Research on Automatic Pricing and Replenishment Strategy of Vegetable Commodities Based on Fourier Series Fitting and Linear Programming

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Abstract. Vegetable goods are a common category of goods sold in superstores. In order to determine the relationship between commodity price and sales quantity, and develop a reasonable replenishment and pricing strategy, this paper firstly uses the curve fitter linear regression in the MATLAB toolbox to analyse the relationship between total sales volume of different categories and cost plus pricing, and secondly, uses the curve fitter Fourier series in the MATLAB toolbox to fit the sales volume curve in June and calculates the degree of fit for validation to predict the sales volume of each vegetable category in the first week of July, calculate the daily replenishment volume, and determine the pricing of each category using the results of linear regression. Vegetable category sales, calculating daily replenishment, and using linear regression results to determine pricing for each category. Then, we consider the pricing and replenishment strategy when the total number of single items is restricted, and construct a linear programming decision optimisation model with single items as the main body, taking the replenishment quantity of single items as the decision variable, the restriction of the total number of single items, the minimum display quantity and the satisfaction of category demand as the constraints, and the maximum revenue of the superstore as the objective function, and then we construct the linear programming decision optimisation model, and find out the pricing and replenishment quantities for a total of 28 individual items as well as for each single item.

Keywords: Linear regression, Fourier series fitting, linear programming, decision optimisation models.

1. Introduction

In fresh food supermarkets, the shelf life of vegetable items is usually shorter and their quality deteriorates as the selling time goes by. For example, most of the vegetable varieties cannot be sold further on the next day if they are not sold on that day. Therefore, supermarkets usually replenish their stocks on a daily basis, taking into account the historical sales situation and market demand for various types of commodities [1-2].

Because supermarkets sell a wide variety of vegetables and usually stock them between 3 and 4 a.m., merchants must make replenishment decisions for each vegetable category on the same day without knowing the specific individual items and the prices at which they will be purchased. Vegetables are generally priced using the "cost-plus pricing" method, while supermarkets will sell at a discount for goods that are damaged in transit and in poor condition [3]. Therefore, reliable market demand analysis is essential for replenishment and pricing decisions.

From the demand side, there is a correlation between the sales volume of vegetables and time of year. For example, in spring and summer, due to the increased demand for vegetables, the sales volume of vegetable items in supermarkets will increase accordingly. On the supply side, vegetable supply varieties are more abundant from April to October, but the limitation of sales space in supermarkets makes a reasonable sales mix extremely important. Therefore, in the replenishment and pricing process, market demand and supply need to be thoroughly considered and analysed [4-5].

2. Fitting a linear regression of the relationship between pricing and sales quantities

2.1. Linear regression fit

In order to get the relationship between total sales and cost-plus pricing for different categories, firstly, the daily sales and category cost-plus pricing for each category for each day of June are counted [6-7].

For cost-plus pricing (selling price), the basic idea is that the target price of the product = cost base + the number of components. Cost-plus pricing method formula: price = unit cost × (1 + markup rate), unit cost = (total fixed cost + total variable cost) ÷ sales volume = unit fixed cost + unit variable cost, markup rate = (selling price - purchase price) ÷ purchase price × 100%. Daily sales and category cost-plus pricing for each day in June is shown in figure 1.

