Chapter 19

Supply Chain Coordination

Supply chain performance depends on the actions taken by all of the organizations in the supply chain; one weak link can negatively affect every other location in the chain. While everyone supports in principle the objective of optimizing the supply chain's performance, each firm's primary objective is the optimization of its own performance. And unfortunately, as shown in this chapter, self-serving behavior by each member of the supply chain can lead to less than optimal supply chain performance. In those situations, the firms in the supply chain can benefit from better operational coordination.

In this chapter we explore several challenges to supply chain coordination. The first challenge is the *bullwhip effect:* the tendency for demand variability to increase, often considerably, as you move up the supply chain (from retailer, to distributor, to factory, to raw material suppliers, etc.). Given that variability in any form is problematic for effective operations, it is clear the bullwhip effect is not a desirable phenomenon. We identify the causes of the bullwhip effect and propose several techniques to combat it.

A second challenge to supply chain coordination comes from the *incentive conflicts* among the supply chain's independent firms: An action that maximizes one firm's profit might not maximize another firm's profit. For example, one firm's incentive to stock more inventory, or to install more capacity, or to provide faster customer service, might not be the same as another firm's incentive, thereby creating some conflict between them. We use a stylized example of a supply chain selling sunglasses to illustrate the presence and consequences of incentive conflicts. Furthermore, we offer several remedies to this problem.

19.1 The Bullwhip Effect: Causes and Consequences

Barilla is a leading Italian manufacturer of pasta. Figure 19.1 plots outbound shipments of pasta from its Cortese distribution center over a one-year period along with the orders Cortese placed on Barilla's upstream factories. Think of the outbound shipments as what was demanded of Cortese by its downstream customers and the orders as what Cortese demanded from its upstream suppliers. Clearly, Cortese's demand on its upstream suppliers is more volatile than the demand Cortese faces from its customers.

This pattern, in which a stage in the supply chain amplifies the volatility of its orders relative to its demand, is called the *bullwhip effect*. If there are several stages (or levels) in the supply chain (e.g., retailer, wholesaler, distributor, factory), then this amplification

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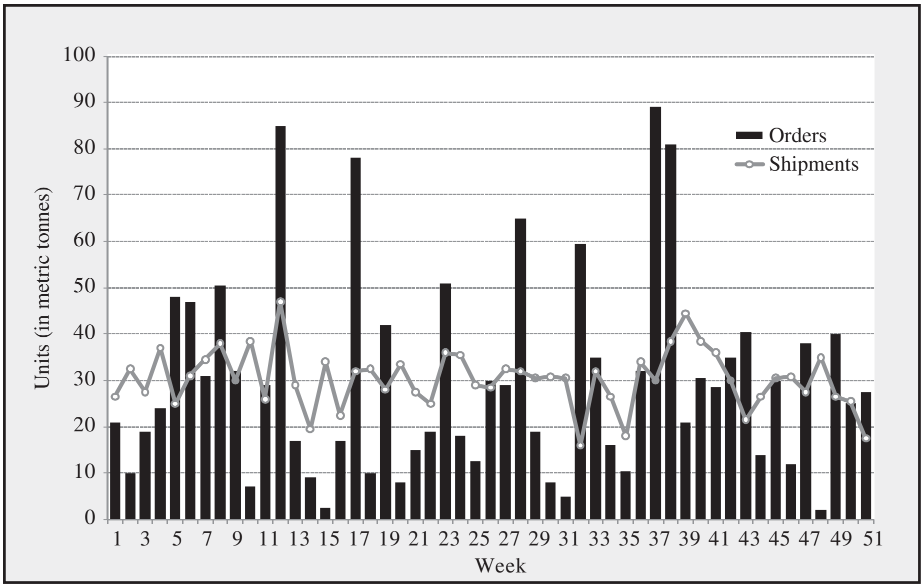
FIGURE 19.1
Barilla's Cortese Distribution Center Orders and Shipments

Source: Harvard Business School, Barilla Spa case.



can feed on itself—one level further amplifies the amplified volatility of its downstream customer. This accentuation of volatility resembles the increased amplitude one observes as a whip is cracked—hence the name, the bullwhip effect. In fact, Procter & Gamble coined the term to describe what they observed in their diaper supply chain: They knew that final demand for diapers was reasonably stable (consumption by babies), but the demands requested on their diaper factories were extremely variable. Somehow variability was propagating up their supply chain.

The bullwhip effect does not enhance the performance of a supply chain: Increased volatility at any point in the supply chain can lead to product shortages, excess inventory, low utilization of capacity, and/or poor quality. It impacts upstream stages in the supply chain, which must directly face the impact of variable demand, but it also indirectly affects downstream stages in the supply chain, which must cope with less reliable replenishments from upstream stages. Hence, it is extremely important that its causes be identified so that cures, or at least mitigating strategies, can be developed.

Figure 19.1 provides a real-world example of the bullwhip effect, but to understand the causes of the bullwhip effect, it is helpful to bring it into the laboratory; that is, to study it in a controlled environment. Our controlled environment is a simple supply chain with two levels. The top level has a single supplier and the next level has 20 retailers, each with one store. Let's focus on a single product, a product in which daily demand has a Poisson distribution with mean 1.0 unit at each retailer. Hence, total consumer demand follows a Poisson distribution with mean 20.0 units. (Recall that the sum of Poisson distributions is also a Poisson distribution.) Figure 19.2 displays this supply chain.

Before we can identify the causes of the bullwhip effect, we must agree on how we will measure and identify it. We use the following definition:

The bullwhip effect is present in a supply chain if the variability of demand at one level of the supply chain is greater than the variability of demand at the next downstream level in the supply chain, where variability is measured with the coefficient of variation.

For example, if the coefficient of variation in the supplier's demand (which is the sum of the retailers' orders) is greater than the coefficient of variation of the retailers' total demand, then the bullwhip effect is present in our supply chain.

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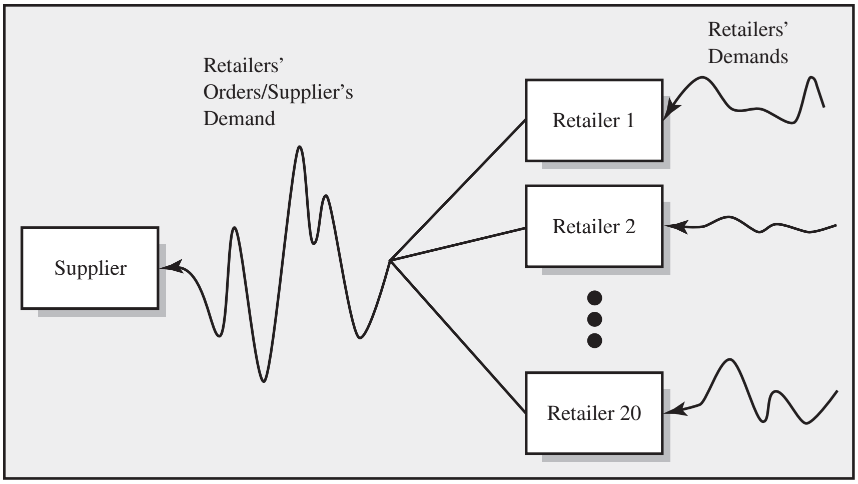
FIGURE 19.2
A Supply Chain with One Supplier and 20 Retailers

Daily demand at each retailer follows a Poisson distribution with mean 1.0 unit.



We already know how to evaluate the coefficient of variation in the retailers' total demand: Total demand is Poisson with mean 20, so the standard deviation of demand is $\sqrt{20} = 4.47$ and the coefficient of variation is $4.47/20 = 0.22$. The coefficient of variation of the supplier's demand (i.e., the coefficient of variation of the retailers' orders) depends on how the retailers place orders with the supplier.

Interestingly, while the way in which the retailers submit orders to the supplier can influence the standard deviation of the retailers' orders, it cannot influence the mean of the retailers' orders. To explain, due to the law of the conservation of matter, what goes into a retailer must equal what goes out of the retailer on average; otherwise, the amount inside the retailer will not be stable: If more goes in than goes out, then the inventory at the retailer continues to grow, whereas if less goes in than goes out, then inventory at the retailer continues to fall. Hence, no matter how the retailers choose to order inventory from the supplier, the mean of the supplier's demand (i.e., the retailers' total order) equals the mean of the retailers' total demand. In this case, the supplier's mean demand is 20 units per day, just as the mean of consumer demand is 20 units per day. We can observe this in Figure 19.1 as well: Cortese's average shipment is about 30 tonnes and their average order is also about 30 tonnes.

To evaluate the coefficient of variation in the supplier's demand, we still need to evaluate the standard deviation of the supplier's demand, which does depend on how the retailers submit orders. Let's first suppose that the retailers use an order-up-to policy to order replenishments from the supplier.

A key characteristic of an order-up-to policy is that the amount ordered in any period equals the amount demanded in the previous period (see Chapter 16). As a result, if all of the retailers use order-up-to policies with daily review, then their daily orders will match their daily demands. In other words, there is no bullwhip effect!

> *If all retailers use an order-up-to policy (with a constant order-up-to level* S *), then the standard deviation of the retailers' orders in one period equals the standard deviation of consumer demand in one period; that is, there is no bullwhip effect.*

So we started our experiment with the intention of finding a cause of the bullwhip effect and discovered that the bullwhip effect need not occur in practice. It does not occur when every member at the same level of the supply chain implements a "*demand-pull*" inventory policy each period; that is, their orders each period exactly match their demands. Unfortunately, firms do not always adopt such "distortion-free" inventory management. In fact,

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they may have good individual reasons to deviate from such behavior. It is those deviations that cause the bullwhip effect. We next identify five of them.

Order Synchronization

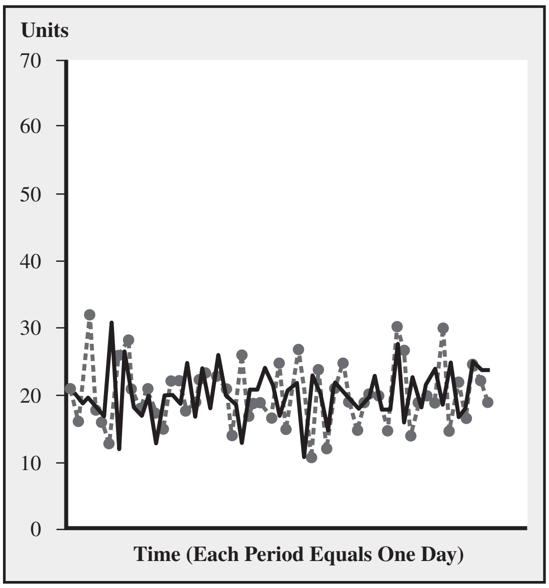
Suppose the retailers use order-up-to policies, but they order only once per week. They may choose to order weekly rather than daily because they incur a fixed cost per order and therefore wish to reduce the number of orders they make. (See Section 16.8.) Hence, at the start of each week, a retailer submits to the supplier an order that equals the retailer's demand from the previous week. But because we are interested in the supplier's *daily* demand, we need to know on which day of the week each retailer's week begins. For simplicity let's assume there are five days per week and the retailers are evenly spaced out throughout the week; that is, 4 of the 20 retailers submit orders on Monday, 4 submit orders on Tuesday, and so forth. Figure 19.3 displays a simulation outcome of this scenario. From the figure it appears that the variability in consumer demand is about the same as the variability in the supplier's demand. In fact, if we were to simulate many more periods and evaluate the standard deviations of those two data series, we would, in fact, discover that the standard deviation of consumer demand *exactly* equals the standard deviation of the supplier's demand. In other words, we still have not found the bullwhip effect.

