Computers & Industrial Engineering 158 (2021) 107433

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Optimal pricing and replenishment policy for perishable food supply chain under inflation

Xiangmeng Huang [a], Shuai Yang [a,*], Zhanyu Wang [b]

[a] Business School, Changshu Institute of Technology, Suzhou, China
[b] School of Computer Science and Engineering, Changshu Institute of Technology, Suzhou, China

ARTICLE INFO

Keywords:
Inflation
Optimal pricing
Replenishment strategy
Supply chain
Time value of money
Perishable food

ABSTRACT

The COVID-19 outbreak-caused blockade and disruption of the supply chain have dramatically increased the prices of perishable food and other products that rely heavily on the timeliness of supply chains. In the case of inflation, this study aims to make some adjustment to the pricing and replenishment strategy of perishable food and compare it with the scenario without considering inflation to determine the impact of the inflation rate, quality deterioration, time value of money, and characteristics of cash flow of perishable food sales on the supply chain decision-making. We used the discounted cash flow (DCF) model to measure retailers' revenue, which established that the optimal pricing and replenishing strategy could maximize the retailers' profit. Besides, the findings were compared with the traditional profit model. Moreover, numerical experiments and sensitivity analysis were provided for decision support to retailers. Overall, this study validates that inflation significantly affects the pricing and replenishment strategy, and the DCF model is more suitable to evaluate the profits of perishable food.

1. Introduction

Since the spread of the COVID-19 pandemic, many countries have been issuing excessive currencies to stimulate economic recovery, resulting in some degree of inflation. Particularly, the trade of perishable food, such as seafood, vegetables, and fresh meat, heavily depends on the offline trade in most countries worldwide. Nevertheless, the barrier caused by the pandemic creates a poor offline circulation, rendering the inflation of perishable food predominantly serious. For example, according to the market research firm Nielsen, bread prices in the United States increased by almost 20% in June of 2020 alone, and meat prices increased by 17%. In addition, food inflation has become a concern in India, with potato prices rising the most, at 92%, followed by onions at 44%. Meanwhile, the pandemic has also halted international and domestic trade. For example, while some countries implement quarantine measures, others conduct nucleic acid tests on commodities, all resulting in the slower circulation of commodities and higher costs, especially in developing countries (Ginn & Pourroy, 2020; Iddrisu & Alagidede, 2020). Eventually, all these factors combined cause inflation, longer lead time, and higher financial pressure, further affecting the replenishment strategy of retailers. This study aims to investigate how perishable retailers decrease losses and increase earnings through pricing and replenishment strategies under inflation conditions.

The traditional supply chain model does not consider the impact of the product quality change or shelf life on product demand; however, the sales of most perishable food, especially raw food like seafood, vegetables, and meat, depend heavily on the quality at the time they are sold. Previously, as it was challenging to monitor and predict the quality of fresh produce, it was mostly ignored. At present, through the Internet of Things technology, such as big data, wireless communication, temperature and humidity sensors, RFID, and blockchain, plenty of information can be integrated to forecast or monitor the quality of perishable food by monitoring one or more indicators in the surrounding environment (Addo-Tenkorang, Gwangwava, Ogunmuyiwa, & Ude, 2019; Chang, Chen, & Lu, 2019). The use of advanced technologies enables the quality of perishable food to be incorporated into the model. Regarding the assumptions about the quality of perishable food, as early as 1957, a stock-dependent requirement was proposed to simulate the demand characteristics of perishable food (Whitin, 1957), or set a fixed (Goyal & Giri, 2001; Olsson & Tydesjö, 2010) or random expiration date (Tai, Xie, He, & Ching, 2019) for perishable items later. Mandal and Phaujdar (1989) set the deterioration rate and assumed that parts of perishable food disappeared, and the quality of the rest remained unaffected.

* Corresponding author.
E-mail address: 201500001@cslg.edu.cn (S. Yang).

https://doi.org/10.1016/j.cie.2021.107433

Available online 2 June 2021

Nomenclature

$D(t)$	demand rate at time t
$q(t)$	quality at time t
q_0	quality at the beginning of the cycle
Q	replenishment quantity per cycle
T	length of each replenishment cycle
p	price
r	discount rate per unit time
λ	deterioration rate of the quality
C_0	product purchase cost per unit
L	planning horizon
g	fixed cost per shipment
f	transportation cost per unit product
a	market scale
b	price elasticity
d	product quality sensitivity
Π	profit per unit time
PV	present value of the first cycle
PVL	present value of planning horizon

Zanoni and Zavanella (2012) introduced the quality change into the model, and the quality or value of goods declines with time. As the quality of perishable food alters quickly and simultaneously, most perishable food are price-sensitive goods; thus, reasonable pricing can effectively influence the sales of perishable food (Chen, 2018; Liu, Zhao, & Ren, 2019; Önal, Yenipazarli, & Kundakcioglu, 2016). Of note, the quality change of perishable food affects cash flow, pricing, and replenishment strategy. While the existing literature mentioned above focuses less on the cash flow fluctuation, this study attempts to consider the cash flow fluctuation to enhance the decision-making of perishables retailers.

