The Effect of Semi-Rational Supply Chain Members on the Decision Parameters Used in Managing the Stock of an Echelon[1]

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Abstract

A supply-chain is a series of connected stock management structures. Therefore, the structure of a supply-chain consists of many cascading inventory management problems. It is shown that the optimal inventory control parameter values suggested by the literature are also valid for a supply-chain. The motivation for this study is to investigate the effect of the literature suggested optimal values of the decision parameters in the presence of semi-rationally managed supply-chain echelons. We use a soft coded version of The Beer Game as an experimental platform to carry out the study. According to the results of the simulation experiments, it is not rational to continue to use the optimal parameters when other echelons' inventories are managed sub-optimally, especially if the time horizon is long.

Keywords: anchor-and-adjust; beer game; stock adjustment time; stock management; supply chain management; weight of supply line.

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[1] *This research is supported by a Marie Curie International Reintegration Grant within the 7th European Community Framework Programme (grant agreement number: PIRG07-GA-2010-268272) and also by Bogazici University Research Fund (grant no: 6924-13A03P1).*

Introduction

A supply-chain is a series of connected stock management structures. Therefore, the structure of a supply-chain consists of many cascading inventory management problems. Supply chains are known for their interesting rich dynamics such as oscillations, bullwhip effect, and chaotic behavior and, thus, subject to many scientific studies (Mosekilde and Laugesen , 2007; Sterman, 1989; Thomsen et al., 1991). In his famous Beer Game paper, Sterman (1989) suggests a stock control ordering policy, namely the *anchor-and-adjust heuristic*, to be used in managing the level of a stock. According to the results reported in that paper, the proposed heuristic is a good representation of the decision making processes of the participants who were managing inventories on a supply chain. Therefore, we represent the decision making processes of the computer simulated participants (i.e., the echelon of concern and the rest of the three echelons) using the anchor-and-adjust heuristic. In this study, the parameters of the anchor-and-adjust heuristic are called "decision parameters" and the variables of the same heuristic are called "decision variables". We optimize the parameters of the anchor-and-adjust heuristic for the selected echelon by keeping the parameters of the anchor-and-adjust heuristic constant for the rest of the three positions. We carry out this optimization process for each one of the four echelons of the game, selecting them one by one. To observe the long-term effects of the parameters on the dynamics, the time horizon is selected as 520 weeks for the simulations.

The Echelons in the Beer Game

In this study, we use a soft coded version of The Beer Game as an experimental platform to carry out the simulations (Edali, 2014; Edali and Yasarcan, *forthcoming*). The Beer Game is a four echelon supply chain consisting of a retailer, wholesaler, distributor, and factory; there is an inventory control problem for each one of these echelons. During the game, every participant in a group of four is responsible for one of the four echelons and manages the associated inventory by placing orders. A supply chain can be modeled as a series of connected stock management structures. Therefore, the structure of the game consists of four cascading stock management problems. The orders flow from downstream echelons towards upstream echelons and cases of beer flow in the opposite direction. The aim of the game is to minimize the accumulated total cost obtained by the participants of a group managing each echelon. The accumulated cost generated by each individual echelon is calculated at the end of the game by adding up all inventory holding and backlog costs obtained at the end of each simulated week (Sterman, 1989). A representative stock-flow diagram for only a single echelon is given in Figure 1.

