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Demand forecasting based on natural computing approaches applied to the foodstuff retail segment

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ABSTRACT

The purpose of this paper is to compare the accuracy of demand forecasting between two classical linear forecasting models (Autoregressive and Integrated Moving Average -ARIMA and Holt-Winter) and two nonlinear forecasting models based on natural computing approaches (Wavelets Neural Networks - WNN and Takagi-Sugeno Fuzzy System - TS), all applied to the aggregated retail sales of three groups of perishable food products from 2005 to 2013. Moreover, this paper evaluates the impact of demand forecasting accuracy on the demand satisfaction rate and on the overall economic performance of retail business operations. The most accurate model, WNN, had a demand satisfaction rate of 98.27% for Group A, 98.83% for Group B and 98.80% for Group C. WNN estimated a loss of revenue of R$1329.14 million/year with a minimum loss of 166 tons/year, which means that the results of WNN are 37.67% more efficient than the TS, 57.49% higher than the ARIMA and 76.79% higher than HW. This paper presents three main contributions: (i) it examines a question not evaluated in the literature on demand forecasting based on natural computing approaches in the foodstuff retail segment that generates better practical results, (ii) it proposes that a single forecasting model could be applied to different product groups and serves the organization as a whole with a good relationship between the cost and the benefit of the process and (iii) like previous studies, it proves that demand forecasting plays an important role and can generate a competitive advantage for the organization to be incorporated into its strategy.

1. Introduction

Demand forecasting aids the strategic planning of an organization, as it allows administrators to anticipate the future and plan activities in many functional areas. Forecasting future demand provides the best assessment of the business information available. Therefore, an accurate forecasting system is required that plays a crucial role in the quality of the decision-making process (Kuo and Xue, 1999; Majhi and Anish, 2015). In the business operations of the foodstuff retail segment, forecasting accuracy is even more important to the quality of the decision-making process because retailing is widely recognized as a competitive industry in both mature and developing markets (Alon et al., 2001; Ma et al., 2016; Schneider and Gupta, 2016). Consumers have a wide choice of retailers, retail channels and formats. Thus, retailers continuously strive to differentiate themselves from their competitors and provide a good value proposition to consumers based on the right balance of price, quality, and service.[1]

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[1] https://www2.deloitte.com/content/dam/Deloitte/ie/Documents/ConsumerBusiness/2015-Deloitte-Ireland-Food_Value_Chain.pdf.

To be successful in this goal, the retail company needs to design its demand and supply planning processes to avoid customer service issues along with rising inventory and substantial write-offs due to expired products. These are sensitive issues in retail companies because of the complex relationship in the demand data with considerable monthly fluctuations, the presence of many intermediaries in the process, diversity of products and the quality service required by the consumer (Stank and Daugherty, 1997). In a general way, "accurate demand forecasting is crucial for profitable retail operations (…) directly affecting revenue and competitive position" (Agrawal and Schorling, 1996, p. 383).

Much effort has been devoted over the past several decades to the development and improvement of forecasting models. There are currently at least 70 time series forecasting models using linear and/or nonlinear structures for quantitative demand forecasting (Kerkkanen et al., 2009). In the recent literature, it is well established that there is a need for investigative studies on the most appropriate forecasting model for every situation since there is no universal model that will make accurate predictions for all problems. Historically, many scientific papers have focused on modeling, analysis and forecasting approaches of time series that show irregular variations, seasonality and trends (Santos et al., 2007; Bulut, 2014; Gan et al., 2014; Panapakidis, 2016; Lahmiri, 2016), as is typical of retail sales (Ma et al., 2016). Many theoretical and heuristic models have been developed and evaluated empirically in recent decades (Wang et al., 2015). In general, the linear mathematical models are preferred over more complex models, as linear models have the important practical advantage of easy interpretation and implementation (Green and Armstrong, 2015). On the other hand, if linear models fail to perform well in both in-sample fitting and out-of-sample forecasting, more complex nonlinear models should be considered (Chu and Zhang, 2003).