But we made a critical assumption in our simulation. We assumed the retailers' order cycles were evenly spaced throughout the week: The same number of retailers order on Monday as on Wednesday as on Friday. But that is unlikely to be the case in practice: Firms tend to prefer to submit their orders on a particular day of the week or a particular day of the month. To illustrate the consequence of this preference, let's suppose the retailers tend to favor the beginning and the end of the week: Nine retailers order on Monday, five on Tuesday, one on Wednesday, two on Thursday, and three on Friday. Figure 19.4 displays the simulation outcome with that scenario.

We have discovered the bullwhip effect! The supplier's daily demand is clearly much more variable than consumer demand. For this particular sample, the coefficient of variation of the supplier's demand is 0.78 even though the coefficient of variation of consumer demand is only 0.19: The supplier's demand is about four times more variable than consumer demand! And this is not the result of a particularly strange demand pattern; that is,

FIGURE 19.3
Simulated Daily Consumer Demand (solid line) and Daily Supplier Demand (circles)

Supplier demand equals the sum of the retailers' orders.



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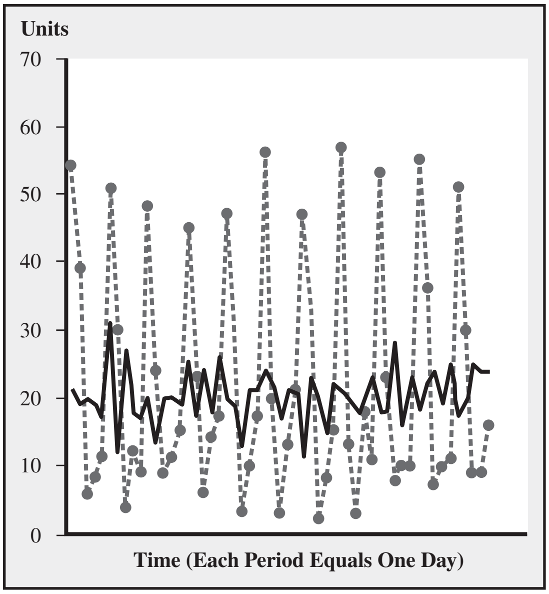

FIGURE 19.4
Simulated Daily Consumer Demand (solid line) and Supplier Demand (circles) When Retailers Order Weekly

Nine retailers order on Monday, five on Tuesday, one on Wednesday, two on Thursday, and three on Friday.

the same qualitative result is obtained if a very long interval of time is simulated. In fact, for comparison, you can note that the consumer demand in Figure 19.4 is identical to consumer demand in Figure 19.3.

Not only do we now observe the bullwhip effect, we have just identified one of its causes, *order synchronization:* If the retailers' order cycles become even a little bit synchronized, that is, they tend to cluster around the same time period, then the bullwhip effect emerges. While the retailers order on average to match average consumer demand, due to their order synchronization there will be periods in which they order considerably more than the average and periods in which they order considerably less than the average, thereby imposing additional demand volatility on the supplier.

Order synchronization also can be observed higher up in the supply chain. For example, suppose the supplier implements a materials requirement planning (MRP) system to manage the replenishment of component inventory. (This is a computer system that determines the quantity and timing of component inventory replenishments based on future demand forecasts and production schedules.) Many firms implement their MRP systems on a monthly basis. Furthermore, many implement their systems to generate replenishment orders in the first week of the month. So a supplier's supplier may receive a flood of orders for its product during the first week of the month and relatively little demand later in the month. This has been called *MRP jitters* or the *hockey stick phenomenon* (the graph of demand over the month looks like a series of hockey sticks, a flat portion and then a spike up).

Order Batching

We argued that the retailers might wish to order weekly rather than daily to avoid incurring excessive ordering costs. This economizing on ordering costs also can be achieved by *order batching:* Each retailer orders so that each order is an integer multiple of some batch size. For example, now let's consider a scenario in which each retailer uses a batch size of 15 units. This batch size could represent a case or a pallet or a full truckload. Let's call it a pallet. By ordering only in increments of 15 units, that is, in pallet quantities, the retailer can facilitate the movement of product around the warehouse and the loading of product onto trucks. How does the retailer decide when to order a pallet? A natural rule is to order a batch whenever the accumulated demand since the last order exceeds the batch size.

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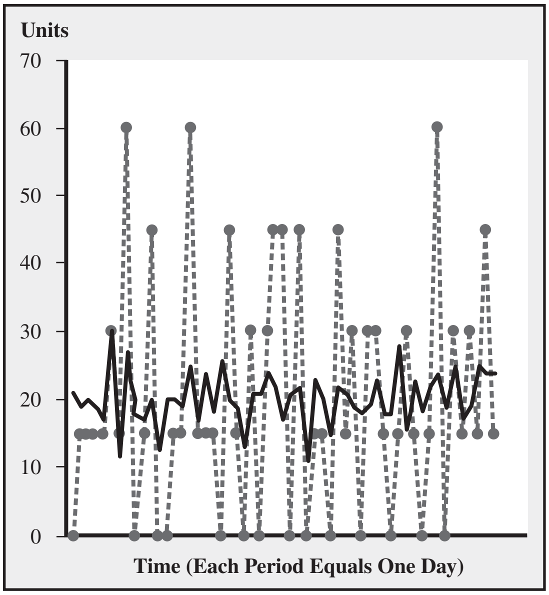
FIGURE 19.5
Simulated Daily Consumer Demand (solid line) and Supplier Demand (circles) When Retailers Order in Batches of 15 Units

Every 15th demand, a retailer orders one batch from the supplier that contains 15 units.



Therefore, in this example, every 15th demand triggers an order for a pallet. Naturally, ordering in batches economizes on the number of orders the retailer must make:

$$\text{Average number of periods between orders} = \frac{\text{Batch size}}{\text{Mean demand per period}}$$

In this situation, the retailer orders on average every 15/1 = 15 periods.

Figure 19.5 displays a simulation outcome with batch ordering. Because the retailers only order in pallet quantities, the supplier's demand equals a multiple of 15: On some days there are no orders, on most days one pallet is ordered by some retailer, on a few days there are up to four pallets ordered.

We again observe the bullwhip effect: The variability of the supplier's demand is considerably greater than the variability of consumer demand. To be specific, the supplier's demand has a coefficient of variation equal to 0.87 in this example, which contrasts with the 0.19 coefficient of variation for consumer demand. Thus, we have identified a second cause of the bullwhip effect, *order batching:* The bullwhip effect emerges when retailers order in batches that contain more than one unit (e.g., pallet quantities or full truckload quantities). Again, the retailers' total order on average equals average consumer demand, but not the variability of their orders. This occurs because, due to the batch quantity requirement, the retailer's order quantity in a period generally does not match the retailer's demand in that period: It tends to be either greater than or less than consumer demand. In other words, the batch quantity requirement forces the retailer to order in a way that is more variable than consumer demand even though, on average, it equals consumer demand.

Trade Promotions and Forward Buying

Suppliers in some industries offer their retailers *trade promotions:* a discount off the wholesale price that is available only for a short period of time. Trade promotions cause retailers to buy on-deal, also referred to as a *forward buy,* which means they purchase much more than they need to meet short-term needs. Trade promotions are a key tool for a supplier when the supplier wants to engage in the practice of *channel stuffing:* providing incentives to induce retailers (the channel) to hold more inventory than needed for

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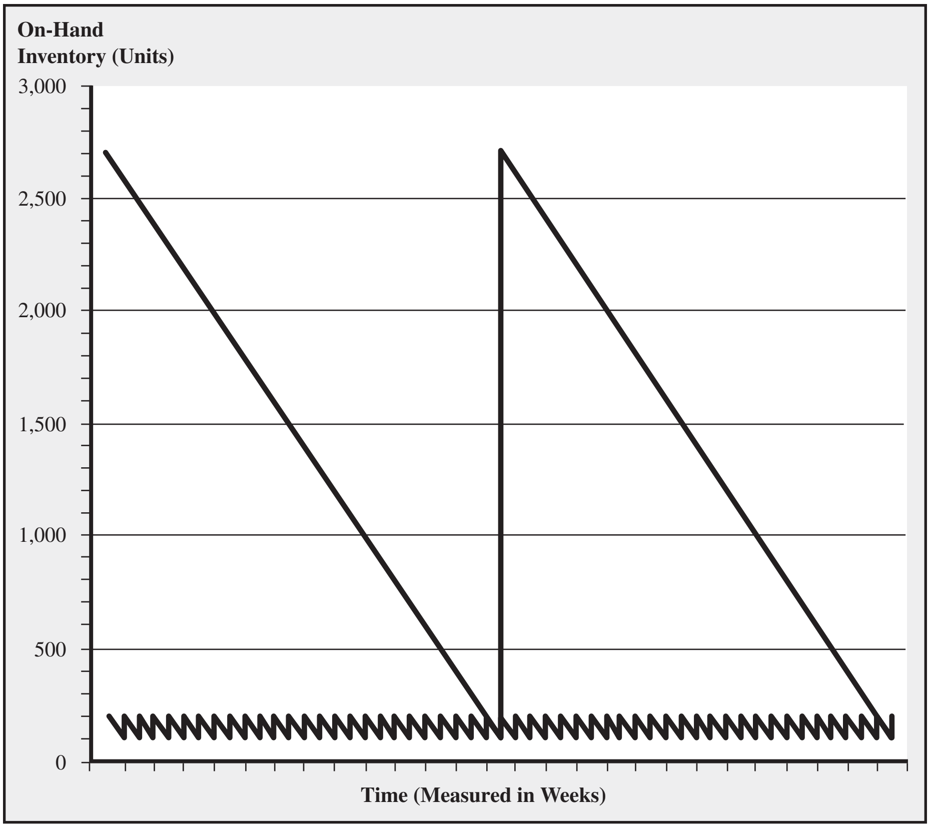
FIGURE 19.6
On-Hand Inventory of Chicken Noodle Soup at a Retailer under Two Procurement Strategies

The first strategy, called demand-pull (lower sawtooth), has the retailer ordering 100 cases each week. The second strategy, called forward buying (upper sawtooth), has the retailer ordering 2,600 cases twice per year.



the short term. Because with trade promotions many retailers purchase at the same time (order synchronization) and because they order in large quantities (order batching), trade promotions are capable of creating an enormous bullwhip. Let's illustrate this with another simple scenario.

