Whitepaper

Literature Review - Dynamic Pricing in Food Supply Chains

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1 Introduction Dynamic Pricing in Food Supply Chains

Food Supply Chains (FSC) are a managerial challenge because the perishable products have a limited shelf life with degrading freshness and quality. Therefore, food loss and food waste are a problem along the whole supply chain. This paper focuses on food waste at the retailer and consumer levels. In Germany, one of the target countries of ImPUISe, 52% of food waste occurs in private households and 34% of this waste is fresh fruits and vegetables (Schmidt et al., 2019, BMEL, 2021). One reason is the high perishability of these products, but also purchase and meal planning decisions of the consumers (FAO, 2019, p. xiii-xiv). Therefore, it is necessary to implement a technique to improve the operational efficiency of the FSC. Throughout the literature on FSC, Dynamic Pricing (DP) is an appropriate measure to reduce food waste and, at the same time, increase the retailer's profit (Yang et al. 2022).
According to Liu et al. (2008), Dynamic Pricing describes the assignment of different prices to a product throughout the whole sales period due to changes in the product quality or product characteristics. The objective is to stimulate the demand for perishables with deteriorating quality by lowering the price when the product is approaching its date of expiry. Consumers will rather purchase a product with a longer shelf-life than a perishable with a closer date of expiry if the prices are the same (Yan and Han, 2022). As a result, more perishables are thrown away, which, on the one hand, causes food waste because the inedible products are discarded, and on the other hand, causes a loss of sales for the retailer. DP offers incentives for consumers to buy fruits and vegetables with a shorter remaining shelf-life and help them improve meal planning. The goal is to reduce food waste caused by retailers and consumers and increase the retailer's profit (Chung and Li, 2014).

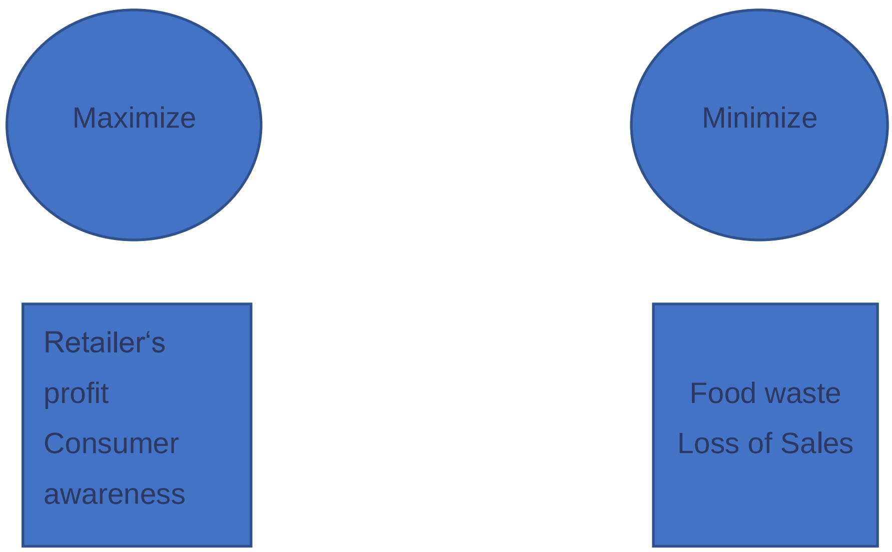

Figure 1: Goals of DP in FSC (own figure)

From the explanations above, it becomes clear that applying DP to the FSC for perishables highly meets the project targets of ImPUlSe. DP has the potential to optimize the efficiency of physical supply and consumption patterns. The supply chain can be managed in a more sustainable way and contributes to the reduction of waste. The following paper is organized as follows: after a brief introduction into the general concept of DP and the connection to the ImPUlSe project, section 2 offers a literature review on DP with a focus on the FSC. The goal is to offer a comparison of current practices and possible improvements by implementing new pricing strategies.
Section 3 summarizes the managerial insights and concludes the literature review.

2 Literature Review

The literature on DP in FSC can be categorized into two groups. The first group includes papers that apply operations research methods. This group contains most of the papers. The second group consists of papers that apply other methods, e.g., surveys of retailers. A classification of all papers on DP in the FSC can be found in the appendix.

In the first part of this chapter operations research applying papers are focused and are further separated into sub-categories. The basis of this separation are two criteria: First, the structure of the supply chain: one- or two-echelon supply chain and the actors that are considered on every level. Second, the papers are classified into papers that, additionally to DP, take replenishment and inventory decisions into account and papers without these considerations. Within these groups, the papers are analyzed and compared regarding their objective, decision variables, solving methods, results and managerial insights.

The second part of this chapter reviews papers that apply other methods than OR.

