"Experimenting with industrial dynamics in the forest sector – a Beer Game application"

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Introduction

The ”Beer Distribution Game” (Beer Game) is used in many logistics courses to give students an entertaining experience of participating in a commodity distribution chain. The game provides empirical evidence of industrial dynamics in a four-stage supply chain where production demand at each stage are controlled by market ”pull” principles. Because of the structure of the game, most players experience demand amplification and find themselves unable to secure a stable operation of the system. The results of the game are judged in terms of supply chain costs (sum of inventory and stock-out penalties), while the chain dynamics is described using statistical measures of weekly demand and supply oscillations.

A primary characteristic of wood procurement process is the sorting of the raw material into a number of quality classes for further processing into products or product components. In terms of logistics or supply chain theory, this represents an unusual case, having a divergent material flow. For this reason two divergent-flow versions of the Beer Game have been developed for use in forestry education. In this paper they are referred to as Wood Supply Games.

The original Beer Game consists of four stages: the brewery, which produces the beer, and ships it through a distributor and a wholesaler, before the retailer sells the beer according to consumer demand. The Wood Supply Games also have four stages: wood supply group, paper mill/sawmill, wholesalers and retailers. When comparing the Beer Game with the Wood Supply Games the stages are numbered from first to fourth, starting with the brewery and the wood supply group, respectively.

The first divergent version is based on a chain with a common source for raw materials (the forest) that diverges at the first position (wood supply group) into two chains. One chain is for sawlogs, with a sawmill (second position), followed by a wholesaler and a retailer of lumber (third and fourth positions). The other chain is for pulpwood, with a paper mill followed by two stages for distribution of paper products. In this paper, this game is referred to as the divergent version of the Wood Supply Game.

The second divergent version has the same basic structure as the first, but includes the flow of chips from the sawmill to the paper mill position (second positions for each chain). The by-products from the sawmill create an additional point of divergence for the lumber chain, but a point of convergence for the paper chain. In this paper this game is referred to as the integrated version of the Wood Supply Game.

Different restrictions for material flow may be applied to the different structures. In the divergent version, the mix of sawlogs or pulpwood ordered by wood supply group (first position) is subjected to limitations of range (e.g. minimum and maximum percentage of pulpwood). In the integrated version, the mix of chips and pulpwood used to produce paper may also be subjected to varying limitations of range (e.g. minimum and maximum percentage of chips). The integrated version also divides lumber and paper production into main products (lumber, paper) and by-products.

Supply chains in reality have a network structure, rather than being a linear sequence of actors with vendor/customer relationships. While most models of supply chains are unable to take into account effects of dependencies not following the main flow of materials, the two versions of the Wood Supply Game, may be used to study such effects. The results of the games are highly variable and dependent on the decision-making behaviour of the actors involved. In order to conduct valid statistical analyses of differences between supply chain structures, a great number of replications are required.

Goal

The goal of this paper is to generate hypotheses comparing supply chain costs and demand amplification between different supply chain structures. Empirical results from pilot studies of the divergent (three replications) and integrated (one replication) versions of the Wood Supply Game are compared with results from earlier studies of the Beer Game. In both versions of the Wood Supply Game, the same cost assumptions are used as in the original Beer Game. Results are, however, adjusted for different levels of demand required by the different structures.

Results - Inventory Costs

The total supply chain costs from earlier studies of the Beer Game are on average USD 2028 for the 35-week playing period. Results indicate that the total costs are somewhat higher for the divergent version (USD 2260/35 wks) and highest for the integrated version (USD 8508/35 wks). The differences between the structures are largest for the first position and smallest for the fourth position.

Results - Peak Order Rates

When studying how demand is amplified, two measures of the weekly order rates are used: the peak order and the sample variance of the 35 orders placed by each position. For all the cases, the peak demand for the final sales is 8 units per week. In the Beer Game, the largest peak demand is found for the first position (peak order = 32), and the smallest is found for the fourth position (peak order = 15). For the first position of the divergent Wood Supply Game, the peak order was 90 % higher than the first position of the Beer Game. For the second, third and fourth positions the differences were smaller, with peak orders for the divergent version 15-35 % higher than for the corresponding positions in the Beer Game. Peak order rates were highest for the Integrated Wood Supply game; 85-120% higher than the Beer Game for all positions.

Results - Order Variance

In the Beer Game, the variance of order rates decreases along the flow of materials, from 72 at first position (brewery) to 13 at the fourth position (retailer).

For the first position of the divergent version the variance of order rates was approximately 400% greater than what was found for this position in the Beer game. For the second and third positions, the variance of order rates increased by 55-75% compared to the corresponding positions in the Beer Game. The fourth position produced only slightly higher variances (20%) than the fourth position in the Beer Game.

The variance of order rates was greatest for the integrated version of the Wood Supply Game. Even for the smallest relative increase the observed variance was 450 % higher than found in the Beer Game. For the first position, which also is the point of divergence, the variance was more than 800 % higher than the first position in the Beer Game.

All three measures of supply chain efficiency (where high costs, high order peak values and high order variance indicate low efficiency) show the same ranking of the supply chain structures. The highest efficiency was found for the original Beer Game. The divergent version of the Wood Supply Game produces results on an intermediate level, and the integrated version had the lowest supply chain efficiency.

The effect of restrictions in the Wood Supply Game

The divergent version of the Wood Supply Game has been run with strict constraints at the point of divergence (first position), and with relaxed constraints. Relaxing the constraints implies that the flexibility with respect to the proportions of sawlogs/pulpwood in the total mix delivered from the forest increases. Relaxing constraints at the point of divergence appears to reduce the impact of the diverging structure to the point that results are similar to the original Beer Game.

On the background of pilot experiments with the divergent version, the following hypothesis is proposed:

H1: In a simple diverging environment, increasing the rigidity of constraints applied to the point of divergence will negatively influence supply chain performance.

In the integrated version the dependencies between the lumber and the paper chain are even greater. An interesting observation is that if one of the chains is not managed well, costs seem to increase for both chains, particularly for the upstream positions (the first and second positions). This is partly a result of the points of divergence at the wood supply group and at the sawmill, (first and second positions), and partly the effect of the convergence at the paper mill (second position). It is not possible, given the data, to estimate the two effects separately.

The results obtained using the integrated version had moderate constraints for the linkage between the paper mill and the sawmill (second positions). That is, the paper mill had high degrees of freedom when selecting the mixture of chips and pulpwood to enter paper production, and the sawmill had small penalties for not being able to deliver chips.

On the background of the pilot experiment with the integrated version, the following hypothesis is proposed:

H2: Given the same rigidity of constraints, further increasing the complexity (degree of divergence/convergence) in a supply chain will negatively affect performance.

This hypothesis is vague due to the limited experience with the Wood Supply Game. However, even the integrated version is suitable for further studies in an educational environment. Students may vary the constraints with the aim of increasing the knowledge of effects of divergence and dependencies between linked supply chains operating in different markets.