As perishables typically have a relatively short selling cycle, inflation and time value of money are overlooked. However, if statistics are run over a long period, such as 1 year, inflation and time value of money exert a huge impact on income settlement and daily operational decisions. Especially after the outbreak of the COVID-19 pandemic, the inflation of perishable food in various countries has become relatively common. Thus, inflation and time value of money should be included in the model. For example, the early use of the discounted cash flow (DCF) model is to evaluate the future cash flow and maximize the net present value using the replenishment quantity decisions (Chung & Liao, 2006; Jaggi, Aggarwal, & Geol, 2006). When inflation and time value of money are considered in the model, the replenishment strategy markedly affects both demand and profit settlement (Yang, Lee, & Zhang, 2013). The duration of the replenishment cycle affects the quality of perishable food and the replenishment cost, thereby further affecting the profit (Janssen, Diabat, Sauer, & Herrmann, 2018; Sarkara, Sarkara, Ganguly, & Cárdenas-Barrónd, 2021; Zhou & Yang, 2003). For example, by considering both replenishment policy and inflation, studies have found a critical number of replenishment periods, in excess of which the optimal schedule is characterized by the inclusion of token orders at the end of the planning horizon (Gilding, 2014). In addition, by considering inflation, Khan, Shaikh, Panda, Konstantaras, and Taleizadeh (2019) not only found retailers' optimal replenishment policies but also minimized the total average cost. However, limited studies have considered perishable pricing and replenishment strategies under inflation at the same time. Hence, this study will enrich the literature by examining the optimal pricing and replenishment strategy for the perishable food supply chain under inflation.

Overall, previous studies have established models to assess the quality of perishable food and propose a pricing strategy. Indeed, some studies have also proposed the DCF model to measure the time value of money and inflation. However, limited research has focused on the impact of the fluctuation of cash flow caused by the quality change of perishable goods on pricing and replenishment strategy. Thus, this study attempts to use the DCF model by simultaneously considering the cash flow fluctuation caused by the quality change of perishable goods to propose an optimal pricing and replenishment strategy. Hence, this study will have both theoretical and practical contributions. First, it extends the theoretical model in the decision-making of the food supply chain and provides the existence of an optimal solution. Second, as we examine the variables of deterioration rate, inflation rate, price elasticity, market scale, quality sensitivity, purchasing cost, and transportation cost affect the present value, pricing, and replenishment strategy; thus, retailers of different sizes are supposed to make more reasonable decisions on pricing and replenishment strategy.

2. Notations and assumptions

The following notations and assumptions were used in this study to formulate the problem as a mathematical model:

Assumptions.

(1) The demand at time t depends on the price p and the quality $q(t)$ at time t, $D(t) = a - bp + dq(t)$, where a denotes the market scale and b denotes the price sensitivity.
(2) The quality of perishable food decreases exponentially over time. The quality of perishable food at time t is $q(t) = q_0 e^{-\lambda t}$, where q_0 reflects the initial quality of perishable food when they arrive at the store, which is normally expressed in a percentage. For example, when the fruit is first picked, set it as 100%. Furthermore, λ denotes the deterioration rate of quality.
(3) As the quality of the perishable food is decaying, the retailer will restock after all goods have been sold out.
(4) The lead time is zero, and out-of-stock is not allowed.
(5) Within a planning period, the number of periods must be an integer.
(6) The transportation cost of each replenishment is $g + fQ$, where g denotes the fixed cost of each replenishment, and f denotes the transportation cost of each unit of goods.
(7) The discount rate is r per unit time, which correlates with the inflation rate and time value of money.

3. Model formulation

3.1. Model formulation for the perishable food supply chain considering the time value of money

This section provides the Profit model of retailers. The replenishment period of fresh products is T, and the replenishment amount at the beginning of the period is Q. At the end of the replenishment cycle, as the requirements are deterministic (nonrandom), the inventory is reduced to zero. In a given planning horizon L, there are integer m replenishment cycles, as shown in Fig. 1.

Thus, the replenishment amount of each replenishment period is:

$$\begin{aligned} Q &= \int_0^T D(t)dt \\ &= \int_0^T [a - bp + dq(t)]dt \\ &= (a-bp)T + \frac{1}{\lambda} dq_0 (1 - e^{-\lambda T}) \end{aligned} \tag{1}$$

As the purchasing cost during replenishment occurs at the beginning of the period, the present value of replenishment cost is:

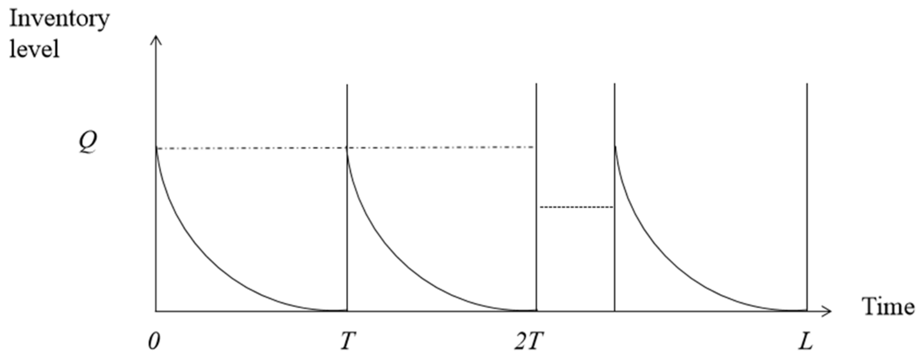

Fig. 1. The retailer's inventory cycles in the planning horizon.

$$\begin{aligned} C_0Q &= C_0\int_0^T D(t)dt \\ &= C_0\int_0^T [a-bp+dq(t)]dt \\ &= C_0(a-bp)T+\frac{1}{\lambda}C_0dq_0(1-e^{-\lambda T}) \end{aligned} \tag{2}$$

The selling price of the unit product is p, and the sales take place in the whole cycle. Thus, the present value of sales revenue is:

$$\begin{aligned} &p\int_0^T D(t)e^{-rt}dt \\ &= p\int_0^T [(a-bp)e^{-rt}+dq_0e^{-\lambda t}e^{-rt}]dt \\ &= \frac{1}{r}p(a-bp)(1-e^{-rT})+\frac{1}{\lambda+r}pdq_0(1-e^{-(r+\lambda)T}) \end{aligned} \tag{3}$$