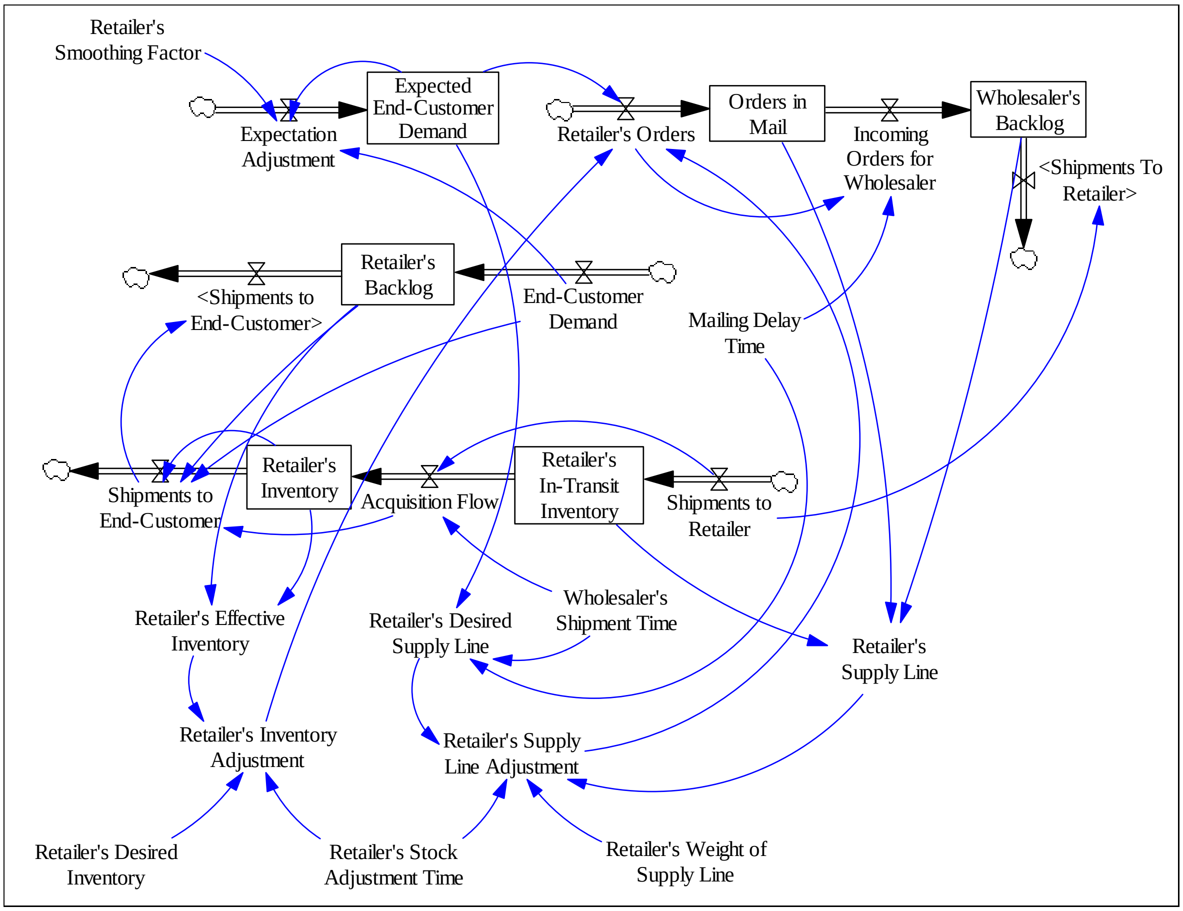

Figure 1. A representative stock-flow diagram for the retailer echelon

The Decision Parameters and Their Values

Stock adjustment time (*sat;* $1/\alpha_S$ in Sterman, 1989), *weight of supply line* (*wsl*; β in Sterman, 1989), *desired inventory* (*I**; *S** in Sterman, 1989), and *smoothing factor* (θ; also θ in Sterman, 1989) are the main decision parameters of the anchor-and-adjust heuristic. *Stock adjustment time* (*sat*) determines the intended time to close the gap between the desired level of the stock and the current stock itself. In The Beer Game, *sat* represents the number of weeks in which a decision maker wants to bring his current inventory level to the desired level. Smaller values of *sat* results in aggressive corrections while higher values correspond to mild corrections. According to Sterman (1989), the optimum value of this parameter is one unit of time (i.e., a week). Therefore, *sat* is taken as one week for the echelon of concern.

Weight of supply line (*wsl*) represents the relative importance given to the supply line compared to the main stock. In other words, *wsl* is the fraction of supply line considered in the control decisions (i.e., order decisions). When *wsl* is taken as one, the main stock and its supply line will be effectively reduced to a single stock that cannot oscillate (Barlas and Ozevin, 2004; Sterman, 1989 and Chapter 17 in 2000; Yasarcan and Barlas, 2005a and 2005b). However, a zero value of *wsl* means that supply line is totally ignored in decision-making process and it may potentially create an unstable stock behavior. According to Sterman (1989), the optimum value of this parameter is unity. Therefore, *wsl* is taken as unity for the echelon of concern.

