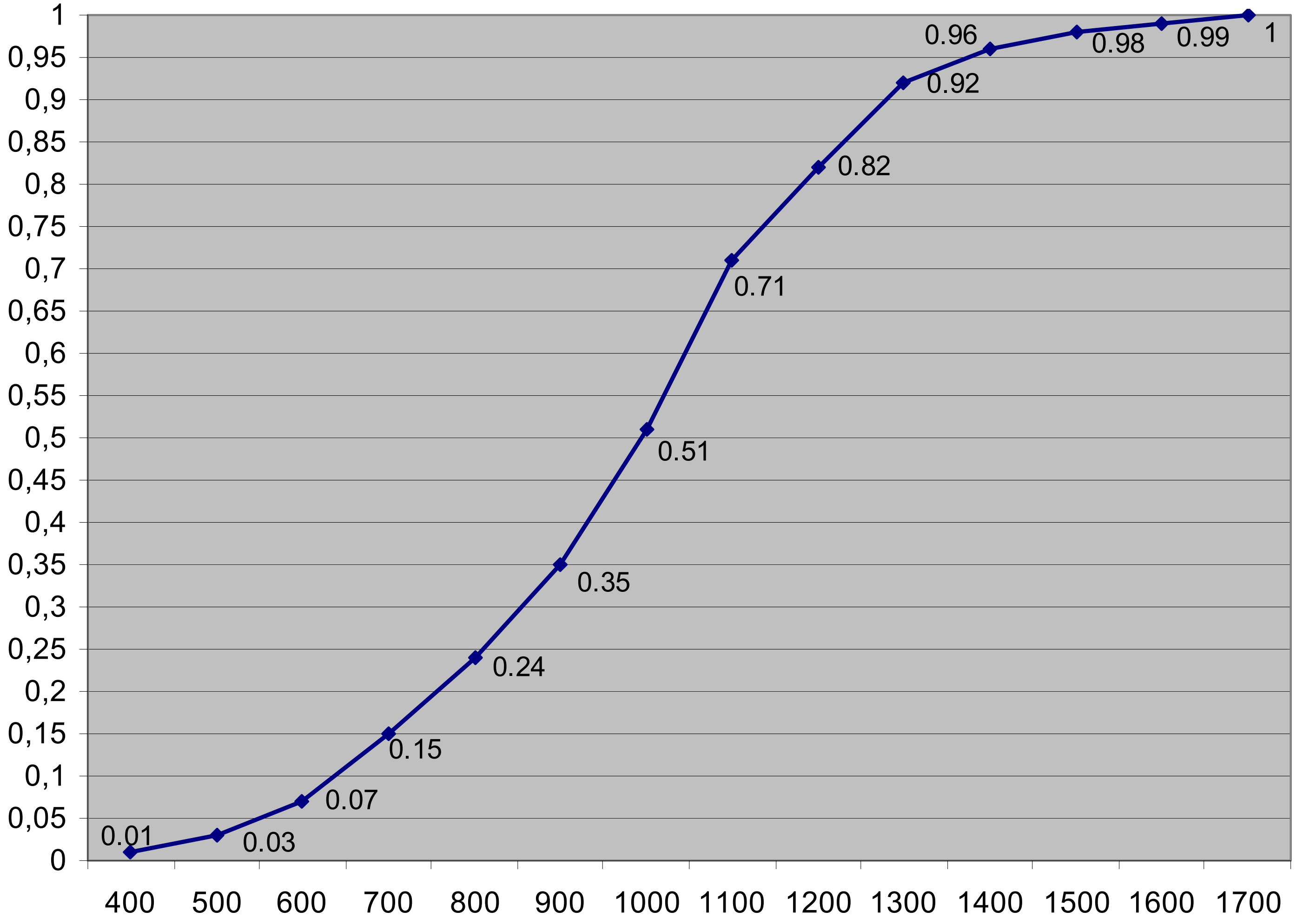
Overall, incorporating uncertainty and deciding on the optimal level of product availability can increase profits relative to using a consensus forecast.

DISTRIBUTION OF PROBABILITY OF SALES

Based on demand over the past few years, the buying committee that decides on the quantity of each product to be ordered at Tiger have estimated the demand distribution for a red women's parka to be as shown below.

Demand (D_i) in hundreds	Probability (p_i)	Cumulative probability of demand being D_i or less (P_i)	Cumulative probability of demand being greater than D_i ($1 - P_i$)
4	0.01	0.01	0.99
5	0.02	0.03	0.97
6	0.04	0.07	0.93
7	0.08	0.15	0.85
8	0.09	0.24	0.76
9	0.11	0.35	0.65
10	0.16	0.51	0.49
11	0.20	0.71	0.29
12	0.11	0.82	0.18
13	0.10	0.92	0.08
14	0.04	0.96	0.04
15	0.02	0.98	0.02
16	0.01	0.99	0.01
17	0.01	1.00	0.00

DISTRIBUTION OF PROBABILITY OF SALES



UNIT PROFIT AND UNIT LOSS

From the previous table, we can evaluate the expected demand of parkas as follows:

$$\text{Expected demand} = \Sigma D_i p_i = 1\ 026 \text{ units}$$

Following the traditional policy of ordering the expected value, the buyers would have ordered the average historical demand as the consensus forecast, that is, 1 000 parkas. However, demand is uncertain, and the previous table shows that a policy of ordering 1 000 parkas will result in a cycle service level of 51%.

⇒ The company should then decide on an order size and cycle service level that maximizes the profits from the sale of parkas.

- Each parka costs Tiger c = \$45, and is priced in the catalog p = \$100.
- Any unsold parka at the end of the season are sold at the outlet store for \$50.
- Holding the parka in inventory and transporting it to the outlet store costs Tiger \$10.

- Thus, the company recovers a salvage value of s = \$50 – \$10 = \$40 for each parka that is unsold at the end of the season.

⇒ Overall, each parka sold provides a profit of $p - c$ = \$55, while each unsold parka that is sent to the outlet store generates a loss of $c - s$ = \$5.

EXPECTED PROFIT AND MARGINAL CONTRIBUTION

The expected profit from ordering 1 000 parkas is given as follows:

$$\left\{\sum_{i=4}^{10}\left[D_i\left(p-c\right)-\left(1000-D_i\right)\left(c-s\right)\right]p_i\right\}+\left(1-P_i\right)1000\left(p-c\right)$$

= 190 + 500 + 1 240 + 2 960 + 3 870 + 5 390 + 8 800 + 26 950 = $49 900

To decide whether to order 1 100 parkas, the company needs to determine the potential outcome of buying the extra 100 units.

If 1 100 units are ordered, the extra 100 units are sold (with a profit of $5 500 if demand is 1100 or more. Otherwise, the extra 100 units are sent to the outlet store at a loss of $500.

