

Research on Game-Theoretic Supply Chain Optimisation Strategies Based on Multiple Linear Regression and BP-PSO Combined Time Series Analysis

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Abstract. Vegetable commodities have a short cycle, and supermarkets generally replenish goods based on historical sales and demand for each commodity. Vegetable commodities are different from other commodities with relatively stable supply chain planning and market environment, so the automatic pricing and replenishment decisions of fresh food superstores on commodities are of great significance. This paper focuses on the problem of commodity pricing and replenishment strategy. Firstly, through multiple linear analysis regression analysis, the relationship between total quantity and cost plus pricing, fit a one-dimensional linear fitting equation, and visualise the correlation between sales price and total quantity, secondly, observe the trend of various types of vegetables through matlab time-series analysis, establish BP neural network prediction model, predict the total quantity of sales and total quantity of replenishment in the coming week, and formulate the commodity pricing and replenishment strategy using Linear programming to establish the optimization model, verify the feasibility of the model, the parameter normality test and residual test and visual inspection error, analyse the parameter significance, use BP neural network to test the fitting effect. The results of the study, based on the game theory of supply chain replenishment and pricing strategy to establish a mathematical model.

Keywords: Multiple linear regression, BP neural network, Vegetable marketing optimisation decisions, Time series, Game theory.

1. Introduction

After the improvement of the living standard of the residents, the food consumption structure has produced a huge change, vegetable production and demand are basically in a relatively balanced state, people have gradually shifted from the quantity type to the quality type of vegetables^[1]. Therefore, reliable analysis of market demand is necessary for businessmen. In the fresh food supermarkets, general vegetable commodities have short cycle characteristics, most varieties cannot be re-sold the next day, for this reason, supermarkets will generally be based on the historical sales of each commodity and demand for replenishment. Because of the many varieties of vegetables, different places of origin, vegetable purchase transaction time is usually in the morning 3 to 4 o'clock, and in the case of specific single product and purchase price does not know, merchants must also be on the day of the replenishment of various vegetable categories to make the corresponding decision. Supermarkets usually sell at a discount for damaged and deteriorated goods, and use the "cost-plus pricing" method to price vegetables. From the demand side, the sales volume of vegetables is usually related to the time of day; from the supply side, the supply of vegetables is abundant from April to October, and the limitation of the sales space of supermarkets makes a reasonable sales mix especially important. To make rational replenishment and pricing decisions.

In order to make reasonable replenishment and pricing decisions, previous researchers used dual-channel sales of fresh produce when making replenishment and pricing decisions, which triggered a new joint optimisation problem of pricing and inventory, with the goal of maximising cycle profit, using the theory of metamorphic inventory, and constructing a joint decision model of retailer dual-channel pricing and inventory replenishment with demand dependent on price and inventory levels^[2]; in addition, there are also scholars who consider the fact that fresh products are easy to wear and tear,

not easy to store, quality and freshness is the typical characteristics and basic requirements of fresh food cold chain operation. On the basis of comprehensive consideration of multi-product replenishment, non-immediate deterioration cycle of inventory goods and pricing, a joint replenishment and pricing model of fresh products based on investment in preservation technology is constructed through the introduction of preservation technology investment parameters^[3]; some others consider the increasing demand for fresh products from urban residents. Based on this, from the perspective of urban cold chain logistics enterprises, the joint decision-making problem of cold chain distribution location and pricing based on demand space clustering is explored, and three models for joint decision-making of cold chain distribution location and pricing are established, including the basic model, the non-nested model and the nested model^[4].

Through literature review, it is understood that in order to maximise profits, a multi-species combination of sales volume can be used^[5], for this reason we have taken all the imports of the 6 categories to attract the attention of the customers. The revenue of the superstore is maximised by not stocking the 6 categories in different quantities, in which the corresponding import weights of the 6 categories are calculated by using the topsis method^[6]. This paper requires replenishment planning on a category-by-category basis. Firstly, the correlation between sales volume and cost-plus pricing of each vegetable category is analysed, and then, through the neural network prediction, the daily sales volume of each category is predicted for 1-7 July 2023, for which replenishment strategies are made, and pricing decisions are made for the categories based on the relationship between sales volume and cost-plus pricing, as well as on the basis of the wholesale price taking into account the wastage.

