Supply Chain Simulation Games

The goal of supply chain management is to match supply with demand effectively by coordinating the activities of multiple firms involved in the production, distribution, and sales of a physical good. The performance of a supply chain depends on how well the material flows, information flows, and financial flows within the supply chain are coordinated. The intertwined relationships between these flows have made this coordination process challenging in practice. To demonstrate the challenge of coordination between the material and information flows to students, the “Beer Game” is often employed in operations management (OM) courses. While a supply chain includes financial flows, they are seldom discussed in the OM curriculum. The recent financial crisis has demonstrated the importance of incorporating financial flows into operations decisions – many supply chains were disrupted because upstream firms failed to maintain their normal operations due to financial illiquidity. To illustrate the importance of considering financial flows when making inventory decisions, we augment the Beer Game by incorporating cash flows. We refer to this revised game as Cash Beer Game.

This note starts with an inventory model with cash flows that sets the stage for the formulation of both games. We provide a condition under which the inventory decision and cash flows can be decoupled. This result leads to the standard inventory model in the literature as well as the Beer Game. On the other hand, when this condition does not hold, the cash flow does influence the inventory decision. This motivates the formulation of the Cash Beer Game. Section 2 discusses the pedagogical goals, and illustrates the rules and settings of the games. Section 3 depicts how both games are delivered in sequence in the classroom and provides screen shots of key steps. Section 4 discusses lessons from past teaching.

1. An Inventory Model with Cash Flows

Consider a firm facing nonstationary random demand in a finite horizon. At the beginning of each period, an order is placed to meet the uncertain demand. The objective is to maximize the expected net worth at the end of the horizon. For simplicity, let us assume the firm has no investment activities other than investing in inventory and in the money markets with the cash it accumulates. Thus, the objective is equivalent to maximizing the expected working capital at the end of the horizon. Different objectives have been proposed in the textbooks. For example, Baye and Prince (2014) define that the value of a firm is the present value of the firm’s current and future profits. As we shall see later, this objective is equivalent to maximizing the expected terminal working capital we assume here. In some corporate finance textbooks, the value of a firm is defined as the present value of the total dividend payments. Notice that the dividend payment cycle for most firms is on a quarterly or bi-annual basis, whereas the inventory order decision is mostly on a daily or weekly basis. Thus, our objective of maximizing the asset of the firm does not contradict the latter perspective as the firm can
maximize its asset for better utilizing its dividend policy (i.e., either paying dividends with cash or keeping cash as retained earnings) at the end of the planning horizon.

Without loss of generality, we assume that the order lead time is zero. Define the following parameters for the system.

\[
\begin{align*}
    h_p &= \text{physical holding cost rate ($/unit/period);} \\
    b_p &= \text{physical backorder cost rate ($/unit/period);} \\
    r &= \text{interest return rate for investing in the money market;} \\
    d &= \text{borrowing rate from the capital market, where } d \geq r; \\
    p &= \text{unit selling price;} \\
    c &= \text{unit purchase cost.}
\end{align*}
\]

Here, the physical holding cost rate \( h_p \) refers to the costs related to storing and maintaining inventory, insurances, shrinkage, etc. average out total units sold over a certain period of time. There are more discussions on assessing the costs later in this note. For now, let’s view \( h_p \) as the cost rate that does not include the financial opportunity cost due to holding inventory. The physical backorder cost rate \( b_p \) should be viewed the same way – it is the tangible, monetary penalty costs related to backlogging, e.g., expediting delivery costs.

