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Study on Supermarket Replenishment and Pricing Based on Time Series Forecasting Algorithm and Nonlinear Multi-Objective Optimization Model

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Abstract: This study explores the correlation between the total sales volume of various vegetable categories and cost-plus pricing in supermarkets. It encompasses data processing for weekly totals across six categories, establishing the relationship between sales volume and pricing, predicting future replenishment volume and pricing strategies using a time series forecasting algorithm and nonlinear multi-objective optimization models, and integrating constraints to maximize total profits. The research aims to optimize pricing and replenishment decisions, offering insights for improving profitability and resource utilization in the retail industry.

1. Introduction

In fresh produce superstores, the freshness period of general vegetable commodities is relatively short, and the quality deteriorates with the increase in sales time, and most varieties, if not sold on the same day, cannot be re-sold on the next day. Therefore, supermarkets usually replenish their stocks on a daily basis according to the historical sales and demand of each commodity. Because of the many varieties of vegetables sold in supermarkets, the origins are not the same, and merchants must not know exactly the specific products and purchase price of the case, to make the decision to replenish the day of each vegetable category. Vegetables are generally priced using the "cost-plus pricing" method, and supermarkets usually sell at a discount for shipping losses and poor quality goods. Reliable market demand analyses are particularly important for replenishment and pricing decisions.

Some scholars have already conducted research on this topic, and Chew Lian Chua et al. [1] show that consumers' inflation expectations are overly influenced by specific elements of the cross-sectional distribution of price changes. These estimates provide new evidence that the right tail of supermarket price changes is an important factor in explaining inflation expectations. Aldo Crossa et al [2], in order to study food pricing in New York City (NYC), collected a defined Standard Food Basket (SFB) at supermarkets in the NYC neighbourhood. The paper created a dataset that included price data for 10 predefined food items collected between March and August 2019 from 163 supermarkets in 71 of the 181 communities in NYC. Using these data, researchers, policy analysts, and educators will learn about the methodology used to generate SFB pricing data. Chandra S.R. Nuthalapati et al [3] demonstrated that prices are significantly higher in the supermarket channel even after controlling for quality differences. Positive price effects were confirmed by hedonic price modelling and propensity score matching. Supermarkets had an average effect of 20% or more on farm-delivered prices. Christina Zorbas et al [4] classified beverages into four categories (sugar-sweetened beverages, artificially sweetened beverages, flavoured milk, and 100% fruit juices, milk and water). The proportion of each category contributing to the total price-proportional volume, the proportion of price promotions within the available product categories, the average discount and the weekly variation in price promotions were calculated. Josine M Stuber et al [5] conducted a secondary analysis of a mixed randomised experiment consisting of five conditions (within subjects) and three conditions (between subjects) to investigate the effect of price promotions on the food groups (fruit and vegetables, cereals, dairy products, protein products, fats, beverages, snacks and other food products), the single and combined effects of a push (e.g., resulting in a significant increase in healthy products), a tax (25 per cent price increase) and/or a subsidy (25 per cent price decrease).

In the retail industry, the pricing and replenishment of products, especially perishable items such as vegetables, are crucial for maintaining profitability and customer satisfaction. This study delves into the complex dynamics of sales volume, pricing, and replenishment strategies for various vegetable categories in supermarkets. By analyzing historical data and employing advanced algorithms, this research aims to provide insights into optimizing pricing and replenishment decisions, ultimately leading to improved profitability and resource utilization.

The paper is structured as follows: it begins by elucidating the relationship between sales volume and cost-plus pricing for different vegetable categories. Subsequently, it outlines the methodology used to predict the future replenishment volume and pricing strategies for each category. The study then introduces a comprehensive model that integrates various constraints and aims to maximize total profits. By undertaking this research, the paper seeks to contribute to the understanding and enhancement of pricing and replenishment strategies in the supermarket industry. This paper analyzes the data in http://www.mcm.edu.cn/upload_cn/node/690/ Y20WPner9fa62862794e6dc 82731a5561 ce 1132f. rar in order to provide an effective solution strategy.