It is known that the aforementioned optimal values of *sat* and *wsl* are also valid for a single isolated inventory control problem. This study focuses mainly on the values of *sat* and *wsl*. Accordingly, the motivation for this study is to investigate the optimality of the literature suggested optimal values of *sat* and *wsl* in the presence of semi-rationally managed supply-chain echelons. The *sat* and *wsl* values for the semi-rationally managed supply-chain echelons are taken as 3.85 weeks and 0.34, respectively. These values are the averages of the estimated parameter values of the participants of The Beer Game (Sterman, 1989).

Desired inventory (I^*) is another parameter of the anchor-and-adjust heuristic and it simply represents the target inventory level. In The Beer Game, the cost function is asymmetric; *unit backlog cost* is \$1.00/(case·week) while *unit inventory holding cost* is \$0.50/(case·week). Therefore, it is usually less costly to have a positive on-hand inventory than having a backlog. Comparatively speaking, a better control decreases the requirement for large values of I^* while a worse control increases this requirement. The value of I^* is assumed to be 0 for all echelons. The reason for selecting $I^* = 0$ is that if inventory and backlog are both zero for an echelon in a simulated week, that echelon produces no costs in that week. In this study, we do not experiment with the selected value of this parameter.

Smoothing factor (θ) is the main parameter of exponential smoothing forecasting method and it represents the weight given to recent observations in the forecasting process. Although smoothing-factor is one of the parameters of the anchor-and-adjust heuristic, its optimization is out of the scope of this study. Theoretically, θ can take a value between 0 and 1. A zero value of θ means no corrections in the forecasted values. On the other hand, when it is taken as one, the exponential smoothing method will be equivalent to a naive forecast. It may not be practical to use a randomly selected *smoothing factor* value, even if that value fall in the theoretical range. According to Gardner (1985), the *smoothing factor* of a simple exponential smoothing forecasting method should be between 0.1 and 0.3 in practice. As a reasonable value, we suggest using a *smoothing factor* of 0.2 in forecasting, which is the middle point of the range suggested by Gardner (1985). This value of *smoothing factor* also falls in the range of 0.01 and 0.3 that is suggested by Montgomery and Johnson (1976). Therefore, θ is taken as 0.2 for the echelon of concern. The value of θ for the semi-rationally managed supply-chain echelons is taken as 0.36 per week. This value is the average of the estimated θ value of the participants of The Beer Game (Sterman, 1989). In this study, we do not experiment with the selected value of this parameter.

Results for the Optimal Values of *sat* and *wsl*

In these experiments, the optimal value of *sat* that is one week and the optimal value of *wsl* that is unity are used as the decision parameter values of the selected echelon only. The *sat* and *wsl* values of the other three echelons (i.e., the semi-rationally managed supply-chain echelons) are taken as 3.85 weeks and 0.34, respectively. The results are reported in Table 1. The experiment is repeated for all the echelons by changing the echelon of concern for each simulation run. Note that we focus on the supply-chain dynamics in the long run. Accordingly, the length of simulation runs is taken as 520 weeks (i.e. ten years).

Table 1. Total cost values generated by changing the echelon of concern

The echelon of concern	Total Team Cost	Total Cost of Retailer	Total Cost of Wholesaler	Total Cost of Distributor	Total Cost of Factory
Retailer	4715.0	701.0	1056.5	1603.0	1354.5
Wholesaler	34684.5	6909.5	9611.0	9955.0	8209.0
Distributor	33302.0	4919.5	9162.5	10192.5	9027.5
Factory	32937.5	4401.0	8094.5	11808.0	8634.0

Extremely high costs are obtained when the echelon of concern is the wholesaler, the distributor, or the factory. The reason behind these high cost values is the oscillations in the dynamics as it can be observed from figures 2, 3, and 4.