In the previous table, it appears that the probability that demand is 1 100 or more is 0.49, and the probability is 1 000 or less 0.51.

Therefore, the marginal contribution of 100 extra units is:

$$5\,500\times \Pr\left[\text{demand}\geq 1100\right]-500\times \Pr\left[\text{demand}<1100\right]=$$
$$\$5\,500\times 0.49-\$500\times 0.51=\$2\,440$$

The total expected profit from ordering 1 100 units is then $52 340, which is larger by 5% than the total expected profit of ordering 1 000 units.

EXPECTED MARGINAL CONTRIBUTION

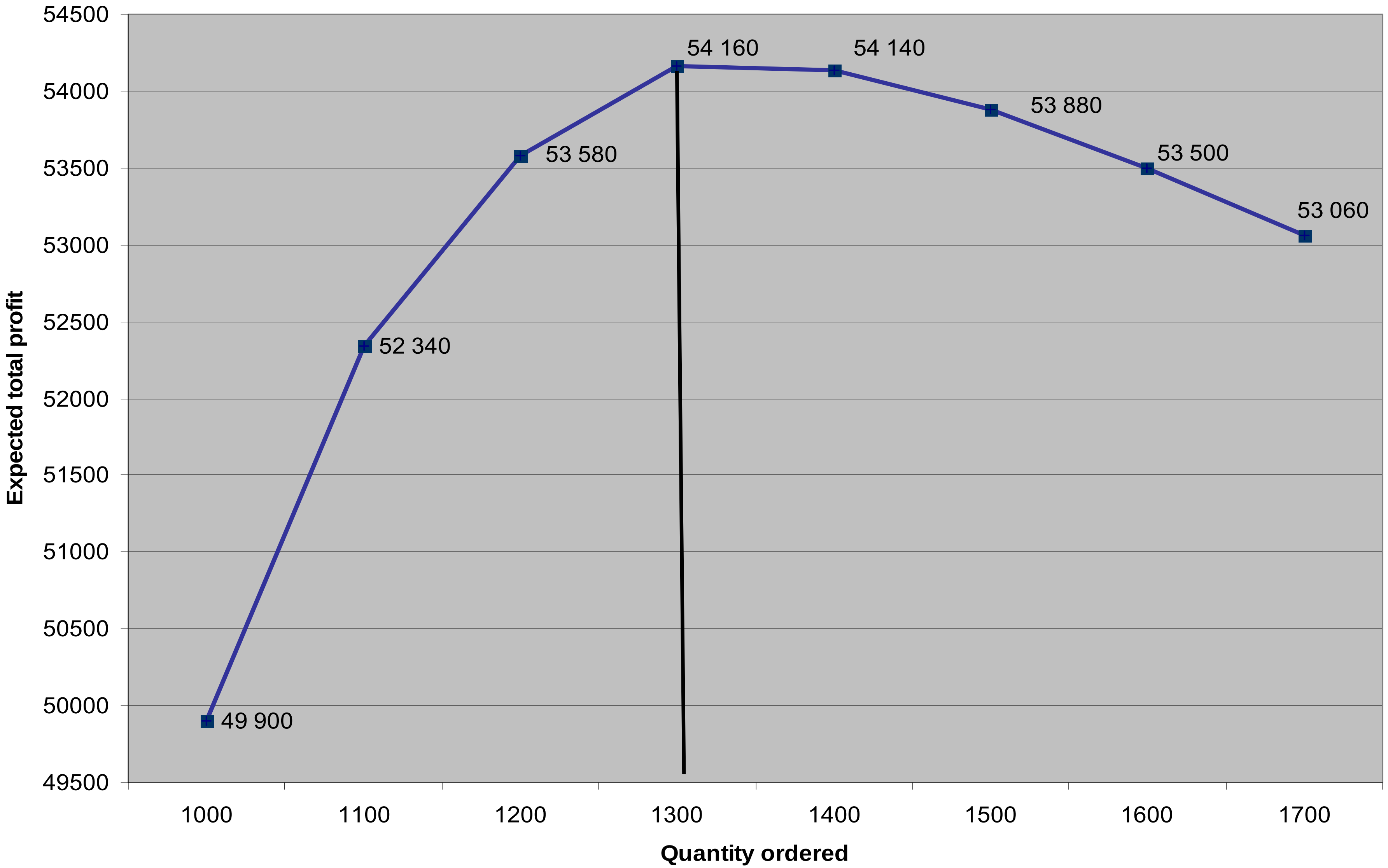
Additional hundreds	Expected marginal benefit	Expected marginal cost	Expected marginal contribution
11	5 500 x 0.49 = 2 695	500 x 0.51 = 255	2 695 – 255 = 2 440
12	5 500 x 0.29 = 1 595	500 x 0.71 = 355	1 595 – 355 = 1 240
13	5 500 x 0.18 = 990	500 x 0.82 = 410	990 – 410 = 580
14	5 500 x 0.08 = 440	500 x 0.92 = 460	440 – 460 = -20
15	5 500 x 0.04 = 220	500 x 0.96 = 480	220 – 480 = -260
16	5 500 x 0.02 = 110	500 x 0.98 = 490	110 – 490 = -380
17	5 500 x 0.01 = 55	500 x 0.99 = 495	55 – 495 = -440

The expected marginal contribution is positive up to 1 300 units, but it is negative beyond that point. Thus, the optimal order size is 1 300 units, which provides the total expected profit:

$$\$49\ 900 + \$2\ 440 + \$1\ 240 + \$580 = \$54\ 160.$$

This over an 8% increase in profitability relative to the policy of ordering the expected value of 1 000 units.

OPTIMAL ORDER



SERVICE LEVEL AND FILL LEVEL

The customer service level provided by the optimal order quantity of 1 300 units is 92%.

With a CSL of 92%, the fill rate is much higher.

- If demand is 1 300 units or less, the company achieves a fill rate of 100%.

- Conversely, if demand is larger than 1 300 units (say *D*), a fill rate of 1 300/*D* is achieved.

Overall, the fill rate achieved at Tiger if 1 300 units are ordered is given as follows:

$$fr = 1 \times \Pr\left[\text{demand} \leq 1300\right] + \sum_{D_i \geq 1400} \left(1300/D_i\right) p_i = 0.99$$

Thus, with a policy of ordering 1 300 parkas, the company satisfies on average 99% of its demand.

SEASONAL ITEMS WITH A SINGLE ORDER IN THE SEASON

Denote by *CSL** the optimal customer service level and *O** the corresponding optimal order quantity.

*CSL** is the probability that demand during the season is equal or less than *O**, for which the marginal contribution related to the purchase of one additional unit is zero.