2. Relationship-fitting model building and solving

Start by processing the data, and do the calculations on a weekly basis for each of the 6 categories.

Use Excel to do a pivot table, act 6 categories, listed as time, the value is the sum of the daily pricing of each category, the sum of the cost price and the sum of the sales volume, to get the data set of 1085*18.

Then use Matlab to chunk the 1085*18 data set, one chunk for every 7 days, you can get 155 chunks, and chunk every 3 columns of the 155 chunks (selling price, sales volume, cost), i.e., the 155 chunks also contain 3 7*6 chunks.

Summing each column of the smallest block, the sum of the first column of each fast is stored in order in a new matrix sj (155 * 6), 2, 3 columns are stored in the same way in the xsl, cb matrix, the matrix sj, xsl, cb copied to Excel for storage.

Then Excel was used to fit the data in column i corresponding to the selling price and sales volume to obtain the $ri(Yi)$ function, i.e., the relationship between the total sales volume and the weekly selling price for each vegetable category.

A time series model is used in Matlab to predict the sales volume for the next 7 days to find the ratio of daily sales volume to the sum of weekly sales volume for each category.

Substitute to find the relationship between total sales volume and cost-plus pricing for each vegetable category.

Predicting the cost of each category for the next 7 days using Matlab's time series model, respectively, we have the total weekly cost of each category αi, the average discount rate calculated by Excel for each category $\bar{\beta i}$, the average discount rate calculated by Excel for each category

$\bar{\boldsymbol{\lambda i}}$, $\bar{\boldsymbol{\lambda i}}$, although it varies over time, is calculated as an average due to the small value.

The results obtained by fitting the data in column i corresponding to the selling price and sales volume through Excel are shown in Figure 1.

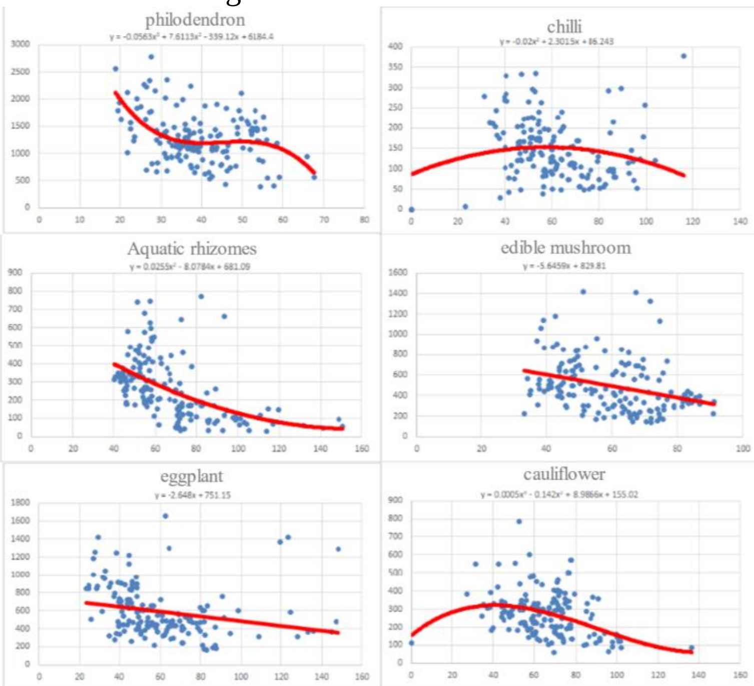

Figure 1: Relationship between sales volume and cost-plus pricing for each category.

The graph shows that the relationship between the sales volume of edible mushrooms and cost-plus pricing and the sales volume of eggplant and cost-plus pricing is linear, the sales volume decreases with the increase in cost, the rest of the categories have a non-linear relationship but in general, when with the cost is very large, the sales volume is decreasing. This shows that when the cost of vegetables is too high, people will not choose to buy that category of vegetables.