We count the time forward, i.e., \( t = 1, 2, ..., t, t + 1, ... T \), where \( T \) is the end of the horizon. Let \( D_t \) is the demand occurred in period \( t \). To examine the system dynamics, we introduce the following state variables:

\[
\begin{align*}
    x_t &= \text{net inventory level at the beginning of period } t; \\
    w'_t &= \text{net cash level at the beginning of period } t; \\
    w_t &= \text{working capital at the beginning of period } t = w'_t + cx_t.
\end{align*}
\]

Let \( y_t \) is the inventory position after ordering, and the order quantity is \( (y_t - x_t) \). Define the inventory-related cost and the cash-related gain in period \( t \):

\[
\begin{align*}
    G_t(y_t) &= \text{inventory-related cost;} \\
    R_t(y_t) &= \text{cash-related gain.}
\end{align*}
\]

where \( x^+ = \max\{x, 0\}, x^- = -\min\{x, 0\} \), and \( \mathbb{E}[\cdot] \) is the expected value over the random demand. The first term \( (y_t - D_t)^+ \) in the \( G_t \) function is the on-hand inventory at the end of the period, whereas the second term \( (y_t - D_t)^- \) is the backorder level. The \( G_t \) function represents the inventory holding and backorder cost, or the inventory-related cost in short in period \( t \). Similarly, the term \( (w'_t - c(y_t - x_t))^+ - d(w'_t - c(y_t - x_t))^- \) in the \( R_t \) function is the net cash level after inventory payment. It yields an interest gain \( r \) if positive and an interest loss \( d \) if negative (representing the borrowing rate from financial institutions in order to pay the ordered inventory). The \( R_t \) function is the cash-related gain in period \( t \).
The transitions of the inventory and cash states between periods are as follows:

\[ x_{t+1} = y_t - D_t, \]  
\[ w_{t+1} = w_t' - c(y_t - x_t) + pD_t + R_t(y_t) - G_t(y_t) \]

\[ = \left(1 + r\right)\left(w_t' - c(y_t - x_t)\right) + \left(1 + d\right)\left(w_t' - c(y_t - x_t)\right) + pD_t - G_t(y_t). \]  

Equation (2) states that the next period’s net cash is the result of total cash inflows and outflows of the current period. Here, we assume that the customer will pay on order so the revenue is \( pD_t \). If there is debt, i.e., \( w_t' - c(y_t - x_t) \) is negative, it will incur an interest loss and this debt will carry over to the next period.

The net working capital is

\[ w_{t+1} = \left(1 + r\right)(w_t - cy_t)^+ - \left(1 + d\right)(w_t - cy_t)^- + pD_t - G_t(y_t) + c(y_t - D_t) \]

\[ = \left(1 + r\right)w_t + \left(p - c\right)D_t - rcy_t - G_t(y_t) - \left(d - r\right)(w_t - cy_t)^- \]

\[ = w_t + \left(p - c\right)D_t - G_t(y_t) + r(w_t - cy_t)^+ - d(w_t - cy_t)^-. \]

So far, we have considered a very practical and general environment for a firm that can invest and borrow with different rates.

1.1 Perfect Financial Markets

Let’s consider a special case in which the financial market is perfect.\(^2\) In our model, this is equivalent to assuming that \( r = d \), i.e., the interest return rate is equal to the borrowing rate. In this case, the firm can freely borrow cash so cash is no longer a concern. This is exactly what the classic inventory model assumes. With this assumption, Equation (4) becomes

\[ (1 + r)w_t + (p - c)D_t - rcy_t - G_t(y_t) \]

\[ = (p - c(1 + r))D_t + (1 + r)w_t - (hp + rc)(y_t - D_t)^+ - (bp - rc)(y_t - D_t)^-. \]  

Notice that \( D_t \) is an exogenous random variable, and \( w_t \) is the initial system state at the beginning of period \( t \). Thus, to maximize the expected working capital in period \( t + 1 \), one only needs to minimize the expected cost in Equation (5), i.e.,

\[ \mathbf{E}[(hp + rc)(y_t - D_t)^+ + (bp - rc)(y_t - D_t)^-]. \]

Equation (6) is the single-period inventory-related cost in in the classic inventory model. We have a sound economic meaning for the cost parameters. The holding cost rate \( h \) is \((hp + rc)\),