Suppose a supplier sells chicken noodle soup; let's consider one of the supplier's retailers. The supplier's regular price of chicken noodle soup is \$20 per case, but twice a year the supplier offers an 8 percent discount for cases purchased during a one-week period, for example, the first week in January and the first week in July. The retailer sells on average 100 cases of soup per week and likes to carry a one-week safety stock; that is, the retailer does not let its inventory fall below 100 cases. To avoid unnecessary complications, let's further assume that the retailer's order at the beginning of a week is delivered immediately and demand essentially occurs at a constant rate. The retailer's annual holding cost rate is 24 percent of the dollar value of its inventory.

We now compare the retailer's profit with two different ordering strategies. With the first strategy, the retailer orders every week throughout the year; with the second strategy, the retailer orders only twice per year—during the trade promotion. We call the first strategy *demand-pull* because the retailer matches orders to current demand. The second strategy is called *forward buying* because each order covers a substantial portion of future demand. Figure 19.6 displays the retailer's on-hand inventory over the period of one year with both ordering strategies.

With demand-pull, the retailer's inventory "saw-tooths" between 200 and 100 units, with an average of 150 units. With forward buying, the retailer's inventory also "saw-tooths" but now between 2,700 and 100, with an average of 1,400 units. Note, although

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throughout the text we measure inventory at the end of each period, here, we are measuring average inventory throughout time. That is, we take average inventory to be the midpoint between the peak of each sawtooth and the trough of each sawtooth. This approach is easier to evaluate and leads to the same qualitative results (and from a practical perspective, nearly the same quantitative result as well).

Let's now evaluate the retailer's total cost with each strategy. With demand-pull, the retailer's average inventory is 150 units. During the two promotion weeks, the average inventory in dollars is $150 \times \$18.4 = \$2{,}760$ because the promotion price is $\$20 \times (1 - 0.08) = \$18.40$. During the remaining 50 weeks of the year, the average inventory in dollars is $150 \times \$20 = \$3{,}000$. The weighted average inventory in dollars is

$$\frac{(\$2{,}760 \times 2) + (\$3{,}000 \times 50)}{52} = \$2{,}991$$

The annual holding cost on that inventory is $\$2{,}991 \times 24\% = \$718$.

The purchased cost during the year is

$$(\$20 \times 100 \times 50) + (\$18.40 \times 100 \times 2) = \$103{,}680$$

because 100 units are purchased at the regular price over 50 weeks of the year and 100 units are purchased at the discount price during the two promotion weeks of the year. The demand-pull strategy's total cost is $\$718 + \$103{,}680 = \$104{,}398$.

The analysis of the forward buying strategy is analogous to the demand-pull strategy. A summary is provided in Table 19.1.

From Table 19.1 we see that forward buying is more profitable to the retailer than weekly ordering with demand-pull: The forward buying total cost is 2.4 percent less than the demand-pull strategy, which is a considerable amount in the grocery industry. We can conclude that a relatively small trade promotion can rationally cause a retailer to purchase a significant volume of product. In fact, the retailer may wish to purchase enough product to cover its demand until the supplier's next promotion. In contrast, it is highly unlikely that an 8 percent discount would induce consumers to purchase a six-month supply of chicken noodle soup; rational retailers are more price sensitive than consumers.

The impact of the trade promotion on the supplier is not good. Imagine the supplier sells to many retailers, all taking advantage of the supplier's trade promotion. Hence, the retailers' orders become synchronized (they order during the same trade promotion weeks of the year) and they order in very large batch quantities (much more than is needed to cover their immediate needs). In other words, trade promotions combine order synchronization and order batching to generate a significant bullwhip effect.

Interestingly, with the forward buying strategy, the retailer does not ever purchase at the regular price. Hence, if the supplier were to offer the retailer the $18.40 price throughout

TABLE 19.1
Analysis of Total Holding and Procurement Costs for Two Ordering Strategies

In demand-pull, the retailer orders every week; in forward buying, the retailer orders twice per year during the supplier's trade promotions.

	Demand-Pull	Forward Buying
Annual purchase (units)	5,200	5,200
Average inventory (units)	150	1,400
Average inventory	$2,991	$25,760
Holding cost (24% of average inventory cost)	$718	$6,182
Units purchased at regular price	5,000	0
Units purchased at discount price	200	5,200
Total purchase cost	$103,680	$95,680
Total holding plus procurement cost	$104,398	$101,862

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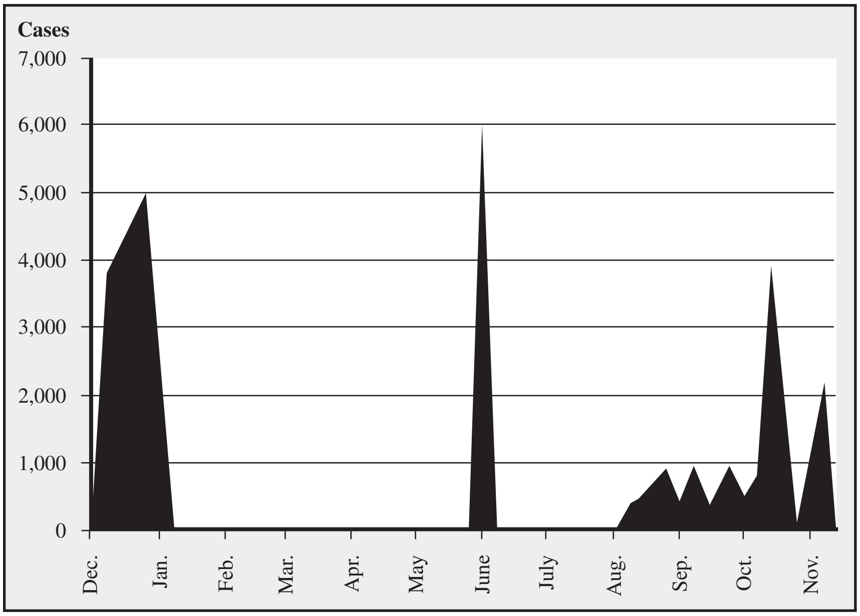
FIGURE 19.7
One Retailer's Purchases of Campbell's Chicken Noodle Soup over One Year



the year (instead of just during the two trade promotion weeks), then the supplier's revenue would be the same. However, the retailer could then order on a weekly basis, thereby reducing the retailer's holding cost. It is not too difficult to calculate that the retailer's total cost in this constant-price scenario is $96,342, which is 5.4 percent less than the forward buying cost and 7.7 percent less than the original demand-pull strategy. Thus, due to forward buying, the supply chain's costs are about 5 percent higher than they need be without providing any benefit to the firms in the supply chain (the retailer surely does not benefit from holding extra inventory and the supplier does not benefit from higher revenue).

While our analysis has been with a theoretical supply chain of chicken noodle soup, Campbell Soup would concur that this analysis is consistent with their experience. For example, Figure 19.7 presents data on one retailer's purchases of Campbell's Chicken Noodle Soup over the course of the year. This product is traditionally promoted in January and June even though consumers primarily eat soup during the winter months.[1] As a result, this retailer requires substantial storage space to hold its forward buys. Other retailers may lack the financial and physical capabilities to be so aggressive with forward buying, but they nevertheless will take advantage of trade promotions to some extent. This is confirmed by Figure 19.8, which shows total consumption and shipments of Campbell's Chicken Noodle Soup over a one-year period: Shipments are clearly more volatile than consumption, thereby indicating the presence of the bullwhip effect.

Due to the trade promotion spike in demand in January of every year, Campbell Soup must put its chicken deboning plants on overtime from September through October, its canning plant works overtime November through December, and its shipping facility works overtime throughout January. All of these activities add to production costs, and all because of a spike in demand caused by the company's own pricing.

The negative effects of forward buying also are not limited to the supplier's operational efficiency. Some retailers purchase on-deal with no intention of selling those units to

[1] Campbell's traditionally raises the price of its Chicken Noodle Soup during the summer, so the June buy avoids the imminent price increase. While this is technically not a promotion, the analysis is quite similar and the effect is essentially the same as a trade promotion.

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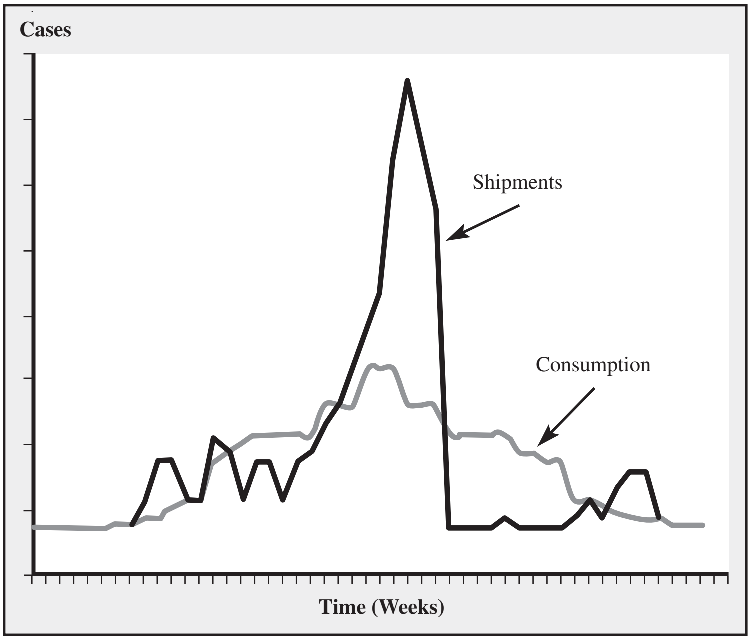
FIGURE 19.8
Total Shipments to Retailers and Consumption by Consumers of Campbell's Chicken Noodle Soup over a One-Year Period (roughly July to July)



consumers. Instead, they intend on selling to other retailers that cannot take advantage of the deal due to either physical or capital constraints. Those retailers that sell to other retailers are called *diverters* and that practice is called *diversion*. In addition to extra handling (which reduces quality and leads to spoilage), diversion needlessly adds to transportation costs. It also should be mentioned that diversion occurs when a supplier attempts to lower its price in one region of the country while maintaining a higher price in another region, possibly because the supplier faces a regional competitor in the former region. That form of diversion was greatly reduced in the grocery industry when several national grocery chains emerged (Kroger, Safeway, etc.) in the late 1980s and early 1990s. Those national chains insisted that they would receive a single low price from their suppliers, thereby preventing regional price discrimination.

Reactive and Overreactive Ordering

So far in our experimental supply chains, we have assumed the retailer knows what expected demand is in each period even though demand could be stochastic. This is a reasonable assumption for well-established products such as chicken noodle soup. But for many other products, a retailer might not know expected demand with certainty. And this uncertainty creates a complication for the retailer's inventory management.