If the optimal order quantity increases from *O** to *O** + 1, the additional unit ordered will be sold if demand is larger than *O**. This happens with the probability 1 – *CSL** and provide a unit profit *p* – *c*. As a result, we obtain:

$$\text{Expected profit of purchasing extra unit} = (1 - CSL^*)(p - c).$$

The additional unit remains unsold if demand is at or below O*. This occurs with probability *CSL** and results in a cost of *c* – *s*. We thus have the following:

$$\text{Expected cost of purchasing extra unit} = CSL^*(c - s).$$

The expected marginal contribution of raising the order size from *O** à *O** + 1 is given by:

$$(1 - CSL^*)(p - c) - CSL^*(c - s).$$

Because the expected marginal contribution must be 0 at the optimal cycle service level, we have the following:

$$CSL^* = \Pr\left[\text{demand} \leq O^*\right] = \frac{p - c}{p - s} = \frac{C_u}{C_u + C_o} = \frac{1}{1 + \left(C_o / C_u\right)}$$

SEASONAL ITEMS WITH A SINGLE ORDER IN THE SEASON (Continued)

The resulting optimal order quantity O^* maximizes the firm's profit.

If demand during the season is normally distributed with a mean of μ and a standard deviation of σ, the optimal order quantity is given by:

$$O^* = F^{-1}(CSL^*, \mu, \sigma) = NORMINV(CSL^*; \mu; \sigma)$$

The expected profit of ordering O units is given by:

$$O(p - c) - (p - s)[(O - \mu)F(O, \mu, \sigma) + \sigma f_S((O - \mu)/\sigma)]$$

where F_S is the *standard* normal cumulative distribution function and f_S is the *standard* normal density function .

The expected profit from ordering O units is evaluated in Excel as follows:

$$O(p - c) - (p - s)[(O - \mu)NORMDIST(O ; \mu ; \sigma ; 1) + \sigma NORMDIST((O - \mu)/\sigma ; 0 ; 1 ; 0)]$$

EXAMPLE: SMARTSPORT

The manager at Smartsport, a sports store, has to decide on the number of skis to purchase for the winter season.

Considering past demand data and weather forecasts for the year, management has forecast demand is normally distributed with a mean of μ = 350 and a standard deviation of σ = 100.

Each pair of skis costs c = \$100 and retails for p = \$250. Any unsold skis at the end of the season are disposed of for \$85. The inventory holding cost for the season is \$5.

<u>Analysis:</u>

s = \$85 – \$5 = \$80 ; $C_u = p - c$ = \$250 - \$100 = \$150 ; $C_o = c - s$ = \$100 - \$80 = \$20.

The optimal CSL is:

$$CSL* = \Pr\left[\text{demand} \leq R*\right] = \frac{C_u}{C_u + C_o} = \frac{150}{150+20} = 0.88$$

The optimal order quantity is:

$$O^* = F^{-1}(CSL^*, \mu, \sigma) = NORMINV(0{,}88 ; 350 ; 100) = 468$$

The expected profit from ordering O^* units is:

70 200 – 170[(468–350)*NORMDIST*(468;350;100;1)+100*NORMDIST*(1,18;0;1;0)] = \$49 146.

The expected profit from ordering 350 units is only \$45 718. Thus, an order quantity of 468 units increases the expected profit from ordering the expected value of 8%.

EXPECTED OVERSTOCKING AND EXPECTED UNDERSTOCKING

When O units are ordered, the company can be left with either too much or too little inventory, depending on demand.

When demand is normally distributed with expected value μ and standard deviation σ, the expected overstocking quantity at the end of the season is given as follows:

$$(O-\mu)F_S\left(\frac{O-\mu}{\sigma}\right)+\sigma f_S\left(\frac{O-\mu}{\sigma}\right)$$

In Excel, this formula rewrites:

$(O - \mu)NORMDIST((O - \mu)/\sigma ; 0 ; 1 ; 1) + \sigma NORMDIST((O - \mu)/\sigma ; 0 ; 1 ; 0)$

The expected understocking quantity at the end of the season is given as follows:

$$(\mu-O)\left[1-F_S\left(\frac{O-\mu}{\sigma}\right)\right]+\sigma f_S\left(\frac{O-\mu}{\sigma}\right)$$

In Excel, this formula rewrites:

$(\mu - O)[1 - NORMDIST((O - \mu)/\sigma ; 0 ; 1 ; 1)] + \sigma NORMDIST((O - \mu)/\sigma ; 0 ; 1 ; 0)$

EXAMPLE: SMARTSPORT (Continued)

Demand for skis at Smartsport is normally distributed with a mean of μ = 350 and a standard deviation of σ = 100. The manager has decided to order 450 pairs of skis for the upcoming season. Evaluate expected over- and understock as a result of this policy.

Given that the order size is O = 450, an overstock results if demand during the season is below 450, and is evaluated as follows :

$$(450 - 350)\mathit{NORMDIST}((450 - 350)/100; 0; 1; 1) + 100\mathit{NORMDIST}((450 - 350)/100; 0; 1; 0) = 108.$$

An overstock occurs if demand during the season is larger than 450 units, and is evaluated as follows:

$$(350 - 450)\mathit{NORMDIST}((450 - 350)/100; 0; 1; 1) + 100\mathit{NORMDIST}((450 - 350)/100; 0; 1; 0) = 8.$$

CONTINUOUSLY STOCKED ITEMS

Here, we consider the case of products such as detergents that are ordered repeatedly by a retail store like K-Wal.

For such products, K-Wal uses safety inventory to increase the level of availability and decrease the probability of stocking out between successive deliveries. If detergent is left over in a replenishment cycle, it can be sold in the next cycle. It does not have to be disposed of at a lower cost. However, a holding cost is incurred as the product is carried from one cycle to the next. The manager at K-Wal must then decide on the adequate customer service level.

Two extreme scenarios should be considered:

- All demand that arises when the product is out of stock is backlogged and filled later when inventories are replenished.

- All demand arising when the product is out of stock is lost.

CONTINUOUSLY STOCKED ITEMS (Continued)

Demand is supposed normally distributed.

The following notations are used:

Q: replenishment lot size,
S: fixed cost associated with each order,
ROP: reorder point,
D: average demand per time unit,
σ: standard deviation of demand per time unit,
SS: safety stock ($SS = ROP - D_L$, D_L : average demand during the lead time,
CSL: customer service level,
C: unit cost,
h: holding cost as a fraction of product cost per time unit,
H: holding cost for one unit of product per time unit ($H = hC$).

STOCKOUT AND BACKLOGGING

Here, though the product is out of stock, no demand is not lost. Because no demand is lost, minimizing costs becomes equivalent to maximizing profits. The store manager offers a discount of C_u to each customer wanting to buy detergent when it is out of stock in order to ensure that he returns when inventory is replenished.