\(^2\)Modigliani and Miller (1958) show that if the financial markets are perfect (no frictions), i.e., absence of taxes, bankruptcy costs, agency costs, asymmetric information, the value of a firm is unaffected by how that firm is financed. This is often referred to the capital structure irrelevance principle. Notice that the value of the firm is often created by the operations activities. In other words, this principle basically suggests that operations decisions may be decoupled from finance decisions. Unfortunately, it is not possible that the markets are of no frictions. In our inventory model, the friction comes from the fact that \( d \) is larger than \( r \) as the financial institutions have to make a non-zero profit.
which is the sum of the physical holding cost rate $h_p$ and the opportunity cost of capital $rc$ due to inventory investment. The backorder cost rate $b$ is $(b_p - rc)$, which is the physical backorder cost minus the opportunity cost of capital $rc$.\footnote{It can be shown that the discount rate $\alpha$ is equal to $1/(1 + r)$.} It can be shown that a base-stock policy is optimal. In the Fuqua teaching note An Introduction to Inventory Management, we mention that the holding cost rate $h$ is composed of two parts, the physical holding cost rate and the financial cost of capital due to inventory purchase. The above analysis has demonstrated this point. More specifically, one can view the holding cost rate $h$ and backorder cost rate $b$ as follows:

\[
\begin{align*}
    h &= h_p + rc; \\
    b &= b_p - rc.
\end{align*}
\]

If the demand is i.i.d, the optimal base-stock level $s^*$ can be obtained from the well-known optimality equation as shown in the inventory teaching note: Finding $s^*$ such that

\[
P(D \leq s^*) = \left( \frac{b_p - rc}{b_p + h_p} \right) = \left( \frac{b}{b + h} \right).
\]

For simplicity, let’s write

\[
s^* = F^{-1} \left( \frac{b}{b + h} \right),
\]

where $F$ is the cdf of the demand distribution and $F^{-1}$ is the inverse cdf function.\footnote{If lead time is positive, say $L$, the demand should be replaced with the total demand during lead time and the review period.}

We pose a discussion on estimating the cost parameters in practice here. According to the above analysis, when the financial market is perfect, the inventory holding cost rate is composed of the physical holding cost rate $h_p$ and the financial holding cost rate $rc$. Recall that $r$ is the interest rate due to the cash investment in the capital market. Broadly speaking, if a firm conducts investments by financing through debt and equity, the required expected return would be WACC, the weighted average cost of capital. In most OM textbooks, WACC is often recommended to estimate the financial holding cost rate. To estimate the physical holding cost rate, however, is a tough task. The physical holding cost comes from, for example, managing and maintenance expenses, storage, insurance, obsolescence, etc. The list is very long and often business specific. Technically speaking, one should sum up all these costs in a time period and allocate the cost to each inventory unit sold during this period. There are a number of alternative cost accounting systems that can be relevant for some purposes while being inadequate for others. Thus, it is neither always possible nor economical to keep track of all costs, or to split them and allocate them properly. Fortunately, the physical holding cost rate is often small.

As for the backorder rate, this is the penalty cost incurred for an arriving demand that cannot be satisfied immediately due to stock out. Some physical (tangible) penalty costs may occur,
e.g., expedited shipping cost, overtime production, etc. Let $b_p$ denote the physical backorder cost. Then, the backorder cost rate is $b = b_p - rc$. This is because a unit of inventory shortage implies that additional cash $c$ was invested in the capital market, gaining the return rate $r$. Thus, the actual tangible backorder cost rate is $b$, which is less than $b_p$. Nevertheless, one should know the backorder cost is beyond the tangible costs. There are many intangible costs involved, such as loss of goodwill, market shrinkage, etc.

1.2 Imperfect Financial Markets

So far, we have explained how the inventory model as well as its corresponding cost parameters are formulated when the financial market is perfect, i.e., $d = r$. Let’s turn to a more realistic scenario where the financial market is not perfect, i.e., $d > r$. In this case, Equation (4) suggests that to maximize the expected working capital in period $t + 1$, one has to minimize $E[G_t(y_t)] - R_t(y_t)$, or equivalently,

$$E[h_p(y_t - D_t) + b_p(y_t - D_t) - r(w_t' - c(y_t - x_t))^+ + d(w_t' - c(y_t - x_t))^-. \quad (7)$$

One can see that the inventory decision $y_t$ is affected by the cash level $w_t'$ through the last two terms of Equation (7). Thus, the inventory decision cannot be decoupled from the financial flow.