2. BP neural Network Based Decision Making Models

A review of the literature revealed that to maximise profits, a multi-category combination of sales volumes can be used. For this **purpose**, the study has taken the entire stock of 6 categories. Maximise the revenue of the superstore by stocking the 6 categories without using any quantity. Understand the definition of cost-plus pricing, the difference between cost-plus pricing and pricing, cost-plus pricing is usually used to determine the selling price by adding the cost of purchases to the required profit, usually based on the cost of each category and the expected profit margin to determine the selling price, so that the selling price is usually higher than the cost to achieve profitability, pricing includes cost-plus pricing. Linear Modelling of Market Demand Market demand can be modelled as a function of daily sales volume and sales price. This can be a linear or non-linear function that represents the market's response to different prices and quantities. This function can be estimated from historical sales data or market research.

2.1. Modelling ideas

(1) By analysing the superstore to the category as a unit replenishment plan and model preparation for literature review, professional knowledge, each unit of category replenishment how much replenishment and replenishment in the sales market into a certain linear relationship, for the unit category through the analysis of the total sales and cost plus pricing has a correlation, so the use of matlab programming tools on the total amount of cost plus pricing with a one-dimensional linear regression to analyse the relationship between the relationship between the establishment of the total amount of sales of vegetable categories and the cost of pricing plus the relationship between the.

(2) For the future short-term time prediction model for the super to give the profit maximisation decision, for the beginning of July week of the sales volume of each category is an unknown number, if the rough assumption of the super sales volume this week is not in line with the actual situation, so the use of matlab tools for the beginning of July 2023 week of sales volume of each category using a BP neural network prediction^[7], and through the observation of the 6 categories of vegetables each single product sales in recent years to the statistics of the super stock, analysis using the sum of the

average of each category as the stock, at any time more recently the super every day, whether or not to replenishment, the need to replenishment of the stock of the quantity of goods for the number of.

(3) The analysis leads to two methods in order to maximise the revenue of the superstore.

Method 1: Reverse closed-loop approach. Assuming that the pricing is approximately equal to the cost-plus pricing, calculated in the sales in the development of the regularity model to calculate the total amount of replenishment that is calculated for the supercommercial gain the most time, through the predicted sales of the number of values and the supercommercial average inventory discrepancy to replenish the stock, through the above time series predicted sales of each category of vegetables in the 7-day period, and at the same time, sales of the total amount of the first step in the model fitted to the function can be calculated to cost-plus pricing value, at the same time the unit product; class vegetables for the unit model can be done to calculate the value of replenishment, and finally it can be determined in July 2023 the initial hypermarket revenue maximisation decision scheme.

Method 2: Forward optimisation type method. The use of multivariate linear programming optimisation model^[8], objective function: revenue = total replenishment * pricing; decision variables: for each vegetable category, to determine its replenishment volume (in kilograms) and pricing strategy (sales price) for each day in the coming week; constraints: 1, the total amount of replenishment constraints: the total replenishment volume should be within the acceptable range; 2, the minimum display volume requirements: the daily replenishment volume of each vegetable category shall not be less than 2.5kg; 3. Pricing strategy should be reasonable to ensure market demand. Then matlab is used to find out the target decision scheme of daily supermarket replenishment quantity and cost-plus pricing to maximise the revenue of the superstore based on the use of Particle Swarm System of Equations **algorithm**^[9] (PSO).

2.2. Relationship between total sales and cost-plus pricing for each vegetable category

Linear regression model is used to analyse the relationship between total sales and cost-plus pricing, as total sales are affected by a variety of elements, resulting in a lot of complexity, this paper takes cost-plus pricing as the independent variable, and sales volume as the dependent variable to make the linear relationship between the two, the formula is as follows.

$$S = \beta_0 + C * \beta_1 + \varepsilon \quad (1)$$

The visualisation of the relationship between sales volume and cost-plus pricing and the fitting of the discrete-point one-way linear regression equation are shown in Figure 1:

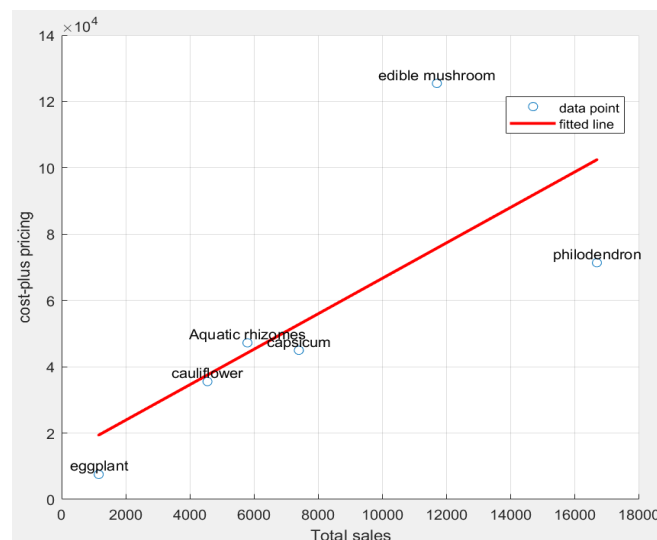


Figure 1. Fitting diagram

The one-dimensional linear fitted equation obtained by fitting the

$$S = 5.351x + 13201.6725 + \varepsilon \quad (2)$$

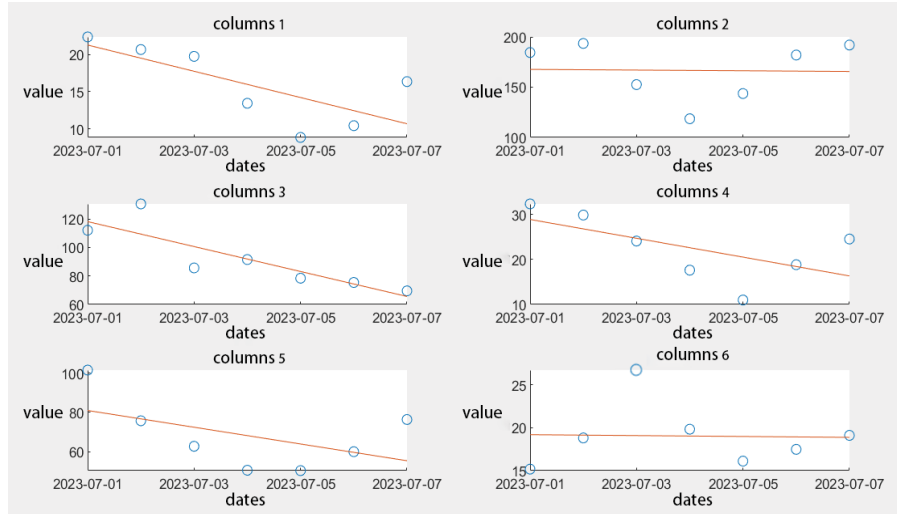


Figure 3. 7 days of sales by category

The formulae for the two methods of calculating profit maximisation are as follows:

Method 1: Reverse closed-loop method.

$$\begin{cases} e_i = D_i - y_i \\ e_i = k * x_i \\ Max Z = (x_i - \alpha_i - \beta_i - \gamma_i) * e_i (i = 1, 2, \dots) \end{cases} \quad (3)$$

Method 2: Forward optimisation approach.

$$\begin{cases} S = 13201.6725 + 5.351x \\ Max Z = (x - \alpha_i - \beta_i - \gamma_i) * e_i \\ e_i = k * x_i (i = 1, 2, \dots) \end{cases} \quad (4)$$

3. Analysis and testing of results

In this paper, the fitted equations obtained are analysed to test the assumptions of the linear regression model through residual analysis and to check whether the model residuals satisfy the assumptions or not, so in this paper, for the above linear fit function is tested for normality and homoskedasticity in two aspects, which is visualised in two aspects through matlab as shown in Figure 4.