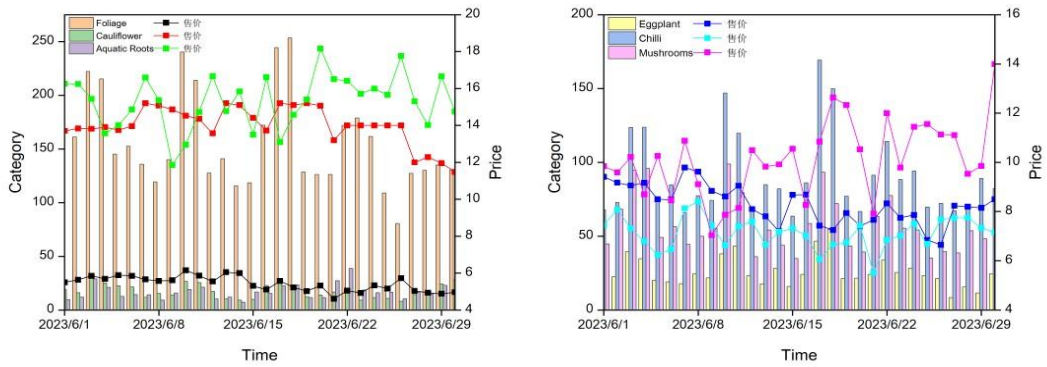


Figure 1. Daily sales and category cost-plus pricing for each day in June

In this regard, a univariate linear regression equation $Q = kP + b$, combined with the above total of 30 independent statistics on the variables, $(Q_1, P_1), (Q_2, P_2) \cdots (Q_n, P_n)(n = 1 \square 30)$ was obtained for the sample, and the equation can be constructed:

$$Q_i = kP_i + b(i = 1, \cdots, n) \tag{1}$$

Using linear regression in the MATLAB curve fitter the values k, b for each category can be fitted and the results are shown in table 1.

Table 1. Linear regression results

Category	*k*	*b*
Cauliflower	-0.0424	14.7691
Foliage	0.0022	5.0887
Chilli	-0.0106	8.1023
Aquatic Roots	-0.0259	15.7510
Eggplant	-0.0076	8.4745
Mushrooms	-0.0267	11.6565

From the above table, it can be seen that the total sales of flowers and foliage category shows a slight positive correlation with cost plus pricing, while other categories show a negative correlation with their cost plus pricing [8].

2.2. Fourier series fitting

To predict the total daily replenishment of each vegetable category in the coming week (1-7 July 2023) and to develop pricing strategies, the objective fitting function is first assumed to be $f(t) = a_0 + \sum_{n=1}^{\infty} \left[a_n \cos(n\omega t) + b_n \sin(n\omega t) \right]$.

$$a_0 = \frac{1}{T}\int_{t_0}^{t_0+T} f(t)\cos(n\omega t)dt, a_n = \frac{2}{T}\int_{t_0}^{t_0+T} f(t)\cos(n\omega t)dt, b_n = \frac{2}{T}\int_{t_0}^{t_0+T} f(t)\sin(n\omega t)dt \quad (2)$$

This paper uses orthogonal function sets for curve fitting, which are theoretically capable of handling curves of infinite length. This is similar to the way functions are approximated using approximation methods, but in the form of orthogonal function groups. Specifically, the function $f(x)$ is defined by a linear combination of a constant and a series of sets of orthogonal functions, where the period of each orthogonal function set is T, $T/2$, and so on, up to T/n. The coefficients in front of these sets of orthogonal functions then denote their weights in $f(x)$. The advantage of Fourier series fitting is that a finer fitting effect on the curve can be achieved by adjusting the orthogonal function groups and their coefficients. That is to say, when adding orthogonal function groups with smaller periods to the fit, the original curve can be better approximated, resulting in more accurate results [9-10].

Secondly, the curve fitter in the MTALAB toolbox was used to fit the Fourier series, to fit the curve of change in the sales volume of each category of vegetables for the 30 days of June and to use this to predict the sales volume of each category of vegetables for the first week of July, using the predicted sales volume ÷ (1 - the average rate of loss) as the replenishment volume, i.e.: $W = Q/(1-\mu)$; at the same time, with the help of the results of linear regression, the predicted sales volume was used to determine the pricing strategy. Sales Forecast Results and Pricing Strategies for Different Categories are shown in table 2 (Due to space constraints, only some results are shown).

Table 2. Sales Forecast Results and Pricing Strategies for Different Categories

philodendron	Forecasted sales /kg	replenishment /kg	Price (yuan/kg)
7.1	201.010	224.041	5.534
7.2	229.609	255.918	5.597
7.3	200.349	223.304	5.532
7.4	144.755	161.341	5.409
7.5	118.225	131.771	5.350
7.6	141.653	157.883	5.402
7.7	180.715	201.421	5.489

In order to ensure the credibility of the results, this paper also calculated the degree of fit of the analytical curve regression on the data of R^2, The results are shown in table 3, R^2 are greater than 0.81, the degree of fit is excellent. Degree of fit of curvilinear regression is shown in table 3.