2.1 Operations Research Methods

2.1.1 One actor without replenishment

Scholz and Kulko (2022) compare static and dynamic pricing strategies for strawberries of different package sizes and freshness stages. They first measure the willingness to pay (WTP) for the different products. They use this information to estimate the demand. Based on WTP and demand the retailer's revenue maximizing and food waste reducing prices are calculated. For a better understanding of the OR methods, the objective function and constraints are explained below. In the further course of this review, the description of the underlying models will be less detailed, and results will be focused on. The following model is used to obtain the optimal prices in a dynamic pricing scenario.

$$Max\ R(p_i) = \sum_{i=1}^{I} d_i(p_i, p_j)p_i \qquad (1)$$

Subject to

$$d_i(p_i, p_j) \leq s_i \qquad \forall i \in I \qquad (2)$$

$$p_i \geq 0 \qquad \forall i \in I \qquad (3)$$

The objective function (1) maximizes the revenue R depending on price p_i, where the subscript i indicates the freshness level i of a package of strawberries. The revenue is the sum of the demand for strawberries of freshness level i multiplied by its price. The demand depends on the corresponding price p_i, but also on the price for the freshness level j, p_j.

The first constraint (2) ensures that the demand or the amount of strawberries sold for products of freshness level i does not exceed the stock level s_i. The second constraint indicates that the calculated prices must be greater or equal than zero because prices cannot

be negative. The result is a price vector that contains the revenue maximizing prices depending on the freshness level of the product. A simulation is then conducted to compare the revenue of the retailer and the amount of food waste when static and dynamic pricing strategies are applied. The result shows that applying a dynamic pricing strategy maximizes the retailer's revenue and, at the same time, reduces food waste significantly. The revenue is 110.2 percent compared to a static pricing scenario. Depending on the demand and package size, food waste is reduced to up to 46.4 percent of the amount in a static pricing scenario.
Kayikci et al. (2022) collect real-time Internet of Things (IoT) sensor data to measure the freshness of a bulk of apples. The data is then used to develop a four-stage-data-driven optimal pricing strategy. In the first stage, when the product's freshness is high, the initial selling price is set by the retailer. The first stage ends, and the second stage begins when the data indicate a significant decrease in food quality. In the second stage, the initial price has to be reduced by a discount rate to motivate consumers to buy less fresh products and avoid food waste. In the third stage, the redistribution stage, the retailer tries to redistribute the leftover food that could not be sold in stages one and two. In the fourth stage, the food waste is disposed of. The retailer must pay disposal costs and generates waste. The authors use a multi-stage recursive dynamic programming approach to find the revenue maximizing and food waste reducing optimal initial price, discount rate, and initial stock. Numerical analysis and simulation are conducted to examine the solutions. The initial selling price is set to 130 and the discount rate is seven percent. Furthermore, the influence of the initial replenishment is analyzed. There is no replenishment during the selling period, therefore it is important for the retailer to buy an optimal amount of apples. The initial amount of food ordered is 345 kilograms. This amount avoids shortages, but also minimizes the amount of waste due to unsold products.
Liu et al.'s (2008) paper focuses on the use of radio frequency identification (RFID) technology to collect data about the product's quality. These data are then used to apply dynamic pricing. The authors compare a deterministic demand scenario and a stochastic demand scenario with a dynamic pricing policy and a fixed price regarding optimal price, initial inventory, and profit. The results clearly show that in both demand scenarios, applying dynamic pricing to perishable food based on RFID data leads to a higher profit. On the one hand, dynamic pricing is especially advantageous when the decay rate is high, that means, when the product quality decreases fast. On the other hand, the authors also consider the influence of holding costs and variable and fixed ordering costs on the optimal price. When holding costs and ordering costs are high, the price reduction is higher at first to motivate consumers to buy the product, but in later periods, the product gets more expensive again. When the costs are relatively low, the price reduction is higher.

Adenso-Diaz et al. (2017) apply a bi-objective approach to quantify and compare dynamic pricing policies under different scenarios. In contrast to other papers, waste reduction is, along with revenue maximization, an objective function of the retailer. The authors assume a deterministic demand and a continuous decay of the food. The model is solved analytically, and experiments are conducted to compare the influence of different parameters on the objective. The results show that price elasticity has a significant influence on the success of a dynamic pricing strategy for perishable food. A low price elasticity reduces waste by up to 50 percent, but also generates a revenue loss of up to 20 percent. An elasticity of one or two generates only a very low or no revenue loss and reduces waste at the same time. When the price elasticity is greater or equal to two, the waste is reduced, and the revenue is slightly higher than in a static pricing scenario. Adenso-Diaz et al. conclude that the price elasticity must be sufficient large to reduce waste and, at the same time, generate higher revenue for the retailer even with a lowered price. Furthermore, the age sensitivity of the consumers regarding the product must not be too low.

Wang and Li (2012) develop a profit maximization model, that applies dynamic pricing strategies. RFID is used to collect data about the freshness level of a product (meat and vegetables) and these data are used to implement dynamic pricing. The authors compare a single price markdown strategy with a multiple markdown strategy during the sales period. The multiple markdown strategy discounts the price twice.

A case study with numerical simulations and a sensitivity analysis is conducted. The numerical experiment compares the situation in different supermarkets and shows that, for meat products, the optimal discount rate is 26.9 to 28.3 percent and causes a profit difference of 3.26 to 6.14 percent. Vegetable products' prices are reduced twice, that is, the multiple markdown strategy is applied. The first discount rate is 25 percent and the second is 36.2 to 37.2 percent, which causes a profit increase of 7 to 12.05 percent in total.