If the store manager increases the level of safety stock, more orders are satisfied from stock, resulting in lower backlogs. However, the cost of holding inventory increases. The store manager must pick a safety stock that minimizes the backlogging and holding costs.

In this case, the optimal cycle service level is given as follows:

$$CSL^* = 1 - HQ/DC_u$$

Given the optimal customer service level, for a constant lead time, the safety stock is given as follows:

$$SS = NORMSINV(CSL^*) \times \sigma_D$$

where σ_D is the standard deviation of demand during the lead time.

Increasing the lot size Q allows the store manager to reduce the cycle service level and thus the safety inventory. This is due to the fact the fill rate is also increased which reduces the quantity backlogged.

However, an increase in lot size raises the cycle inventory. In general, increasing the lot size is not an effective way for a firm to improve product availability.

In practice, the cost of stocking out is hard to estimate. In such a situation, when a precise cost of stockout can not be found, the current inventory policy can be evaluated by identifying the implied cost of a stockout. This implied stoukout cost will at least give an idea on whether inventory should be increased, decreased or kept constant.

EXAMPLE

Weekly demand for detergent at K-Wal is normally distributed with a mean of μ = 100 units and a standard deviation of σ = 20.

The replenishment lead time is 2 weeks. The manager orders 400 units when the available inventory drops to 300 units. Each unit costs $3. The inventory holding cost is 20%. If all unfilled demand is backlogged and carried over to the next cycle, evaluate the cost of stocking out implied by the current replenishment policy.

Lot size Q = 400 units
Reorder point ROP = 300 units
Average weekly demand D = 100 units
Average demand per year D_Y = 100 x 52 = 5 200 units
Standard deviation of demand per week σ_D = 20 units
Unit cost C = $3
Holding cost as a fraction of product cost per year h = 0.2
Cost of holding one unit for one year $H = hC$ = $0.6
Lead time L = 2 weeks

EXAMPLE (Continued)

Analysis:

Mean demand over lead time, $D_L = D \times L = 200$ units

Standard deviation of demand over lead time, $\sigma_L = \sigma_D L^{1/2} = 20 \times 2^{1/2} = 28.3$ units

To evaluate the CSL under the current inventory policy, given that demand is normally distributed, we compute the probability that there is no shortage during the lead time, that is:

$$CSL = \Pr(\text{Demand during the lead time} \leq ROP) = NORMDIST(ROP;\ D_L;\ \sigma_L;\ 1)$$

which is given as:

$$CSL = NORMDIST(300;\ 200;\ 28.3;\ 1) = 0.9998$$

We can deduce that the imputed cost of stocking out is given as:

$$C_u = HQ/[(1 - CSL)D_Y] = (0.6 \times 400)/[0.0002 \times 5\,200] = \$230.8 \text{ per unit}$$

If a shortage costs $230.8 per unit of detergent, then current CSL of 99.98% is optimal. However, it is very unlikely that a shortage of detergent costs $230.8. Thus, the current inventory policy leads to carry too much inventory.

Overall, this analysis can serve to decide if the imputed cost of stocking out, and thus the inventory policy, is reasonable.

STOCKOUT AND LOST SALES

Here, unfilled demand during the stockout period is lost. Under these conditions, the optimal CSL is given as follows :

$$CSL^* = 1 - HQ/(HQ + DC_u)$$

where C_u is the cost of losing one unit of demand during the stockout period.

In general, the optimal customer service level is higher in the case of lost demand than that of backlogging.

EXAMPLE (Continued)

Consider the situation in the previous example, but assume that all demand during a stockout is lost. Assume that the cost of losing one unit of demand is $2.

Lot size Q = 400 units
Reorder point ROP = 300 units
Average weekly demand D = 100 units
Average demand per year D_Y = 100 x 52 = 5 200 units
Standard deviation of demand per week σ_D = 20 units
Unit cost C = $3
Holding cost as a fraction of product cost per year h = 0.2
Cost of holding one unit for one year $H = hC$ = $0.6
Lead time L = 2 weeks
Cost of understocking C_u = $2

Using the previous equation, the optimal CSL is given by:

$$CSL^* = 1 - HQ/(HQ + DC_u) = 1 - 0.6 \times 400/(0.6 \times 400 + 2 \times 5\,200) = 0.98.$$

The store manager should target a cycle service level of 98%.

Accordingly, the safety stock is:

$$SS = NORMSINV(0.98) \times \sigma_L = 2.053749 \times 28.3 = 58.1211 \cong 59 \text{ units.}$$

where σ_L is the standard deviation of demand during the lead time.

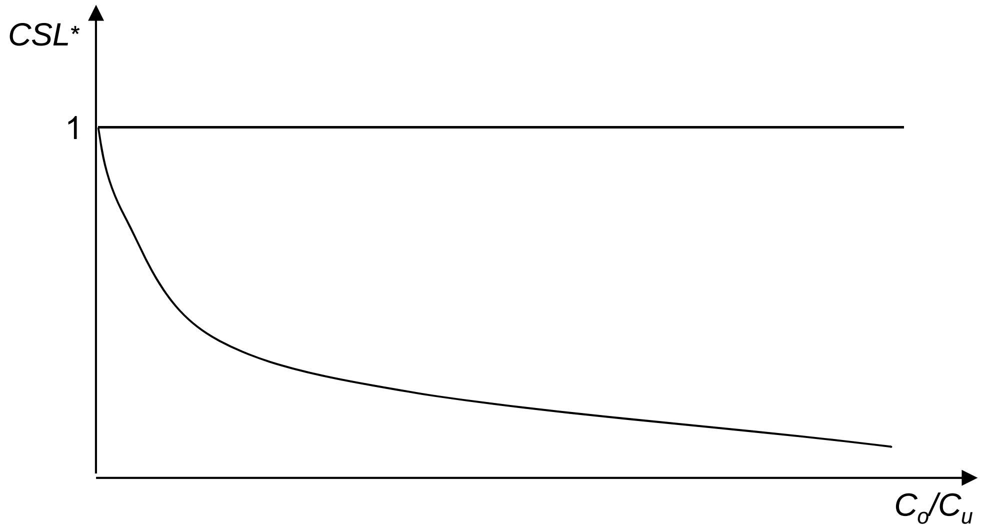
MANAGERIAL LEVERS TO IMPROVE SUPPLY CHAIN PROFITABILITY

As previously shown, the cost of overstocking and the cost of understocking have a direct impact on both the optimal customer service level and the profitability of the supply chain.

Two obvious managerial levers to increase profitability are thus as follows:

1. increasing the salvage value of unsold units (for example, by reselling the unsold items through distribution channels abroad);

2. decreasing the margin lost from a stockout (for example, by arranging for backup sourcing).