Table 3. Degree of fit of curvilinear regression

kind	philodendron	cabbage	chilli	Aquatic rhizomes	eggplant	edible fungi
R^2	0.8148	0.8565	0.9084	0.8585	0.9155	0.9089

3. Pricing and Replenishment Strategies Considering Individual Item Quantity Constraints

3.1. Linear programming

Due to the limited sales space of vegetable goods, the superstore wishes to further develop the replenishment plan for individual items, which requires that the total number of saleable items be controlled at 27-33, and the order quantity of each individual item satisfy the minimum display quantity of 2.5kg, so as to try to satisfy the market's demand for vegetable goods of each category. A linear programming decision optimisation model is developed based on the available varieties from 24-30 June 2023:

$$\max W = \sum_{i=1}^{m} Q_i P_i$$
$$s.t. \begin{cases} 27 \le m \le 33 \\ Q_i \ge 2.5 \\ Q_i, P_i \ge 0 \end{cases} \quad (3)$$

Here the replenishment Q is considered as a decision variable, the total number of items is 27-33, the order quantity of each item satisfies the minimum display quantity of 2.5kg, and the time is controlled in May-June as the constraints to construct a linear programming problem. The results are shown in table 4.

Table 4. Selected Single Products by Category

cabbage	philodendron	chilli	Aquatic rhizomes	eggplant	edible fungi
102900005116714	102900011030097	102900011031100	102900005116899	102900005116257	106949711300259
102900011034026	102900005118831	102900011016701	102900051000944	102900011022764	102900011034330
	102900011030059	102900011032022	102900005118824		106971533450003
	102900005115786	102900011032251	102900011001691		102900005115250
	102900005115762	102900011032848			
	102900011030110	102900011000328			
	102900005115946				
	102900011008164				
	102900005115823				
	102900005119975				

3.2. Fourier series fitting

In order to derive the replenishment of individual items on 1 July and to develop a pricing strategy, the daily sales and category cost-plus pricing of the above individual items from 24-30 June were first counted. Using linear regression in the MATLAB curve fitter a regression curve for each individual item can be fitted and used to determine the pricing strategy. Stacked sales of different individual products from 6.24 to 6.30 days is shown in figure 2. Stacked cost-plus pricing for different individual products from 6.24-6.30 is shown in figure 3.

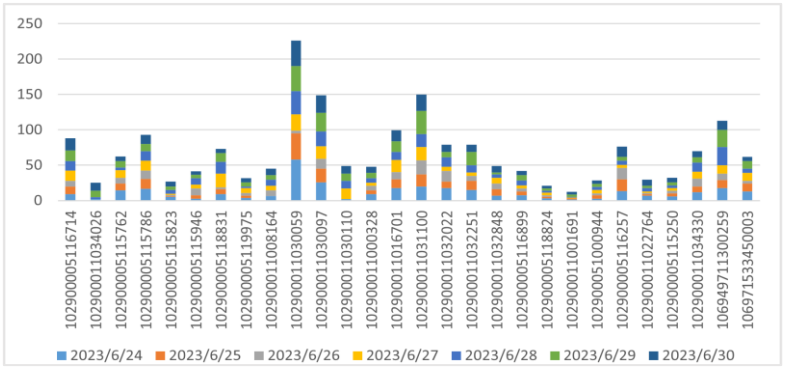


Figure 2. Stacked sales of different individual products from 6.24 to 6.30 days

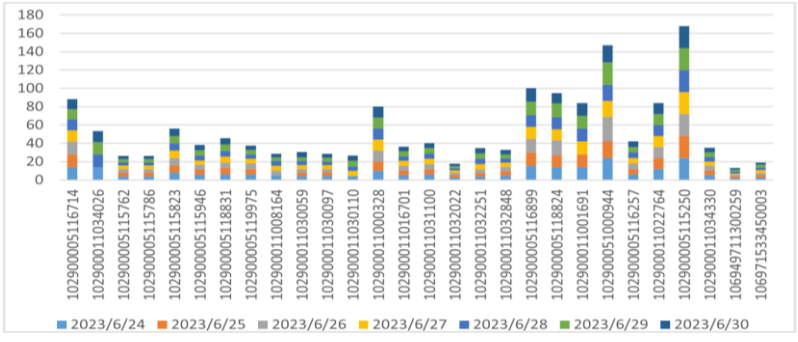


Figure 3. Stacked cost-plus pricing for different individual products from 6.24 to 6.30 days