Suppose the retailer observes higher-than-usual demand in one period. How should the retailer react to this observation? One explanation for this outlier is that it occurred merely due to random fluctuation. In that case, the retailer probably should not change her expectation of future demand and so not change how she manages inventory. But there is another explanation for the outlier: It could signal that demand has shifted, suggesting the product's actual expected demand is higher than previously thought. If that explanation is believed, then the retailer should increase her order quantity to cover the additional future demand; otherwise she will quickly stock out. In other words, it is rational for a retailer to increase her order quantity when faced with an unusually high-demand observation. Analogously, the retailer should decrease her order quantity when faced with an unusually low-demand observation because future demand may be weaker than previously thought. Hence, when

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a retailer cannot be sure that demand is stable over time, a retailer should rationally react aggressively to possible shifts in demand.

These reactions by the retailer contribute to the bullwhip effect. Suppose the retailer's high-demand observation is really due to random fluctuation. As a result, future demand will not be higher than expected even though the retailer reacted to this information by ordering more inventory. Hence, the retailer will need to reduce future orders so that the excess inventory just purchased can be drawn down. Ordering more than needed now and less than needed later implies the retailer's orders are more volatile than the retailer's demand, which is the bullwhip effect.

While it can be rational to react to extreme demand observations, it is also human nature to *over*react to such information; that is, to act too aggressively. For example, a high-demand signal may rationally warrant a 125 percent increase in a retailer's order quantity, but a retailer may "play it safe" and order 150 percent more just in case. Unfortunately, the retailer might not realize the consequence of this action. Suppose the retailer is replenished by a wholesaler, who is replenished by a distributor, who is replenished by a supplier. The retailer sees a blip in demand and so reacts with a larger order. The retailer's order is the wholesaler's demand, and so the wholesaler sees an even larger blip in demand. The wholesaler reacts and increases his order, which surprises the distributor. So the distributor reacts with an increased order, so large that the supplier only concludes that demand has accelerated substantially. In other words, overreactions can propagate up the supply chain, thereby generating a bullwhip effect.

Shortage Gaming

Under normal circumstances, a retailer will only order as much inventory as needed to cover short-term needs; in particular, the inventory needed to cover demand until the next possible replenishment. But it is not always known when the next possible replenishment will occur. If demand is increasing and capacity is constrained, then a retailer may anticipate a long wait for the next possible replenishment. A rational response is to order plenty of inventory, while inventory is potentially available, in case future replenishment opportunities do not materialize.

Imagine a supply chain with one supplier, a hot-selling product, limited capacity, and multiple retailers. Each retailer knows capacity is tight: While it is possible the supplier will have enough capacity to fill all of the retailers' orders, it is quite likely the supplier will not have enough capacity. The retailers also know that if the supplier runs out of capacity, then the supplier will allocate that scarce capacity to the retailers. The supplier may very well use a proportional allocation scheme: A retailer's share of the capacity is proportional to the retailer's order quantity relative to the total order quantity. For example, if a retailer orders 10 units and the other retailers order a total of 40 units, then the retailer will get a one-fifth share of the capacity (10 / (10 + 40)). When this situation occurs with a product, it is often said that the product is *on allocation;* that is, the supplier must allocate capacity because the total amount demanded by retailers exceeds available capacity.

Knowing that a product may be put on allocation, what should a retailer's ordering strategy be? Returning to our example, the retailer wants 10 units but anticipates only one-fifth of that order will be delivered. Hence, if 10 units are ordered, only 2 units will be received, far less than the retailer wants. An obvious solution is to instead order 50 units: If the retailer receives one-fifth of the order, and 50 units are ordered, then the retailer will receive the desired quantity, 10 units. But the other retailers are probably thinking the same thing. So they too may order much more than needed in anticipation of receiving only a fraction of their order. This behavior of ordering more than needed due to the anticipation of a possible capacity shortage is called *shortage gaming* or *order inflation*.

Shortage gaming can result in quite a mess for the supply chain. Some retailers may receive far less than they could sell (because they did not inflate their order enough) while

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others might actually receive much more than they can sell (because they inflated their order too much). For instance, the retailer in our example can order 50 units and actually receive 12 units, still only a fraction of the retailer's order, but 2 units more than wanted. Furthermore, order inflation contributes to the bullwhip effect: Once a supplier's customers believe that capacity may be constrained, the supplier's customers may inflate their orders substantially, thereby creating excessive volatility in the supplier's demand. Interestingly, this may occur even if there is enough capacity to satisfy the retailers' desired quantity; all that is needed to create order inflation is the belief among the retailers that they may not get their full order.

A supplier also can exacerbate the bullwhip effect with her own actions via shortage gaming. For example, suppose a supplier allows retailers to return unsold inventory. With little risk associated with having too much inventory, retailers naturally focus on the risk of having too little inventory, leading them to actively participate in shortage gaming.

Another version of allowing retailers to return orders is to allow them to cancel orders they haven't yet received. With the ability to cancel an order without cost, it is obvious that retailers will submit some orders "just in case" they need the inventory or a shortage materializes. In the industry these orders are sometimes called *phantom orders,* because they are orders that are submitted even though they are likely to disappear, like a phantom.

19.2 The Bullwhip Effect: Mitigating Strategies

This section discusses how firms have changed their business practices to combat the bullwhip effect. In the grocery industry, many of these changes came with the *Efficient Consumer Response* initiative.

Not surprisingly, effective change begins with an understanding of root causes. In the case of the bullwhip effect, we identified five causes in the previous section: order synchronization, order batching, trade promotions, overreactive ordering, and shortage gaming.

Sharing Information

Greater information sharing about actual demand between the stages of the supply chain is an intuitive step toward reducing the bullwhip effect. As we saw in the simulations reported in the previous section, the pattern of retail orders may have very little resemblance to the pattern of retail demand. As a result, when retail orders are fluctuating wildly, it can be extremely difficult for a supplier to correctly forecast demand trends and it is not surprising at all if the supplier overreacts to those data. By giving the supplier frequent access to actual consumer demand data, the supplier can better assess trends in demand and plan accordingly.

But sharing current demand data is often not enough to mitigate the bullwhip effect. Demand also can be influenced by retailer actions on pricing, merchandizing, promotion, advertising, and assortment planning. As a result, a supplier cannot accurately forecast sales for a product unless the supplier knows what kind of treatment that product will receive from its retailers. Without that information, the supplier may not build sufficient capacity for a product that the retailers want to support, or the supplier may build too much capacity of a product that generates little interest among the retailers. Both errors may be prevented if the supplier and retailers share with each other their intentions. This sharing process is often labeled *collaborative planning, forecasting, and replenishment (CPFR).*

While it is quite useful for a retailer to share information with its upstream suppliers, it also can be useful for a supplier to share information on availability with its downstream retailers. For example, a supplier may be aware of a component shortage that will lead to a shortage in a product that a retailer intends to promote. By sharing that information, the

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retailer could better allocate its promotional effort. It also can be useful to share information when the supplier knows that a capacity shortage will not occur, thereby preventing some shortage gaming.

Smoothing the Flow of Product

It is important to recognize that information sharing is quite helpful for reducing the bullwhip effect, but it is unlikely to eliminate it. The bullwhip effect is also a result of physical limitations in the supply chain like order synchronization and order batching.

Order synchronization can be reduced by eliminating reasons why retailers may wish to order at the same time (such as trade promotions). Coordinating with retailers to schedule them on different order cycles also helps.

Reducing order batching means smaller and more frequent replenishments. Unfortunately, this objective conflicts with the desire to control ordering, transportation, and handling costs. The fixed cost associated with each order submitted to the supplier can be reduced with the use of computerized automatic replenishment systems for deciding when and how much to order. In addition, some kind of technology standard, like *electronic data interchange (EDI),* is needed so that orders can be transmitted in an electronic format that can be received by the supplier.

Transportation costs can conflict with small batches because the cost of a truck shipment depends little on the amount that is shipped. Hence, there are strong incentives to ship in full truckloads. There are also economies of scale in handling inventory, which is why it is cheaper to ship in cases than in individual units and cheaper to move pallets rather than individual cases. So the trick is to find a way to have more frequent replenishments while still controlling handling and transportation costs.

One solution is for multiple retailers to consolidate their orders with a supplier through a distributor. By ordering from a distributor rather than directly from a supplier, a retailer can receive the supplier's products on a more frequent basis and still order in full truckloads. The difference is that with direct ordering, the retailer is required to fill a truck with the supplier's products whereas by going through a distributor, the retailer can fill a truck with product from multiple suppliers that sell through that distributor.

Eliminating Pathological Incentives

As we saw in the previous section, trade promotions provide an extremely strong incentive for a retailer to forward buy and forward buying creates a substantial bullwhip effect. A constant wholesale price completely eliminates this incentive. Furthermore, a constant wholesale price might not even cost the supplier too much in revenue, especially if the majority of the retailers never purchased at the regular price.

However, there are perceived negatives associated with eliminating trade promotions. Suppliers began using trade promotions to induce retailers to offer consumer promotions with the objective of using these consumer promotions to increase final consumer demand. And, in fact, trade promotion did succeed somewhat along these lines: Most retailers would cut the retail price during a trade promotion, thereby passing on at least a portion of the deal to consumers. Hence, if trade promotions can no longer be used to induce retailers to conduct consumer promotions, and if consumer promotions are deemed to be necessary, then suppliers must develop some other tool to generate the desired consumer promotions.

Generous returns and order cancellation policies are the other self-inflicted pathological incentives because they lead to shortage gaming and phantom ordering. One solution is to either eliminate these policies or at least make them less generous. For example, the supplier could agree to only partially refund returned units or limit the number of units that can be returned or limit the time in which they can be returned. The supplier also could impose an order cancellation penalty or require a nonrefundable deposit when orders are submitted.

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Shortage gaming also can be eliminated by forgoing retailer orders altogether. To explain how this could work, suppose a supplier knows that a product will be on allocation, which means that each retailer will want more than it can receive. So the supplier does not even bother collecting retailer orders. Instead, the supplier could announce an allocation to each retailer proportional to the retailer's past sales. In the auto industry, this scheme is often called *turn-and-earn:* If a dealer turns a vehicle (i.e., sells a vehicle), then the dealer earns the right to another vehicle. Turn-and-earn allocation achieves several objectives: It ensures the supplier's entire capacity is allocated; it allocates more capacity to the higher-selling retailers, which makes intuitive sense; and it motivates retailers to sell more of the supplier's product. For example, in the auto industry, a supplier can use the allocation of a hot-selling vehicle to encourage a dealer to increase its sales effort for all vehicles so that the dealer can defend its allocation. While this extra motivation imposed on dealers is probably beneficial to the auto manufacturers, it is debatable whether it benefits dealers.