The optimal CSL evolves inversely to the ratio between the cost of overstocking and the cost of understocking: the lower this ratio, the higher the optimal product availability. In contrast with Lidl (hard-discounter), Carrefour has higher profit margins and thus a larger cost of understocking. Therefore, Carrefour should set a higher of product availability than Lidl, which has a lower cost of stockout.

MANAGERIAL LEVERS TO IMPROVE SUPPLY CHAIN PROFITABILITY (Continued)

Another way to increase the supply chain profitability is to reduce the uncertainty that affects demand, in order to reduce both the the cost of overstocking and the cost of understocking.

To do so, the following levers can be considered:

1. improving the forecasts accuracy;
2. reduce the lead time;
3. postponement;
4. tailored sourcing.

IMPROVING FORECAST ACCURACY

The main objective here is to better understand the customer behavior and to coordinate actions within the supply chain to improve forecast accuracy.

Consider a purchasing manager at a company responsible for deciding on the order quantity for a product which only sells over the Christmas season. The purchasing manager places an order for delivery in early November. Each unit costs \$100 and is sold at \$250. All the unsold units are heavily discounted in the post-Christmas sales and sold for a salvage value of \$80. Demand is normally distributed with a mean of $\mu = 350$, and a standard deviation of $\sigma = 150$. The store manager has decided to conduct additional market research to get better forecast. Evaluate the impact of improved forecast accuracy on profitability and inventories as the manager reduces the σ from 150 to 0 in increments of 30.

As we have:

$$C_u = p - c = \$250 - \$100 = \$150 \; ; \; C_o = c - s = \$100 - \$80 = \$20$$

the optimal CSL is:

$$CSL^* = \Pr(\text{Demand} \le O^*) = 150/(150 + 20) = 0.88.$$

The corresponding lot size is:

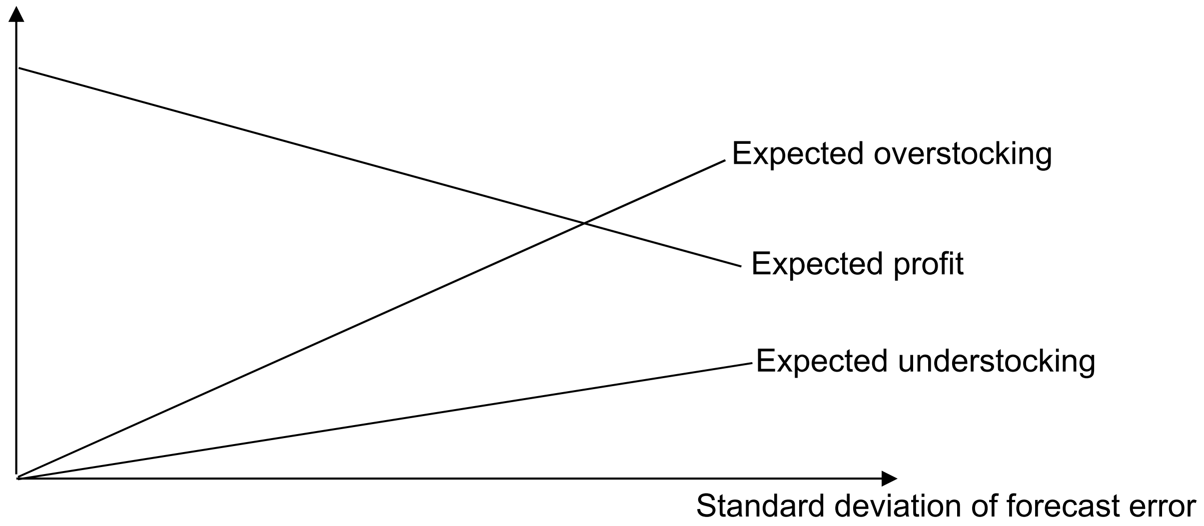
$$O^* = F^{-1}(0.88, 350, \sigma),$$

and the expected profit is given as follows:

$$150O^* - 170[(O^* - 350)NORMDIST(O^*;350;150;1) + 150NORMDIST((O^*-350)/150;0;1;0)]$$

IMPROVING FORECASTS ACCURACY (Continued)

Standard deviation of forecast error σ	Optimal order quantity O*	Expected overstocking	Expected understocking	Expected profit
150	526	186.7	8.6	$47 469
120	491	149.3	6.9	$48 476
90	456	112.0	5.2	$49 482
60	420	74.7	3.5	$50 488
30	385	37.3	1.7	$51 494
0	350	0	0	$52 500



The improvement of sales forecast accuracy both reduces the costs of overstocking and understocking and increases the firm’s profits.

QUICK RESPONSE

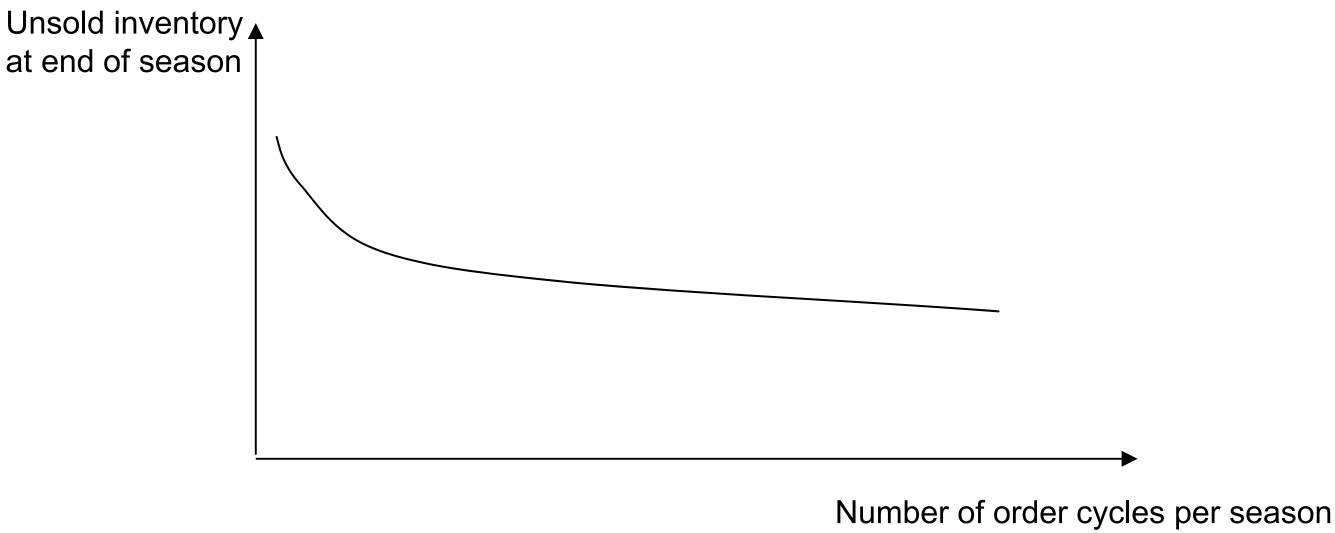
As the lead time diminishes (*quick response*), the supply chain managers are able to increase their forecast accuracy for demand, which implies an increase in the profitability of the supply chain.