3. Development and solution of an optimisation model for total replenishment and pricing strategy

3.1. Modelling

Building a non-linear multi-objective optimisation model has:

$$max\mathbf{z} = \Sigma\left[r_i(1-\lambda_i)Y_i + \cdot\, Y_i \cdot r_i \cdot\cdot\, \bar{\lambda}_i \cdot 0.7 - X_i\alpha_i\right] \tag{1}$$

$$s.t.\begin{cases} \frac{1}{1-\boldsymbol{\beta}_\mathrm{i}}\mathbf{r}_\mathrm{i} \cdot 0.9 \cdot\leq\cdot\, \mathrm{x} < -\frac{1}{1-\boldsymbol{\beta}_\mathrm{i}}\mathbf{r}_\mathrm{i} \cdot 1.1 \\ r_i = f(y_i) \\ \boldsymbol{Min}\ \text{Sales volume} \leq \boldsymbol{Xi} \leq \boldsymbol{Max}\ \text{Sales volume} \\ \boldsymbol{Min}\ \text{pricing} \leq \boldsymbol{Yi} \leq \boldsymbol{Max}\ \text{pricing} \end{cases} \tag{2}$$

The total weekly replenishment and total weekly pricing for the next 7 days are obtained by maximising the supermarket's revenue, and the total daily replenishment and pricing strategy for each vegetable category for the coming week (1-7 July 2023) are obtained by substituting the ratio of the daily sales volume of each category to the sum of the weekly sales volume.

The total daily replenishment and pricing strategy for each vegetable category for the coming week (1-7 July 2023) is obtained by substituting the ratio of daily sales to weekly sales for each category.

3.2. Model solution

The sales volume of each category for the next 7 days based on the time-series forecasting model is used to find the ratio of the sales volume of each category per day to the sales volume of the week. The forecast results are shown in Figure 2 and Figure 3.

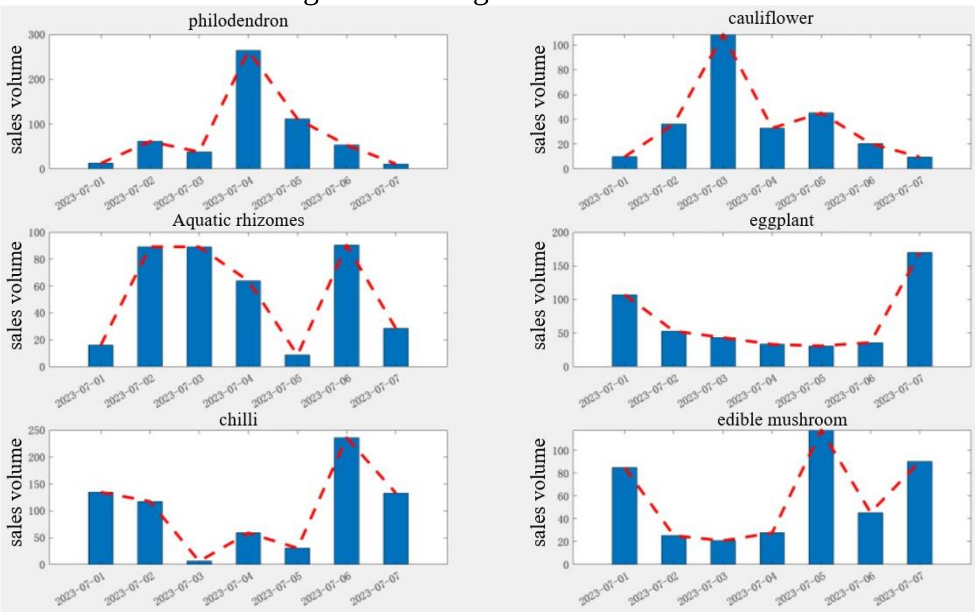

Figure 2: Projected sales by category for the week ahead.