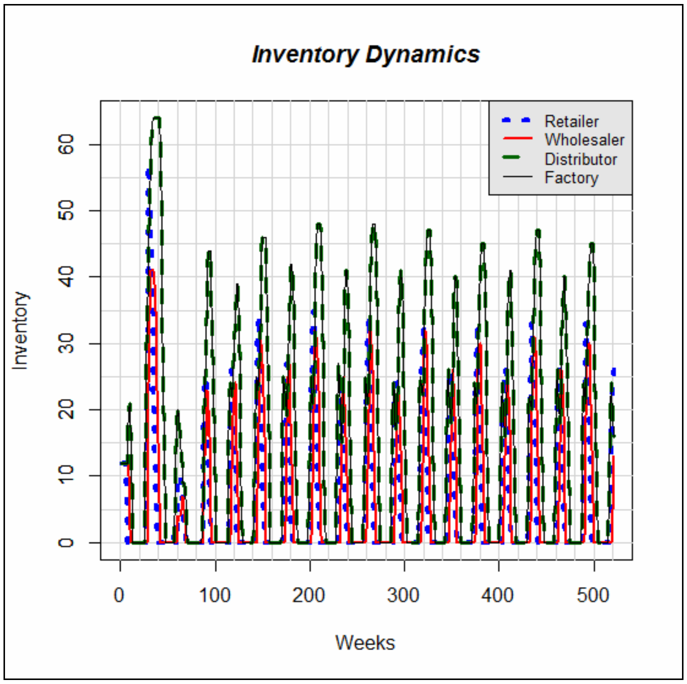

Figure 2. The dynamics of the inventories, when only the wholesaler is using the literature suggested optimum values and the rest are semi-rational supply chain members

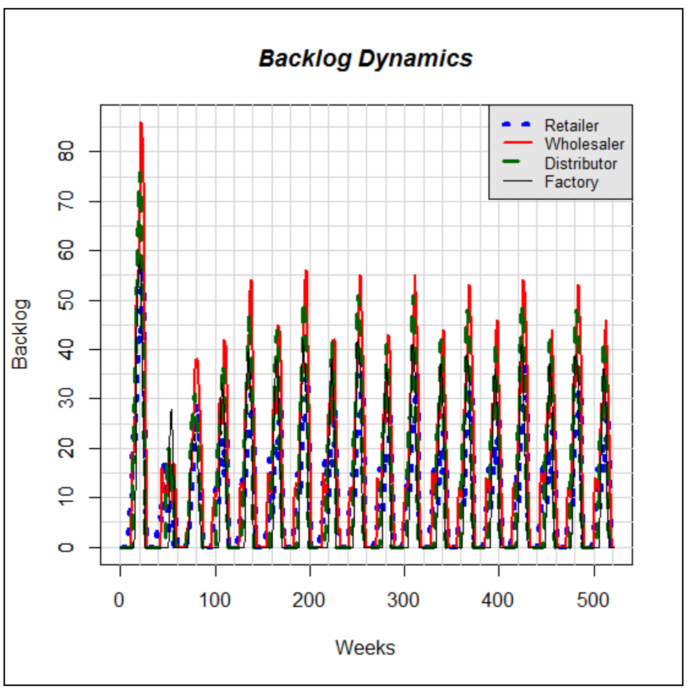

Figure 3. The dynamics of the backlogs, when only the wholesaler is using the literature suggested optimum values and the rest are semi-rational supply chain members

