Competitive Rebalancing in One-Way Car-Sharing

Car-sharing services have grown considerably in recent years. In an outlook towards the future, the Boston Consulting Group predicts about 35 million car-sharing users by 2021, which would generate global revenues of 4.7 billion EUR\textsuperscript{1}. Figures also clearly illustrate that the popularity of car-sharing has been accelerated particularly by the increasing offer of one-way services. The most significant advantage of one-way car-sharing over the two-way system is the higher flexibility, as customers do not have to return the vehicles to the original pick-up point. For car-sharing providers, the flexibility of one-way systems often leads to an uneven distribution of the cars that results in lower customer satisfaction and less usage of the vehicles. Consequently, car-sharing operators have to rebalance their cars regularly in order to keep the system profitable. For that purpose, the providers partition their business area into several zones and move cars from zones with an expected overage to zones with an expected underage.

Many authors have addressed the problem of determining optimal repositioning strategies, considering different user-related factors like adoption rates, booking behaviour or time and day of the week. All publications up to now have the one assumption in common that the car-sharing provider is operating in a monopoly. In real life, however, there are many cities where two or more providers offer their services. For example, the two major players in Europe, car2go and DriveNow, competed in eleven cities in 2017. As findings from retail management show, companies should not neglect competition as it has a direct influence on the customers’ demand. This motivates an important research question:

\textsuperscript{1} The Boston Consulting Group. 2016. \textit{What’s Ahead for Car Sharing?} Report.
How does competition influence the optimal rebalancing plan and how should the companies react to the presence of a competitor?

While inventory based competition and inventory rebalancing by themselves have been studied very well, rebalancing under competition has not been addressed directly so far. In this work, we develop a method for determining the optimal rebalancing under competition for a given pool of stock. We then apply our model to the case of car-sharing.

In retail, one typically distinguishes between two types of competition: stock-out-based and assortment-based competition. In the first case, one assumes that a portion of those customers who cannot find a car of a company will substitute with a competitor’s car. In the latter case, customers make their choice based on the observed availability of cars in a zone. Independent of such assumptions, the decision to reposition more cars to one zone inevitably reduces the coverage in other zones as the total fleet size is fixed and replenishment is not possible at short hand. Consequently, the players have to find the most profitable redistribution of their cars among the zones, at the same time taking into account the competitor’s reaction.

To study rebalancing under competition, we consider two players who act as newsvendors with a given stock that they can distribute over several zones. Our model combines inventory transshipment with inventory competition. To cover different customer behaviours, we consider both stock-out-based and availability-based substitution. Under stock-out-based substitution, we assume that a certain portion of users will substitute with the competitor’s cars if, and only if, they cannot find an available car of their preferred provider in a zone. Under availability-based substitution, the customers’ decision is taken after they observed the number of cars available in the zone.
We state the player’s individual repositioning problem by maximizing the expected profit minus the repositioning cost. Using Lagrangian multipliers, we transform this constrained optimization problem into an unconstrained one. We use this to formulate a non-cooperative game where both players solve their repositioning problems simultaneously. We prove that there exists a unique Nash equilibrium for both assumptions on customer behaviour. Applying Lagrangian transformation and deriving the corresponding Karush-Kuhn-Tucker conditions, we show that the Lagrangian multipliers allow us the partitioning of the zones into sending, dormant and receiving zones. Thus, we can derive the optimal target inventories without explicitly solving the underlying optimization problem.

Our controlled numerical design shows that a provider can increase his profits by taking the presence of a competitor into account. This is mainly due to the awareness that customers, which are willing to substitute, can be attracted. We find that the customers’ behaviour influences the level of competition. In the case of stock-out-based substitution, the providers focus on fulfilling their competitors’ unfulfilled demand. Thus, the providers tend to avoid fierce competition. Under availability-based substitution, the providers vie with each other for market shares, which leads to more competition. A major driver for the increase or decrease of the number of repositionings under competition is the initial distribution of the fleets. Especially in cases of large imbalances, the providers make use of the customers’ willingness to substitute and therefore share the market, thus reducing repositionings.

A case study with real booking data from Munich shows similar results. That is, the players could increase their profits in Munich substantially if they adapt to the competitive environment. Thanks to substitution, the $\beta$-service-level would increase by up to five percent. Furthermore, joint rebalancing could increase the profits by seventeen percent per annum and the number of repositioned cars would decrease by more than twenty percent.