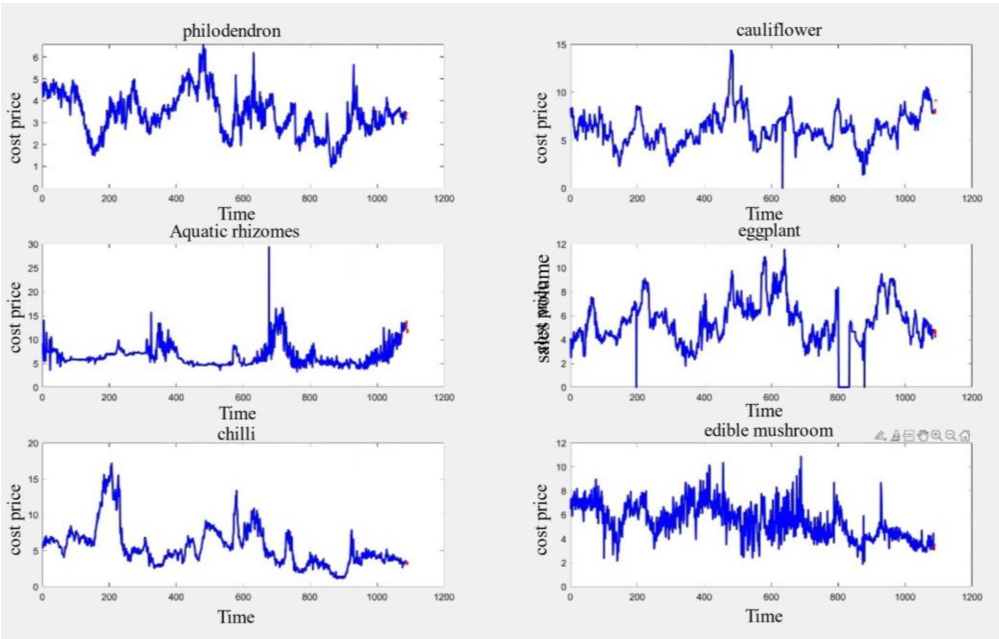

Figure 3: Total cost price for each category for the week ahead.

The results of the solution are shown in Table 1 and Table 2.

Table 1: Total daily replenishment for each vegetable category for the coming week.

Date	Foliage	Cauliflower	Aquatic Roots	Eggplant	Chilli	Mushrooms
2023/7/1	19.9035437	25.00197	21.069848	4.223974	341.01133	129.5809
2023/7/2	96.97736103	92.76792	116.84092	2.096227	297.43893	38.74092
2023/7/3	60.06413801	276.5659	116.72426	1.711512	15.348828	31.92834
2023/7/4	416.4473941	84.01535	83.720554	1.314681	149.32386	42.3772
2023/7/5	175.8539058	115.0627	11.416261	1.223586	77.218085	179.6879
2023/7/6	84.13322406	52.18342	118.45537	1.418634	597.76357	69.54308
2023/7/7	17.86630232	24.66255	37.266485	6.708718	336.54117	137.6971

Table 2: Pricing for each vegetable category for the week ahead

Date	Foliage	Cauliflower	Aquatic Roots	Eggplant	Chilli	Mushrooms
2023/7/1	9.315484449	19.14119198	21.04747595	16.42613237	23.13712896	11.64641913
2023/7/2	9.905335129	18.70464305	21.00702249	17.46661338	21.52378771	11.47338235
2023/7/3	9.718587037	18.62348517	23.40173166	17.28921752	22.11313027	13.21232735
2023/7/4	9.949175382	18.46968744	22.07827739	14.49287955	20.27734735	13.76239038
2023/7/5	9.821924777	19.28055638	22.08995642	15.39687436	19.75831681	14.28411117
2023/7/6	9.833596532	20.69549548	19.25804527	17.10566711	21.53273651	13.89104919
2023/7/7	9.018281694	21.8660145	20.85502583	16.63140472	19.70909839	12.73050944

The total return is obtained as shown in Table 3.

Table 3: Total returns for the week ahead by vegetable category

Foliage	Cauliflower	Aquatic Roots	Eggplant	Chilli	Mushrooms
24272.692	37491.5	38319.333	9161.3	10953.125	13138.9

The total return for the coming week for each vegetable category is shown in Table 3.