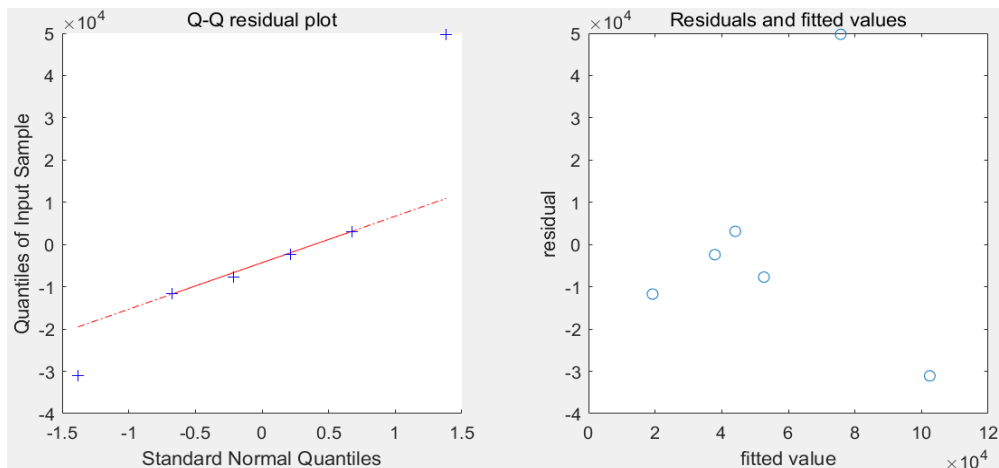


Figure 4. Inspection diagram

Table.2. Test data.

	Intercept term p-value	Independent variable X1 P-value	R-squared	The p-value of the F-statistic
Test results	0.6	0.09	0.545	0.0938
Normal indicators	0.05	0.05	0.5	1

Overall, the results of the model fit (as shown in Table.2.) X1 may be less significant on the dependent variable, as seen by the neural network fit graphic Figure 5 where various other factors have some influence on some extent. Further optimisation of the model can be considered, such as trying different combinations of independent variables or more complex models to improve the fit. In addition, factors in the business context and practical applications need to be considered to determine whether to retain the intercept term and the independent variables X1.

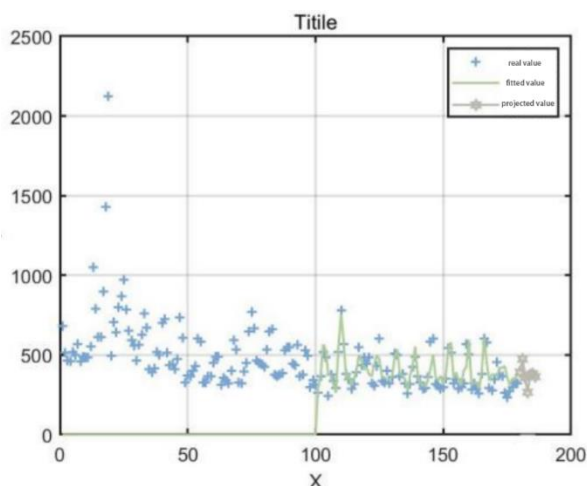


Figure 5. Neural Networks Fitting Graphs

The fitted BP neural network prediction was found to be better with a fitting error of 0.078636 by fitting the graph to the neural network.

4. Conclusions

Vegetable industry is developing rapidly, but vegetable commodities are different from other commodities with relatively stable supply chain planning and market environment, so the automatic pricing and replenishment strategy of fresh food superstores for commodities is of great significance. Supermarkets for shipping losses and poor-quality goods are generally sold at a discount, the use of "cost-plus pricing" method of pricing for vegetables, this paper focuses on the supply chain based on the game theory of commodity pricing and replenishment strategy. A time series, BP neural network prediction model is established and based on probability theory, linear fitting optimization method is used to analyse the game relationship between total replenishment and cost-plus pricing through multiple linear regression. Considering that vegetables are affected by multiple total elements, we firstly observe the trend of change through the equation of the time series, and then we use the BP neural network to predict the quantity of the next 7 days and combine the linear programming model with the particle swarm algorithm to solve the linear equation to find the replenishment price. The algorithm fits the linear equations to solve the mathematical model. The supply chain replenishment and pricing strategy under the "cost-plus pricing" method for vegetable pricing was obtained.

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