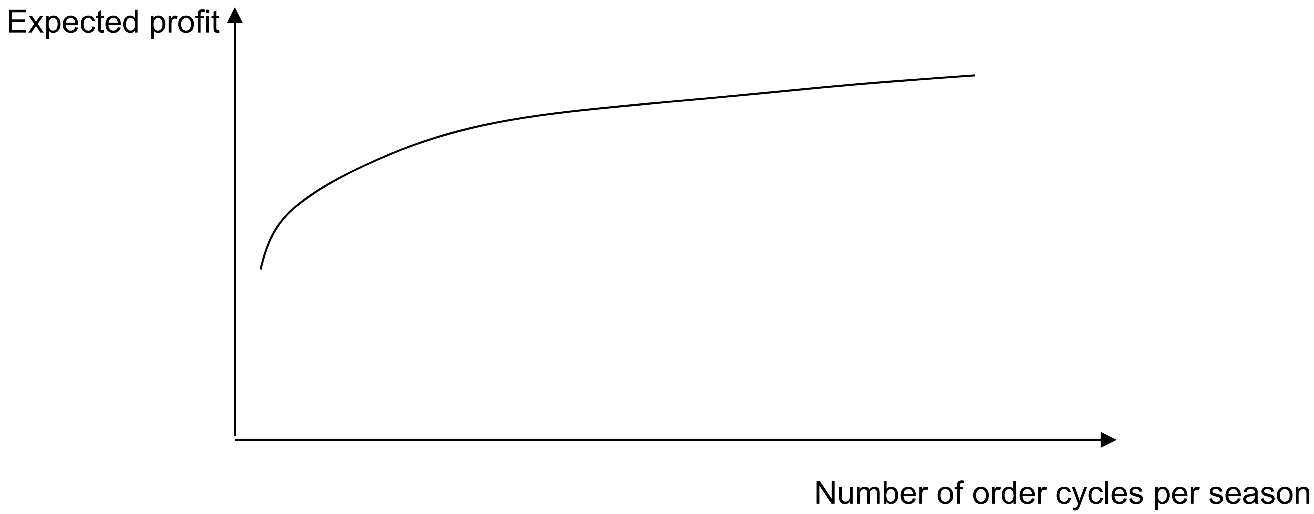
Consider the case of a retailer which sells a product over a season which covers about 14 weeks. The replenishment time is from 25 to 30 weeks. With a thirty-week lead-time, the retailer must order all the stores expects to sell well before the start of the sales season. However, it is hard for the retailer to make an accurate forecast of demand this far in advance. This results in high demand uncertainty, leading the retailer to order either too many or too few units each year.

If the supplier decreases the replenishment lead time to 15 weeks, the retailer must still place the entire order before the start of the sales season. However, the order can now be placed closer to the sales, resulting in a more accurate forecast, thus increasing profits at the retailer.

Typically, buyers are able to make very accurate forecasts once they have observed demand for the first week or two in the season. If the supplier can reduce the replenishment lead time to six weeks, it allows the buyer to break up the entire season’s purchase into two orders: the first order corresponding to what the store expects to sell over the first seven weeks of the season can then placed 6 weeks before the start of the sales season. Once sales start, the buyer observes demand for the first week and then places a second order. The ability to place the second order allows the buyer to match supply and demand more effectively, resulting in higher profits.

QUICK RESPONSE (Continued)





As the total quantity for the season is broken up into multiple smaller orders, the buyer is better able to match supply and demand and increase profitability.

POSTPONEMENT

Postponement refers to the delay of product differentiation until closer to the sale of the product. With postponement, all activities prior to product differentiation require aggregate forecasts, that are more accurate than individual product forecast. Individual product forecast are required close to the time of sale when demand is known with greater accuracy. As a result, postponement allows a supply chain to better match supply with demand.

However, the unit production cost with postponement is higher than that without it. Therefore, the benefits of postponement should be quantified to ensure that they are larger the additional costs.

Postponement is valuable for a firm that sells a large variety of products with demand that is independent and comparable in size.

As an illustration, consider the case of Benetton. A large fraction of Benetton's sales are from knit garments in solid colors. Starting with thread, there are two steps to completing the garment: dying and knitting. Traditionally, thread was dyed and then the garment was knitted (Option 1). Benetton developed a procedure where dying was postponed until after the garment was knitted (Option 2).

Benetton sells each knit garment at a retail price p = \$50. Option 1 results in a manufacturing cost of \$20, whereas Option 2 results in a manufacturing cost of \$22. Any unsold garment at the end of the season is disposed of in a clearance for s = \$10 each. The knitting operation takes a total of 20 weeks. The garments are sold in four colors. Twenty weeks in advance, Benetton forecasts demand for each color to be normally distributed with μ = 1 000 and σ = 500. Demand for each color is independent.

With Option 1, Benetton makes the buying decision for each color 20 weeks before the sales period and holds separate inventories for each color. With Option 2, Benetton forecasts the aggregate uncolored thread to purchase 20 weeks in advance. The decision regarding the quantity for individual colors is made after demand is known.

POSTPONEMENT (Continued)

We evaluate the impact of postponement for Benetton.

Option 1: Benetton must decide on the quantity of colored thread to purchase for each color. The optimal CSL for color is:

$$CSL^* = (p - c)/(p - s) = 30/40 = 0{,}75$$

The optimal purchase quantity of thread in each color is as follows:

$$O^* = NORMINV(0.75;\ 1\ 000;\ 500) = 1\ 337$$

it is then optimal to produce 1 337 units for each color. The expected profit from each color is \$23 644, the expected over- and understocking for each color is 412 units and 75 units. Across all 4 colors, Benetton thus produces 5 348 sweaters, which results in an expected profit of \$94 576, with an average of 1 648 sold on clearance at the end of the season and 300 customers turned away for stockout.

Option 2: Benetton must set the total number of units across all 4 colors to be made as they can be dyed to the right color once demand is known. The optimal CSL for each color is:

$$CSL^* = (p - c)/(p - s) = 28/40 = 0.70$$

Given that demand for each color is independent, the total demand across all 4 colors is normally distributed with $\mu_A = 4 \times 1\ 000 = 4\ 000$ and $\sigma_A = 4^{1/2} \times 500 = 1\ 000$.

The optimal aggregate production quantity for Benetton is:

$$O_A^* = NORMINV(0.7;\ 4\ 000;\ 1\ 000) = 4\ 524$$

It is optimal for Benetton to produce 4 524 undyed sweaters to be dyed as demand by color is available, which results in an expected profit of \$98 092, with an average of 715 sold on clearance at the end of the season and 190 customers turned away for stockout.