The sensitivity analysis reveals the influence of the degree of quality loss, timing and frequency of discount, and demand elasticity on the dynamic pricing strategy's effect. The results indicate that a higher quality loss during the sales period increases the effect of dynamic pricing. The authors recommend starting discounting earlier in the sales period than in the current practice. It is not advantageous to increase the number of times the price is discounted because the operational costs for adapting the price is too high and the demand and profit increase is not sufficient large. It is only recommended when the remaining shelf life of the product is long.

The profit increase caused by a dynamic pricing strategy is higher when the quality elasticity for a certain product is high.

2.1.2 Two-level-SC with replenishment

In contrast to the previous sub-section, this sub-section introduces papers that deal with two actors and replenishment during the sales period. It is important to distinguish between models that include replenishment and those that do not. When the stock of offered products is replenished during the sales period, the consumer can choose from different states of quality for the same product. This situation has a heavy influence on consumer behavior and is also suitable to apply dynamic pricing.

Chen and Chen (2021) consider a supply chain with a retailer and a supply center. It is a centralized system with the goal to maximize the channel profit. The retailer simultaneously offers products of two states of quality, freshly replenished products, and products that have already started to deteriorate. The author's objective is to find an optimal price markdown policy while maximizing the total channel profit. Furthermore, a sensitivity analysis of various parameters is conducted.

This paper takes three different groups of consumers into account, general customers, quality-oriented customers, and price-oriented customers. The results show that the optimal pricing strategy, profit, and influence of parameters are different for the three groups.

The optimal price markdown time is earlier for price-oriented customers than for the other groups and the maximum profit is the highest when most consumers are quality-oriented. The higher the quality orientation of the consumers, the higher the percentage of products sold at the regular price and the amount of unsold quantity and thus the profit. The sensitivity analysis further indicates that the expiry date has the greatest positive impact on profit because the longer the product is fresh, the more it will be sold. The profit is also higher when the quality loss coefficient is low. The order quantity of the products has the largest negative impact on the profit.

Concerning the markdown time, the regular price, demand sensitivity to the markdown price and the demand rate have the largest positive impact, e.g. the higher the regular price, the earlier the markdown time. The impact of the parameters is highest for price-oriented consumers.

Mahmoodi (2021) develops a joint pricing and inventory control model for a deteriorating product. According to the author, the model is suitable for the application in a fresh food supply chain. The situation is described as a manufacturer-Stackelberg game, that is, the manufacturer first decides about the profit maximizing wholesale price, then the retailer decides about the profit maximizing retail price and replenishment cycle. After the model is solved, a sensitivity analysis concerning various parameters is conducted. The results show that a bigger market potential or maximum demand, a high deteriorating rate and high holding costs and shortage costs lead to a shorter replenishment cycle. The bigger the price sensitivity of the customers, the longer the replenishment cycle and the smaller the profit. A larger market size increases the profit. The manufacturer's profit is more sensitive to the parameters than the retailer's profit. The demand parameters have a larger influence on the model than the cost parameters.

Pourmohammad-Zia et al. (2021) consider a two-level supply chain with a farmer as a supplier and a retailer in a joint pricing and inventory model. The farmer breeds new-born animals and sells the meat to the retailer after slaughtering. In contrast to the aforementioned paper, the supply chain in this paper is retailer-led. The retailer first decides about his retailer price and about the order quantity. Then the farmer decides about his order quantity of animals and the length of the breeding period. A special feature of this paper is the separation into two periods, a breeding period and a consumption period. During the breeding period, the animals grow at the farm, which leads to increasing costs for the supplier. During the consumption period, the retailer sells perishable meat to customers.

The authors compare a centralized with a decentralized scenario for the supply chain and the application of dynamic pricing with a static pricing scenario. They also conduct a sensitivity analysis. The results indicate that a centralized scenario with an appropriate profit-sharing contract increases the total profit by 24.5 percent and lowers the retailer's selling price. The dynamic pricing strategy increases the profit by 8.8 percent and decreases waste by 12.03 percent.

2.2 Other Methods

This section deals with papers that apply other methods than OR. In the two cases that are presented below, interviews were conducted to collect data, apply them to a simulation model and conduct numerical experiments. Also, hypothesis testing was applied.

The authors Chung and Li (2014) use a simulation model and numerical experiments to evaluate the impact of the frequency of discounting the price on the retailer's profit, sales volume, and disposal rate. The basis for the model and input data are interviews conducted with retailers in South Korea and the United Kingdom. The collected data show that a two-period pricing model is applied in the supermarkets, which means that the price for perishable food is adjusted once during the sales period, shortly before the expiry date is reached. Furthermore, the stock is replenished every day by the amount that was sold the day before. This strategy causes a challenge because when the price is adjusted only once, but the stock is replenished every day, there are periods in which the supermarket offers the same perishable product for the same price but with different quality. The authors argue that, in the situation described above, consumers will decide to buy the freshest product, which leads to older products being unsold and disposed of. Therefore, the goal of this paper is to find out whether a multi-period pricing strategy, e.g., discounting the price every day or every two days, will reduce the disposal rate and increase the profit and sales volume, since less fresh products can also be sold.