Using Vendor-Managed Inventory

Procter & Gamble and Walmart were among the first companies to identify the bullwhip effect and to take multiple significant steps to mitigate it. (Campbell's Soup was another early innovator in North America.) The set of changes they initiated are often collected under the label *vendor-managed inventory (VMI)*. While many firms have now implemented their own version of VMI, VMI generally includes the following features:

- The retailer no longer decides when and how much inventory to order. Instead, the supplier decides the timing and quantity of shipments to the retailer. The firms mutually agree on an objective that the supplier will use to guide replenishment decisions (e.g., a target in-stock probability). The supplier's "reach" into the retailer can vary: In some applications, the supplier merely manages product in the retailer's distribution center and the retailer retains responsibility of replenishments from the distribution center to the stores. In other applications, the supplier manages inventory all the way down to the retailer's shelves. The scope of the supplier's reach also can vary by application: Generally, the supplier only controls decisions for its own products, but in some cases the supplier assumes responsibility for an entire category, which generally includes making replenishment decisions for the supplier's competitor's products on behalf of the retailer.
- If the supplier is going to be responsible for replenishment decisions, the supplier also needs information. Hence, with VMI the retailer shares with the supplier demand data (e.g., distribution center withdrawals and/or retail store point-of-sale data, POS data for short). The supplier uses those data as input to an automatic replenishment system; that is, a computer program that decides the timing and quantity of replenishments for each product and at each location managed. In addition to normal demand movements, the supplier must be made aware of potential demand shifts that can be anticipated. For example, if the retailer is about to conduct a consumer promotion that will raise the base level of demand by a factor of 20, then the supplier needs to be aware of when that promotion will occur. These computer-guided replenishment systems are often referred to as *continuous replenishment* or *continuous product replenishment.* However, these are somewhat misnomers since product tends to be replenished more frequently but not continuously.
- The supplier and the retailer eliminate trade promotions. This is surely necessary if the retailer is going to give the supplier control over replenishment decisions because a retailer will not wish to forgo potential forward-buying profits. Hence, the adoption of VMI usually includes some agreement that the supplier will maintain a stable price and that price will be lower than the regular price to compensate the retailer for not purchasing on a deal.

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The innovations included in VMI are complementary and are effective at reducing the bullwhip effect. For example, transferring replenishment control from the retailer to the supplier allows the supplier to control the timing of deliveries, thereby reducing, if not eliminating, any order synchronization effects. VMI also allows a supplier to ship in smaller lots than the retailer would order, thereby combating the order-batching cause of the bullwhip. For example, prior to the adoption of VMI, many of Campbell Soup's customers would order three to five pallets of each soup type at a time, where a pallet typically contains about 200 cases. They would order in multiple pallets to avoid the cost of frequent ordering. With VMI Campbell Soup decided to ship fast-moving soups in pallet quantities and slower-moving varieties in mixed pallet quantities (e.g., in one-half- or one-quarter-pallet quantities). Frequent ordering was not an issue for Campbell Soup because they implemented an automatic replenishment system. But Campbell Soup was still concerned about handling and transportation costs. As a result, with VMI Campbell Soup continued to ship in full truckloads, which are about 20 pallets each. However, with VMI each of the 20 pallets could be a different product, whereas before VMI there would be fewer than 20 products loaded onto each truck (because more than one pallet would be ordered for each product). Hence, with VMI it was possible to maintain full truckloads while ordering each product more frequently because each product was ordered in smaller quantities.

In some cases VMI also assists with order batching because it allows the supplier to combine shipments to multiple retailers. Before VMI it would be essentially impossible for two retailers to combine their order to construct a full truckload. But if the supplier has a VMI relationship with both retailers, then the supplier can combine their orders onto a truck as long as the retailers are located close to each other. By replenishing each retailer in smaller than full truckload batches, the supplier reduces the bullwhip effect while still maintaining transportation efficiency.

VMI also can combat the overreaction cause of the bullwhip effect. Because demand information is shared, the supplier is less likely to overreact to changes in the demand. In addition, because VMI is implemented with computer algorithms that codify replenishment strategies, a VMI system is not as emotionally fickle as a human buyer.

While VMI changes many aspects of the supply chain relationship between a supplier and retailer, some aspects of that relationship are generally not disturbed. For example, VMI eliminates trade promotions, but it does not necessarily seek to eliminate consumer promotions. Consumer promotions also can contribute to the bullwhip effect, but there are several reasons why they do not tend to increase volatility as much as trade promotions: Not every retailer runs a consumer promotion at the same time, so order synchronization is not as bad as with a trade promotion, and consumers do not forward buy as much as retailers. In addition, while some companies are willing to forgo trade promotions, only a few are willing to forgo consumer promotions as well: Consumer promotions are viewed as a competitive necessity.

The Countereffect to the Bullwhip Effect: Production Smoothing

Due to the numerous causes of the bullwhip effect, one might expect that the bullwhip effect is a potential problem in nearly any supply chain. But this leads to the following questions: Does the bullwhip effect indeed exist in every supply chain? Is there any natural force that counteracts the bullwhip effect? The short answers are no, the bullwhip effect need not exist everywhere, because there is indeed a force that works to reduce it.

Figure 19.9 shows the monthly inflow and outflow of goods for general merchandisers (such as Walmart, Target, and Kohl's) in the United States over a 10-year period. Outflow of goods is analogous to demand—it is the dollar volume of goods that leaves general

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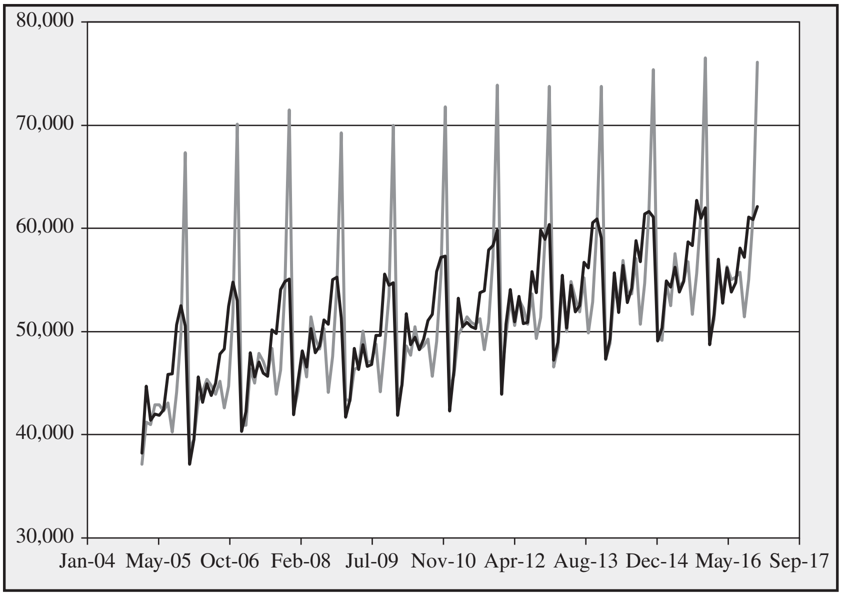
FIGURE 19.9
Inflow and Outflow of Goods to U.S. General Merchandisers

Source: U.S. Census Bureau, Monthly retail trade data.



merchandisers, presumably into the hands of final customers. The inflow of goods is the dollar volume of goods purchased by general merchandisers. The figure reveals that the inflow of goods is actually less variable than the outflow of goods. Put another way, the demand seen by the suppliers of the general merchandisers (the inflow series) is less variable than the demand seen by the general merchandisers themselves (the outflow series)—we do not observe the bullwhip effect (at least at the aggregate level of an entire industry and at the monthly time interval). Why?

Looking at these retailers' demand, we see a noticeable fourth-quarter spike each year, which is particularly strong in November and especially in December. Intuitively, this is the annual holiday season sales surge. This annual spike presents retailers with a significant operational challenge—not only do customers need to be helped, shelves need to be replenished. Replenishing on a just-in-time basis requires a substantial amount of labor, but hiring that many seasonal workers for such a short time would be very expensive (just November and December). Instead, retailers start the process of moving product into their warehouses and stores at the start of the quarter, September and October. Each year, as Figure 19.9 reveals, retailers have a net inflow of goods during those months—inflows are greater than outflows (i.e., they build up their inventory). This prepositioning of inventory allows them to smooth out the inflow of product, thereby reducing the amount of work that needs to be done at the very busiest time of the year. In effect, retailers engage in production smoothing–build inventory during slow times and draw down inventory during hectic times so that the burden on their workforce is not too great. Apparently, it is cheaper to preposition inventory than it is to have large fluctuations in the number of employees. Due to this production-smoothing strategy, the suppliers to these retailers actually experience less volatility in their demand than the retailers do.

In general, when a retailer (or any other firm) faces highly seasonal demand (i.e., predictably variable demand), that retailer will have an incentive to engage in production smoothing. This, as we have seen, will act as a force to counteract the bullwhip effect. Whether this force is strong enough to eliminate the bullwhip effect or not depends on how seasonal demand is and how strong the bullwhip forces are. For general merchandisers, the

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holiday sales spike is sufficiently large and predictable that it overwhelms the bullwhip forces, at least when measured at the industry level and with monthly data. For individual retailers, individual products, and shorter time intervals (weekly or daily), the bullwhip effect may reemerge.

Although seasonality tends to dampen (or eliminate) the bullwhip effect, seasonality is still (almost by definition) a source of variability in the supply chain. But while it creates variability, it does not contribute to amplification—even the suppliers to general merchandisers experience considerable variability and seasonality in their demand, but it is less than the variability faced by their downstream customers.

19.3 Incentive Conflicts in a Sunglasses Supply Chain

The bullwhip effect deteriorates supply chain performance by propagating demand variability up the supply chain. But optimal supply chain performance is also not guaranteed in the absence of the bullwhip effect. This section considers the incentive conflicts that can occur between two firms in a supply chain even without the presence of the bullwhip effect. We illustrate these conflicts with a detailed example based on a supply chain for sunglasses.

Zamatia Ltd. (pronounced zah-MAH-tee-ah, to the cognoscenti) is an Italian upscale maker of eyewear. UV Inc., short for Umbra Visage, is one of their retailers in the United States. To match UV's stylish assortment, UV only operates small boutique stores located in trendy locations. We focus on one of their stores located in Miami Beach, Florida. Zamatia manufactures its sunglasses in Europe and Asia, so the replenishment lead time to the United States is long. Furthermore, the selling season for sunglasses is short and styles change significantly from year to year. As a result, UV receives only one delivery of Zamatia glasses before each season. As with any fashion product, some styles sell out quickly while others are left over at the end of the season.

Consider Zamatia's entry-level sunglasses for the coming season, the Bassano. UV purchases each one of those pairs of sunglasses from Zamatia for \$75 and retails them for \$115. Zamatia's production and shipping costs per pair are \$35. At the end of the season, UV generally needs to offer deep discounts to sell remaining inventory; UV estimates that it will only be able to fetch \$25 per leftover Bassano at the Miami Beach store. UV's Miami Beach store believes this season's demand for the Bassano can be represented by a normal distribution with a mean of 250 and a standard deviation of 125.