The optimal inventory policy no longer has a simple structure. Luo and Shang (2013) shows that a base-stock policy that depends on the working capital level is near-optimal. More specifically, when demand is i.i.d, define

$$s = F^{-1}\left(\frac{b_p - dc}{b_p + h_p}\right),$$

$$s = F^{-1}\left(\frac{b_p - rc}{b_p + h_p}\right).$$

Clearly, $s \leq s$. The optimal policy is executed as follows. When the working capital level $w_t$ is greater (less, respectively) than $cs$ ($cs$, respectively), one should order up to the base stock level $s$ ($s$, respectively). If the working capital is between $cs$ and $cs$, one should order up to the total working capital level $w_t$. We refer to this optimal policy as the $(s, s)$ policy.

2. Online Supply Chain Simulation Games

This section discusses pedagogical objectives of both games and illustrates the game rules and initial settings of the games.

2.1 The Beer Game

The pedagogical objective the Beer Game is two-fold. First, it helps students understand the interaction between information and material flows due to inventory decisions. This facilitates
the subsequent discussion for finite-horizon inventory models in the OM course. Second, the result of the game demonstrates a well-known supply-chain phenomenon, called the bullwhip effect, i.e., the variabilities of order and net inventory are amplified when moving along the supply to the upstream location (Lee et al. 1997). This helps students understand behavioral and operational causes that lead to the bullwhip effect.

The Beer Game is played in teams of four players, with each player on a team representing a role in a simplified serial supply chain: from upstream (the top of the supply chain) to downstream (the bottom), there is a Factory that brews beer, a Distributor that buys from the Factory and sells to a Wholesaler, a Wholesaler that buys from the Distributor and sells to a Retailer, and a Retailer that sells to customers. Note that information (orders for inventory) flows up the supply chain, whereas material (beer) flows down the supply chain. Each player makes an inventory order decision in each period based on her or his local information, while the objective is to minimize the total cost of the supply chain.

After logging into the simulation, students are randomly assigned to teams of four, and each player in the group in permanently assigned to play one of the four roles or “positions” in the supply chain: retailer, wholesaler, distributor, or factory.

The game is played over a series of rounds (weeks). In each round of the game, each player executes seven steps that, in essence, move materials (beer) from down the supply chain, and move information (inventory orders) up the supply chain. There is a two round lead time on both the transmission of information upstream and the shipment of beer downstream. That is, when a retailer, wholesaler, distributor, or factory places an order, the upstream firm receives that order two rounds later, and when factory, distributor, or wholesaler ships beer downstream, the downstream firm receives the shipment two rounds later. The retailer has no shipment lead time, i.e., consumers instantly receive beer from the retailer when they demand it, if the retailer has stock available.

The steps that occur in each round are, with the exception of Step 7, fully automated by the simulation. The seven steps in a period are as follows:

1. Observe the incoming order (from a downstream firm) or demand (from consumers).
2. Attempt to fill the order (including outstanding backorders, if any) from inventory.
3. Record remaining inventory or backorders, and calculate inventory holding cost (if net inventory is positive) or backorder cost (if net inventory is negative).
4. Receive a shipment from upstream to inventory.
5. Advance a shipment the upper stream supplier one position downstream.
6. Transmit the previous round’s order to the supplier.
7. Determine this round’s order quantity.

In Step 3, the inventory holding cost and backorder cost are calculated from that period. These
costs are equal to, respectively, the inventory holding cost rate (typically $h = 0.5$ per case of beer per round) times the number of cases of beer in inventory, and the backorder cost rate (typically $b = 1$ per case of beer per round) times the number of outstanding backorders. Your instructor will notify you if using different cost parameters. These costs are the same for each player. Inventory and backorders both carry over from one round to the next – that is, extra inventory stays in inventory until it is sold, and backorders stay on the ledger until they are fulfilled by beer from inventory. The total cost is accumulative.