As transportation costs occur at the beginning of the period, the present value of transportation costs is:

$$g+fQ \tag{4}$$

In a cycle, a retailer's profit includes the items listed above, as well as sales revenue, purchase cost, and transportation cost; thus, the present value of the retailer's profit in a cycle is:

$$\begin{aligned} PV(T,p) &= p\int_0^T D(t)e^{-rt}dt - C_0Q-(g+fQ) \\ &= \frac{1}{r}p(a-bp)(1-e^{-rT})+\frac{1}{\lambda+r}dq_0(1-e^{-(\lambda+r)T}) \\ &\quad -g-(C_0+f)\left[\left(a-bp\right)T+\frac{1}{\lambda}dq_0(1-e^{-\lambda T})\right] \end{aligned} \tag{5}$$

Within a planning horizon L, it is assumed that there are m replenishment cycles, and m is an integer, then, $L=mT$. In time L, the total present value of the retailer's profit is:

$$\begin{aligned} PVL(T,p) &= \sum_{n=0}^{m-1} PV(T,p)e^{-rnT} \\ &= \frac{1-e^{-rL}}{1-e^{-rT}}PV(T,p) \\ &= \frac{1-e^{-rL}}{1-e^{-rT}}\left\{\begin{array}{l} \frac{1}{r}p(a-bp)(1-e^{-rT})+\frac{1}{\lambda+r}dq_0(1-e^{-(\lambda+r)T}) \\ -g-(C_0+f)\left[\left(a-bp\right)T+\frac{1}{\lambda}dq_0(1-e^{-\lambda T})\right] \end{array}\right\} \end{aligned} \tag{6}$$

where p and T signify decision variables, and all parameters are >0.

3.2. Model formulation for the perishable food supply chain without the time value of money

In this model, inflation and time value of money will not be considered. The retailer's profit composition remains the same as the previous one, comprising sales revenue, replenishment cost, and transportation cost. The retailer's objective is to maximize profit per unit of time, and the transportation cost $g+fQ$ and replenishment cost C_0Q are the same as those in Section 3.1. Thus, the sales revenue is:

$$\begin{aligned} &pQ \\ &= p\int_0^T D(t)dt \\ &= p(a-bp)T+\frac{1}{\lambda}pdq_0(1-e^{-\lambda T}) \end{aligned} \tag{7}$$

The retailer's profit per unit time:

$$\begin{aligned} \Pi(T,p) &= \frac{1}{T}\left[p\int_0^T D(t)dt - C_0Q-(g+fQ)\right] \\ &= p(a-bp)+\frac{1}{\lambda T}pdq_0(1-e^{-\lambda T})-\frac{g}{T}-(C_0+f)(a-bp)-\frac{1}{\lambda T}dq_0(1-e^{-\lambda T}) \end{aligned} \tag{8}$$

where p and T denote decision variables, and all parameters are >0.

4. The optimal solution for the perishable food supply chain

4.1. The optimal solution for the perishable food supply chain with the time value of money

This section demonstrates an optimal solution that maximizes the present value of the retailer's profits.

First, take the first and second partial derivatives of Eq. (6) with respect to p; we get the following:

$$\frac{\partial PVL(T,p)}{\partial p} = \frac{1-e^{-rL}}{1-e^{-rT}}\left[bT(C_0+f)+\frac{1}{r}(a-2bp)(1-e^{-rT})\right] \tag{9}$$

$$\frac{\partial^2 PVL(T,p)}{\partial p^2} = -\frac{1-e^{-rL}}{1-e^{-rT}}\frac{2b}{r}<0 \tag{10}$$

When T is fixed, we get $\frac{\partial^2 PVL(T,p)}{\partial p^2}<0$, while the optimal p can be obtained by $\frac{\partial PVL(T,p)}{\partial p}=0$, and we can get:

$$p=\frac{a}{2b}+\frac{brT(C_0+f)}{2b(1-e^{-rT})} \tag{11}$$

In real life, both pricing p and replenishment period T are ≥ 0, and there is a certain range. Generally, the pricing range is above C_0, where C_0 denotes the purchase price to ensure the profit of goods sold. However, the demand must be >0 under this pricing, that is, $D(t)=a-bp+$

$dq(t) > 0$, and at the beginning of the period ($t = 0$), the demand is >0, that I,s$D(0) = a - bp + dq_0 > 0$. Thus, $p < \frac{a+dq_0}{b}$ can be obtained.

The replenishment period T is typically greater than the minimum possible replenishment period, for example, 1 h, and less than the shelf life or shelf life of the item, which is usually <1 week for fresh goods. Meanwhile, the replenishment cycle T is normally much smaller than the planning horizon (usually 1 year). Moreover, within the planning horizon, replenishment times m is an integer, that is, $m = \frac{L}{T}$, an integer. Based on the limitations mentioned above, we propose a simple solution methodology as follows:

Step 1: Input all the initial data, set the optimal cycle length, the optimal present value of the total cost, and the number of periods as$p^* = 0$, $T^* = 0$, $PVL(T,p)^* = -\infty$, and $m^* = 0$, the minimum replenishment cycle is $T_{\min}$.

Step 2: Set $m = m + 1$. Let $T = \frac{L}{m}$ and get p from $p = \frac{a}{2b} + \frac{brT(C_0+f)}{2b(1-e^{-rT})}$. Then, we obtain$PVL(T,p)$

Step 3: If $PVL(T,p) \geqslant PVL(T,p)^*$, update$p^*$, T^*, $PVL(T)^*$, and m^*, Go to Step 4.

Step 4: If $T \geqslant T_{min}$, go to Step 2. Else, the current p^*, T^*, $PVL(T)^*$, and m^* denote the optimal solution.