UV's procurement quantity decision can be made with the use of the newsvendor model (Chapter 14). Let Q be UV's order quantity. UV's underage cost per unit is $C_u = \$115 - \$75 = \$40$; that is, each lost sale due to underordering costs UV the opportunity cost of \$40. UV's overage cost per unit is $C_o = \$75 - \$25 = \$50$; the consequence of leftover inventory is substantial. UV's critical ratio is

$$\frac{C_u}{C_o + C_u} = \frac{40}{50 + 40} = \frac{4}{9} = 0.4444$$

Hence, to maximize expected profit, UV should choose an order quantity such that 44.4 percent is the probability there is some leftover inventory and 55.6 percent is the probability there is a stockout.

From the Standard Normal Distribution Function Table, we find $\Phi\,(-0.14) = 0.4443$ and $\Phi\,(-0.13) = 0.4483$, so the optimal z-statistic is -0.13 and the optimal order quantity is

$$Q = \mu + z \times \sigma = 250 - 0.13 \times 125 = 234$$

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Using the equations and procedures described in Chapter 14, we also are able to evaluate several performance measures for UV's store:

$$\text{Expected sales(units)} = 192$$
$$\text{Expected leftover inventory} = 42$$
$$\text{Expected profit} = \$5{,}580$$

Zamatia's profit from selling the Bassano at UV's Miami Beach store is $234 \times \$40 = \$9{,}360$, where 234 is the number of Bassano sunglasses that UV purchases and \$40 is Zamatia's gross margin (\$75 − \$35 = \$40).

While Zamatia might be quite pleased with this situation (it does earn \$9,360 relative to UV's \$5,580), it should not be. The total supply chain's profit is \$14,940, but it could be higher. To explain, suppose we choose an order quantity to maximize the supply chain's profit, that is, the combined expected profits of Zamatia and UV. In other words, what order quantity would a firm choose if the firm owned both Zamatia and UV? We call this the *supply chain optimal quantity* because it is the quantity that maximizes the *integrated supply chain*.

We can still use the newsvendor model to evaluate the supply chain's order quantity decision and performance measures. Each lost sale costs the supply chain the difference between the retail price and the production cost, \$115 − \$35 = \$80; that is, the supply chain's underage cost is $C_u = 80$. Each leftover Bassano costs the supply chain the difference between the production cost and the salvage value, \$35 − \$25 = \$10; that is, the supply chain's overage cost is $C_o = 10$. The supply chain's critical ratio is

$$\frac{C_u}{C_o + C_u} = \frac{80}{10 + 80} = 0.8889$$

The appropriate z-statistic for that critical ratio is 1.23 because $\Phi\,(1.22) = 0.8888$ and $\Phi\,(1.23) = 0.8907$. The supply chain's expected profit-maximizing order quantity is then

$$Q = \mu + z \times \sigma = 250 + 1.23 \times 125 = 404$$

which is considerably higher than UV's order of 234 units. The supply chain's performance measures can then be evaluated assuming the supply chain optimal order quantity, 404 units:

$$\text{Expected sales(units)} = 243$$
$$\text{Expected leftover inventory} = 161$$
$$\text{Expected profit} = \$17{,}830$$

Thus, while Zamatia and UV currently earn an expected profit of \$14,940, their supply chain could enjoy an expected profit that is about 19 percent higher, \$17,830.

Why does the current supply chain perform significantly worse than it could? The obvious answer is that UV does not order enough Bassanos: UV orders 234 of them, but the supply chain's optimal order quantity is 404 units. But why doesn't UV order enough? Because UV is acting in its own self-interest to maximize its own profit. To explain further, UV must pay Zamatia \$75 per pair of sunglasses and so UV acts as if the cost to produce each Bassano is \$75, not the actual \$35. From UV's perspective, it does not matter if the actual production cost is \$35, \$55, or even \$0; its "production cost" is \$75. UV correctly recognizes that it only makes \$40 on each sale but loses \$50 on each leftover pair. Hence, UV is prudent to order cautiously.

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TABLE 19.2
UV's Order Quantity *Q* and Performance Measures for Several Possible Wholesale Price Contracts

	Wholesale Price			
	$35	$65	$75	$85
C_u	$80	$50	$40	$30
C_o	$10	$40	$50	$60
Critical ratio	0.8889	0.5556	0.4444	0.3333
z	1.23	0.14	−0.13	−0.43
Q	404	268	234	196
Expected sales	243	209	192	169
Expected leftover inventory	161	59	42	27
Umbra's expected profit	$17,830	$8,090	$5,580	$3,450
Zamatia's expected profit	$0	$8,040	$9,360	$9,800
Supply chain's profit	$17,830	$16,130	$14,940	$13,250

UV's trepidation with respect to ordering is due to a phenomenon called *double marginalization*. Because UV's profit margin ($40) is one of two profit margins in the supply chain, and necessarily less than the supply chain's total profit margin ($80), UV orders less than the supply chain optimal quantity. In other words, because UV only earns a portion ($40) of the total benefit of each sale ($80), UV is not willing to purchase as much inventory as would be optimal for the supply chain.

This example illustrates an important finding:

Even if every firm in a supply chain chooses actions to maximize its own expected profit, the total profit earned in the supply chain may be less than the entire supply chain's maximum profit.

In other words, rational and self-optimizing behavior by each member of the supply chain does not necessarily lead to optimal supply chain performance. So what can be done about this? That is the question we explore next.

There is an obvious solution to get UV to order more Bassanos: Zamatia could reduce the wholesale price. A lower wholesale price increases UV's underage cost (gross margin) and decreases the overage cost (loss on leftover inventory), thereby making stockouts costlier and leftover inventory less consequential. More technically, reducing the wholesale price increases UV's critical ratio, which leads UV to order more. Table 19.2 provides some data on supply chain performance with various wholesale prices.

We indeed see that if Zamatia were to reduce its wholesale price from $75 to $65, then UV would increase its Bassano order from 234 to 268 units. UV is quite happy: Its profit increases from $5,580 to $8,090. Furthermore, the supply chain's profit increases from $14,905 to $16,130. In fact, why stop with a $10 wholesale price reduction? If Zamatia were to reduce the wholesale price down to the production cost, $35, then (1) UV orders the supply chain optimal quantity, 404 units, and (2) the supply chain's profit is optimal, $17,830! That strategy is called *marginal cost pricing* because the supplier only charges the retailer the marginal cost of production.

But while marginal cost pricing is terrific for UV and the supply chain, it is disastrous for Zamatia: By definition, Zamatia's profit plunges to zero with marginal cost pricing.

We now see a classic tension within a supply chain: An increase in one firm's profit might come at the expense of a decrease in the other firm's profit. Some might refer to this distributive situation as a *zero-sum game,* but in fact it is even worse! In a zero-sum game, two parties negotiate over how to split a fixed reward (in this case, the total profit), but in this situation the total amount to be allocated between Zamatia and UV is not even fixed: Increasing Zamatia's profit may result in a smaller total profit to be shared.

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With respect to the allocation of supply chain profit, firms should care about two things:

1. The size of a firm's piece of the "pie," where the pie refers to the supply chain's total profit.
2. The size of the total "pie," that is, the supply chain's total profit.

Number 1 is obvious: Every firm always wants a larger piece of the pie. Number 2 is less obvious. For a fixed piece of the pie, why should a firm care about the size of the pie; that is, the size of the other firm's piece? "Petty jealousy" is not the answer. The answer is that it is always easier to divide a bigger pie: If a pie gets bigger, then it is possible to give everyone a bigger piece; that is, everyone can be better off if the pie is made bigger. In practice this is often referred to as a *win–win* deal, that is, both parties are better off.

Turning back to our discussion of the wholesale price for Zamatia and UV, we see that arguing over the wholesale price is akin to arguing over each firm's piece of the pie. And in the process of arguing over how to divide the pie, the firms may very well end up destroying part of the pie, thereby serving no one. What these firms need is a tool that first maximizes the size of the pie ($17,830) and then allows them to decide how to divide it between them without damaging any part of it. Such a tool is discussed in the next section.

19.4 Buy-Back Contracts

Without changing the wholesale price, Zamatia would get UV to order more Bassano sunglasses if Zamatia could mitigate UV's downside risk of leftover inventory: UV loses a considerable amount ($50) on each unit it is stuck with at the end of the season. One solution is for Zamatia to buy back from UV all leftover sunglasses for a full refund of $75 per pair; that is, Zamatia could offer UV a *buy-back contract,* also called a *returns policy*.

Unfortunately, buy-back contracts introduce new costs to the supply chain. In particular, UV must ship leftover inventory back to Zamatia, which it estimates costs about $1.50 per pair. And then there is the issue of what Zamatia will do with these leftover Bassano sunglasses when it receives them. One possibility is that Zamatia just throws them out, thereby "earning" a zero salvage value on each leftover Bassano. However, Zamatia may be able to sell a portion of its leftover inventory to a European retailer that may be experiencing higher sales or Zamatia may be able to collect some revenue via an outlet store. It is even possible that Zamatia has higher salvage revenue from each Bassano at the end of the season than UV. But let's suppose Zamatia is able to earn $26.50 per Bassano at the end of the season. Hence, from the perspective of the supply chain, it does not matter whether UV salvages these sunglasses at the end of the season (which earns $25) or if Zamatia salvages these sunglasses at the end of the season (which also earns $25, net of the shipping cost). In contrast, Zamatia and UV might care which firm does the salvaging of leftover inventory. We later expand upon this issue.

Let's begin the analysis of UV's optimal order quantity given the buy-back contract. UV's underage cost with this buy-back contract is still the opportunity cost of a lost sale, which is $C_u = \$115 - \$75 = \$40$. However, UV's overage cost has changed. Now UV only loses $1.50 per leftover pair due to Zamatia's generous full refund returns policy, $C_o = \$1.50$. UV's critical ratio is

$$\frac{C_u}{C_o + C_u} = \frac{40}{1.5 + 40} = 0.9639$$

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With a critical ratio of 0.9639, the optimal z-statistic is 1.8 (i.e., $\Phi(1.79) = 0.9633$ and $\Phi(1.8) = 0.9641$), so UV's optimal order quantity is now

$$Q = \mu + z \times \sigma = 250 + 1.8 \times 125 = 475$$

We can evaluate UV's expected profit and discover that it has increased from $5,580 (with no refund on returns) to $9,580 with the returns policy. Furthermore, with an order quantity of 475 units, UV's expected leftover inventory is 227 units.