Step 7 is the only step in the game in which each player has a decision to make, and the player will choose how much beer to order from its supplier in each round (factories choose how much beer to make). However, the decision is made based only on the information that a player has. A player does not know the inventory, backlog, or orders of any other players in the team. Thus, each of the players can be viewed as an independent firm, and each players makes an inventory decision in each round of the game based on her or his own local information, while the objective is to minimize the total cost of the supply chain.

2.2 The Cash Beer Game

The pedagogical objective of the Cash Beer Game is to let students understand the challenge of managing inventory and cash simultaneously, and how cash flow influences the inventory order decision. To that end, we also observe the resulting bullwhip effect.

In the Cash Beer Game, we assume that the financial market is not perfect, i.e., $d > r$. The game is played similarly as the Beer Game, except that each player has to make an inventory order decision according to the cash level, net inventory, and the order received from her or his downstream player. In each round of the game, each player has to execute the nine steps shown below.

1. Observe the incoming order (from a downstream firm) or demand (from consumers).
2. Attempt to fill the order (including outstanding backorders, if any) from inventory.
3. Receive cash from a downstream firm for the ordered inventory in Step 1 (a retailer receives cash from consumer’s demand).
4. Record remaining inventory or backorders, and calculate inventory holding cost (if net inventory is positive) or backorder cost (if net inventory is negative).
5. Receive a shipment from upstream to inventory.
6. Advance a shipment to the upper stream supplier one position downstream.
7. Transmit the previous round’s order to the supplier.
8. Pay an upstream firm for the previous round’s inventory order to the supplier.
9. Determine this round’s order quantity.

In general, the holding cost rate should be higher for a downstream location as the supply chain is a value-added process. Nevertheless, the standard game setting is to assume each player has the same cost structure, as the goal is to demonstrate the bullwhip effect.
Step 3 and Step 8 are new steps compared to the Beer Game. These two steps together essentially move cash from downstream to upstream, which is the same direction as the information flow. In Step 3, the amount of cash received in the current period is equal to the incoming order quantity times the unit selling price; in Step 8, the amount of cash payment to the supplier is equal to the order quantity transmitted in Step 7 times unit purchase cost. In other words, the payment scheme used in this game is the so-called pay-at-order. Each player still makes an inventory order decision in Step 9 and this is the only decision that a player has to make in each round. In each round, the inventory-related costs and cash-related costs are incurred. More specifically, the inventory holding cost and backorder cost are calculated according to the net inventory level in Step 4; that is, the inventory physical holding cost rate \( h_p \) per case of beer per round times the number of cases of beer in inventory, and the physical backorder cost rate \( b_p \) per case of beer per round times the number of outstanding backorders. The cash related cost includes an interest gain (negative cost) if the cash level at the end of the round is positive and a borrowing cost if the cash level is negative. The cash level at the end of a round is equal to the initial cash level plus a downstream player’s payment received in Step 3 minus the physical inventory holding and backorder costs in Step 4 minus the inventory payment in Step 8.

A few caveats follow. First, from the sequence of events, it is clear that the timing of receiving order from a downstream player and transmitting order to an upstream player is the same as that of receiving cash from downstream and sending cash to upstream. This suggests that there is a two-period lead time in the cash transmission. Second, we do not assume that cash is a hard constraint that restricts the inventory order quantity. This allows a player to continue the game even if there is a deficit, but the cash deficit will incur a penalty cost, i.e., the borrowing rate times the negative cash level at the end of a round. This assumes that some financial institutions are willing to lend short-term funds to firms with a borrowing rate.

During the game, the net inventory level and cash level are automatically calculated and each player only needs to make an inventory order decision in Step 9 by trading off the physical holding cost rate \( h_p \) versus the physical backorder cost rate \( b_p \), and the borrowing rate \( d \) versus the interest gain rate \( r \). For the latter tradeoff, this is due to the fact that the inventory order decision will affect the payment to the supplier, which, in turn, affects the cash level. A player attempts to clear the outstanding debt as soon as possible as the borrowing rate \( d \) is larger than the interest return rate \( r \). We also assume that the return from selling the product is higher than that of cash return rate, so a player has a motivation to purchase the inventory.