4.2. The optimal solution for the perishable food supply chain without the time value of money

This section provides the traditional Profit model, wherein the retailer's goal is to maximize the profit per unit time. First, the first and second partial derivatives of Eq. (8) with respect to price p can be obtained as follows:

$$\frac{\partial \Pi(T,p)}{\partial p} = a - 2bp + b(C_0 + f) + \frac{1}{\lambda T} dq_0 (1 - e^{-\lambda T}) \tag{12}$$

$$\frac{\partial \Pi^2(T,p)}{\partial p^2} = -2bp < 0 \tag{13}$$

When T is fixed, we get $\frac{\partial \Pi^2(T,p)}{\partial p^2} < 0$, while the optimal p can be obtained by$\frac{\partial \Pi(T,p)}{\partial p} = 0$, and we can get

$$p = \frac{a}{2b} + \frac{C_0 + f}{2} + \frac{1}{2\lambda bT} dq_0 (1 - e^{-\lambda T}) \tag{14}$$

We propose a simple solution methodology as follows:

Step 1: Input all the initial data, set the optimal cycle length, the optimal present value of the total cost, and the number of periods as $p^* = 0$, $T^* = 0$, $\Pi(T,p) = -\infty$, and the minimum replenishment cycle is $T_{\min}$.

Step 2: Set $m = m + 1$. $m^* = 0$Let $T = \frac{L}{m}$ and get p from $p = \frac{a}{2b} + \frac{C_0+f}{2} + \frac{1}{2\lambda bT} dq_0 (1 - e^{-\lambda T})$. Then, we get $\Pi(T,p)$.

Step 3: If $\Pi(T,p) \geqslant \Pi(T,p)^*$, update$p^*$, T^*, $\Pi(T,p)^*$, and m^*. Go to Step 4.

Step 4: If $T \geqslant T_{min}$, go to Step2. Else, the current p^*, T^*, $\Pi(T,p)^*$, and m^* denote the optimal solution.

5. Numerical examples

In this study, we conducted numerical experiments and examined the effects of the key parameters on the present value of retailer's profit and decision variables and compared the optimal solution and profit difference under if the time value of money was considered. The following parameters were used in our case: $a = 150$; $b = 24$; $d = 25$;$\lambda = 0.05$; $q_0 = 0.95$; $L = 30$; $C_0 = 0.5$; $g = 15$; $f = 0.2$; $r = 0.02$.

As shown in Fig. 2, the retailer's present value of profit (PVL) is more sensitive to price (p), while it is sensitive to the replenishment cycle length (T) before reaching the maximum value; however, it is no longer sensitive when the maximum value is reached, suggesting that pricing should be careful, and retailers can flexibly manage the replenishment cycle.

Table 1 shows that with an increase of the discount rate, the income can be increased by increasing the price, markedly shortening the replenishment period and decreasing the replenishment quantity in the DCF model. Meanwhile, the net PVL is relatively sensitive to the discount rate (r), while for perishable products with high sales frequency, the discount rate is not sensitive, although the price will increase.

From Table 2, it can be deduced that if L is infinite, L/T is no longer constrained by integers, and the limit of L exerts little impact on profits and can be overlooked. To not be constrained by the fact that L/T is an integer and for gaining a better understanding, all the following experiments set L to infinity. More intuitively, as the discount rate increased, the replenishment cycle declined significantly in the DCF model. When the r increased from 0.005 to 0.03, which is a six times increase, p only increased by 0.29%, T decreased by 48.8%, Q also decreased by 48%, and PVL decreased by 83.7%. In addition, PVL is highly sensitive to r in calculating profits. Meanwhile, in the DCF model, it exerted a significant impact on the replenishment cycle and quantity,

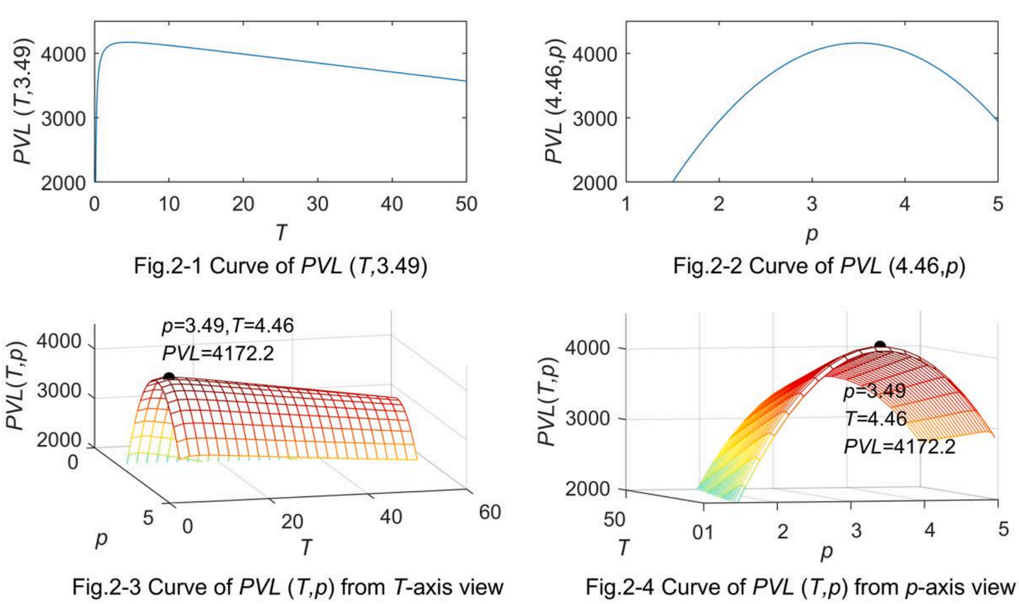

Fig. 2. The retailer's present value of profit with varying T and p.

