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Upgrade auctions in build-to-order manufacturing with loss-averse customers

Andreas Matzke[a,*], Thomas Volling[b], Thomas S. Spengler[a]

[a] Technische Universität Braunschweig, Institute of Automotive Management and Industrial Production, Mühlenpfordtstraße 23, 38106 Braunschweig, Germany
[b] FernUniversität in Hagen, Chair of Production and Logistics Management, Universitätsstraße 41, 58097 Hagen, Germany

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ABSTRACT

We consider the problem of matching capacity and demand in build-to-order manufacturing. Our objective is to assess the ability of upgrade auctions to efficiently allocate excess option capacity to customer orders. We model the Stackelberg game of one manufacturer and a set of loss-averse customers. The manufacturers' decision of extending the existing fixed-price channel by applying upgrade auctions is evaluated in terms of contribution margin and planning reliability. When the manufacturer offers an option in the upgrade auction, customers seek to maximize utility by buying the option instantly at the fixed price or leaving a bid in hope of a better auction price. Their optimal participation and bidding strategy is explained by a gain-loss utility model with two-dimensional preferences and expectation-based reference levels. Due to missing information on capacity and bids, customers' decisions are based on estimations of auction and winning probability. We conclude that applying upgrade auctions can significantly improve contribution margin while maintaining planning reliability. Particularly, loss aversion prevents potential fixed-price buyers from bidding in the auction. The results suggest that further effort of implementing upgrade auctions in build-to-order manufacturing will likely pay off.

1. Introduction

1.1. Motivation

We consider the problem of matching capacity and demand in build-to-order (BTO) manufacturing. BTO is an order fulfillment strategy that enables mass customization. Products are customized by adding predefined product features (called options) to a base model (Da Silveira, Borenstein, & Fogliatto, 2001). Examples can be found in the personal computer and the automotive industry (Gunasekaran & Ngai, 2005). Most of the research on matching capacity and demand in BTO manufacturing has been devoted to the aggregate production volume (Volling, Matzke, Grunewald, & Spengler, 2013). What has widely been neglected in the literature is the matching of capacity and demand at the level of product options. This is rather surprising, given that both, the feasibility and the efficiency of procurement and manufacturing operations are strongly linked to option demand (Boysen, Fliedner, & Scholl, 2009).

One way to better align capacity and demand of product options is to upgrade customer orders in case of excess inventory or assembly capacity (jointly called capacity in the following). Excess capacity occurs when flexibility instruments do not fully cope with demand fluctuations. Reasons could be that firms systematically over-dimension capacity to realize short lead times and reduce lost sales or that random swings in option demand realize on very short notice. Demand management techniques can in such situations be helpful in effectively complementing supply-side flexibility instruments (Waller, 2004). A promising instrument for managing excess capacity for product options is upgrades. The general idea is to either add options to existing orders or to change order configurations from a lower priced option to a higher priced alternative (Shumsky & Zhang, 2009). Ervolina, Ettl, Lee, and Peters (2009) report that integrating upgrades, downgrades und flexible products into a configuration recommender system contributed impressively to saving inventory costs in IBMs server supply chain. In a similar setting, Shimoda, Kosugi, Karino, and Komoda (2010) highlight the idea of clearing excess inventory of components by using configuration flexibility of the customer specification. But the benefits of upgrades for BTO manufacturers are not limited to improved operations and increased sales quantities. Furthermore, upsells can improve profits by segmenting customers and discriminating prices (Gallego & Stefanescu, 2012; In & Wright, 2014).

* Corresponding author. Tel.: +49 531 391 2202; fax: +49 531 391 2203.
E-mail addresses: andreas_matzke@gmx.de (A. Matzke), thomas.volling@fernuni-hagen.de (T. Volling), t.spengler@tu-braunschweig.de (T.S. Spengler).

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In this paper we consider upgrade auctions for upselling BTO products. Our idea is to complement a fixed-price channel, which is currently used by most BTO manufacturers. Following a phase of regular sales, excess option capacity is auctioned off among all customers who did not yet select the option. In this sense, upgrade auctions are a specific type of capacity auctions (e.g., Hall & Liu, 2013; Karabatı & Yalçin, 2014). From a customer's view, upgrade auctions allow for either buying an option without risk at the fixed price or leaving a bid in order to win the option at a lower price. The downside of bidding is the risk of not getting the option due to high fixed-price sales or higher competing bids. Applications of upgrade auctions have recently been introduced by airlines that are starting to auction free business- or first-class seats to holders of lower-class tickets of the same flight (Elowitt, 2012). We extend the scope of upgrade auctions by analyzing their benefits in a BTO environment.

The profitability and supply-chain efficiency of BTO manufacturing with upgrade auctions are subject to several customer and manufacturer characteristics. We motivate our focus on (i) customer loss aversion and (ii) manufacturer planning reliability in the following.