Chung and Li (2014) compare the profit, sales volume, and disposal rate for single-period, two-period and multi-period (every day and every two days) pricing strategies, for different lengths of the sales period (7, 11, and 15 periods) and for different values of the replenishment amount. The results show that the everyday discount strategy leads to a profit increase of, depending on the length of the sales period, 6.25 percent to 20.32 percent. The waste is also reduced if the demand is accurately estimated, and the stock is managed in accordance with the demand prediction. The findings also indicate that the everyday discount strategy is especially suitable for products with a short shelf-life, if the inventory level is higher than the demand and for products with a high sales volume.

Chung and Li (2013) conducted interviews with retail store managers in South Korea to gain insights into the effects of a multi-period DP strategy on customer satisfaction and their willingness for trade-offs between price and quality of a fresh product.

The authors differentiate between the present pricing strategy, which is discounting the products three days before reaching the expiry date by 30 percent, and the multi-period DP strategy, which means reducing the price seven days before by 3.21 percent and raise the discount rate to 22.5 percent on the last day before the expiry date. Four different hypotheses are tested. The results show that, first, if the consumers consider the freshness of a product to be low, the satisfaction with the present pricing strategy is low. Second, if the satisfaction with the present pricing strategy is low, the acceptance of the multi-period pricing strategy is high. Consumers are more willing to trade-off between quality and price when their satisfaction with the multi-period pricing strategy is high.

In contrast to the other journal articles, Chung and Li (2013) offer a different perspective on DP in the FSC.

3 Managerial Insights and Conclusion

The goal of this report was to review the relevant literature on DP in the FSC. Table 1 gives an overview of all considered papers. The reviewed papers were categorized in applying OR methods and others. The OR method using literature was further subdivided according to the number of SC actors and whether replenishment was considered or not. The articles were reviewed in terms of the objective function, solution method, and results.

Author	Number of SC actors	Replenishment	Product	Objective	Solution method
Liu et al. (2008)	1	No	Fresh products in general	Profit Maximization	RFID data are used as input parameters. Comparison of a deterministic demand scenario and a stochastic demand scenario with a dynamic pricing policy and a fixed price regarding optimal price, initial inventory and profit.
Wang, X., Li, D. (2012)	1	No	Meat and vegetables	Profit Maximization	Comparison of two scenarios: single price markdown, multiple price markdown on the basis of a case study in UK supermarkets compared to the pricing policy used. Numerical analysis and sensitivity analysis regarding quality value difference, timing and frequency of discount, cost parameters, demand sensitivity ratio.
Chung, J.; Li, D. (2014)	1	Yes	Fresh products in general	Profit Maximization	Interview with Food Reatilers in South Korea and UK Data used to develop a simulation model and conduct numerical experiments to evaluate the impact of the frequency of discounting the price on the retailer's profit, sales volume and disposal rate.
Adenso-Diaz et al. (2017)	1	No	Fresh products in general	Bi-Objective: waste reduction and revenue maximization	Analytical solution, scenarios with and without DP are compared. Numerical studies and sensitivity analysis regarding price elasticity and age sensitivity are conducted.
Chen, S.-P., Chen, C.-Y. (2021)	2	Yes	Fresh products in general	Total channel profit maximization, optimal markdown time	Analytical solution for different customer groups and sensitivity analysis regarding expiration date, cost parameters, quality loss and price sensitivity.
Mahmoodi, A. (2021)	2	Yes	No specific product, but author argues that fruits and vegetables is most suitable for application.	Profit Maximization	Model is a manufacturer-Stackelberg game. After solving the model, a sensitivity analysis is conducted.
Pourmohammad-Zia et al. (2021)	2	Yes	Meat	Profit Maximization	Comparison of a centralized with a decentralized scenario for the supply chain and the application of dynamic pricing with a static pricing scenario. They also conduct a sensitivity analysis.
Kayikci et al. (2022)	1	No	Apples	Profit Maximization	Four-stage model to identify the optimal initial price, discount rate for the quality decreasing product and initial stock amount. Numerical analysis and simulation
Scholz, M., Kulko, R.-D. (2022)	1	No	Strawberries	Revenue Maximization	Obtain revenue maximization prices Simulation to compare static and dynamic pricing strategies in terms of revenue and food waste

Table 1: Overview of all considered papers (own figure)

Except for one paper, that applied a bi-objective approach and minimized food waste, the objective was profit or revenue maximization, either for the retailer in the case of one actor or for the whole channel in the case of two actors.

Concerning the solution method, the underlying models were first solved with different mathematical methods and then a numerical experiment and sensitivity analysis was conducted to measure the influence of input parameters on the result. Furthermore, different scenarios were compared, e.g., a static and a dynamic pricing scenario to investigate the difference in profit/revenue and food waste.