Zamatia has surely provided an incentive to UV to increase its order quantity, but is this offer also good for Zamatia? Zamatia's expected profit has several components: It sells 475 units to UV at the beginning of the season, which generates $475 × $75 = $35,625 in revenue; its production cost is 475 × $35 = $16,625; it expects to pay UV 227 × $75 = $17,025 to buy back the expected 227 units of leftover inventory; and it collects 227 × $26.5 = $6,016 in salvage revenue. Combining those components together yields an expected profit of $7,991 for Zamatia, which is *lower* than Zamatia's profit without the returns policy, $9,350.

How did Zamatia go wrong with this buy-back contract? Zamatia did encourage UV to order more Bassano sunglasses by reducing UV's exposure to leftover inventory risk. But Zamatia reduced that risk so much that UV actually ordered more than the supply chain optimal quantity, thereby setting Zamatia up for a large bill when leftover inventory gets shipped back. Is there a compromise between the wholesale price contract with too little inventory and the full refund buy-back contract with too much inventory? (Of course there is.)

Instead of giving a full refund on returned inventory, Zamatia could give a partial refund. For example, suppose Zamatia offers to buy back inventory from UV for $65 per pair. This is still not a bad deal for UV. Its underage cost remains $C_u = 40$, but now its overage cost is $C_o = \$1.50 + \$75 - \$65 = \$11.50$: Each unit left over costs UV the $1.50 to ship back and due to the partial credit, it loses an additional $10 per unit. Table 19.3 provides data on UV's optimal order quantity, expected sales, expected leftover inventory, and expected profit. The table also indicates Zamatia's profit with this partial refund is $9,528, which is slightly better than its profit without a buy-back at all. Furthermore, the supply chain's total profit has jumped to $17,600, which is reasonably close to the maximum profit, $17,830. One way to evaluate the quality of a contract is by its *supply chain efficiency,* which is the fraction of the optimal profit the supply chain achieves. In this case, efficiency is 17,600 / 17,830 = 99 percent; that is, the supply chain earns 99 percent of its potential profit.

Instead of holding the wholesale price fixed and reducing the buy-back price, Zamatia could hold the buy-back price fixed and increase the wholesale price. For example, it could

TABLE 19.3 UV's Order Quantity Q and Performance Measures for Several Possible Wholesale Price Contracts

Wholesale price	$75	$75	$75	$85
Buy-back price	$55	$65	$75	$75
C_u	$40	$40	$40	$30
C_o	$21.50	$11.50	$1.50	$11.50
Critical ratio	0.6504	0.7767	0.9639	0.7229
z	0.39	0.77	1.80	0.60
Q	299	346	475	325
Expected sales	221	234	248	229
Expected leftover inventory	78	112	227	96
Expected profits:				
Umbra	$7,163	$8,072	$9,580	$5,766
Zamatia	$9,737	$9,528	$7,990	$11,594
Supply chain	$16,900	$17,600	$17,570	$17,360

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increase the wholesale price to \$85 and still agree to buy back inventory for \$75. That contract indeed works well for Zamatia: it earns a whopping \$11,594. It even is not a bad deal for UV: its profit is \$5,766, which is still better than the original situation without any refund on returned inventory. But overall supply chain performance has slipped a bit: efficiency is now only 17,360 / 17,830 = 97 percent.

While we seem to be making some progress, we also seem to be fishing around without much guidance. There are many possible combinations of wholesale prices and buy-back prices, so what combinations should we be considering? Recall from the previous section that our objective should be to maximize the size of the pie and then worry about how to divide it. Every firm can be given a bigger piece if the pie is made bigger. So let's first look for wholesale/buy-back price combinations that maximize supply chain profit. In other words, we are looking for a wholesale price and a buy-back price such that UV's expected profit-maximizing order quantity given those terms is the supply chain optimal order quantity, 404 Bassanos. If we find such a contract, then we say that contract "coordinates the supply chain" because the supply chain achieves 100 percent efficiency; that is, it earns the maximum supply chain profit.

We could hunt for our desired wholesale/buy-back price combinations in Excel (for every wholesale price, slowly adjust the buy-back price until we find the one that makes UV order 404 Bassanos), or we could take a more direct route by using the following equation:

$$\text{Buy-back price} = \text{Shipping cost} + \text{Price} - (\text{Price} - \text{Wholesale price}) \times \left(\frac{\text{Price} - \text{Salvage value}}{\text{Price} - \text{Cost}}\right) \quad \textbf{(19.1)}$$

In other words, if we have chosen a wholesale price, then Equation (19.1) gives us the buy-back price that would cause UV to choose the supply chain optimal order quantity. In that case, the pie would be maximized; that is, we coordinate the supply chain and supply chain efficiency is 100 percent! (If you are curious about how to derive Equation (19.1), see Appendix D.)

Let's evaluate Equation (19.1) with the wholesale price of \$75:

$$\text{Buy-back price} = \$1.50 + \$115 - (\$115 - \$75) \times \left(\frac{\$115 - \$25}{\$115 - \$35}\right) = \$71.50$$

Hence, if the wholesale price is \$75 and Zamatia agrees to buy back leftover inventory for \$71.50 per pair, then UV orders 404 Bassano sunglasses and the supply chain earns the maximum profit, \$17,830.

Table 19.4 provides performance data for several different wholesale prices assuming Equation (19.1) is used to choose the buy-back price.

Interestingly, with a wholesale price of \$75, the firms split the supply chain's profit, that is, each earns \$8,915. In that case, UV does much better than just a wholesale price contract, but Zamatia does worse. However, both firms do significantly better with the wholesale price of \$85 and the buy-back price of \$82.75 than they do with the original contract we considered (just a \$75 wholesale price and no buy-back).

Table 19.4 reveals some remarkable observations:

- There are many different wholesale price/buy-back price pairs that maximize the supply chain's profit. In other words, there are many different contracts that achieve 100 percent supply chain efficiency.

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TABLE 19.4 Performance Measures When the Buy-Back Price Is Chosen to Coordinate the Supply Chain—To Ensure 100 Percent Supply Chain Efficiency

Wholesale price	$35	$45	$55	$65	$75	$85	$95	$105
Buy-back price	$26.50	$37.75	$49.00	$60.25	$71.50	$82.75	$94.00	$105.25
C_u	$80	$70	$60	$50	$40	$30	$20	$10
C_o	$10.00	$8.75	$7.50	$6.25	$5.00	$3.75	$2.50	$1.25
Critical ratio	0.8889	0.8889	0.8889	0.8889	0.8889	0.8889	0.8889	0.8889
z	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
Q	404	404	404	404	404	404	404	404
Expected sales	243	243	243	243	243	243	243	243
Expected leftover inventory	161	161	161	161	161	161	161	161
Expected profits:								
Umbra	$17,830	$15,601	$13,373	$11,144	$8,915	$6,686	$4,458	$2,229
Zamatia	$0	$2,229	$4,458	$6,686	$8,915	$11,144	$13,373	$15,601
Supply chain	$17,830	$17,830	$17,830	$17,830	$17,830	$17,830	$17,830	$17,830

- Virtually any allocation of the supply chain's profit between the two firms is feasible; that is, there exist contracts that give the lion's share of the profit to the supplier, contracts that equally divide the profit, and contracts that give the lion's share to the retailer.
- The firms now truly do face a zero-sum game; that is, increasing one firm's profit means the other firm's profit decreases. However, at least now the sum that they can fight over is the maximum possible.

Which contracts will the firms ultimately agree upon? We cannot really say. If Zamatia is the better negotiator or if it is perceived to have more bargaining power than UV, then we would expect Zamatia might get UV to agree to a buy-back contract with a high wholesale price. Even though Zamatia's profit can increase substantially, it is important to note that UV's profit also may increase relative to the status quo because buy-back contracts increase the size of the pie. However, if UV has the stronger negotiating skills, then it is possible UV will secure a contract that it favors (a buy-back contract with a low wholesale price).

19.5 More Supply Chain Contracts

The previous section focused on buy-back contracts, but those are not the only type of contracts that are implemented in supply chains. This section briefly describes several other types of contracts and how they may alleviate supply chain incentive conflicts. This is by no means an exhaustive list of the types of contracts that are observed in practice.

Quantity Discounts

Quantity discounts are quite common, but they come in many different forms. For example, with an all-unit quantity discount, a buyer receives a discount on all units if the quantity ordered exceeds a threshold; whereas with an incremental quantity discount, a buyer receives a discount on all units purchased above a threshold. No matter the form, quantity discounts encourage buyers to order additional inventory because the purchase price of the last unit purchased is decreasing with the amount purchased. (See Section 5.6.) In the context of the newsvendor model, a quantity discount increases the underage cost, thereby increasing the critical ratio. In contrast, recall that the buy-back contract increases the critical ratio by decreasing the overage cost.

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Options Contracts

With an options contract, a buyer pays one price to purchase options, say w_o, and another price to exercise the purchased options, w_e. These contracts are often used when a buyer wants a supplier to build capacity well in advance of the selling season. At that time, the buyer has only an uncertain forecast of demand. As the selling season approaches, the buyer anticipates that she will have a much better demand forecast, but by then it is too late to build additional capacity if demand is quite high. Without the options contract, the supplier bears all of the supply chain's risk, so the supplier is likely to build too little capacity. The options contract allows the firms to share the risk of demand–supply mismatches: The supplier earns at least something upfront (the option's price) while the buyer doesn't have to pay for all of the unused capacity (the exercise price is paid only on capacity actually exercised). Hence, just as with buy-back contracts, options contracts are able in some settings to achieve 100 percent supply chain efficiency (i.e., the supplier builds the right amount of capacity) and arbitrarily divide the supply chain's profit between the two firms (i.e., there is more than one options contract that achieves supply chain coordination).

Revenue Sharing

With revenue sharing, a retailer pays a wholesale price per unit purchased to a supplier but then also pays a portion of the revenue earned on that unit to the supplier. As with buy-back contracts, revenue sharing allows the firms in the supply chain to share the risk of demand–supply mismatches: The retailer pays something to the supplier upfront (the wholesale price) but only pays an additional amount if the unit actually generates revenue (the revenue share).

Quantity Flexibility Contracts

Consider an ongoing relationship between a buyer and a supplier. For example, the buyer is Sun Microsystems, the supplier is Sony, and the product is a monitor. Sun's demand fluctuates over time, but Sun nevertheless wants Sony to build enough capacity to satisfy all of Sun's needs, which could be either higher or lower than forecasted. But since Sun probably doesn't incur the cost of idle capacity, Sun is biased toward giving Sony overly rosy forecasts in the hope that Sony will respond to the forecast by building extra capacity. But Sony is no fool; that is, Sony knows that Sun is biased toward optimistic forecasts and so Sony may view Sun's forecasts with a skeptical eye. Unfortunately, Sun may actually have an optimistic forecast, but due to its lack of credibility with Sony, Sony may not respond with additional capacity.

