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The Craft Beer Game and the Value of Information Sharing

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Abstract. The craft beer supply chain in the USA differs from the supply chain of macro breweries in its structure, handled volumes and product shelf-life. In this work, we study how these smaller craft breweries can benefit from transparency in their supply chain. We consider additional information sharing of orders and inventories at downstream nodes. The levels that we investigate grant the brewery incremental access to distributor, wholesaler, and retailer data. We show how this knowledge can be incorporated effectively into the brewery's production planning strategy. Extending the well-known beer game, we conduct a simulation study using real-world craft beer supply chain parameters and demand. We quantify the impact of information sharing on the craft brewery's sales, spoilage, and beer quality. Our model is designed to directly support the brewery when evaluating the value of downstream information and negotiating data purchases with brokers. Through a computational analysis, we show that the brewery's benefits increase almost linearly with every downstream node that it gets data from. Full transparency allows to halve the missed beer sales, and beer spoilage can even be reduced by 70% on average.

Keywords: Craft beer industry · Supply chain management · Information sharing · Production planning · Simulation

1 Introduction

The classic beer game of supply chain management (SCM) has received significant attention for demonstrating the bullwhip effect and the value of vertical collaboration in supply chains. With the rising popularity of craft beers, the craft beer game naturally emerges as a variant of the classic game with slightly altered rules and different insights to be gained for SCM (education). In contrast to the supply chains of the large breweries and many other supply chains, information in craft beer supply chains (CBSCs) is mostly not shared directly between the supply chain members but bought from data brokers [6]. Thus, the player of the

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craft beer game has to take two decisions: how many units of stock to order and how much information to buy.

This, however, involves understanding a trade-off between the cost and the value of shared information. As an integral element of self-thinking supply chains [4], information sharing and its value for supply chains have been investigated considering different scenarios. Lee et al. [11], for instance, investigated the case of a simple two-stage supply chain and found that the manufacturer could reduce inventory costs with information sharing. Ouyang [15], on the other hand, showed that information sharing could improve the supply chain stability and mitigate the bullwhip effect. Nevertheless, the value of information sharing in CBSCs has not yet been investigated, and the impact of information sharing on important metrics of the sector such as average beer age, spoilage, and missed sales is not yet well understood. Existing CBSC literature rather focuses on sustainability factors of the supply chain [1,5] or develops models for the inherent supply uncertainty in these supply chains [19]. A general overview on the craft beer industry is given by Biano [2] considering the special craft requirements in terms of food quality. Further works on craft beer address, amongst other aspects, corporate social responsibility [9], sustainability objectives [8,14], economies of scale [20], and craft beer as a means of economic developments [12].

In this work, we model different levels of information sharing in the craft beer supply chain and develop a simulation approach based on real-world data to understand the value of information sharing concerning the CBSC metrics, average beer age, spoilage (in total and at each stage of the supply chain), and missed sales. We observe that all of the above metrics are significantly reduced when more information becomes available, and with more information, this reduction becomes more significant. Moreover, we find that the variability in the results over different scenarios is also clearly lowered with more information sharing. These findings and the presented approach generally help to understand the potential of information sharing platforms in CBSCs and related domains. On top of that, they help to improve the product quality in the considered supply chains.

2 The Craft Beer Supply Chain

The origins of beer can be traced as far back as 7000 BCE and the recipe has basically been the same to this day: water, malt, hops and yeast. While the ingredients have stayed constant over thousands of years, the US American Beer Industry has been relatively short with some notable occurrences have altered demand, manufacturing and supply chain operations. Most recently, the resurrection of US American Craft Breweries has changed the way that beer products must be managed within the supply chain. While most supply chain analyses are done under the model assumptions developed in the Beer Game [7], this model does not consider modern quality standards and beer style preferences.

We consider the Craft Beer Supply Chain (CBSC) in the USA. The CBSC is used by so-called craft breweries to supply end customers with craft beer.

The majority of the US beer industry is controlled by a small amount of macro-breweries, or breweries that produce over 6,000,000 barrels (9.5 MM hL) of beer, controlling over 87% of the market in 2020[1]. On the other side, there are thousands of craft breweries that provide the remaining volume[2]. Even though the craft beer segment has seen dramatic growth over the past 30 years, it still only controls a small portion of the market and has a strikingly different relationship with the other agents in the supply chain. The US American beer supply chain, also called the *Three Tier System* [13], consists of four echelons, and is illustrated in Fig. 1. The Three Tier System dates back to the 1920s and refers to a law that enforces breweries to sell their product to a distributor before being sold to wholesale and retail locations.