The results generally indicate that the application of DP, in contrast to a static pricing strategy, in a FSC can increase the profit of the actors and reduce food waste as well. The sensitivity analyses reveal that, e.g., the higher the price elasticity of the consumers, the higher the effects of DP and the higher the revenues. The more consumers are quality rather than price oriented, the more products are sold at the regular price. The price is discounted more often when the decay rate of a product is high. When holding costs and fixed costs are low, the price reduction is higher. Concerning the replenishment cycle, a high decay rate and high holding costs lead to a shorter replenishment cycle, a high price sensitivity causes a longer replenishment cycle. When more than one actor of the SC is considered, a centralized scenario with a profit-sharing contract increases the channel profit by decreasing the retailer price. When the price changes too often, the costs of implementing the changes outweigh the positive effects of the DP strategy.

Appendix

Author(s)	Title	Year	Journal	Volume, pages	Industry	SC actors	Number of products	Replenishment	Objective	Solution method	Results	Special features
Adenso-Díaz, B., Lozano, S., Palacio, A.	Effects of dynamic pricing of perishable products on revenue and waste	2016	Applied Mathematical Modelling	45, 148-164	Fresh products in general	Retailer	1	No	Bi-Objective: waste reduction and revenue maximization	Analytical solution, scenarios with and without DP are compared. Numerical studies and sensitivity analysis regarding price elasticity and age sensitivity are conducted.	The effects of price discounting are different in each scenario and also depend on the speed at which the price is reduced as it ages. Although a dynamic price strategy helps reduce spoilage, its effect on total revenue depends heavily on the scenario. In some specific cases total revenue can slightly increase or, at least, maintain its level (price elasticity of 1 or higher). In other scenarios, the spoilage reduction comes as a loss in total revenue that can go from small to significant, depending on the scenario and the speed of the price discounting strategy (price elasticity lower than 1).	Bi-objective approach: waste reduction is target function
Buisman, M. E., Haijema, R., Bloemhof-Ruwaard, J. M.	Discounting and dynamic shelf life to reduce fresh food waste at retailers	2019	International Journal of Production Economics	209, 274-284	Meat	Retailer Distribution Center	1	Yes	Profit and product quality maximization waste and shortage minimization	simulation-based optimization	DSL outperforms a fixed shelf life (FSL) in terms of profit, waste, shortages and food safety. Further-more, replenishment quantities can be higher. The benefits of DSL are greater when demand is low or when the shelf life of products is short. Discounting is a successful strategy to reduce food waste for both FSL and DSL. DSL without discounting is more effective than FSL with discounting. Combining DSL and discounting, allows for a further reduction of food waste.	Focus lies on Dynamic Shelf Life, but in combination with DP
Chen, S.-P., Chen, C.-Y.	Dynamic markdown decisions based on a quality loss function in on-site direct-sale supply chains for perishable food	2021	Journal of the Operational Research Society	72(4), 822-836	Fresh products in general	Retailer and supply center	1	Yes	Total channel profit maximization, optimal markdown time	Analytical solution for different customer groups and sensitivity analysis regarding expiration date, cost parameters, quality loss and price sensitivity.	The optimal price markdown time is earlier for price-oriented customers than for the other groups and the maximum profit is the highest when most consumers are quality-oriented. The higher the quality orientation of the consumers, the higher the percentage of products sold at the regular price and the amount of unsold quantity and thus the profit. The sensitivity analysis further indicates that the expiry date has the greatest positive impact on profit because the longer the product is fresh, the more it will be sold. The profit is also higher when the quality loss coefficient is low. The order quantity of the products has the largest negative impact on the profit. Concerning the markdown time, the regular price, demand sensitivity to the markdown price and the demand rate have the largest positive impact, e.g. the higher the regular price, the earlier the markdown time. The impact of the parameters is highest for price-oriented consumers.	Quality loss function is detailly derived.
Kayikci, Y., Demir, S., Mangla, S. K., Subramanian, N., Koc, B.	Data-driven optimal dynamic pricing strategy for reducing perishable food waste at retailers.	2022	Journal of Cleaner Production	344, 131068	Apples	Retailer	1	No	Profit maximization	Four-stage data-driven optimal dynamic pricing strategy using real-time IoT sensor data Numerical analysis Simulation experiments are performed to analyse the effect of the sales price, initial replenishment amount and discount rate on proft and food waste.	A 7% discount rate maximizes the retailer's profit and reduces food waste to zero. The grocery achieves maximum profit with zero food waste when 345 kg of apples are purchased at the beginning of the selling season.	Target group are low and middle income countries.