The most common nonlinear models applied in retail demand forecasting are artificial neural networks (ANNs), which are able to learn from data and experience, identify the pattern or trend and make generalizations regarding the future. However, this model has black-box structures that embody a large degree of uncertainty concerning its use in static linear processes, difficulty in interpreting results, overfitting problems and difficulty in identifying the best network structure (Alexandridis and Zapranis, 2013). Recently, fuzzy systems and wavelet analysis (Alexandridis and Zapranis, 2013) have been proposed as supplementary tools to ANNs. These models are capable of solving complex situations, thereby providing solution techniques to problems that could not be satisfactorily resolved by other more traditional techniques, such as linear, nonlinear, and dynamic programming. Despite the popularity and the promising results presented by Wavelet Neural Network (WNN) (Zhang and Benveniste, 1992) and Takagi-Sugeno Fuzzy System (TS) (Takagi and Sugeno, 1985) in various knowledge fields, their application for demand forecasting in the foodstuff retail segment is unprecedented and there are several innovative aspects in their operational procedures and in the adjustment parameter of the models. Furthermore, there have been few descriptions in the literature on the impact of demand forecasting accuracy in the performance of the retail supply chain. This information is strategic for the decision-making process as it promotes improvements in demand satisfaction rate and leads to reduced costs in retail business operations.

In this paper, we focus on comparing the accuracy of demand forecasting between two classical linear forecasting models (Autoregressive and Integrated Moving Average, ARIMA and Holt-Winter, HW) and two nonlinear forecasting models based on natural computing approaches (WNN and TS), all applied to the aggregated retail sales of three groups of perishable food products from 2005 to 2013. We have chosen ARIMA and HW as linear forecasting model for specific reasons. ARIMA has been extensively studied and applied in retail demand forecasting and therefore it has considerable validated empirical evidence that has been used as a forecasting technique in several fields (Lee and Ko, 2011; Wang et al., 2015; Askari and Montazerin, 2015; Veiga et al., 2016). Furthermore, ARIMA has equivalence with most exponential smoothing models, except for the multiplicative HW, which explains the concomitant use of these two linear models (Makridakis et al., 1998). Moreover, high accuracy demand forecasting has an impact on organizational performance because it improves many features of the retail supply chain (Syntetos et al., 2016). To contribute to the previous scientific literature, this paper evaluates the impact of demand forecasting accuracy on the demand satisfaction rate and on the overall economic performance of retail business operations.

This study makes important contributions to the business practices of retail companies and to demand forecasting as a scientific discipline (Petropoulos et al., 2014). The first contribution of this paper is to examine a question not evaluated in the literature on demand forecasting based on a natural computing approach in the foodstuff retail segment that generates better practical results. The second contribution is to propose that a single forecasting model could be applied to different product groups of the retail organization. Therefore, this study demonstrates operational facilities in implementing a demand forecasting system to serve the organization as a whole and provide the possibility of establishing a good relationship between the cost and benefit of the process. Finally, the third contribution is to prove that demand forecasting plays an important role and can generate a competitive advantage for the organization to be incorporated into its strategy. The fierce competition among retail organizations requires an ability to make quick and accurate decisions based on quality information.

The remainder of this paper is organized as follows. In Section 2, the HW, ARIMA, WNN and TS approaches used for demand forecast are described. Section 3 describes the research design, including the data source, data preprocessing, accuracy, demand satisfaction rate and overall economic performance measures. Section 4 compares the results obtained from each forecasting model and explores the significance of the results. Section 5 provides concluding remarks.

2. Previous studies

Quantitative forecasting techniques vary considerably, having been developed by many disciplines for different purposes. Each has its own properties, accuracies and costs that must be considered when choosing a specific model. In general, it is widely agreed across roles and across situations that accuracy is the most important criterion used to select forecasting models, but other criteria are rated as being almost as important. In particular, factors related to implementation, such as ease of interpretation and ease of use (Yokum and Armstrong, 1995). Numerous comparative studies between traditional and nonlinear forecasting models have been conducted in the literature. However, the findings are contradictory regarding when and under what conditions one model is better than another (Armstrong and Fildes, 2006). This section provides a theoretical background on the comparative advantage of the different models used in this study.

2.1. Linear models

Linear models were first developed in the late 1950s by operations research (Makridakis et al., 1998). The major advantages of widely used linear models are their simplicity and low cost. These models are useful when forecasts are needed for a large number of items and when forecasting errors on a single item will