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Supply and demand uncertainty reduction efforts and cost comparison

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ABSTRACT

In industries like health care, consumer goods and agriculture, shortages are widely observed and the consequences can be costly. One of the main drivers of such shortages is the uncertain nature of supply and demand. To reduce uncertainties, sufficient information about supply and demand can be obtained by gathering relevant data (e.g., auditing suppliers and conducting market research). In this paper, we conduct an analysis to examine the impacts of supply uncertainty, demand uncertainty and uncertainty reduction efforts on production quantity and total cost. We show that in the absence of uncertainty reduction efforts, when the financial consequences of shortages are large or when the unit benefit is large, supply uncertainty is more costly than demand uncertainty. In addition, exerting supply uncertainty reduction effort always causes the firm to produce fewer units than exerting demand uncertainty reduction effort. Although supply uncertainty reduction effort delivers a larger degree of improvement to total cost (and hence, is more efficient), reduced supply uncertainty still leads to a higher system cost than does reduced demand uncertainty.

1. Introduction

Shortages and their related consequences are widely observed in the healthcare industry. According to Clapp et al. (2013), over 300 drugs experienced shortage issues as of July 2013, up from 211 in just one year earlier. These shortages are costly to healthcare providers, patients and governments alike (Federgruen, 2012). To illustrate, CBC News (2011) reported that shortages in chemotherapy drugs caused a sharp rise in prices, putting both patients and doctors in difficult situations. In response to the public's demand to know why these shortages keep happening, Canada's federal government assigned a high priority to the task of finding a remedy for drug shortages (Health Canada, 2013; Duffin, 2014).

Uncertainty in supply represents an important driver of drug shortages. For example, the vaccine-manufacturing process involves the use of chicken eggs and is therefore subject to uncertain yields due to the manufacturing process itself and the quality of the eggs (e.g., Deo and Corbett, 2009; Arifoglu, 2012). Furthermore, the American Society of Health-System Pharmacists indicates that cancer drug shortages occur due to supply issues, such as problems with the quality of the ingredients (ASHP, 2013). Uncertainty in demand represents another equally important driver of drug shortages. For example, Tamiflu, an antiviral flu drug, was stocked out in 2013, mainly because demand unexpectedly doubled from the previous year (The Canadian Press, 2013). Demand for flu shots is also difficult to predict, even for an average flu season, leaving officials wondering, "What makes Canadians clamor for flu shots one year and shun them the next?" (Grant, 2014). A recent news article shows that rather than improving, the issue of drug shortages is actually getting worse (Favaro and Philip, 2016).

Besides being piqued by the headlines about drug shortages, our interest in this topic started with discussions with two contacts in the high tech industry, where knowing which uncertainty is costlier and reducing uncertainty in both demand and supply is crucial. (The names of our interview subjects have been hidden for confidentiality reasons.) Our first industry contact was Intel's global commodity manager. During our discussion, the interviewee stated that "managing supply and demand in our business is extremely challenging due to the manufacturing yield uncertainty and capacity adjustments [of expensive equipment] and the quick and unpredictable changes in demand [due to high turnover in technology products]. There are ways to reduce uncertainties in manufacturing [e.g., process improvements] and demand [e.g., conducting market research], but these are expensive undertakings, and we need to know the effect and benefit of the improvement before undertaking such efforts. Reduction in uncertainties has a positive direct effect on our performance."

Our second industry contact was the logistics planning director for one of the largest consumer electronics companies in Korea.

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During our interview, the director elaborated on shortages: "Shortages are an ongoing problem for our company. In the consumer electronics industry, product life cycles are getting shorter and shorter, which has an impact on both supply and demand. Let us start with the supply side. We are required to manufacture new products with brand new specifications. This adds uncertainty to production yield. Furthermore, new suppliers are often used to support new products launches, and we are not usually fully informed as to the new suppliers' performances, thus adding more uncertainty to the supply side. It is not uncommon that a supplier's deliverable does not meet our standards, and we discard its delivery and end up with fewer items than we originally planned to deliver. Short product cycles also affect the demand side and make demand forecasting more difficult, as we need to forecast for new products that were not in the market before. Heavy competition in the high tech industry adds another layer of difficulty in this forecasting. We mostly end up with stockouts in some markets for our new products." Our interview subject continued: "Ideally, we would like to reduce both supply uncertainty and demand uncertainty. However, resources are limited and, more importantly, we would like to know which one to go after first—that is, which one is more profitable. Based on our experience, we think supply uncertainty is more costly than demand uncertainty for our firm. However, it would be nice to confirm this point with research-based evidence."

Based on these interviews, we aim to quantify the effect of uncertainty reduction for both supply and demand, and to determine which type of uncertainty reduction is more beneficial.

