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An EOQ model for MRO customers under stochastic price to quantify bullwhip effect for the manufacturer

ManMohan S. Sodhi [a,*], Navdeep S. Sodhi [b], Christopher S. Tang [c]

[a] Cass Business School, City University London, 106 Bunhill Row, London WC1E7AU, UK
[b] Sodhi Pricing, Minneapolis, MN, United States
[c] UCLA Anderson School, UCLA, 110 Westwood Plaza, CA 90095, United States

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ABSTRACT

Motivated by a particular multinational cutting-tools manufacturer, we extend the traditional economic order quantity (EOQ) model for maintenance-repair-and-overhaul (MRO) customers under stochastic purchase price and use it to show how price variance leads to bullwhip effect for the MRO manufacturer despite constant consumption by the customer. Our extension of the EOQ model is based on two assumptions that are reasonable for MRO customers: (a) customer consumption rate of the product is constant; and (b) the customer places each order when the inventory level drops to a pre-specified level (say, zero). We determine the customer's optimal ordering quantity in closed form expressions, which enables us to examine the impact of sales price variance on the variance in the orders the customer places on the manufacturer, thus creating a pricing-induced bullwhip effect. We then extend our analysis to multiple products and multiple customer segments and discuss ways for the manufacturer to mitigate the variance in the customer's orders.

1. Introduction

Pricing has typically been studied as a strategic topic in the operations literature and day-to-day transactional pricing, say, by way of discounts in orders, has been largely ignored. However, variable discounts across sales transactions are a common phenomenon in Business-to-Business (B2B) transactions that are well documented in the practitioner literature (cf. Marn and Rosiello, 1992; Marn et al., 2003; Sodhi and Sodhi, 2005; Kotler et al., 2006). Such variable price discounting, sometimes seen as 'hockey-stick' unit sales whereby sales personnel seek to make their month-end sales quotas by offering customers big discounts, has been recognized as causing order variance (Lee et al., 1997); however, the impact of sales price fluctuations on the variance in the customer's orders has not been quantified analytically.

Although we are motivated by the setting at a particular multinational cutting-tools manufacturer, we seek general results for the maintenance-repair-and-overhaul (MRO) sector. Taking the setting to be of constant consumption, as with an MRO customer, we extend the EOQ model for the customer's orders incorporating stochastic price and show how this implies order variance for the MRO manufacturer thus showing how price variance causes bullwhip effect.

In this paper, we provide *closed-form* expressions capturing the impact of such transaction-level varying sales prices on the variance in the customer's orders even when the customer has constant consumption. We start with the base case with a manufacturer having a single product and one customer whose consumption rate is constant and who orders when inventory goes to zero. These assumptions are reasonable for MRO customers in general including cutting tools. The reader is referred to Erlenkotter (1990, 2013) and Khan et al. (2011) for comprehensive reviews of the evolution of the EOQ model and analysis since Harris presented the EOQ model for the first time in 1913 (Harris, 1913). While the customer seeks to determine her optimal order quantity so as to minimize long-run average costs including the fixed ordering cost, we extend the traditional EOQ model to capture the fact that the customer faces uncertain varying sales prices offered by the manufacturer through variable discounts or surcharges. We then obtain closed-form expressions for "variance" of the customer's orders for this base case. Next we extend the results to the MRO manufacturer having multiple products and multiple customer segments. Moreover, we discuss the managerial implications of our analysis and ways to mitigate the customer's order variance.

Our contribution is twofold: *One*, we add to the EOQ literature by extending the EOQ model for a customer facing stochastic purchase price. Sana (2011) has analyzed the production quantity and the selling price of a firm who faces price-dependent random demand using the EOQ setting while Sana (2012) has examined a more general problem based on the newsboy problem setting.

* Corresponding author.
E-mail addresses: m.sodhi@city.ac.uk (M.S. Sodhi), Navdeep@sodhipricing.com (N.S. Sodhi), ctang@anderson.ucla.edu (C.S. Tang).

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In contrast to Sana's (2011, 2012) customer demand as "exogenous", we take customer's demand on the manufacturer to be "endogenous" in that it is derived from the customer's rational purchasing behavior having observed varying prices in the past. Netessine and Tang (2009) have compiled articles dealing with endogenous customer demand in the operations management literature.

Two, we contribute to the bullwhip-effect literature by quantifying the impact of sales price variance on the customer's order variance (cf. Lee et al., 1997; Ozelkan and Cakanyildirim, 2009; Hamister and Suresh, 2008). In the business-to-consumer (B2C) literature promotions of staple products like shampoo only increase the shampoo manufacturer's bullwhip effect without changing the consumer's consumption of shampoo. In this context, Ho et al. (1998) focused on *mean* effects pertaining to a shopper's rational shopping behavior for a single product by way of expected purchase quantity and expected shopping frequency. However, our focus is on the *variance* for the manufacturer (not the customer) and moreover, we take into account multiple products and multiple customer segments.