Table 1 shows the parameters of each player. These parameters are chosen to make a player choose the same base-stock level when the borrowing rate \( d \) is equal to the interest return rate \( r \) if the player optimizes her decision based on the base-stock policy. To see this, take Wholesaler as an example. The physical holding cost rate \( h_p = 0.95 \) per unit per round and the physical backorder cost \( b_p = 3.55 \) per unit per round. The financial hold-
Table 1: Parameters for Each Player

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Retailer</th>
<th>Wholesaler</th>
<th>Distributor</th>
<th>Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cash level</td>
<td>40</td>
<td>30</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Selling price $p$</td>
<td>6</td>
<td>3.85</td>
<td>2.75</td>
<td>2.2</td>
</tr>
<tr>
<td>Purchase cost $c$</td>
<td>3.85</td>
<td>2.75</td>
<td>2.2</td>
<td>2</td>
</tr>
<tr>
<td>Physical holding cost rate $h_p$</td>
<td>1.00</td>
<td>0.95</td>
<td>0.67</td>
<td>0.3</td>
</tr>
<tr>
<td>Physical backorder cost rate $b_p$</td>
<td>5.00</td>
<td>3.55</td>
<td>2.33</td>
<td>1.2</td>
</tr>
<tr>
<td>Borrowing rate $d$</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Return rate $r$</td>
<td>0.25</td>
<td>0.2</td>
<td>0.15</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The critical ratio is then equal to $b/(b + h) = 3/4.5$, which is the same as that of Wholesaler in the Beer Game, i.e., $1/(1 + 0.5)$. Based on the near-optimal policy derived in Luo and Shang (2013), the average order quantity in the Cash Beer Game should be smaller that that of the Beer Game, meaning the bullwhip effect should dampened. Here, we refer to the “order” bullwhip effect. The “material” bullwhip effect – the variability of shipments – may behave differently; see Chen, et al. (2015).

3. Game Delivery

This game is designed to be used in the classroom where the instructor does not need to know who will attend the class session. The system has robots that can fill a team that misses members. There is at most one robot in a team and the robot is set to Retailer as default. All system parameters including demand can be changed by the instructor. Below are the key steps for the team registration with snapshots.

Step 1. Go to https://beergame.fuqua.duke.edu/beergame/.
Step 2. Enter Fuqua NetID and password.
Step 3. Click “Add”.

![Image of Kevin Shang](image.png)
The student will see the image below to indicate that he/she has jointed a team.

Step 4. Click “Begin Game” to start the game.

The team registration process is complete and students can start playing the game. The time allowed in a round to make an order decision is one minute. If a player does not insert any value in a minute, the default value of order quantity is zero. Below is the user interface during the game.
As shown, students can see their team members as well as their team index and the current period. The on-hand inventory, backorders, and the total cost is automatically calculated. The winning team is the one with the minimum average cost per period for the entire supply chain.

When the Beer Game is complete, the instructor can start the Cash Beer Game without changing teams. The instructor only needs to turn the Cash Game lever “on” in the instructor panel. Students will see their browsers refreshed, and then the initial state of the game appears. Below is the image during the game.

Notice that the default demand for Retailer is a normal distribution with mean 10 units and standard deviation 3 units. This is to avoid the learning effect from the Beer Game. Again, the system automatically calculates on-hand inventory, backorders, net cash level, as well as the working capital. The winning team is the one with the maximum working capital per period for the entire supply chain.
4. Lessons from Past Teaching

This game is delivered in a core course of a Fuqua’s master of science program. The course has a module that discusses inventory management. In this module, I first discussed a one-time inventory decision model, i.e., the newsvendor model. Then, I introduced these two games in a single class session before I introduced finite-horizon models, i.e., the EOQ model, the base-stock model, and the model with cash flows. There is a teaching note to provide an overview of both simulation games in the course pack. As stated, these games are designed to let students be familiar with system dynamics for the finite-horizon inventory models. Students should read the teaching note before attending the class. The teaching note is an abridged version of this document. The pre-class preparation will help the instructor illustrate the games in class.