(i) The first essential question of assessing upgrade auctions is whether profits can be increased when compared to the predominant fixed-price mechanism. The simple answer in the face of rational and strategic customers is that the manufacturer has no advantage as customers will exploit their additional degree of freedom for maximizing consumption utility (see Shunda (2009) for a similar discussion in the context of buy-price auctions). However, customizing an individual product is a very emotional process for customers (e.g., Bendapudi & Leone, 2003; Franke, Schreier, & Kaiser, 2010). The more intense the consideration of a particular product option, the higher the customer's engagement with this feature (Carmon, Wertenbroch, & Zeelenberg, 2003). This is why products will be sold with better configurations when starting with a full configuration rather than a base model (Herrmann, Hildebrand, Sprott, & Spangenberg, 2013; Park, Jun, & MacInnis, 2000) and why framing high-level options as the default choice can be used by sellers to systematically increase the sales quantity (Herrmann et al., 2011). A well-developed framework for explaining customer behavior in general (Bendoly, Croson, Goncalves, & Schultz, 2010; Fudenberg, 2006; Ho, Lim, & Camerer, 2006) and in the context of option framing (Biswas & Grau, 2008) is prospect theory (Barberis, 2013; Kahneman & Tversky, 1979; Tversky & Kahneman, 1991). Similar to option framing, the setting considered in this paper allows customers to select an option at the fixed-price by default or to accept the risk of ending without the option, i.e. with a lower-equipped product. While there certainly are alternative ways of modeling customer preferences, we will build on the existing evidence on prospect theory and option framing when assessing the consequences of introducing upgrade auctions for customer behavior and manufacturer profits.

(ii) The second essential question of assessing upgrade auctions is whether upstream supply-chain efficiency can be improved. While flexible allocation and late upgrading are generally beneficial for capacity utilization and revenue (e.g., Shumsky & Zhang, 2009), there potentially are some disadvantages for the upstream supply-chain, if product configurations are changed on short notice. Most firms that apply upgrading rely on very simple product and supply chain architectures. Examples can for instance be found in the service and computer industry (e.g., Shumsky & Zhang, 2009; Steinhardt & Gönsch, 2012). Upgrade auctions are, however, also attractive for BTO industries that have much more complex product architectures and procurement networks in place. Part requirements are in such settings no longer linked to single product options but to the combination of multiple options. Examples can be found in the automotive and furniture industry. For instance, a car's battery and generator type depend on the number of optional electrical systems like seat heating, electrical sunroof and air conditioning (e.g., Gebhardt, Rugheimer, Detmer, & Kruse, 2004). As a result, upgrading the configuration of a product might induce short-term variations of parts demand into the supply chain, a well-known source of inefficiency (Chen, Drezner, Ryan, & Simchi-Levi, 2000). The larger the share of auction sales, the larger the short-term swings in demand and the lower planning reliability. As the dissemination of upgrade auctions in such industries as the automotive industry will heavily rely on the persistent reliability of advance part demand information, we complement our analysis by considering their impact on planning reliability.

Taking customer loss aversion and planning reliability into account, the objective of this paper is to analyze the potentials of upgrade auctions for matching capacity and demand of options in BTO manufacturing.

1.2. Literature review

To the best of our knowledge, upgrade auctions have not been considered in the academic literature, yet. However, extensive literature has been published on (i) upgrades and (ii) auctions to assess their benefits from a seller's perspective.

(i) The application of upgrades and upsells and the more general concepts of product substitution and flexible products have motivated research in different areas. Scholars have investigated the advantages of upgrades in airline overbooking (Alstrup, Boas, Madsen, & Vidal, 1986), multiproduct inventory management (Bassok, Anupindi, & Akella, 1999), car rental und hospitality services (e.g. Karaesmen & van Ryzin, 2004; Netessine, Dobson, & Shumsky, 2002), network capacity control (Steinhardt & Gönsch, 2012), and also BTO manufacturing (Shumsky & Zhang, 2009). In all cases, customers are assumed to be myopic. Customers can therefore be segmented effectively such that the sales quantity, total profit and capacity utilization increase. Upselling techniques further facilitate price discrimination and profit improvements. Gallego and Stefanescu (2012) consider upselling to myopic customers with fixed prices and with pricing flexibility. Considering loss-averse customers in upselling, Rosato, 2013a, 2013b) shows that under specific conditions, myopic customers will pay higher prices than their original willingness to pay. Our paper extends the literature on upgrades and upsells by considering auctions as a new pricing mechanism for upselling. We incorporate reference-dependent preferences, loss aversion and strategic behavior into the analysis of customer choice and manufacturer's profits and provide some further insights into supply-chain efficiency from evaluating planning reliability.

(ii) The extensive economic theory on auctions has among others been reviewed by Klemperer (1999); McAfee and McMillan (1987), Milgrom (1989; 2008) and Krishna (2010). Closest to our paper are works considering reference-dependent preferences and loss aversion. These works are mainly driven by empirically assessed anomalies from rational bidding behavior (for a literature review see Kagel, 1995; Kagel & Levin, 2014). Many of the empirical results can be explained when applying prospect theory. Based on the model of Köszegi and Rabin (2006; 2007), Lange and Ratan (2010) replicate empirical findings on first-price and second-price sealed-bid auctions and show that the definition of multidimensional preferences ("narrow bracketing") is a strong prerequisite of transferring experimental findings into practice.