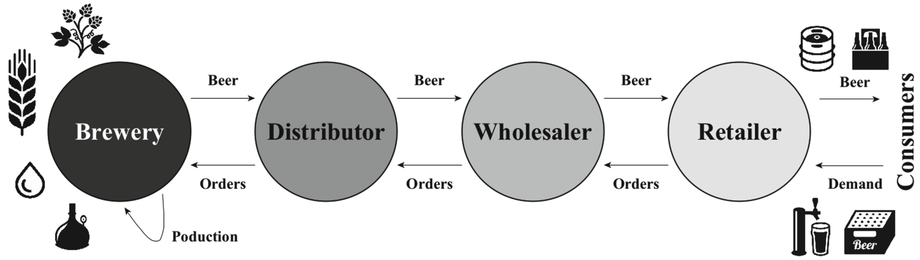

Fig. 1. The Three-Tier beer supply chain used by both macro breweries and craft breweries with its nodes (brewery, distributor, wholesaler, and retailer) down to the consumers.

The main contrasts between the regular beer supply chain and the CBSC are in ownership, information access and product shelf life. These differences directly affect the breweries' abilities to manage their production strategies efficiently, as well as control their storage and spoilage costs. In the following, we explain these differences in more detail.

Ownership and Information Access. Macro breweries' distributing centers exist around the country and are wholly owned by the breweries' themselves. This is a luxury that craft breweries rarely have. They rely on third party distributors for additional warehousing. These inventory transactions with external parties adds cost for the craft breweries.

Further, the Three-Tier Laws also dictate that breweries can have ownership of no more that 5% of the wholesalers that sell its products. Though, due to the sheer dominance that macro breweries have on the industry and benefits they can provide (e.g., vehicles), they have nearly full control on the wholesalers' operations for their products. These wholesalers are even barred from carrying other macro brewery products and are referred to as 'houses' for their connected

[1] https://www.brewersassociation.org/statistics-and-data/craft-brewer-definition.

[2] A craft brewery is considered a micro brewery when producing less than 15,000 barrels (ca. 17900 hL) per year.

macro brewery. This control includes ordering strategy decision making and information systems integration that allows full visibility of inventory movement. Ownership structure and information access are depicted in Fig. 2.

At the retail level, the macro breweries are on a more similar playing field with the craft breweries due to another set of laws called the Tied House Laws which penalize manufacturers for influencing retailers. Though, where macro and craft differ is in the access of information of direct consumer sales from the retailers themselves. The cost of this data through third party data brokers is in the six figures annually and while macros have no problem purchasing the data, it is nearly impossible for craft breweries to justify the cost.

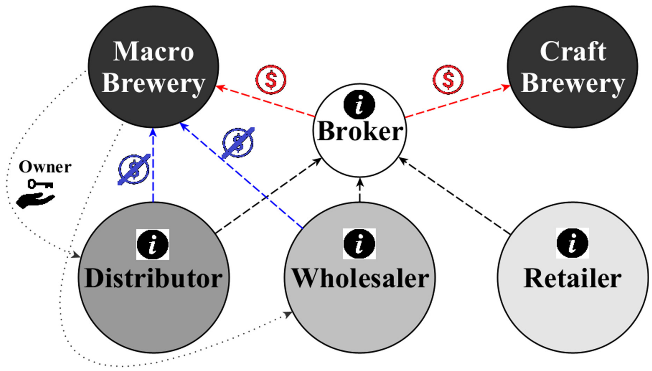

Fig. 2. Ownership relation, and paid and unpaid flow of information between supply chain members and data brokers.