The problem in this relationship is that Sony bears the entire risk of excess capacity; hence, Sun is biased toward rosy forecasts. One solution is to implement *quantity flexibility (QF) contracts:* with a QF contract, Sun provides an initial forecast but then must purchase some quantity within a certain percentage of that forecast. For example, suppose the firms agree to a 25 percent QF contract. Furthermore, it is the first quarter of the year and Sun forecasts its demand for the fourth quarter will be 2,000 units. By the time the fourth quarter rolls around, Sun is committed to purchasing from Sony at least 1,500 units (75 percent of the forecast) and Sony is committed to delivering up to 2,500 units (125 percent of the forecast) should Sun need more than the forecast. If demand turns out to be low, Sony is somewhat protected by the lower collar, whereas if demand turns out to be high, Sun can take advantage of that upside by knowing that Sony has some additional capacity (up to the upper collar). Hence, via quantity flexibility contracts, it can be shown that both firms are better off; that is, the supply chain pie gets bigger and each firm gets a bigger share.

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Price Protection

In the tech industry, distributors are concerned with holding too much inventory because that inventory could become obsolete; that is, they must sell that inventory at deeply discounted prices. But there is another concern with holding too much inventory. Suppose a distributor purchases 1,000 units today at $2,000 each, but one week later the supplier cuts the price to $1,800. Unless the distributor sells the entire batch of 1,000 units in the next week, the distributor would be better off to purchase fewer units at $2,000 and to purchase the remainder one week later at $1,800. In other words, the tendency of suppliers to cut their wholesale prices frequently and without notice creates an incentive among distributors to be cautious in the purchase quantities. If distributors then curtail their purchases below the supply chain optimal amount, it can be beneficial to provide them with an incentive to increase their order quantities.

Allowing distributors to return inventory helps to encourage distributors to order more inventory, but it is not the only way. *Price protection* is another way: With price protection, a supplier compensates the distributor for any price reductions on remaining inventory. For example, suppose at the end of the week the distributor sold 700 units purchased at $2,000, but has 300 units remaining. With price protection, the supplier would then send the distributor a check for 300 × ($2,000 − $1,800) = $60,000. In other words, the distributor becomes indifferent between purchasing 1,000 units for $2,000 now and purchasing 700 units for $2,000 now and 300 units for $1,800 in one week.

19.6 Summary

Optimal supply chain performance is not guaranteed even if every firm in the supply chain optimizes its own performance. Self-interest and decentralized decision making do not naturally lead to 100 percent supply chain efficiency. As a result, firms in a supply chain can benefit from better coordination of their actions.

The bullwhip effect (the propagation of demand variability up the supply chain) provides a serious challenge to supply chain operations. There are many causes of the bullwhip effect (order synchronization, order batching, trade promotions, overreactive ordering, and shortage gaming) and more than one of them can be present at the same time. Solutions to the bullwhip effect such as sharing demand information, removing pathological incentives, and vendor-managed inventory are designed to combat those root causes.

The bullwhip effect is not the only challenge posed upon supply chains. Given the terms of trade between supply chain members, it is quite possible that supply chain actions will not be taken because of conflicting incentives. For example, with a simple wholesale price contract, it is generally found that the retailer's incentive to order inventory leads it to order less than the supply chain optimal amount of inventory, a phenomenon called double marginalization. Fortunately, incentive conflicts can be alleviated or even eliminated with the use of carefully designed contractual terms such as buy-back contracts.

19.7 Further Reading

For a description of the causes, consequences, and solutions to the bullwhip effect, see Lee, Padmanabhan, and Whang (1997).

Buzzell, Quelch, and Salmon (1990) provide a history of trade promotions and discuss their pros and cons.

For the original research on buy-back contracts, see Pasternack (1985). For a more managerial description of the application of buy-back contracts, see Padmanabhan and Png (1995). For a review of the theoretical literature on supply chain contracting, see Cachon (2004).

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19.8 Practice Problems

The following questions will help in testing your understanding of this chapter. After each question, we show the relevant section in parentheses [Section x].

Solutions to problems marked with an "*" are available in Appendix E. Video solutions to select problems are available in Connect.

Q19.1* **(Buying Tissues)** Procter & Gamble, the maker of Puffs tissues, traditionally sells these tissues for $9.40 per case, where a case contains eight boxes. A retailer's average weekly demand is 25 cases of a particular Puffs SKU (color, scent, etc.). P&G has decided to change its pricing strategy by offering two different plans. With one plan, the retailer can purchase that SKU for the everyday-low wholesale price of $9.25 per case. With the other plan, P&G charges the regular price of $9.40 per case throughout most of the year, but purchases made for a single delivery at the start of each quarter are given a 5 percent discount. The retailer receives weekly shipments with a one-week lead time between ordering and delivery. Suppose with either plan the retailer manages inventory so that at the end of each week there is on average a one-week supply of inventory. Holding costs are incurred at the rate of 0.4 percent of the value of inventory at the end of each week. Assume 52 weeks per year.

a. Suppose the retailer chose the first plan ($9.25 per case throughout the year). What is the retailer's expected annual purchasing and inventory holding cost? [19.1]
b. Suppose the retailer chooses the second plan and only buys at the discount price ($9.40 is the regular price and a 5 percent discount for delivery at the start of each quarter). What is the retailer's expected annual purchasing and inventory holding cost? [19.1]
c. Consider the first plan and propose a new everyday-low wholesale price. Call this the third plan. Design your plan so that both P&G and the retailer prefer it relative to the second plan. [19.1]

Q19.2* **(Returning books)** Dan McClure is trying to decide on how many copies of a book to purchase at the start of the upcoming selling season for his bookstore. The book retails at $28.00. The publisher sells the book to Dan for $20.00. Dan will dispose of all of the unsold copies of the book at 75 percent off the retail price, at the end of the season. Dan estimates that demand for this book during the season is normal with a mean of 100 and a standard deviation of 42.

a. How many books should Dan order to maximize his expected profit? [19.3]
b. Given the order quantity in part a, what is Dan's expected profit? [19.3]
c. The publisher's variable cost per book is $7.50. Given the order quantity in part a, what is the publisher's expected profit? [19.3]

The publisher is thinking of offering the following deal to Dan. At the end of the season, the publisher will buy back unsold copies at a predetermined price of $15.00. However, Dan would have to bear the costs of shipping unsold copies back to the publisher at $1.00 per copy.

d. How many books should Dan order to maximize his expected profits given the buyback offer? [19.4]
e. Given the order quantity in part d, what is Dan's expected profit? [19.4]
f. Assume the publisher is able on average to earn $6 on each returned book net the publisher's handling costs (some books are destroyed while others are sold at a discount and others are sold at full price). Given the order quantity in part d, what is the publisher's expected profit? [19.4]
g. Suppose the publisher continues to charge $20 per book and Dan still incurs a $1 cost to ship each book back to the publisher. What price should the publisher pay Dan for returned books to maximize the supply chain's profit (the sum of the publisher's profit and Dan's profit)? [19.4]

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Q19.3 **(Component options)** Handi Inc., a cell phone manufacturer, procures a standard display from LCD Inc. via an options contract. At the start of quarter 1 (Q1), Handi pays LCD $4.50 per option. At that time, Handi's forecast of demand in Q2 is normally distributed with mean 24,000 and standard deviation 8,000. At the start of Q2, Handi learns exact demand for Q2 and then exercises options at the fee of $3.50 per option, (for every exercised option, LCD delivers one display to Handi). Assume Handi starts Q2 with no display inventory and displays owned at the end of Q2 are worthless. Should Handi's demand in Q2 be larger than the number of options held, Handi purchases additional displays on the spot market for $9 per unit.

For example, suppose Handi purchases 30,000 options at the start of Q1, but at the start of Q2 Handi realizes that demand will be 35,000 units. Then Handi exercises all of its options and purchases 5,000 additional units on the spot market. If, on the other hand, Handi realizes demand is only 27,000 units, then Handi merely exercises 27,000 options.

a. Suppose Handi purchases 30,000 options. What is the expected number of options that Handi will exercise? [19.5]

b. Suppose Handi purchases 30,000 options. What is the expected number of displays Handi will buy on the spot market? [19.5]

c. Suppose Handi purchases 30,000 options. What is Handi's expected total procurement cost? [19.5]

d. How many options should Handi purchase from LCD? [19.5]

e. What is Handi's expected total procurement cost given the number of purchased options from part d? [19.5]

Q19.4 **(Selling Grills)** Smith and Jackson Inc. (SJ) sells an outdoor grill to Cusano's Hardware Store. SJ's wholesale price for the grill is $185. (The wholesale price includes the cost of shipping the grill to Cusano). Cusano sells the grill for $250 and SJ's variable cost per grill is $100. Suppose Cusano's forecast for season sales can be described with a Poisson distribution with mean 8.75. Furthermore, Cusano plans to make only one grill buy for the season. Grills left over at the end of the season are sold at a 75 percent discount.

a. How many grills should Cusano order? [19.3]

b. What is Cusano's expected profit given Cusano's order in part a? [19.3]

c. What is SJ's expected profit given Cusano's order in part a? [19.3]

d. To maximize the supply chain's total profit (SJ's profit plus Cusano's profit), how many grills should be shipped to Cusano's Hardware? [19.3]

Suppose SJ were to accept unsold grills at the end of the season. Cusano would incur a $15 shipping cost per grill returned to SJ. Among the returned grills, 45 percent of them are damaged and SJ cannot resell them the following season, but the remaining 55 percent can be resold to some retailer for the full wholesale price of $185.

e. Given the possibility of returning grills to SJ, how many grills should be sent to Cusano's to maximize the supply chain's total profit? [19.4]

Suppose SJ gives Cusano a 90 percent credit for each returned grill; that is, SJ pays Cusano $166.50 for each returned grill. Cusano still incurs a $15 cost to ship each grill back to SJ.

f. How many grills should Cusano order to maximize his profit? [19.4]

g. What is Cusano's expected profit given Cusano's order in part f? [19.4]

h. What is SJ's expected profit given Cusano's order in part f? [19.4]

i. To maximize the supply chain's total profit, what should SJ's credit percentage be? (The current credit is 90 percent.) [19.4]

Dave Luna, the director of marketing and sales at SJ, suggests yet another arrangement. He suggests that SJ offer an advanced purchase discount. His plan works as follows: There is a 10 percent discount on any grill purchased before the season starts (the prebook order),

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but then retailers are able to purchase additional grills as needed during the season at the regular wholesale price (at-once orders). With this plan, retailers are responsible for selling any excess grills at the end of the season; that is, SJ will not accept returns. Assume SJ makes enough grills to satisfy Cusano's demand during the season and any leftover grills can be sold the next season at full price.

j. Given this advanced purchase discount plan, how many grills should Cusano prebook to maximize his profit? [19.5]

k. What is Cusano's expected profit given Cusano's prebook order quantity in part j? [19.5]

l. What is SJ's expected profit from sales to Cusano this season given Cusano's prebook order quantity in part j? [19.5]

m. As a thought experiment, which one of these contractual arrangements would you recommend to SJ? [19.5]

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