Postponement allows a firm to raise profits, and better match supply and demand if the firm produces a large variety of products whose demand is independent and about the same size.

TAILORED SOURCING

In tailored sourcing, firms use a combination of two supply sources. However, it is not sufficient to have supply sources where one serves as the backup to the other. The two sources must focus on different capabilities. The low-cost must focus on being efficient and should only be required to supply the predictable portion of the demand. The flexible source should focus on being responsive and be required to supply the uncertain portion of the demand. As a result, tailored sourcing allows a firm to increase its profits and better match supply and demand.

Depending on the source of uncertainty, tailored sourcing may be volume based or product based. In volume-based tailored source, the predictable part of a product's demand is produced at an efficient facility, whereas the uncertain portion is produced at a flexible facility.

Benetton provides an example of volume-based tailored sourcing. Benetton requires retailers to commit to about 65% of their orders about 7 months before the start of the sales season. Benetton subcontracts production of the portion without uncertainty to low-cost sources that have long lead times of several months. For the other 35%, Benetton allows retailers to place orders much closer to or even after the start of the selling season. All uncertainty is concentrated in this portion of the order. Benetton produces this portion of the order in a plant they own that is very flexible, wherein the cost of production is more expensive than at the subcontractor. However, the plant can produce with a lead time of weeks. A combination of the two sources allows Benetton to reduce its inventories while incurring a high cost of production for only a fraction of its demand. This allows it to increase profits.

Volume-based tailored sourcing is appropriate for firms that have moved a lot of their production overseas to take advantage of lower costs. Having a flexible local source reduces safety inventories and supply any excess demand from the local source.

TAILORED SOURCING (Continued)

In product-based tailored sourcing, low-volume products with uncertain demand are obtained from a flexible source while high-volume products with less demand uncertainty are obtained from efficient source.

An example of product-based tailored sourcing is Levi Strauss, which sells standard-sized jeans as well as jeans that can be customized to fit an individual. Standard jeans have relatively stable demand while demand for custom jeans is unpredictable. Custom jeans are produced at a flexible facility while standard jeans are produced at an efficient facility.

In some instances, new products have very uncertain demand while well-established products have more stable demand. Product-based tailored sourcing may be implemented with a flexible facility focusing on new products, and efficient facilities focusing on the well-established products.

SUPPLY CHAIN CONTRACT AND THEIR IMPACT ON PROFITABILITY

A contract specifies the parameters within which a buyer places orders and a supplier fulfills them. It may contain specifications regarding quantity, price, time, and quality.

At one extreme, a contract may require the buyer to specify the precise quantity required, with a very long lead time. In this case, the buyer bears the risk of over- and understocking, whereas the supplier has exact order information well in advance of delivery.

At the other extreme, buyers may not be required to commit to the precise purchase quantity until they are certain of their demand, with the supplier arriving with a short lead time. In this case, the supplier has little advance information, whereas the buyer can wait until demand is known before ordering. As a result, the supplier must build inventory in advance and bear most of the risk of over- or understocking.

Any modification in the contract parameters affects the risk that each of the supply chain members bears, as well as their decisions and the supply chain profitability.

Consider for example FT a manufacturer of synthetic fibers used in ski jackets and other winter outwear. FT has patented a new lightweight fiber that is very inexpensive but has the warmth and water-repellent properties of very expensive natural fibers. FT has designed a new jacket using this fiber that it want to bring to the market through an exclusive retailer AS. Each jacket cost v = \$10 to produce and FT sets its transfer price to c = \$100. The retailer plans to sell the jacket for a price of p = \$200. At this price, demand at AS is estimated to be normally distributed with μ = 1 000 and σ = 300. SA is unable to salvage anything for unsold jackets, that is s = \$0.

SUPPLY CHAIN CONTRACT AND THEIR IMPACT ON PROFITABILITY (Continued)

The optimal CSL of AS is *CSL** = 0.5 and the optimal order size is 1 000 units. The expected profit of AS at the end of the season is $76 063. FT sells 1 000 units for an expected total profit of $90 000. The supply chain's expected total profit is then $166 063.

The supply chain makes a profit of $190 for each jacket sold. The ordering decision, however, is made by the manager at AS, and AS makes a margin of $100 per unit, which is lower than the margin for the entire supply chain. Meanwhile, AS loses $100 for each unsold jacket, whereas the supply chain only loses $10.

As a result, the manager at AS orders fewer jackets than is optimal from the perspective of the entire supply chain. From the perspective of the entire supply chain, the cost of understocking is $190 and the cost of overstocking is $10. It is then optimal for the supply chain to provide a cycle service level of 0.95, and produce 1 493 units, which results in a total supply chain profit of $183 812.

The gap in profit exists because of *double marginalization*, which refers to the fact that the total supply chain margin of $190 is divided between $90 for FT and $100 for AS. Each supply chain member makes decisions considering only a portion of the total supply chain margin. In this case, a decision (the size of the order) by AS affects profits at FT, despite the fact that AS does not take FT profits into account when making her decision.

In order to mitigate the double marginalization effect, which is typical of wholesale-price contracts (WPC), various contractual alternatives can be considered, among which:

- the buy-back contract,

- the revenue-sharing contract,

- the quantity-flexibility contract.

BUY-BACK CONTRACT

A manufacturer can increase the quantity the retailer purchases by offering to buy back any leftover units at the end of the season at a fraction of the purchase price.

This increases the salvage value per unit for the retailer who, as a result, increases its order size. The manufacturer may benefit by taking on some of the cost of overstocking because the supply chain will, on average, end up selling more units.

In a buy-back contract, the manufacturer produces at unit cost v, and specifies a wholesale price c along with a buy-back price b at which the retailer can return any unsold units at the end of the season. The manufacturer can salvage $\$s_M$ for any units that the retailer returns. The expected manufacturer profit thus depends on the overstock at the retailer that is returned, that is:

Expected manufacturer profit = $O^*(c - v) - (b - s_M)$ x Expected overstocking at the retailer

Considering the previous example, the following table provides different buy-back contracts that FT offers AS. The sale price of jackets at AS is p = \$200 and demand at this price is supposed normally distributed with μ = 1 000 and σ = 300. For simplicity, we assume no transportation or other cost associated with any returns.

