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Forecast errors and inventory performance under forecast information sharing

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ABSTRACT

Previous research has shown that the forecast accuracy is to be distinguished from the performance of the forecasts when utility measures are employed. This is particularly true in an inventory management context, where the interactions between forecasting and stock control are not yet fully understood. In this paper, the relationship between the forecasting performance and inventory implications is explored under an ARIMA representation of the demand process. Two distinct scenarios are incorporated in our analysis: Forecast Information Sharing (FIS) and No Information Sharing (NIS) in a two-stage supply chain. We approach the problem analytically and by means of simulation. The validity of the theoretical results is assessed on a real sales dataset from a major European superstore. The results indicate that the gain in accuracy from Forecast Information Sharing depends on the demand process. The translation to inventory savings then depends on the magnitude of the forecast accuracy improvement, regardless of the demand process. Insights into pertinent managerial issues are also offered, and our paper concludes with an agenda for further research in this area.

1. Introduction

Previous research has shown that forecast accuracy is to be distinguished from forecast utility (e.g. Syntetos, Nikolopoulos, & Boylan, 2010, and Timmermann & Granger, 2004). Goodwin (2009, p. 10) argued that forecast accuracy metrics often provide a poor indication of the costs and benefits resulting from forecasts. He recommended '*…that we should never see forecasting as an isolated task, carried out for its own sake*', and called for more theoretical contributions exploring the relationship between forecast accuracy and empirical utility.

The relationship between accuracy and utility is particularly complex in an inventory management setting. In the context of this application, replenishment requirements are calculated according to an anticipated probability distribution of demand, obtained from the results of a forecasting procedure. However, parametric stock control theory has been developed based on the assumption of known distribution parameters. The interactions between forecasting and stock control are not yet fully understood. Nevertheless, many researchers have shown that the performance of a stock control system is not always directly related to the forecasting accuracy, as calculated by standard measures (see, for example, Eaves & Kingsman, 2004, Flores, Olson, & Pearce, 1993, Gardner, 1990, Mahmoud & Pegels, 1989, Sani & Kingsman, 1997, and Syntetos & Boylan, 2006). These papers argue that improvements in forecast accuracy must be distinguished from improvements in inventory performance, i.e. a more accurate forecast does not necessarily imply reduced inventory costs and/or an

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increased service level, which is what matters from a practitioner's perspective (see also Boylan & Syntetos, 2006).

In this paper, we explore, in a two-stage supply chain, the relationship between forecast accuracy and inventories, and the factors upon which this relationship depends. We analyse a supply chain with one member at each stage (say, a retailer and a manufacturer). We do so by assuming an underlying ARIMA demand process at the retailer. In particular, we focus on three stationary processes, namely AR(1), MA(1), and ARMA(1, 1). Such processes are prevalent in industrial sales data, and, as is discussed in Section 5.1, they also collectively represent more than half of the data series available for the purposes of our research. Two distinct scenarios are incorporated in our analysis: Forecast Information Sharing (FIS) and No Information Sharing (NIS) between the retailer and the manufacturer. In the NIS scenario, the retailer does not share any information with the manufacturer, and therefore the latter organisation forecasts on the basis of the orders received from the former. Conversely, in the FIS scenario, the retailer shares its forecasts with the manufacturer. The orders placed with its supplier by the latter organisation are then based on these shared forecasts. The two approaches are compared here by calculating the forecast accuracy, inventory holdings and inventory costs.

The literature abounds in discussions of the benefits of sharing information in supply chains, and metrics such as the forecast accuracy and inventory costs have been employed to measure such benefits. However, the linkage between these metrics has never been explored systematically in the academic literature, and this constitutes the main contribution of our work. We start by assuming an AR(1) demand process at the retailer, and mathematically analyse the association between the Mean Squared Error (MSE) and inventory holdings. Owing to the mathematical complexity of extending this association to inventory costs, we continue by employing simulations on theoretically generated data. This helps us to establish the relationship between the MSE and inventory costs and to explore the effects of the autoregressive parameter on this relationship. It also enables us to assess the accuracy of approximate mathematical relationships. We repeat this exercise for the MA(1) and ARMA(1, 1) processes.

The results indicate that information sharing leads to considerable reductions in MSE, particularly for an AR(1) process at the retailer, confirming previous findings by Lee, So, and Tang (2000). However, the MSE reductions for MA(1) processes are found to be more modest. The analysis of ARMA(1, 1) shows reductions in MSE between those achieved for the AR(1) and MA(1) processes. The findings relating to the MA(1) and ARMA(1, 1) processes constitute new results in the academic literature.

The analytical findings show that the translation of the MSE improvements into inventory savings is independent of the underlying demand process. Greater reductions in MSE imply greater reductions in inventory holdings and costs. The validity of the theoretical/simulation results is assessed using a real dataset from a major European superstore.

The remainder of our paper is structured as follows: in Section 2 we review the literature on the relationship between forecast accuracy and inventory performance, and we also consider previous studies that refer to the value of information sharing in supply chain management. The supply chain model used for the purposes of our research is discussed in Section 3, where approximate theoretical results on the relationship between the mean squared error and the inventory holdings are presented. This is followed by a simulation experiment, developed in Section 4, that is used to extend our analysis to inventory costs. Section 5 describes the empirical study carried out for the purposes of our research and its results. Managerial insights are offered in Section 6, along with the conclusions of our work and some natural avenues for further research.

2. Research background

2.1. Forecasting—stock control interactions

In practical parametric approaches to inventory management it is inevitable that future demand be forecasted in some way. The decision parameters in the inventory model are then based on an estimated demand distribution, obtained from the results of the forecast procedure. These two stages of practical inventory management (i.e. forecasting and stock control) are traditionally treated as independent of each other. The majority of studies look at demand forecasting as if this were an end in itself, or at stock control models as if there were no preceding stages of computation. Nevertheless, it is very important to understand the interaction between demand forecasting and inventory control, since the performance of the inventory system is determined by the two components in combination.

Unfortunately, most research on inventories ignores forecasting altogether, and simply assumes that the distribution of demand and all of its parameters are known. Only a few studies on the interactions between forecasting and inventory decisions are available. Brown (1963), Croston (1972), Eppen and Martin (1988), Strijbosch, Moors, and de Kok (1997) and Watson (1987), amongst others, showed that forecast errors can seriously distort projections of customer service. Minimum-variance unbiased estimators are desirable from a statistical perspective, but one should note that the forecasts are not the final output of the system. What really matters, from a practitioner's perspective, is the achievement of a target Customer Service Level (CSL) or the minimisation of a cost function, dependingon the circumstances. Theoretically, minimum-variance estimators of the mean demand enable the minimization of inventory holdings, assuming that an appropriate stock rule is in place and the distribution of the demand is known. Unbiased forecasts of the mean demand enable the achievement of a service target, also assuming a valid demand distributional representation. However, in practical applications, such theoretical expectations will not necessarily be sustained. In that respect, it has become apparent that the forecast accuracy is to be distinguished from the empirical utility (stock control performance) of the estimators being used; for a summary of various arguments in this area and a review of the relevant literature, please refer to Syntetos and Boylan (2008).