As shown in the table, the total return for the coming week for the flower and leafy category is 24272.692 CNY, the total return for the coming week for the cauliflower category is 37491.5 CNY, and the total return for the coming week for the aquatic root and tuber category is 38,319.333 CNY, and so on.

4. Optimisation model with constraints on saleable items and display volume

Target planning based on the varieties available for sale from 24 June 2023 to 30 June 2023.

27-33 varieties, each order quantity should be greater than or equal to 2.5 kg, and solve for the maximum return while meeting all the constraints.

First of all, first of all, use Excel to filter the data of 24-30, to get the relevant order information.

Do a pivot table to get the total daily sales of each product for the seven days, as well as the daily unit price (selling price), wholesale price (cost price), the number of discounts and discount rate of each product.

$$\lambda_j = \frac{\textit{Number of discounts}}{\text{Total sales of each individual product}} \quad (3)$$

λj is the discount rate.

The wholesale price and time series model is used to predict each individual item by its respective wastage βj

cost price αj on 1 July 2023, and use Excel functions to calculate the sales transaction price (unit price*sales volume) and the total cost price (wholesale price*sales volume) can be subtracted to find the profit of each order.

Use a pivot table to calculate the total profit for each individual product for 7 days to sort.

Select the top 33 items with non-zero predicted costs as the ordering items.

The maximum selling price $Ymax$ and the minimum selling price $Ymin$ of each individual item for 7 days are calculated using a pivot table. fit the sales volume of each individual item as a function of profit (yuan/kg).

Develop a non-linear multi-objective optimisation model:

$$\boldsymbol{L}_j = \begin{cases} 0, \text{ out of order} \\ 1, \text{ order} \end{cases} \quad (4)$$

$$maxG = \Sigma\left[r_j(1-\lambda_j)Y_j + Y_j r_j - \lambda_j \cdot 7 - X_j \alpha_j\right] \quad (5)$$

Among them.

$$r_j =\cdot f(Y_j - \alpha_j) \quad (6)$$

xj ≥ 2.5, **xj** is the order quantity, and Yi is the pricing.

According to the target planning of the available varieties from 24th June 2023 to 30th June 2023, the total number of available items is 49, and 27-33 sales items are selected.

Use Excel to filter the data of No. 24-30. The relevant order information to do pivot, through Excel and pivot table will be the total number of single product sales, each single product daily unit price and wholesale price, the number of discounts and other data to find out, substituting into the nonlinear multi-objective optimization model, simulated annealing method to find 7 groups of options, and then find the total return on the options, select the option with the largest return as the final plan. The result is shown in Table 4.

Table 4: Table of optimal solutions

Item Name	product replenishment	product pricing	Profit
Millet Pepper (portion)	29.14	5.77	123.03
Broccoli	2.53	13.99	160.50
Xixia Mushroom(1)	3.20	24.00	61.04
Yunnan Lettuce(portion)	54.52	5.77	53.95
Yunnan Oil Wheat Vegetable(portion)	8.03	4.43	48.82
Screw Pepper	3.99	14.00	50.52
Wuhu Green Pepper(1)	5.58	5.20	48.57
Purple Eggplant(2)	4.42	9.00	408.88

5. Conclusions

In conclusion, this study has shed light on the intricate interplay between sales volume, pricing, and replenishment strategies for various vegetable categories in supermarkets. By leveraging data processing, time series forecasting, and nonlinear multi-objective optimization, the research has provided valuable insights into enhancing decision-making processes in the retail sector.

The findings of this study have not only revealed the relationships between sales volume, pricing, and replenishment but have also yielded practical strategies for future decision-making. The proposed models offer a systematic approach to determining replenishment volumes and pricing strategies, considering various constraints and maximizing total profits.

Moving forward, the insights and methodologies presented in this paper can serve as a foundation for further research and practical implementation in the retail industry. By continually refining and adapting these approaches, supermarkets can optimize their operations, improve customer satisfaction, and achieve sustainable profitability.

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