Table 1
The optimal solutions with varying discount rates and finite planning horizon.

	DCF model				Profit model				
r	*p*	*T*	*Q*	*PVL*	*p*	*T*	*Q*	*Π*	*PVL*
0.005	3.48	7.5	646.85	5226.29	3.93	3	233.2	239.47	5042.93
0.01	3.49	6	521.18	4835.83	3.93	3	233.2	239.47	4680.18
0.015	3.49	5	436.47	4486.50	3.93	3	233.2	239.47	4351.56
0.02	3.49	30/7	375.48	4172.08	3.93	3	233.2	239.47	4053.46
0.025	3.49	30/7	375.08	3888.33	3.93	3	233.2	239.47	3782.66
0.03	3.5	3.75	329.16	3631.60	3.93	3	233.2	239.47	3536.33

Column 1, DCF Model, the optimal outcome of the DCF model by considering inflation and time value; Column 2, Profit model, the outcome of the Profit model without accounting for them.
NOTE: The *PVL* value in Column 1 is calculated by bringing the values of *p* and *T* into the DCF model.

Table 2
The optimal solutions with varying discount rates and infinite horizon.

	DCF model				Profit model				
r	*p*	*T*	*Q*	*PVL*	*p*	*T*	*Q*	*Π*	*PVL*
0.005	3.48	7.30	630.13	37520.65	3.93	3.09	239.69	239.47	36227.90
0.01	3.49	5.85	508.9	18658.2	3.93	3.09	239.69	239.47	18068.28
0.015	3.49	5.02	438.18	12380.92	3.93	3.09	239.69	239.47	12014.91
0.02	3.49	4.46	390.36	9247.13	3.93	3.09	239.69	239.47	8988.11
0.025	3.49	4.05	355.22	7369.61	3.93	3.09	239.69	239.47	7171.94
0.03	3.49	3.74	328	6119.67	3.93	3.09	239.69	239.47	5961.07

while it exerted no impact on the decision variables in the traditional Profit model; this is because after considering inflation, the time value of money is fully considered, so when the discount rate increases, PVL can be improved by shortening the replenishment cycle. When inflation is not considered, cash flow characteristics are ignored; thus, the replenishment cycle is much shorter. As inflation is considered in the Profit model, discount rate (*r)* does not affect the retailer's decision-making. In addition, without inflation, prices are higher than when inflation is considered, and the cycle is shorter; this is because it is expected that both purchase and sales prices will increase, and the sales price is higher than the purchase price. Notably, stocking more goods is conducive to decreasing the purchase cost and increasing the sales revenue, which is also consistent with the common understanding. However, under inflation, the overall sales volume decreases, the replenishment cycle becomes longer, and the economic vitality declines.

Table 3 shows that in the DCF model, deterioration rateλincreases from 0.05 to 0.3 and expands to six times, *T* decreases by 13.23%, and *Q* decreases by 20.45%. In addition, *Q* decreases more than *T* becauseλincreases, making quality decrease more rapidly, thereby further reducing demand. Of note, PVL only decreases by 1.11% because the DCF model can measure the impact ofλchanges on sales without adjusting the price. Furthermore, the adjustment of the replenishment strategy exerts little impact on profits.

In the traditional Profit model, *p* decreased by 1.27%, *Q* decreased by 55.89%, *T* decreased by 55.02%, PVL decreased by 2.63%, and Π decreased by 5.62%. As the traditional Profit model cannot measure the impact of the time value brought by λ, it exerts a great impact on the replenishment cycle and quantity. The DCF model is more robust and more suitable for cost and profit accounting than the Profit model when the value of perishable products varies markedly, and the sales rate changes. Without considering the time value of money, prices, replenishment cycles, and profits per unit time are relatively sensitive to the deterioration rate.

In the DCF model (Table 4), *b* increased by 55.56%, *p* decreased by 32.89%, *T* increased by 1.81%, *Q* increased by 2.39%, and PVL decreased by 42.04%. In the Profit model, *p* decreased by 33.66%, *T* increased by 32.56%, and *Q* increased by 26.4%. The change proportion of *Q* and *T* was higher than that of the DCF model, which was also because the time value of sales was not measured. In combination with Tables 3 and 4, in reality, a larger λ leads to a higher price of perishable products, which is typically several or even dozens of times of the cost. Thus, the higher cost and price, including higher costs of transportation, labor, retail, rotting, inflation, and other risks, lead to the decline of *b*. Affected by the COVID-19 pandemic, rational retailers are at increased risk of making conservative decisions and decreasing the purchase of perishable goods, especially for nonessential products. To manage this situation, e-commerce companies use online presale, express small-batch transportation, community group purchase, and other ways to avoid risks while enjoying the high profits of perishable goods.

In the DCF model (Table 5), the market scale (*a*) increased by 111.11%, *p* increased by 92.86%, *T* decreased by 23.6%, *Q* increased by 44.47%, and PVL increased to 5.48 times. The change in parameter *a* made the reverse change of *T* and *Q*, which is the power source of marketing activities of big supermarkets and the embodiment of the scale effect of perishable food retail. The higher the sales, the fresher the product, and the more customers there are, creating a virtuous circle.

Table 3
The optimal solutions with varying deterioration rates.

	DCF model				Profit model				
λ	*p*	*T*	*Q*	*PVL*	*p*	*T*	*Q*	*Π*	*PVL*
0.05	3.49	4.46	390.36	9247.13	3.93	3.09	239.69	239.47	8988.11
0.1	3.49	4.24	362.81	9220.42	3.92	2.24	173.03	235.50	8919.83
0.15	3.49	4.09	343.36	9197.59	3.91	1.87	143.65	232.52	8865.99
0.2	3.49	3.98	329.12	9177.76	3.9	1.65	126.22	230.05	8821.77
0.25	3.49	3.91	318.50	9160.31	3.89	1.50	114.4	227.92	8784.21
0.3	3.49	3.87	310.53	9144.84	3.88	1.39	105.73	226.02	8751.76

Table 4
The optimal solutions with varying price elasticity.