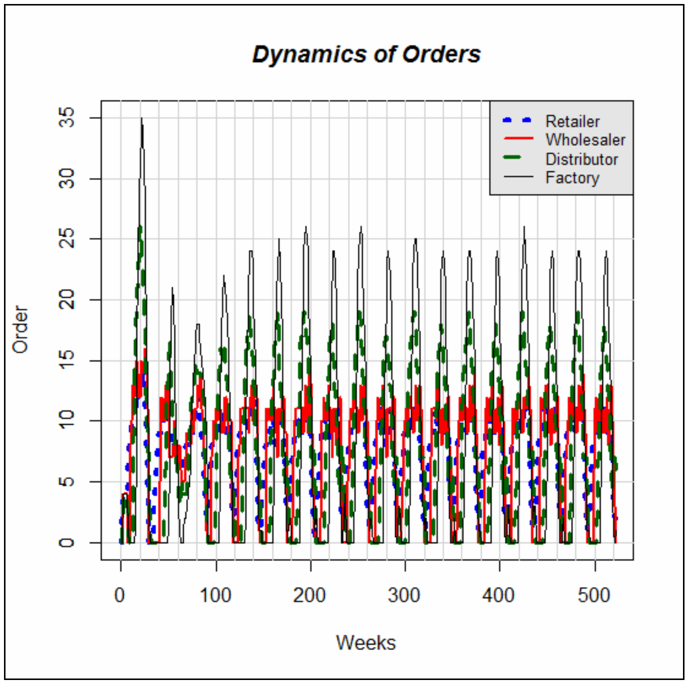

Figure 4. The dynamics of the orders, when only the wholesaler is using the literature suggested optimum values and the rest are semi-rational supply chain members

Results for the Re-Optimized Values of *sat* and *wsl*

In these experiments, the optimal value of *sat* that is one week and the optimal value of *wsl* that is unity are not used as the decision parameter values of the selected echelon. Instead, they are re-optimized for each echelon. Similar to the experiments in the previous section, the *sat* and *wsl* values of the other three echelons (i.e., the semi-rationally managed supply-chain echelons) are taken as 3.85 weeks and 0.34, respectively. The results are reported in Table 2.

Table 2. The re-optimized parameter values and the corresponding total cost values

The echelon of concern	α_s (1/*sat*) of the echelon of concern	*wsl* of the echelon of concern	Total Team Cost	Total Cost of Retailer	Total Cost of Wholesaler	Total Cost of Distributor	Total Cost of Factory
Retailer	0.8	1.0	4681.5	695.0	1042.0	1584.0	1360.5
Wholesaler	0.1	0.2	7495.0	1258.0	2094.0	2096.5	2046.5
Distributor	0.5	1.0	8081.5	1121.5	1870.0	2606.5	2483.5
Factory	0.8	0.6	7708.0	1137.0	1787.5	2679.5	2104.0

The extreme costs reported in Table 1 are eliminated when the re-optimized parameter values are used (see Table 2). Remember that the parameter values used in obtaining the results reported in Table 2 are not valid if the other supply-chain members use literature suggested optimal values. The reason behind the decrease in the costs values is caused by the damping oscillations as it can be observed from figures 5, 6, and 7.

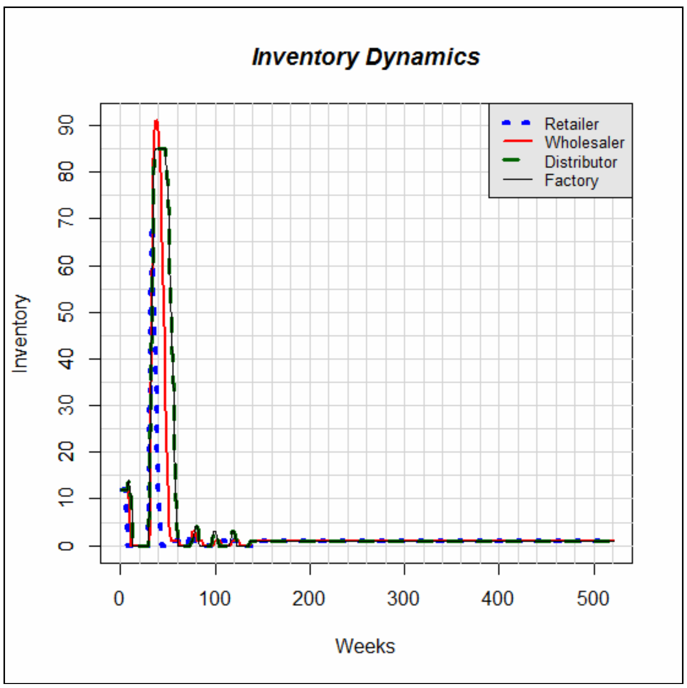

Figure 5. The dynamics of the inventories, when only the wholesaler is using the re-optimized parameter values and the rest are semi-rational supply chain members