Managerial implications of our work are as follows. (1) To reduce the customer's order variance, manufacturers should aim to reduce not only the variance in the transaction prices but also the fixed ordering cost for its customers. (2) Even though increasing market share by increasing the number of customers can reduce the coefficient of variation of the customer orders, the marginal benefit of this effect diminishes quickly with increasing number of customers. (3) Managers should avoid invoice-level discounting and choose new segments of customers carefully because market heterogeneity increases the variance of customer orders.

This paper is organized as follows. Section 2 provides the details of the particular cutting tools manufacturing company that motivates our work along with the MRO sector as a whole. In Section 3, we present our base model that examines the rational purchasing behavior minimizing long-term total of purchasing, holding and ordering costs of a single customer with constant consumption, and ordering from a manufacturer who offers variable prices. Section 4 extends the base model to the case when the manufacturer sells multiple products. Section 5 extends the base model to multiple customer segments, each with its own consumption rate. A discussion of the results to the company's situation follows in Section 6 and we conclude with some ideas for future research.

2. A cutting-tools manufacturer and the MRO sector

Our work is motivated by a global manufacturer of cutting tools whose customers include original-equipment-manufacturer (OEM) auto companies at one extreme and small-scale service shops at the other. The company has about 6000 basic Stock Keeping Units (SKU) of cutting tools. Moreover, customized tooling for particular customers increases the number of products to over 30,000 SKUs at any given time.

Fluctuating prices: As is common in most B2B transactions, the company allows its salespeople to provide transaction-specific discounts on list prices to customers. It also plans promotions and adjusts standard discounts for large customers on a regular basis. The company knows that the "realized" prices (i.e., after the transaction discount) of its various products, both at the SKU level and at the family level, vary considerably across transactions as do SKU-specific unit sales. Based on our analysis for some SKUs, we find, for instance, that when the coefficient of variation of prices across all customers for a week was 0.09, the coefficient of variation of the unit sales was 0.46. Indeed, the variation in discounts for SKUs in the same family varies from 2% to 80% (Fig. 1).

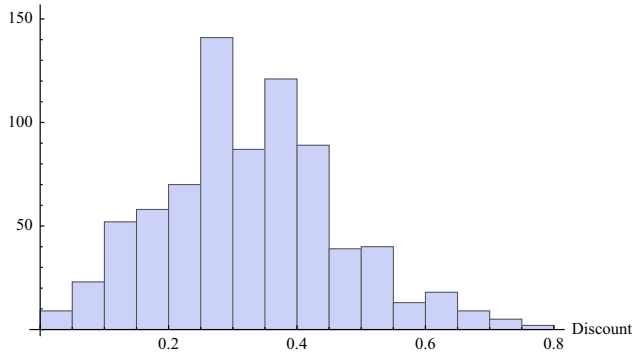

Fig. 1. Discounts across 776 transactions in a quarter on products in the same family.

Transaction sales prices fluctuate due to multiple reasons: The marketing department plans various promotions such as "buy three drills, get the sleeve free" generally for its smaller customers; similarly volume-based price discounts apply for bigger customers as well globally. There are also "local" promotional initiatives" at the country-level. Each salesperson can offer different discounts and that too at the level of an individual transaction. System-programmed rules for discounting also create price variations with the application of multiple discounting rules: a customer gets a discount based on its category, with a larger customer getting a larger discount. Sales personnel also used a quantity-specific discount schedule for different product families. Customers negotiate further discounts on individual products to try and have each cutting tool at the same per piece price even though list prices vary quite a bit. There were also single-use transactional discounts offered at customers' request to close deals. In practice, there are price discounts at different levels: item-level, invoice level, customer-level (Marn and Rosiello, 1992). Finally, dramatically fluctuating prices of specialized steels and other raw materials require the company to occasionally impose temporary surcharges (negative discounts) to pass at least some of the increased costs to customers.

The impact of price fluctuations on manufacturing operations: According to the director of pricing in the company, these price fluctuations not only diluted profitability, but also caused unit sales to fluctuate which in turn lead to scheduling problems in production, with resulting delays leading to further discounts. Given the constant usage of the products, unit sales fluctuation could result in longer replenishment intervals, which can trigger more price discounts. Also, the variance of unit sales could lead to wrong pricing decisions. For example, a downward trend across a few weeks raised arguments for lowering the price (or do another promotion) despite the argument that customers who bought more in one week would buy less in subsequent weeks.

As such, we were motivated to seek to quantify the impact of the price variance on the variance of manufacturer's orders (and hence on the manufacturer's operations).

Assumptions. Given the nature of use of cutting tools by the manufacturer's customers, we sought empirically justifiable simplifications by way of two modeling assumptions for the customers, the same as those for the standard EOQ model:

1. *Customer's consumption is constant*: Customers of this company such as auto OEMs consume cutting tools at a constant rate regardless of the mix of car models they are producing at any time. Their consumption of cutting tools is independent of the purchasing price because the opportunity cost of a cutting tool being unavailable is much higher than its purchase price.