Shelf Life. Quality standards within the US beer industry have changed dramatically since the 1960s, mainly due to the advancements in brewing technology and increased consumer product knowledge. These two changes have led to the development of and adherence to shelf-life standards for beer products. These standards designate how long products can age before they are deemed spoiled and discarded. Quality focused breweries and consumers are keen to minimizing the age of beer products as they make their way through the supply chain [16]. Aging speeds up with increasing exposure to oxygen and light. Beer becomes oxidized when it is introduced to oxygen and produces off-flavors described as cardboard or paper. Oxidation speed increases with heat and agitation, which are common with transportation. Hops are the primary cause of oxidation and thus beers with more hops are more susceptible to oxidation [10]. Beer becomes 'light-struck' when UV light reacts with hops producing a skunky smell. This flavor is evident in many popular beer brands that are found in green or clear glass bottles [3].

With increased visibility to information of their down line agents, macro breweries have the ability to control inventory levels at each agent and monitor the shelf-life of their products throughout. This ability becomes significantly more important for products that have shorter and gradually decreasing shelf-lives, which describes nearly all products produced by craft breweries. While keeping larger days on hand inventory at each agent, can help maximize the fulfillment rates to the consumer, this strategy can also lead to a longer aging of product at time of consumer purchase. Therefore, craft breweries' lower visibility to information of their down line agents, decreases the quality of their product and increases their cost.

The difference in shelf life standards and the corresponding cost factor are illustrated in Fig. 3.

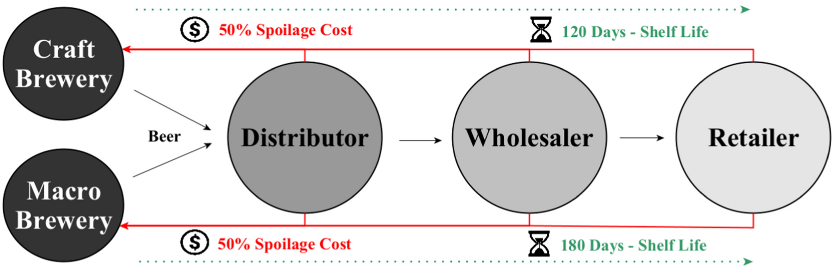

Fig. 3. Cost allocation for spoiled beer for macro and craft breweries based on the corresponding shelf life standards.

The predominant cost factors to be considered in the craft beer supply chain are as follows. *Missed Beer Sales*: The cost for the retailer of not fulfilling customer orders. *Beer Age*: The cost of providing a customer a beer product that is past its prime drinking age. *Beer Spoilage*: The cost of beer product that has been destroyed due to reaching its beer spoilage age. Note that beer spoilage can occur at any tier in the supply chain. The brewery is interested in minimizing all three metrics to reduce costs and increase product quality.

We assume sufficient transport capacity since shipping in the CBSC is done at lower quantities than for macro breweries. However, we account for shipping times. We do not consider costs related to transportation and inventory since they play a minor role in the CBSC.

The Craft Beer Game. The Beer Game is a well-known and heavily analyzed model that is used for applications, not limited to, but including classrooms, business management seminars and scientific research. The fundamental logic of the game is based on a multi-player system where product orders are placed upstream and fulfillment of these orders is completed downstream. Each player has its own strategies on how to fulfill these orders while considering their own limitations in storage capacity, transportation time and order quantities. The objective of the Beer Game is to come up with strategies at the player level to either minimize costs, maximize sales or a combination of the two.

In this work, we introduce the Craft Beer Game, which extends the Beer Game. In addition to the fundamental four steps (check deliveries, check orders, deliver beer, make order decision), we consider a new *acquire information* step. The latter is conducted in every round prior to making an order decision. The obtained information includes insights into the other players' operations. This is so important in the CBSC because of both, the strong competition in the craft beer industry, and the need to compete with larger breweries.

3 Information Sharing

Reordering strategies at the different tiers are key mechanisms in a supply chain. We take the perspective of the manufacturer, i.e., the brewery, which does not order but plan production instead. In practice, this operational planning step takes into account historical demands, current inventories and the planners' domain expertise. The main challenge is to predict future demands at the best possible level of accuracy. These demands are dependent on the next node's requirements which stem from the demand that it is facing.

There is a difference between information sharing and transparency. Information sharing leads to transparency. It can follow a mutual agreement between two supply chain members, resulting in collaboration. Or, it can be asymmetric, so that only one node obtains (partial) access to the node's data. We focus on the latter case and restrict ourselves to down-stream transparency resulting from up-stream sharing. Moreover, information can be obtained after involuntary disclosure, possibly through third-parties. That is, a node might not be willing to share information, but peripheral analysis could give insights into some of its operations. For example, shipping companies delivering products from the wholesaler to the retailer may provide insight into the corresponding order patterns. Cooperation between competitors, also called *coopetition*, happens when all involved parties expect benefits.