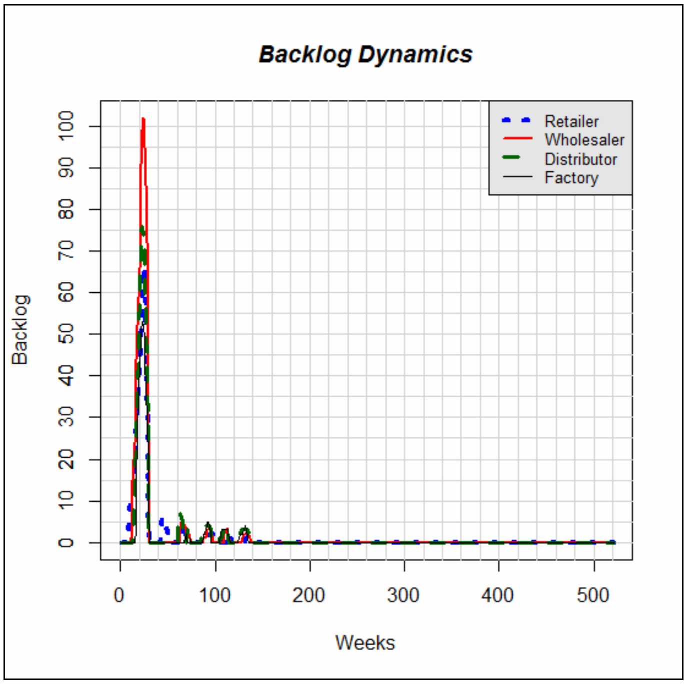

Figure 6. The dynamics of the backlogs, when only the wholesaler is using the re-optimized parameter values and the rest are semi-rational supply chain members

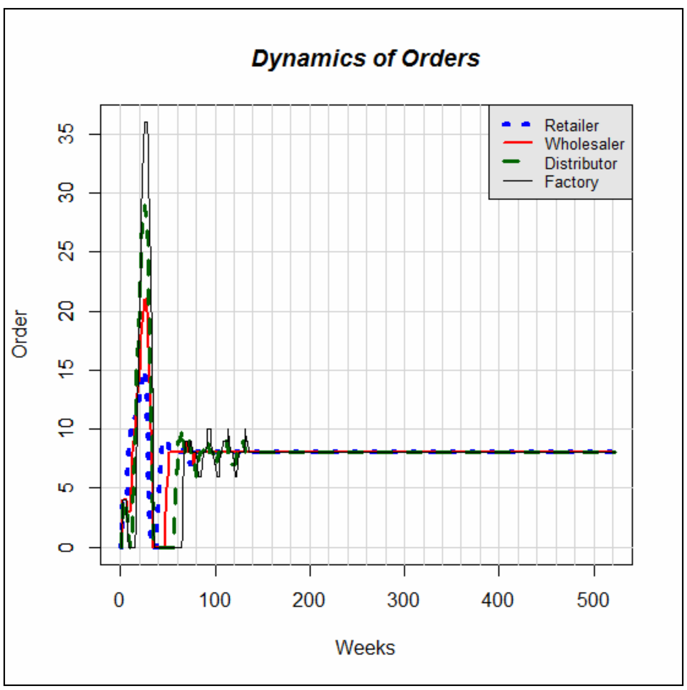

Figure 7. The dynamics of the orders, when only the wholesaler is using the re-optimized parameter values and the rest are semi-rational supply chain members

Conclusions

According to the results of the simulation experiments conducted in this study, it is not rational to continue to use the optimal parameter values when other echelons' inventories are managed sub-optimally. In fact, using optimal values suggested by the literature produces approximately 3-4 times more cost compared to the re-optimized parameter values reported in Table 2. Therefore, one can claim that the optimal values suggested by the literature are valid only if all echelons' inventories are managed with these same optimal parameter values. More work is necessary to understand this counter-intuitive result.

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