BUY-BACK CONTRACT (Continued)

Transfer price *c* ($)	Buy-back price *b* ($)	Optimal order AS	Expected profit AS ($)	Expected returns FT	Expected profit FT ($)	Supply chain's expected profit ($)
100	0	1 000	76 063	120	90 000	166 063
100	30	1 067	80 154	156	91 338	171 492
100	60	1 170	85 724	223	91 886	177 610
110	0	962	66 252	102	96 230	162 482
110	78	1 191	78 074	239	100 480	178 555
110	105	1 486	86 938	493	96 872	183 810
120	0	924	56 819	80	101 640	158 459
120	96	1 221	70 508	261	109 225	179 733
120	116	1 501	77 500	506	106 310	183 810

Buy-backs allows both the manufacturer and the retailer to increase their profits. The use of buy-back contracts increases total supply chain profits by about 10%.

For a fixed transfer price, increasing the buy-back price always increases retailer profits. Also, the greater the transfer price, the greater the manufacturer profits.

In 1932, Viking Press was the first book publisher to accept returns. Today, buy-back contracts are common practice in the book industry.

For a fixed transfer price, the higher the buy-back price, the higher the orders and the returns of the retailer. As the cost associated with a return increases, buy-back contracts become less attractive

REVENUE-SHARING CONTRACT

In revenue-sharing contracts (RSC), the manufacturer charges the retailer a low transfer price and shares a fraction of the revenue generated by the retailer.

Even if no returns are allowed, a lower transfer price decreases the cost of overstocking at the retailer.

Assume that the manufacturer has a production cost of v, charges a transfer price of c, and shares a fraction f of the revenue generated by the retailer. The retailer charges a retail price p and can salvage any leftover units for s_R.

The cost of understocking of the retailer is $C_u = (1 - f)p - c$ and the cost of overstocking is $C_o = c - s_R$, which gives:

$$CSL^* = C_u/(C_u + C_o) = [(1 - f)p - c]/[(1 - f)p - s_R]$$

The expected profit of the manufacturer is:

$$O^*(c - v) + fp(O^* - \text{Expected overstocking at the retailer})$$

The expected profit of the retailer is:

$$(1 - f)p(O^* - \text{Expected overstocking at the retailer}) + s_R \times \text{Expected overstocking at the retailer} - cO^*$$

Consider the previous example where FT charges only c = $10 for each jacket. AS in turn sells the jacket for p = $200. Demand at this price is normally distributed with μ = 1 000 and σ = 300. AS has no salvage value for any leftover jackets. The following table provides the outcome for different revenue-sharing fractions.

REVENUE-SHARING CONTRACT (Continued)

Transfer price *c* ($)	Sharing parameter *f*	Optimal order AS	Expected overstocking AS	Expected profit AS ($)	Expected profit FT ($)	Supply chain's expected profit ($)
100	0	1 000	120	76 063	90 000	166 063
10	0.3	1 440	449	124 273	59 429	183 702
10	0.5	1 384	399	84 735	98 580	183 315
10	0.7	1 290	317	45 503	136 278	181 781
10	0.9	1 000	120	7 606	158 457	166 063
20	0.3	1 320	342	110 523	71 886	182 409
20	0.5	1 252	286	71 601	109 176	180 777
20	0.7	1 129	195	33 455	142 051	175 506

The RSC allows both FT and AS to increase their profits. The use of RSC increases total supply chain profits by about 10%.

With a WPC with c = \$100, the optimal order of AS is 1 000 units, which provides \$90 000 of profits for FT and \$76 063 for AS. With a RSC with c = \$10 and f = 0.5, the optimal order of AS is 1 384 units, which provides \$98 580 of profits for FT and \$84 735 for AS. AS is willing to increase its order size under RSC because the cost of overstocking is only \$10 per unit whereas it is \$100 per unit with a WPC.

RSC have been used in the video rental industry (e.g., Blockbuster).

QUANTITY FLEXIBILITY CONTRACT

In quantity flexibility contracts, the manufacturer allows the retailer to change the quantity ordered after observing demand.

If a retailer orders O units, the manufacturer commits to providing $Q = (1 + \alpha)O$ units, and the retailer is committed to buying at least $q = (1 - \beta)O$ units, $\alpha, \beta \in [0, 1]$. The retailer can purchase up to Q units depending on the demand they observe.

These contracts are similar to buy-back contracts in that the manufacturer now bears some of the risk of have excess inventory. When the cost of return is high, these contracts can be more effective than buy-back contracts.

Quantity flexibility contracts increase the average amount the retailer purchases and may increase total supply chain profits.

Assume that the manufacturer incurs a production cost of $\$v$ per unit and charge a transfer price of $\$c$ from the retailer. The retailer in turn sells to customers for a price of $\$p$. The retailer salvages any leftover units for s_R and the manufacturer salvages any leftover units for s_M. Demand is normally distributed with a mean of μ and a standard deviation of σ.

If the retailer orders O units, the manufacturer is committed to supplying Q units. The retailer orders q units if demand D is less than q, D units if demand D is between q and Q, and Q units if demand is higher than Q.

Expected quantity purchased by retailer:

$$Q_R = qF(q) + Q[1 - F(Q)] + \mu[F_S((Q - \mu)/\sigma) - F_S((q - \mu)/\sigma)] - \sigma[f_S((Q - \mu)/\sigma) - f_S((q - \mu)/\sigma)]$$

Expected quantity sold by retailer: $D_R = Q[1 - F(Q)] + \mu F_S((Q - \mu)/\sigma) - \sigma f_S((Q - \mu)/\sigma)$

$$\text{Expected overstock at the retailer} = Q_R - D_R$$

$$\text{Expected retailer profit} = D_R \times p + (Q_R - D_R) \times s_R - Q_R \times c$$

$$\text{Expected manufacturer profit} = Q_R \times c + (Q - Q_R) \times s_M - Q \times v$$

QUANTITY FLEXIBILITY CONTRACT (Continued)

Considering the previous example with FT and AS, we assume that *c* = \$100, *v* = \$10, *p* = \$200. At this price, demand at AS is normally distributed with μ = 1 000 and σ = 300. FT and AS do not receive any salvage value for any unsold units. Various instances of the quantity flexibility contract are considered in the following table.

α	β	**Transfer price *c* (\$)**	**Order size *O***	**Expected purchase SA**	**Expected sales SA**	**Expected profit SA (\$)**	**Expected profit FT (\$)**	**Supply chain's expected profit (\$)**
0	0	100	1 000	1000	880	76 063	90 000	166 063
0.2	0.2	100	1 000	1000	955	90 933	88 000	178 933
0.4	0.4	100	1 000	1000	987	97 456	86 000	183 456
0	0	120	924	924	838	56 819	83 160	139 979
0.2	0.2	120	924	959	927	70 331	84 791	155 122
0.5	0.5	120	924	990	986	78 353	85 170	163 524

All contracts considered are such that α = β.

The quantity flexibility contract allows both FT and AS to increase their profits. As the manufacturer increases the transfer price, it is optimal for them to offer greater flexibility to the retailer.

Quantity flexibility contracts are common for components in the electronic and computer industry.