The information of interest in the CBSC can be categorized as order-related and inventory-related. Information is closely related to parameters that can be used to describe a supply chain. Both types can be static or dynamic (i.e., historical). Information can be stored in a centralized or a decentralized fashion. Currently, information is available from free data consolidators (e.g., VIP[3], GP-Analytics[4]) providing data-analytics services to distributors, wholesalers, and retailers. They commonly sell the data to breweries at a relatively high cost. They are information-sharing platforms to the distributors etc., and a data broker to the brewery.

We consider four information sharing models yielding different supply chain transparency from the manufacturer's (i.e., the brewery's) perspective.

I. Baseline: No transparency at all. The brewery has no insights in current or past downstream operations.

II. First-Level Transparency: The distributor's inventory and historical demand are known.

[3] https://www.mysoftwaresolutions.com/vip-analytics.
[4] https://www.gp-analytics.com.

III. Second-Level Transparency: In addition to distributor data access, the wholesaler's inventory and historical demand are known.
IV. Third-Level Transparency: First and second-level transparency is extended by retailers information.

Figure 4 illustrates the considered information sharing levels within the supply chain. Note that the brewery always has access to its own inventory levels and the current and historical orders submitted by the distributor. In this work, we do not consider information sharing with other nodes than the manufacturer, since we are interested in potential benefits for the brewery.

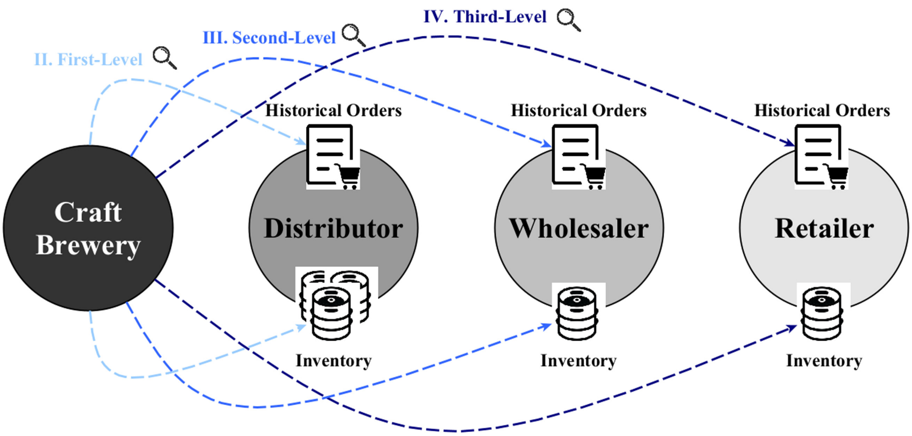

Fig. 4. The considered levels for information access for the brewery in the craft beer supply chain: No Sharing (I), Distributor (II), Distributor+Wholesaler (III), Distributor+Wholesaler+Retailer (IV).

4 Reordering and Production Planning

We first describe the base reorder strategy used at each node. Afterwards, we explain how the information sharing levels are used to adjust the brewery's beer production planning. All beer quantities in our model are measured using *case equivalents* (CEs), the standard measure utilized in the U.S. Beverage Wholesale industry. A CE is comparative to 24 cans of 12 fluid ounces.

4.1 Reorder Strategies

We build the reorder strategies for our Craft Beer Game based on the existing strategies for beer supply chains in [17,18]. Let $n \in \{1, .., 4\}$ denote the supply chain node from the brewery to the retailer (increasing from left to right). Each node places an order once per reorder cycle with node-dependent *cycle time* (CT_n) measured in days. The considered time periods t are the end times of the order cycles, which are different for the nodes. For every node n, reorders are executed at times in $\{0, 1 \cdot CT_n, 2 \cdot CT_n, 3 \cdot CT_n, \ldots\}$. In time period t at node n, the *suggested order quantity* ($SOQ_{n,t}$) in CEs is calculated as follows:

$$SOQ_{n,t} = max\{ED_{n,t} + AS_{n,t} + ASL_{n,t}, 0\} \tag{1}$$

The *expected demand* is defined as

$$ED_{n,t} = \theta \cdot INC_{n,t} + (1 - \theta) \cdot ED_{n,t-CT_n}$$

where $INC_{n,t}$ stands for the total *incoming orders* over the last cycle to node n (sent by node $n+1$), and $\theta \in [0, 1]$ is an expectation update The *adjusted supply* is defined as

$$AS_{n,t} = \alpha_S \cdot (DINV_{n,t} - INV_{n,t} + BL_{n,t})$$

where $DINV_{n,t}$ is the node's *desired inventory*; $INV_{n,t}$ is the actual *inventory*, including the beer that is currently being transported to the corresponding node; $BL_{n,t}$ the *backlog*; and $\alpha_s \geq 0$ is a fractional adjustment rate. The *Adjusted supply line* is defined as

$$ASL_{n,t} = \alpha_{SL} \cdot (-BL_{n-1,t})$$

where α_{SL} is a fractional adjustment rate. Note that $BL_{n-1,t}$ is known because node n knows both, what order was placed and how much of it was fulfilled by up-stream node $n-1$. This equation slightly differs from [17] since we use reorder cycle times that are longer than the summation of fulfillment and shipping times. This is common for a CBSC because of low volume and short transportation distances. At the wholesaler and the distributor, the $SOQ_{n,t}$ value will be rounded up to the next suitable batch size (see also Sect. 5), whereas the retailer precisely orders SOQ_t units. The reorder strategy defined above applies in particular to the brewery, where orders correspond to production orders. In Sect. 4.2, we will present a set of revised strategies that take into account the additional information that is being shared when planning the beer production.

4.2 Brewery Reordering with Different Information Levels

In the following, we incorporate the additional information available at the different sharing levels into the brewery's production planning. To this end, we suggest effective demand forecasting methods for all scenarios. Under additional information sharing using level L, the base strategy for the brewery node given in Eq. (1) extends as follows.

$$SOQ_{1,t} = \max\{ED_{1,t} + AS_{1,t} + ASL_{1,t} + ATS^L_{1,t}, 0\} \tag{2}$$

Here, the newly integrated level-dependent *adjusted total supply* is defined as

$$ATS^L_{1,t} = \alpha_{TS} \cdot (DTS^L_{1,t} - TS^L_{1,t}) \tag{3}$$

Similar to the adjusted supply $AS_{n,t}$, α_{TS} functions as a fractional adjustment rate. The *total supply* reflects the known actual amount of beer in all downstream node inventories, dependent on the information level:

$$TS_{1,t}^{L} = \begin{cases} 0 & \text{if } L = \text{I} \\ INV_{1,t} + INV_{2,t} & \text{if } L = \text{II} \\ INV_{1,t} + INV_{2,t} + INV_{3,t} & \text{if } L = \text{III} \\ INV_{1,t} + INV_{2,t} + INV_{3,t} + INV_{4,t} & \text{if } L = \text{IV} \end{cases} \tag{4}$$

We intentionally set the $TS_{1,t}^{L}$ to 0 (as we do for $DTS_{1,t}^{L}$) in the case that no additional information is available (Level I). Herewith, we ensure that the adjustment term $ATS_{1,t}^{L}$ cancels out in this information sharing level. The *desired total supply* corresponds to the desired amount of inventory contained in the entire supply chain, the strategy we use is defined as

$$DTS_{1,t}^{L} = \begin{cases} 0 & \text{if } L = \text{I} \\ \gamma_L \cdot \frac{INC_{2,t}}{CT_2} & \text{if } L = \text{II} \\ \gamma_L \cdot \frac{INC_{3,t}}{CT_3} & \text{if } L = \text{III} \\ \gamma_L \cdot \frac{INC_{4,t}}{CT_4} & \text{if } L = \text{IV} \end{cases} \tag{5}$$

where the parameter $\gamma_L \in \{1, 2, \ldots\}$ is used to specify the days of inventory that the brewery desires to be available in the supply chain down to the last node that it has data access to. A larger value typically results in an increased adjustment (see Eq. (3)) and yields overproduction. Conversely, reducing γ_L tends to decrease production. Note that for level I, this strategy reduces to the base strategy defined in Eq. (1), since no desired downstream inventories and total supply are included. $ATS_{1,t}^{L}$ can be negative, since it is used to adjust the production quantities.