	DCF model				Profit model				
b	*p*	*T*	*Q*	*PVL*	*p*	*T*	*Q*	*Π*	*PVL*
18	4.53	4.41	396.00	13113.25	5.14	2.58	205.95	341.64	12724.5
20	4.12	4.43	394.13	11564.12	4.65	2.75	217.65	300.69	11233.83
22	3.77	4.44	392.25	10299.09	4.26	2.92	228.87	267.26	10004.79
24	3.49	4.46	390.36	9247.13	3.93	3.09	239.69	239.47	8988.11
26	3.25	4.48	388.46	8359.08	3.66	3.25	250.16	216.02	8119.48
28	3.04	4.49	386.55	7599.80	3.41	3.42	260.33	195.98	7396.66

Table 5
The optimal solutions with varying market scale.

	DCF model				Profit model				
a	*p*	*T*	*Q*	*PVL*	*p*	*T*	*Q*	*Π*	*PVL*
90	2.24	5.34	304.11	2848.96	2.67	4.16	197.06	83.27	2618.5
110	2.66	4.99	335.05	4563.94	3.09	3.69	212.11	126.92	4323.37
130	3.08	4.70	363.64	6696.73	3.51	3.35	226.29	179.00	6446.67
150	3.49	4.46	390.56	9247.13	3.93	3.09	239.69	239.47	8988.11
170	3.91	4.26	415.52	12215.00	4.35	2.88	252.39	308.33	11947.29
190	4.32	4.08	439.36	15600.22	4.77	2.71	264.49	385.57	15324.31

The change trend of the Profit model is similar to that of the DCF model. Combined with Tables 4 and 5, the profit does not increase markedly in general in the real market because the sensitivity of the crowd to price follows a specific distribution law. Retailers must decrease prices and marketing to gain market expansion, which would also increase some costs. During the COVID-19 period, a large number of offline consumption was transferred to online consumption, and such was the situation that the quantity and price inflated together, exerting a similar impact. In addition, small retailers can make higher profits by continuously introducing new products or niche products, while hypermarkets typically have relatively stable suppliers; meanwhile, they need to maintain the stability and continuity of supply. With a large scale and a complex management hierarchy, it is challenging for hypermarkets to manage new and niche products, so they have low recommendation intention and are not superior in launching such products.

In the DCF model (Table 6), the quality sensitivity (d) increased by 166.67%, p remained basically unchanged, while T decreased 16.94%, Q increased 6.15%, and PVL increased 3.16%. In the Profit model, p increased 12.83%, T decreased 45.24%, and Q decreased 36.6%. The increase in d implied that consumers are more sensitive to quality, resulting in an increase in sales volume. The DCF model can measure the change in the cash flow caused by the change in the sales volume and calculate its time value. As the Profit model cannot measure the time value, the increased quality sensitivity is addressed by significantly shortening the replenishment cycle and quantity. In the DCF model, the impact of quality changes over time on sales is depicted in the present value conversion of earnings; thus, the effect on price is negligible. As the quality sensitivity increases over time, its impact on sales volume and income decreases, reflected in the DCF model. Thus, its impact on the replenishment strategy is less than that of the Profit model. In the Profit model, the quality sensitivity cannot be reflected in real-time in terms of time value, so it exerts a significant impact on the replenishment cycle. Concurrently, the decrease of the replenishment cycle and the increase of the sales volume caused by the increase of quality sensitivity lead to the sharp rise of price. Thus, when calculating the profit of perishable products, the DCF model is more reasonable, which considers not only the impact of inflation but also the time value that affects supply chain decisions.

It can be seen from Table 7, With the purchasing cost (C_0) increasing to 3.33 times, p increased by 15.34%. Upon observing the increase of C_0 and p, we found that the cost rise was borne by both retailers and consumers. In addition, T decreased by 12.02%, Q decreased by 23.94%, and PVL decreased by 43%, which exerted a high impact on PVL. The change trend of the Profit model is similar to that of the DCF model. In the retail segment of perishables, purchasing costs do not account for a large proportion; thus, retailers have some resistance to increased purchasing costs. Meanwhile, this also implies that the intermediate cost of perishable food is relatively high, and farmers' profit is relatively small in the final retail price. Moreover, new sales modes, such as direct selling and presale, as well as big data prediction in the future, and whole-process monitoring of blockchain helps to elucidate the specific situation of production and marketing to precisely match production and marketing, decrease distribution costs, and enhance the supply chain efficiency. Perhaps, the online boom brought by the COVID-19 pandemic could further accelerate the process. It is also true that in the real market, a rising cost leads to a higher price, followed by a lower market demand; thus, retailers decrease the purchase quantity owing to the higher capital occupation and shorten the replenishment cycle to adopt a more conservative purchase strategy.

In the DCF model (Table 8), the fixed transportation cost (g) increased 181.82%, p increased sparsely, while T increased 71.05%, and Q increased 68.01%. Of note, g exerted a significant impact on the

Table 6
The optimal solutions with varying quality sensitivity.

	DCF model				Profit model				
d	*p*	*T*	*Q*	*PVL*	*p*	*T*	*Q*	*Π*	*PVL*
15	3.49	4.84	381.33	9133.19	3.74	4.20	306.68	214.78	9055.10
20	3.49	4.64	385.76	9189.90	3.84	3.54	266.35	226.83	9029.20
25	3.49	4.46	390.36	9247.13	3.93	3.09	239.69	239.47	8988.11
30	3.49	4.30	395.08	9304.83	4.03	2.76	220.51	252.65	8917.08
35	3.49	4.15	399.89	9362.95	4.13	2.50	205.93	266.35	8815.54
40	3.49	4.02	404.77	9421.47	4.22	2.30	194.42	280.56	8711.67

Table 7
The optimal solutions with varying purchasing cost.