Li, D., Tang, O., O'Brien, C., Wang, X.	Improve food retail supply chain operations with dynamic pricing and product tracing	2006	Service Operations and Informatics	1(4), 347-362	Fresh products in general	Multi echelon Centrally coordinated SC with focus on retailer	1	No	Retailer's profit maximization	A pricing model is developed for optimizing profits using a price-dependant demand model and dynamic product value assessment facilitated by the AutoID technology. Numerically solved.	The simulation result shows benefits from the product value tracing and improved retailer profits comparing the 'No-tracing' approach. With the varied elasticity, the dynamic pricing approach persistently outperforms the 'No-tracing' approach, although the adjusted delivery based on new forecasts incur penalty costs. An appropriately assessment of product values in the perishable food supply chains would improve dynamic pricing performance and increase the profit.	Focus lies on the assessment of the use of RFID technology.
Li, D., Wang, X.	Dynamic supply chain decisions based on networked sensor data: an application in the chilled food retail chain	2015	International Journal of Production Research	55(17), 5127-5141	Chilled Food SC	Manufacturerdistribution centre retailer	1	No, unplanned replenishment during the sales period is possible but penalty costs are high.	Retailer's profit maximization	Comparison of two scenarios : 1. Without use of Big Data and static pricing 2. With use of Big Data and dynamic pricing Numerical experiments	The proposed sensor data based dynamic pricing approach is feasible and capable of improving the chilled food supply chain management. The sensor data driven supply chain decision model provides opportunities of technological development and strategic innovation in perishable food supply chain management. The magnitude of benefit also depends on the demand sensitivity nature of the food product, the pricing policy, and the actual product quality control conditions.	
Li, D., Wang, X.	A dynamic product quality evaluation based pricing model for perishable food supply chains	2012	Omega	40(6), 906-917	Meat and vegetables	Retailer	1	Yes	Profit maximization	Comparison of two scenarios: single price markdown, multiple price markdown on the basis of a case study in UK supermarkets zcompared to the pricing policy used. Numerical analysis and sensitivity analysis regarding quality value difference, timing and frequency of discount, cost parameters, demand sensitivity ratio.	When prices change too often, implementation costs outweigh the advantes of DP. Retailers risk upsetting consumers who expect prices to remain constant over most of the selling period. Analytical and simulation results have demonstrated that product shelf life features, demand sensitivity, the length of the price markdown period and quality control throughout the supply chain processes affect model performance considerably. An appropriate price policy needs to be adopted according to shelf life features and accurately identified product deterioration rates in order to guarantee the maximization of profit.	Detailed deriviation of quality loss and decay rate.
Liu, G., Zhang, J., Tang, W.	Joint dynamic pricing and investment strategy for perishable foods with price-quality dependent demand	2015	Annals of Operations Research	226, 397–416	Fresh products in general	Retailer	1	No	Profit maximization	Joint dynamic pricing and investment strategy model. Numerical experiments and sensitivity analysis.	Numerical analysis shows that for relatively high natural deterioration coefficient and low unit investment cost, there exists a time threshold, before which, the retailer will implement investment activity and after which, the retailer will not invest. Whereas, when the natural deterioration coefficient is relatively low and unit investment cost is relatively high, the optimal strategy for the retailer is not to invest. When a retailer faces a higher deteriorating rate, he may adopt a lower initial price to promote demand. A higher deterioration rate will overall drop the demand rate, and increase the corresponding sales cycle for a given initial inventory level, thus leading to a lower total profit.	Consideration of investment strategy for preservation technology.
Liu, X., Tang, O., Huang, P.	Dynamic pricing and ordering decision for the perishable food of the supermarket using RFID technology	2008	Asia Pacific Journal of Marketing and Logistics	20(1), 7-22	Fresh products in general	Retailer	1	No	Profit maximization	RFID data are used as input parameters. Comparison of a deterministic demand scenario and a stochastic demand scenario with a dynamic pricing policy and a fixed price regarding optimal price, initial inventory and profit.	In both demand scenarios, applying dynamic pricing to perishable food based on RFID data leads to a higher profit. DP is especially advantageous when the decay rate is high. When holding costs and ordering costs are high, the price reduction is higher at first to motivate consumers to buy the product, but in later periods, the product gets more expensive again. When the costs are relatively low, the price reduction is higher.	Focus lies on RFID technology and ist application in the context of DP
Mahmoodi, A.	Pricing and inventory decisions in a manufacturer-Stackelberg supply chain with deteriorating items	2021	Kybernetes		No specific product, but author argues that fruits and vegetables is most suitable for application.	manufacturer retailer manufacturer-Stackelberg	1	Yes	Profit maximization	Model is a manufacturer-Stackelberg game. After solving the model, a sensitivity analysis is conducted.	The results show that a bigger market potential or maximum demand, a high deteriorating rate and high holding costs and shortage costs lead to a shorter replenishment cycle. The bigger the price sensitivity of the customers, the longer the replenishment cycle and the smaller the profit. A larger market size increases the profit. The manufacturer's profit is more sensitive to the parameters than the retailer's profit. The demand parameters have a larger influence on the model than cost parameters.	