We point out that adjusting the production has an impact on the brewery's objectives in two ways. If the adjustment is negative (i.e., less is produced than originally planned) then we will likely see less beer spoilage. If adjustment is positive (i.e., we produce more) then we expect to reduce the missed beer sales.

In the base production planning, the brewery is dependent on the distributor's estimation of downstream demand in form of the corresponding distributor orders. This might not be ideal for the brewery's objective to reduce the beer age. In information sharing levels II-IV, the brewery's planning can bypass the distributor's planning by adjusting according to an own real-data-based downstream demand estimation. Example: Consider the case that the distributor overestimates the future demand. If this is reflected in low retailer demand (that we have access to) then the brewery would adjust by reducing its production. Even if this way it is not possible to meet the distributors orders, we expect to avoid beer sitting in downstream inventories longer than needed.

Distributors are set up to hold large inventories with long shelf lives (Macro-Beer), but that causes a problem for Craft Breweries whose product has shorter shelf-life. Distributors are focused on selling the product within the spoilage window, which means they will focus on holding as much product, as possible as long as it does not spoil. Whereas, breweries want their product sold as fresh as possible, which would mean smaller inventories. Therefore, the Craft Breweries are self-regulating the supply chain by not filling every distributor order.

5 A Simulation Approach

We use simulation to quantify the impact of availability of downstream data for the brewery. The considered scenarios emanate from the information sharing models and the corresponding brewery production planning strategies introduced in Sect. 3 and Sect. 4. The used real and simulated market data is described in Sect. 5. We develop a hybrid agent-based and discrete-event simulation system to model the CBSC. We use AnyLogic[5] as simulation modelling system. In the following, we present our simulation approach including model logic, parameters, data, and metrics which is inspired by [17].

Model and Logic. We model every supply chain node (brewery, distributor, wholesaler, retailer, and customer) as a separate section of the agent flow logic. Orders (in CEs) are explicitly modelled as agents on all levels. They originate at distributor, wholesaler, retailer, and customer, and are terminated at the preceding node (see Fig. 5). Moreover, backorder agents originate at distributor, wholesaler, and retailer in case of insufficient inventory.

In Fig. 5, we illustrate the generic logic used to represent the supply chain nodes using the wholesaler. A recurring event causes an order agent to be generated at the order source with a quantity parameter defined by the node's reorder strategy. The order agent then functions as a container and picks up the desired quantity of CE agents from the previous node's inventory. The order and CE agents pass through a delay representing shipping, then the beer is dropped into this node's inventory while the order is disposed. In the case that an order attempts to pick up more beer than the previous node has, a new back order agent is put into a queue. The next time an order picks up from that node, it will attempt to pickup the new order quantity in addition to the quantity on back order.

The main events correspond to recurring customer demand (based on daily stochastic market data), reorders, beer production, backorders (dropped after one reorder cycle if not filled, which is common), and inventory quality control (spoilage check).

[5] www.anylogic.com.

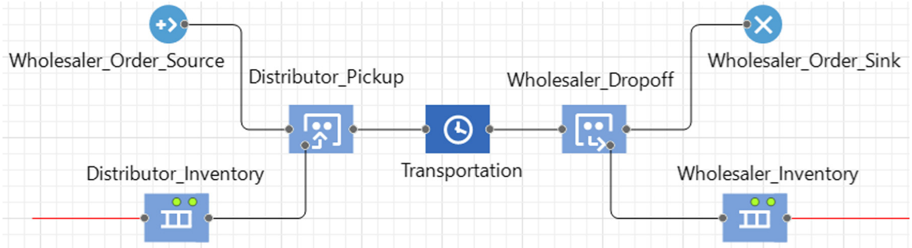

Fig. 5. The generic node logic with inventory queues, ordering, and shipping in our AnyLogic simulation model illustrated by the wholesaler.