	DCF model				Profit model				
C_0	p	T	Q	PVL	p	T	Q	Π	PVL
0.3	3.39	4.66	418.88	10175.23	3.83	3.15	251.64	250.83	9911.20
0.5	3.49	4.46	390.36	9247.13	3.93	3.09	239.69	239.47	8988.11
0.7	3.59	4.32	367.31	8345.74	4.03	3.03	228.23	228.59	8090.52
0.9	3.70	4.21	348.23	7470.76	4.13	2.98	217.23	218.20	7218.81
1.1	3.80	4.14	332.20	6622.04	4.24	2.93	206.66	208.29	6361.89
1.3	3.91	4.10	318.61	5799.44	4.34	2.89	196.47	198.86	5541.41

Table 8
The optimal solutions with varying fixed transportation cost.

	DCF model				Profit model				
g	p	T	Q	PVL	p	T	Q	Π	PVL
11	3.49	3.80	334.17	9297.58	3.94	2.62	203.83	240.87	9028.47
15	3.49	4.46	390.56	9247.13	3.93	3.09	239.69	239.47	8988.11
19	3.49	5.04	439.43	9203.00	3.93	3.50	271.43	238.26	8943.21
23	3.49	5.57	483.55	9163.26	3.92	3.88	300.32	237.17	8913.64
27	3.50	6.05	523.95	9126.79	3.92	4.23	327.09	236.19	8876.88
31	3.50	6.50	561.44	9092.89	3.92	4.56	352.21	235.28	8842.85

replenishment strategy, and the change trends of the two models were similar. However, the Profit model has shorter replenishment cycles, leading to higher prices and higher margins. Consequently, transportation costs occupied a smaller proportion and were relatively less affected.

Comparison of Tables 7 and 9 clarified that the change trend of the variable transportation cost was the same as the changing of the purchasing cost (C_0). Table 9 shows that in the DCF model, the transportation cost per unit (f) changes to five times from 0.2 to 1, p increases by 12.03%, T decreases by 8.07%, Q decreases by 18.42%, and PVL decreases by 37.28%. The change trend in the Profit model is similar because the increase in the variable cost of transportation could result in a higher unit cost of goods, which would consequently restrain the market demand, and it is the same impact as the increase of the replenishment cost. In addition, the calculation of the fixed transportation cost closely correlated with the replenishment cycle and exerted little impact on the selling price of the product. In the real market, small retailers typically adopt the mode of shipping outsourcing or in-house purchasing when the replenishment volume is low, and it is often priced according to the unit weight. Conversely, large retailers typically establish their own logistics or sign long-term supply contracts with third-party logistics companies to save costs. The transportation cost structure of both is different. Both experiments above demonstrated that the small retailers' cost structure was markedly affected by the replenishment quantity; large retailers, on the other hand, had relatively stable transportation costs. Thus, the pricing of larger retailers was less affected by transportation costs, and consumers could be offered a stable price expectation. In contrast, small retailers typically go with the market, and significant fluctuations occur in the purchasing cost, transportation cost, and selling price, which is determined by the cost structure and is hard to avoid.

6. Conclusions

This study obtained some exciting findings, and we also attempted to provide some recommendations to retailers based on these findings.

First, PVL is more sensitive to price and less sensitive to the replenishment cycle. In joint replenishment, the replenishment cycle can be appropriately extended, with little impact on PVL.

Second, the discount rate is only effective for the DCF model but not for the traditional Profit model. When the DCF model is used to evaluate the profit, the replenishment cycle is longer than the Profit model, regardless of the discount rate; this is because we assume that the selling price and cost will increase in the same fixed proportion. When the discount rate increases, in the DCF model, the replenishment cycle becomes shorter. When the replenishment cycle is fixed with several values, such as 8 h, once a day or once every 2 days, the replenishment cycle can be fixed and then the selling price can be adjusted to match the replenishment cycle. Although the profits of both models have strong robustness, the DCF model performs more robustly.

Third, the cost structure of large and small retailers is quite different. Large retailers have a higher proportion of fixed costs, while small retailers have a higher proportion of variable costs. The advantage of large retailers lies in their stability and less flexibility; thus, a more stable pricing strategy is more suitable for large retailers. In the real market, higher sales can lead to the better quality of perishable products and a shorter replenishment cycle, creating a virtuous cycle. Smaller retailers are more flexible and have a greater advantage in changing prices, introducing new products, changing suppliers, and replenishment strategies. Thus, small retailers can attempt to constantly launch new products or sell a higher proportion of seasonal goods, or even create a monopoly in local markets to uphold a higher profit margin for gaining a competitive advantage, rather than competing with big retailers on a

Table 9
The optimal solutions with varying transportation cost per unit.

	DCF model				Profit model				
f	p	T	Q	PVL	p	T	Q	π	PVL
0	3.39	4.66	418.88	10175.23	3.83	3.15	251.64	250.83	9911.20
0.2	3.49	4.46	390.56	9247.13	3.93	3.09	239.69	239.47	8988.11
0.4	3.59	4.32	367.31	8345.74	4.03	3.04	228.23	228.59	8090.98
0.6	3.70	4.21	348.23	7470.76	4.13	2.98	217.23	218.20	7218.81
0.8	3.80	4.14	332.20	6622.04	4.24	2.93	206.66	208.29	6361.89
1	3.91	4.10	318.61	5799.44	4.34	2.89	196.47	198.86	5541.41

price war over a perennial supply of products. Notably, a larger market implies more customers, which leads to a fresher perishable food supply and a higher profit margin. Large retailers can attain the market share by virtue of their supply chain advantages, while small retailers can launch high-end, seasonal, and new products by virtue of their flexible characteristics to occupy the niche or high-end market, or launch distinctive products for the local market.