Table 2: Classification of all papers about DP in FSC – OR methods (1/2) (own figure)

Author(s)	Title	Year	Journal	Volume, pages	Industry	SC actors	Number of products	Replenishment	Objective	Solution method	Results	Special features
Pourmohammad-Zia, N., Karimi, B., Rezaei, J.	Dynamic pricing and inventory control policies in a food supply chain of growing and deteriorating items	2021	Annals of Operations Research	-	Meat	Farm Retailer Centralized and decentralized scenario	1	Yes	Profit maximization	Comparison of a centralized with a decentralized scenario for the supply chain and the application of dynamic pricing with a static pricing scenario. They also conduct a sensitivity analysis.	The centralized scenario with an appropriate profit-sharing contract increase the total profit by 24.5 percent and lower the retailer's selling price. The dynamic pricing strategy increases the profit by 8.8 percent and decreases waste by 12.03 percent.	
Scholz, M., & Kulko, R. D.	Dynamic pricing of perishable food as a sustainable business model	2021	British Food Journal	2021	Strawberries	Retailer	1	No	Revenue maximization	Obtain revenue maximization prices Simulation to compare static and dynamic pricing strategies in terms of revenue and food waste	The freshness of strawberries significantly and substantially affects consumers' WTP. We demonstrate that consumers are not only willing to pay more for fresher strawberries but also show lower price sensitivity for fresher food products. These are necessary requirements to implement dynamic pricing strategies. A dynamic pricing strategy not only positively affects a retailer's revenue but also the sustainability of a retailer's business model through a reduced food waste. Especially if there are more products available than consumers, a dynamic pricing strategy helps to avoid waste and improve a retailer's revenue.	
Wang, H., Zou, H., Wang, C., & Li, H.	Dynamic Pricing of Tropical Fruits in Hainan Based on Internet of Things Technology.	2021	Asian Agricultural Research	13(4), 7-17	Fresh fruits	Retailer	1	No	Profit maximization	IoT data are used to evaluate the fruit quality and DP is used for different groups consumers: strategic and short-sighted consumers.	Authors recommend to use DP on the basis of quality data and for different kinds of consumers.	
Widodo, E., Prihadianto, R. D., Hartanto, D.	Multi period pricing for managing local fruit supply chain	2018	MATEC Web of Conferences EDP Sciences	Vol. 154, p. 01049	Fruits	Supplier Wholesale Retailer	1	No	Profit maximization	Conducting numerical testing on three optimization scenarios. First scenario is using single prices on each echelon, while, second and third scenario are dynamic prices which is automatically yield by optimization process. Sensitivity analysis is conducted.	DP scheme yields higher profit compared to using single price scheme.	
Xiao, Y., Yang, S.	The Retail Chain Design for Perishable Food: The Case of Price Strategy and Shelf Space Allocation	2016	Sustainability	9(1), 12	Meat and vegetables	Retailer	1 and multiple products are considered.	Yes	Profit maximization	Mathematical model for a single-item retail chain and determine the pricing strategy, shelf space allocation, and order quantity to maximize the retailer 's total profit with the application of tracking technologies. Then the single-item retail chain is extended into a multi-item one with a shelf space capacity and a simple algorithm is developed to find the optimal allocation of shelf space among these items. Numerical experiments and real-life examples are conducted to illustrate the proposed models.	The results showed that the discount rate is positively related to the decision variables (price, shelf space, and order quantity) and its optimal value can be obtained by numerical analysis. Larger shelf space could reduce the opportunity cost of the shelf space and bring about more profit. The results also showed that the discount and pricing strategy and shelf space can greatly affect the performance of the retail chain. As shown in the results, when larger shelf space is available, the retailer should allocate more space to the products whose demands are sensitive to the shelf space and expand the types of goods, which may attract more customers and sales.	Shelf Space Allocation
Yan, B., Han, L.	Decisions and coordination of retailer-led fresh produce supply chain under two-period dynamic pricing and portfolio contracts	2022	RAIRO-Oper. Res.	56(2022), 349–365	agricultural products fruits and vegetables	Farmer Retailer Centralized and decentralized scenario	1	No	Profit maximization	This study uses game theory to examine the decision-making and coordination of two-period pricing in the fresh agricultural produce supply chain that utilizes option contract, wholesale pricing, optimal ordering, and two-period pricing	The quantity of orders at the optimal wholesale price increases with the decline of the price in the first period, and then becomes more stable with the decline of the price in the second period. In contrast, the price change in the first period is considered to have a greater impact on the optimal order quantity decision- making. Both the optimal option order quantity and the optimal total order quantity are concave functions of two-period prices. The existence of an optimal price maximizes the optimal option order quantity and the optimal total order quantity.	Option Contracts
Yang, C., Feng, Y., Whinston, A.	Dynamic Pricing and Information Disclosure for FreshProduce: An Artificial Intelligence Approach	2022	Production and Operations Management	31(1), 155-171.	Fresh products in general	Retailer	1	No	Profit maximization	deep reinforcement learning algorithm to derive the optimal pricing and information strategies Simulation and comparison of different models with DP and without.	Our simulation results show that a quality-based pricing strategy yields lower prices than a pricing strategy that does not consider quality. We find that prices generally decrease over time. When information disclosure is allowed, the retailer is able to further improve profits and reduce food waste when a large portion of customers have perceptions of low quality. The retailer has greater incentives to disclose informa- tion at an early stage when customers' perception biases are high. DP increases consumer surplus.	
You, P.-S., Chen, T. C.	Dynamic pricing of seasonal goods with spot and forward purchase demands	2007	Computers and Mathematics with Applications	54(2007), 490–498	Seasonal goods in general	Retailer	1	Yes	Profit maximization	Perishable inventory model to resolve the optimal decisions for this problem. Generally, the purpose of this paper is to maximize the total profit through the simultaneous determination of (1) the order quantity, (2) the number of price settings, (3) the advance sales prices, and (4) the regular sales prices.	We show that for any number of price settings, the profit function is a concave function of the sales prices, and the advance and spot sales prices can be obtained optimally. From this characteristic, we then developed a procedure to find the order size, number of price settings, advance sales prices and spot sales prices optimally	Two types of consumers: spot purchase customers and the forward purchase customers.