Parameters. The following parameters are used to configure the CBSC. The beer production time is 21 days per batch (100 CE). Reorder cycle times are 1/14/14/7 days, and reorder quantities are rounded up to the next 100 (in CE) at the distributor and the wholesaler (not rounded at the retailer). The reorder parameters (used in Sect. 4) reflect industry standards: $\theta = 0.5$, $\alpha_S = 0.5$, $\alpha_{SL} = 1$, $\alpha_{TS} = 1$, $\gamma_{II} = 30$, $\gamma_{III} = 45$, $\gamma_{IV} = 60$. A desired inventory level for node n in time period t ($DINV_{n,t}$) is set to be a single order cycle's expected demand ($ED_{n,t}$). The retailer holds twice this volume. The brewery's production quantities are rounded up to the next 100 (in CE). The corresponding production limit is assumed to be 1000 CE; no limits at other nodes. The maximum beer age in number of days before being discarded during the inventory quality control, also called *hold days*, is 40 (brewery), 70 (distributor), 90 (wholesaler), and 120 (retailer). A spoilage check is performed on a daily base at every node. We set the transportation times to one day and do not incorporate capacity or cost. Moreover, we do not use inventory capacity limits.

Real-World Data. The customer demand is assumed to be stochastic. We base our experiments on real-world data from a craft beer brewery. Using four-year daily demand, we generate 19 randomly simulated time series. These are derived by a time series decomposition approach in which we detect the error distribution after subtracting linear trend and exponentially smoothed pattern. The historical demand data for the four-year period is illustrated on a monthly base in Fig. 6. Furthermore, the figure shows the simulated demands. A steady demand growth can be seen that is typical for early-stage craft beer breweries.

Key Performance Indicators. The performance of the CBSC is measured using the following metrics (see also Sect. 4).

1. Beer Sales: The relative missed beer sales in CE with respect to the overall customer demand.
2. Average Beer Age: The average number of days that a CE spends in the supply chain before reaching the end consumer.
3. Beer Spoilage: The relative beer in CE that is spoiled at any node due to an excess of shelf life.

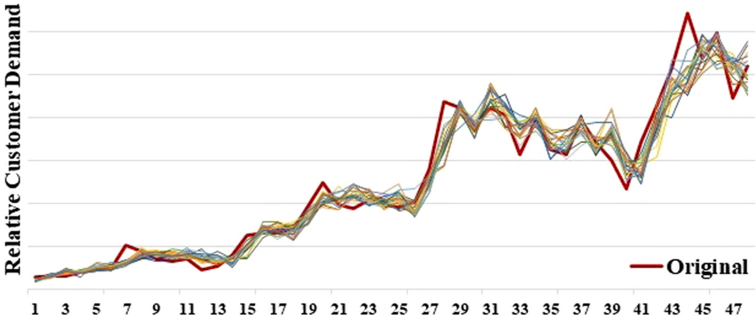

Fig. 6. Real-world time series and 19 simulations of customer beer demand data over the four-year horizon (monthly aggregation).

6 Computational Analysis

In this section, we present and analyze the results of our simulation study. We quantify the impact of the four different information sharing levels (Sect. 4) and the corresponding brewery planning strategies (Sect. 4) on the CBSC model described in Sects. 2 and 5. The used simulation data and parameters are described in Sect. 5.

We report our main results in Table 1 using the metrics introduced in Sect. 5: Missed Beer Sales, Beer Age, and Beer Spoilage. These numbers correspond to a breakdown of major cost factors associated to a craft brewery. Relative missed beer sales are given with respect to the overall customer demand. The spoilage at a node is compared to the overall beer volume that entered the node. The average beer age is calculated over the beer that is delivered to the end customer, not considering spoiled material. We recall that level I does not allow the brewery to look into the other nodes' operations at all.

We observe a significant reduction of missed beer sales when augmenting the information shared in the different levels. When allowing full transparency, the missed sales can almost be halved (4.9% → 2.5%). An even stronger impact can be seen in terms of beer spoilage. The overall spoilage can be reduced from 24.0% to 7.1%. The node-dependent breakdown confirms this gradual improvement. Brewery and distributor benefit the most since the corresponding detected spoiled beer reduces to 0.8% and 1.8%, respectively. However, the beer age remains consistently around 67%, indicating that the information levels do not help. This minimal effect on the beer age could be due to the fact that each node holds enough inventory to cover till their next shipment. Thus, the average beer age is rather correlated to the sum of days between shipments for each node, i.e., the reorder cycles. The distributions for missed beer sales, average beer age and beer spoilage are further described in Fig. 7. We observe some variation in missed sales but only small changes for spoilage and beer age. Overall, the missed beer sales range from 0.8% to 8.6%, whereas the average beer age is greater than 64.0% does not exceed 69.8%. Moreover, the standard deviation in all metrics decreases as more information becomes available: 1.9 → 1.3% (missed sales);