There are numerous examples of shortages in industries other than health care. In the agriculture industry, cases often arise wherein a critical chemical ingredient needed by farmers is out of stock due to an unforeseen increase in seeding (demand) and insufficient inventory of the chemical (supply) (Prendergast, 2013). In the retail industry, Canadians were initially excited about Target's expansion into Canada, but their retail enthusiasm resulted in severe stockouts (Strauss, 2013) and, ultimately, a complete shutdown of all 133 Target stores in Canada (Evans, 2015). Further, many consumers regularly wait weeks for the latest iPhone because of ongoing high demand (Jordan, 2012). Because of its commonality across a wide range of industries, the topic of shortages has always been of interest to practitioners and academics.

In the classic newsvendor (NV) problem, supply is assumed to be deterministic, and therefore, shortages are solely caused by an uncertainty in demand. However, as described in the previous paragraphs, shortages may also be attributed to an uncertainty in supply. To deal with shortages and reduce uncertainties in demand and supply, firms can exert costly efforts to obtain data that will help them gain a better understanding of the subject. For example, a firm can audit its raw material providers to reduce the uncertainty in its production process or to improve its estimation of the production process (e.g., on-time delivery and quantity delivered), such that the firm can obtain the supply information with lower uncertainty (Kitamura et al., 2010; Yang et al., 2012). Alternatively, a firm can conduct market research and survey potential users to improve demand forecast (Hess and Lucas, 2004).

In this paper, we examine a model where there is a newsvendor that needs to decide the order quantity in the presence of demand and/or supply uncertainty. This firm can exert effort to reduce uncertainty. To obtain analytical insights, we first consider each uncertainty separately. Then we verify the robustness of our result by considering a system where both types of uncertainty exist simultaneously. In particular, this paper -addresses the following research questions:

1. What is the profitability of each uncertainty reduction effort?
2. What are the impacts of uncertainty reduction efforts on production quantity and total cost?

We find that, in the absence of effort, if the financial consequences of shortages are substantially larger than the unit production cost, then supply uncertainty is more costly than demand uncertainty. However, when the firm has the option of exerting uncertainty reduction efforts, we find that supply uncertainty reduction effort is more profitable than demand uncertainty reduction effort. Consequently, the optimal effort exerted to reduce supply uncertainty is larger than the effort exerted to reduce demand uncertainty. Yet even though supply uncertainty decreases as more efforts are exerted, it still results in a higher total cost when compared with demand uncertainty. Moreover, as a result of these efforts, we find that demand uncertainty would always cause the firm to produce more than would supply uncertainty.

Our results imply that a firm facing both supply and demand uncertainty should first focus efforts to reduce supply uncertainty (e.g., establishing better communication with its suppliers, finding and working with more suppliers and improving production yield) if shortage cost is relatively large, and the firm should exert effort to decrease demand uncertainty (e.g., market research for its products, targeted consumer surveys and better demand forecasting) first if shortage cost is relatively small.

In the next section, we present a review of the relevant literature. In Section 3, we present our framework for the no-effort case, whereas the analysis with the efforts is provided in Section 4. We conclude the paper in Section 5, and our proofs are provided in the appendix.

2. Literature review

The main contribution of our study is to provide an analysis of uncertainty reduction (with respect to both demand and supply), offering a comparison with and without efforts. Therefore, our paper relates to the literature on supply uncertainty and demand uncertainty, and on how a firm can exert effort to minimize these uncertainties.

The first block of literature addresses the topic of supply uncertainty. Cho (2010) investigates a problem with composition selection for an influenza vaccine. The timing of the composition selection matters since there is a tradeoff between yield rate and effectiveness of the vaccine. Deo and Corbett (2009) combine competition with supply uncertainty and find that, up to a certain threshold of supply uncertainty, entry into the market becomes more attractive compared to no supply uncertainty. Arifoglu (2012) develop an epidemiological and economical model to deal with random production supply and rational customer behavior. Arifoglu (2012) extends Arifoglu et al. (2012) by imposing mechanisms (e.g., taxes and subsidies) for rational customers and by comparing their model's performance with the outcomes of other models from the literature. Ozaltin et al. (2011) model supply uncertainty to optimize the social benefits of annual influenza vaccination.

Within the literature on supply uncertainty, some papers study supply chain coordination. Chick et al. (2008) perform disease modeling and study random supply with a newsvendor model with no information asymmetry. Chick et al. (2012) extend Chick et al. (2008) by considering private information on supply and the option of late delivery, where the buyer's objective is to design a contract to minimize information rent due to private information on random supply of the supplier. Yang et al. (2009) examine supply disruptions with a manufacturer and a supplier under asymmetric information, where the supplier has private information about supply disruptions and pays a penalty if shortages occur. In a follow-up paper, Yang et al. (2012) extend their study to a system with two suppliers to quantify supplier reliability competition and diversification.