These two online simulation games were played in a class of two hours and fifteen-minutes. The total number of students in two sections is 95. Most students have a quantitative background. I first explained the game rule of the Beer Game, followed by the students playing the game. I ran the game for about thirty rounds. Then, I showed the ranking of all teams and demonstrated the bullwhip effect by showing their team work. The bullwhip effect is a well-established topic and the debrief is fairly standard. An instructor usually asks for students’ experience, reveals the demand information, explains the causes of the bullwhip effect and discusses the mitigation strategies. Below is a snapshot of a sample team work. The total time for the Beer Game is about 65 minutes.

After students returned from a 15-minute break, I started the Cash Beer Game. I first explained the game rule and the focus is on the cash flows as well as the new system state – the net cash level. I did not spend too much time on how the inventory order decision affects the inventory-related and cash-related costs, as well as their tradeoffs. This is one of the objectives that I hope students can figure out the tradeoffs during the game and how operations decision will influence cash and inventory simultaneously. The explanation of the game is about 10 minutes, followed by a game time of 30 minutes (30 rounds). The debrief is about 15 minutes.

This is a newly developed game and I think there is a lot of room to develop and improve teaching materials. In my view, there are two approaches in terms of delivering this new cash game.
**Approach 1: Focus on the optimal control policy.** This is the approach that I used for my course. I first had students play the Beer Game. During the debrief, students often figured out the causes of bullwhip effect and came up with mitigation strategies, such as shortening the lead time and sharing the demand information with supply chain partners. Some students also discovered that they should not overreact to the demand. Interestingly, not many students came up with the idea of an effective ordering policy – ordering the demand in the previous round – can eliminate the bullwhip effect. At this point, I intentionally did not mention the base-stock policy.

After the break, I started the Cash Beer Game. In order to minimize the “learning effect” from the Beer Game, I randomized the retailer’s demand with a normal distribution. While students may have had a better idea of managing inventory by not overly reacting to the demand, they still had a hard time making an order quantity decision by considering cash and inventory simultaneously. As a result, students still made the order decision based on their hunch. In order words, the learning effect does not seem to take effect. At the end of the game, to my surprise, the bullwhip effect remained and seemed further amplified. However, I did not make a rigorous experiment on this claim. During the debrief, I asked students how they made their order decision and whether they took cash level into consideration. Almost all students found it difficult to come up with a good strategy. Below is a sample of a team’s work.

![Cash Game Charts for Team 1 (1) Currently on week 9](image)

**Approach 2: Focus on the bullwhip effect.** If class time is shorter, one might consider an alternative method to deliver the cash game by comparing the bullwhip effect between scenarios with and without cash. That is, students can be divided into two groups, one playing the Beer Game and the other the Cash Beer Game. The instructor can discuss the bullwhip effect from the Beer Game group and examine the impact of cash flows on the bullwhip effect from the other. A careful design of the lecture may lead to an interesting empirical study.
As stated, I am still at the stage of developing and improving teaching materials. My current approach is to let students play the games and gain some experience on the system dynamics of the finite-horizon inventory problems and the challenges of managing the system. In the subsequent class session, I formally introduce the base-stock model. In particular, I discuss how the holding cost rate and backorder cost rate are derived when the financial market is perfect in the standard inventory model. I also emphasize the importance of keeping track of the inventory on order, which leads to the concept of inventory position as well as the base-stock policy. I further state that, in addition to shortening the lead time and sharing the demand information, an effective policy, such as the base-stock policy, can mitigate the bullwhip effect. Lastly, I move the discussion to the scenario in which the financial market is not perfect and introduce an effective control policy. The goal is to emphasize the importance of considering a firm’s working capital when making inventory decisions. The lecture is based on the material in Section 1 of this document. At this point, I did not test students on the model with cash flows, but I see it as a possibility in the future. Finally, I refer the interested reader to Luo and Shang (2015) for the optimal joint inventory replenishment and cash payment policy for a serial supply chain.

References