2.2 → 1.7% (spoilage); 1.2 → 0.7 days (average beer age). To better understand the beer production adjustments $ATS^{L}_{1,t}$ (Sect. 4), we illustrate the absolute values in Fig. 8. The data is presented in a monthly aggregated form for the original beer demand. Note that there is a notable impact on the production volumes.

Table 1. The average missed beer sales, beer age and spoilage at different supply chain nodes for information sharing models I-IV.

Metrics	Information Sharing Level			
	I	II	III	IV
Missed Sales (%)	4.9	4.5	3.5	2.5
Beer Age (∅)	67.7	66.0	66.2	68.1
Spoilage (%)				
Total	24.0	15.8	8.1	7.1
Brewery	13.4	6.0	0.5	0.8
Distributor	8.4	7.3	5.5	4.6
Wholesaler	3.2	3.0	2.5	1.8
Retail	0.00	0.00	0.00	0.00

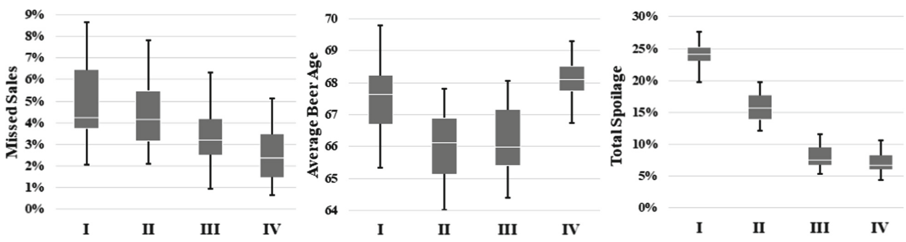

Fig. 7. The distributions of average relative missed beer sales (left), average beer age (center), and relative beer spoilage (right) observed over the simulation repetitions.

7 Conclusion

We studied the US American craft beer supply chain from the brewery's perspective in a beer game fashion. After defining its industry-specific properties, we developed practically relevant scenarios for how availability of down-stream information can be incorporated into production planning. Our main goal is to help the brewery's production planning regarding sales, product quality, and spoilage. We conducted a simulation study based on real-world craft beer data, in which we quantified the value of information sharing in the craft beer supply chain. We showed that the acquisition of downstream information from third-party brokers yields significant benefit. With every node for that the brewery

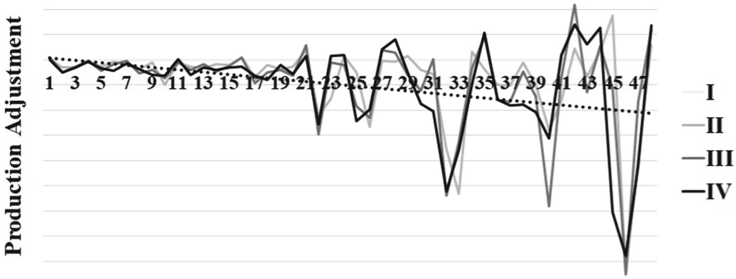

Fig. 8. Adjustment in beer production ($ATS^L_{1,t}$) at the brewery for the different information sharing levels (I-IV); shown for original demand date in monthly aggregation; level I indicates zero adjustment.

obtained data access, its planning improved near-linearly. In the case of complete supply chain transparency, the missed beer sales could be reduced by 50% on average. The costly beer spoilage could even be decreased by 70%.

From a managerial perspective, the developed approach can be used to support breweries when negotiating with data brokers. In addition, it can be used to evaluate collaboration opportunities with respect to information sharing in the platform economy. Based on these positive results, we suggest exploring further adaptation of the brewery's production planning strategy concerning demand forecasting and collaboration. Also, the investigation of interplay of production and reorder mechanisms could be of interest. Moreover, we see importance in an in-depth formalization and study of the generic Beer Game with information sharing.

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