Finally, the DCF model is more suitable to calculate the profit of perishable food because the sales volume of perishables does not increase linearly over time, as well as owing to a decline in the sales rate. As the traditional Profit model cannot be calculated per the characteristics of the sales process, it shortens the replenishment cycle excessively and tries to increase the price to increase the profit per unit time. Hence, in the case of high inflation and nonlinear sales process, the supply chain decision-making mechanism of the DCF and Profit models differs significantly, and the decision of the DCF model is more reasonable.

CRediT authorship contribution statement

Xiangmeng Huang: Visualization. **Shuai Yang:** Conceptualization, Methodology, Supervision, Funding acquisition. **Zhanyu Wang:** Software, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The research was funded by the National Natural Science Foundation of China, grant number 71901042 and the Philosophy and Social Science Research of Jiangsu Higher Education Institutions of China, grant number 2018SJZDI044.

References

Addo-Tenkorang, R., Gwangwava, N., Ogunmuyiwa, E. N., & Ude, A. U. (2019). Advanced animal track-&-trace supply-chain conceptual framework: An internet of things approach. *Procedia Manufacturing, 30*, 56–63.

Chang, S. E., Chen, Y. C., & Lu, M. F. (2019). Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process. *Technological Forecasting and Social Change, 144*, 1–11.

Chen, Z. (2018). Optimization of production inventory with pricing and promotion effort for a single-vendor multi-buyer system of perishable products. *International Journal of Production Economics, 203*, 333–349.

Chung, K. J., & Liao, J. J. (2006). The optimal ordering policy in a DCF analysis for deteriorating items when trade credit depends on the order quantity. *International Journal of Production Economics, 100*, 116–130.

Gilding, B. H. (2014). Inflation and the optimal inventory replenishment schedule within a finite planning horizon. *European Journal of Operational Research, 234*, 683–693.

Ginn, W., & Pourroy, M. (2020). Should a central bank react to food inflation? Evidence from an estimated model for Chile. *Economic Modelling, 90*, 221–234.

Goyal, S. K., & Giri, B. C. (2001). Recent trends for modeling deteriorating inventory. *European Journal of Operation Research, 134*, 1–16.

Iddrisu, A. A., & Alagidede, I. P. (2020). Monetary policy and food inflation in South Africa: A quantile regression analysis. *Food Policy, 90*, Article 101816.

Jaggi, C. K., Aggarwal, K. K., & Geol, S. K. (2006). Optimal order policy for deteriorating items with inflation induced demand. *International Journal of Production Economics, 103*, 707–714.

Janssen, L., Diabat, A., Sauer, J., & Herrmann, F. (2018). A stochastic micro-periodic age-based inventory replenishment policy for perishable goods. *Transportation Research Part E: Logistics and Transportation Review, 118*, 445–465.

Khan, M. A., Shaikh, A. A., Panda, G. C., Konstantaras, I., & Taleizadeh, A. A. (2019). Inventory system with expiration data: Pricing and replenishment decisions. *Computer & Industrial Engineering, 132*, 232–247.

Liu, L., Zhao, L., & Ren, X. (2019). Optimal preservation technology investment and pricing policy for fresh food. *Computers & Industrial Engineering, 135*, 746–756.

Mandal, B. N., & Phaujdar, S. (1989). An inventory model for deteriorating items and stock-dependent consumption rate. *Journal of the Operational Research Society, 40*(5), 483–488.

Olsson, F., & Tydesjö, P. (2010). Inventory problems with perishable items: Fixed lifetimes and backlogging. *European Journal of Operational Research, 202*(1), 131–137.

Önal, M., Yenipazarli, A., & Kundakcioglu, O. E. (2016). A mathematical model for perishable products with price- and displayed-stock-dependent demand. *Computers & Industrial Engineering, 102*, 246–258.

Sarkara, B., Sarkara, M., Ganguly, B., & Cárdenas-Barrónd, L. E. (2021). Combined effects of carbon emission and production quality improvement for fixed lifetime products in a sustainable supply chain management. *International Journal of Production Economics, 231*, Article 107867.

Tai, A. H., Xie, Y., He, W., & Ching, W. K. (2019). Joint inspection and inventory control for deteriorating items with random maximum lifetime. *International Journal of Production Economics, 207*, 144–162.

Whitin, T. M. (1957). *The Theory of Inventory Management*. New Jersey: Princeton University Press.

Yang, S., Lee, C., & Zhang, A. (2013). An inventory model for perishable products with stock-dependent demand and trade credit under inflation. *Mathematical Problems in Engineering, 2013*, 1–8.

Zanoni, S., & Zavanella, L. (2012). Chilled or frozen? Decision strategies for sustainable food supply chains. *International Journal of Production Economics, 140*, 731–736.

Zhou, Y. W., & Yang, S. L. (2003). An optimal lot-sizing model for items with inventory level dependent demand and fixed lifetime under the LIFO policy. *Journal of the Operational Research Society, 54*, 585–593.

Dr. Xiangmeng Huang is the Associate Professor of Logistics at Business School of Changshu Institute of Technology in China and her research interest is sustainable supply chain management.

Dr. Shuai Yang is the Associate Professor of Logistics at Business School of Changshu Institute of Technology in China and his research interest is supply chain and inventory management.

Dr. Zhanyu Wang is the Lecturer of Computer Science at School of Computer Science and Engineering of Changshu Institute of Technology in China and his research interest lies in intelligent computation and intelligent control.