Secondly, Fourier series fitting was performed using the curve fitter in the MTALAB toolbox to fit the curve of change in the sales volume of each item from 24th to 30th June and this was used to predict the vegetable sales volume of each item on the 1st of July, using the predicted sales volume ÷ (1 - average wastage rate) as the replenishment volume, i.e., $W = Q/(1-\mu)$. Meanwhile, with the help of linear regression results, the predicted sales volume is used to determine the pricing strategy. Individual product replenishment and pricing strategy on 1 July are shown in table 5.

Table 5. Individual product replenishment and pricing strategy on 1 July

item	Forecasted sales (kg)	Replenishment (kg)	fix a price (Yuan /kg)
102900005116714	18.51	21.56	10.30
102900011034026	6.03	7.02	10.06
102900005115762	4.33	4.82	3.44
102900005115786	16.52	18.41	4.05
102900005115823	9.47	10.56	8.00
102900005115946	3.32	3.70	5.75
102900005118831	3.66	4.07	6.40
102900005119975	3.70	4.13	5.49
102900011008164	3.35	3.74	2.39
102900011030059	56.94	63.47	4.69
102900011030097	20.21	22.52	4.05
102900011030110	7.06	7.87	3.83
102900011000328	10.34	11.31	11.07
102900011016701	8.48	9.27	5.20
102900011031100	8.35	9.13	5.77
102900011032022	9.58	10.47	2.54
102900011032251	2.92	3.19	5.12
102900011032848	3.98	4.35	4.44
102900005116899	5.38	6.11	14.15
102900005118824	6.99	7.94	7.84
102900011001691	5.17	5.88	20.79
102900051000944	3.55	4.04	22.22
102900005116257	18.76	20.20	6.00
102900011022764	17.60	18.95	12.00
102900005115250	9.91	10.79	24.00
102900011034330	9.95	10.83	5.03
106949711300259	4.46	4.86	1.77
106971533450003	5.32	5.79	2.62

In order to ensure the credibility of the results, this paper at the same time on the data were randomly sampled, calculated and analysed the degree of fit of the curve regression, the results are shown in table 6, are greater than 0.81, the degree of fit is very good.

Table 6. Degree of fit of curvilinear regression

item	1	2	3	4	5	6
R^2	0.9972	0.9635	0.8736	0.999	0.8101	0.9114

4. Conclusion

For the determination of pricing and sales quantity, firstly, the relationship between the total sales volume of different categories and cost-plus pricing is analysed using the curve fitter linear regression in the MATLAB toolbox, and it is found that the total sales volume of flowers and foliage category shows a slight positive correlation with the cost-plus pricing, whereas the other categories show a negative correlation with their cost-plus pricing; secondly, the Fourier level of curve fitter in the

MATLAB toolbox is used to Secondly, use the curve fitter Fourier level in MATLAB toolbox to fit the June sales curve and calculate the degree of fit for verification, predict the sales of each vegetable category in the first week of July, calculate the daily replenishment quantity, determine the pricing of each category by using the results of linear regression, and construct the pricing decision-making optimisation model, which provides the optimal sales suggestions for each category of vegetables.

When there is a limit on the number of single items, firstly, the decision optimization model of linear programming is constructed with single items as the main body, with the replenishment quantity of single items as the decision variable, the limit on the total number of single items, the minimum display quantity and meeting the demand of categories as the constraints, and the maximum revenue of the superstore as the objective function, so as to construct the decision optimization model of linear programming and find out a total of 28 single items, which include each category; then, Fourier series fitting is carried out to calculate the degree of fitting Validation is carried out to predict the sales of each individual product on 7.1, calculate the daily replenishment, and use the linear regression results to determine the pricing of each category, providing the optimal pricing decision for each individual vegetable.

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