Table 3: Classification of all papers about DP in FSC – OR methods (2/2) (own figure)

Author(s)	Title	Year	Journal	Volume, pages	Content focus of papers included	Period publishing of papers included	Categories included	Results	Special features
He, Y., Huang, H., Li, D., Shi, C., Wu, S. J.	Quality and Operations Management in Food Supply Chains: A Literature Review	2018	Journal of Food Quality	2018	Different challenges in the FSC, contains one section about DP.	2005 until 2017	Section 3.4. about DP: Models with Single Products and Homogenous Customer Preferences Models Considering Product Differentiation Models Considering Heterogeneous Customer Preferences Models Combined with Inventory Decisions	Supply chain disruption should be considered in the existing models. Food quality should be modeled in more practical ways.	Contains only paper that apply quantitative models.
Lemma, Y., Kitaw, D., Gatew, G.	Loss in perishable food supply chain: an optimization approach literature review.	2014	International Journal of Scientific & Engineering Research	5(5), 302-311	Optimization of Food SC in terms of food waste.	Last Decade	segmentation of research papers regarding product type used, optimization approach, identification of gaps that need further investigation.	5% of the papers were published in the last two years including 2014. In most of the research LP models are used to optimize the food supply chain, in addition few recent papers apply the state of the art optimization technique like evolutionary optimization approach and most papers uses case studies to test the model. This paper considers production, transportation and inventory as the main issues due to loss is high at these stages of agricultural supply chain. From the review we observed that many researches focused on maximizing revenue in the supply chain.	Difference between developed and developing countries in terms of food waste.
Nguyen T.-D., Nguyen-Quang T., Venkatadri U., Diallo C., Adams, M.	Mathematical Programming Models for Fresh Fruit Supply Chain Optimization: A Review of the Literature and Emerging Trends	2021	AgriEngineering	3(3), 519-541	Optimization problems of the Fresh Food Supply Chain in general.	1976 until 2021	deterministic models and their variants stochastic models special categories	main challenges for FFSC models: (1) the efficiency of the entire FFSC in function of the coordination between different stages; (2) the development of integrated planning models which are capable of acquisitioning data or updating parameters from such high-tech informative systems; (3) lack of standardization of all FFSC model outputs and performance metrics is observed	Relevant for obtaining general information about the Fresh Food Supply Chain and research fields.
Yamsaard, S.	Managing International Perishable Food Supply Chain: A Literature Review	2021	In 2021 1st International Conference On Cyber Management And Engineering	pp. 1-6	International Food Supply Chain, contains	?	perishable product inventory models, multi-period dynamic pricing, optimization techniques for integrating production and distribution, Fuzzy condi- tions in perishable product management	There are still some gaps in operation research, especially in a fuzzy business environment to be filled. The in tegration management between each stakeholder in the supply chain is also a considerable challenge. A future study that may improve this conceptual framework could involve operational factors that affect lead time and quality of the product which might allow a better alignment with the real-world practice.	Section 2.B for literature about DP.

Table 4: Classification of all papers about DP in FSC – Literature reviews (own figure)

Author(s)	Title	Year	Journal	Volume, pages	Industry	Number of SC actors	Number of products	Replenishment	Method	Results	Special features
Chung, J., Li, D.	The prospective impact of a multi-period pricing strategy on consumer perceptions for perishable foods	2013	British Food Journal	115(3),	diatry, meat and vegetable products in supermarkets in South Korea.	Retailer	3	Yes	Empirical study in South Korean supermarkets: Managers: how is DP applied Consumers: attitude towards DP Statistical evaluation of results.	Enhance customer satisfaction by offering an earlier but lower discount, and increasing it as perishable food items approach their expiry date, rather than a higher discount when the expiry date is imminent.	
Chung, J.	Effective Pricing of Perishables for a More Sustainable Retail Food Market	2019	Sustainability	11(17), 4762	Fresh products in general	Retailer	1	Yes	Simulation on the basis of models developed by other authors. Different scenarios are examined regarding the influence on revenue, waste and	This research contributes to our understanding of consumer demand and consumption plans with regard to perishables, which has been understudied in the literature. Prior studies have not considered the impact of providing trade-offs between price and the remaining days left on expiration and retailer performance based on the package size. basis for follow-up studies considering display shelf and price management for perishable foods with different package sizes. This study found that dynamic pricing may or may not perform better than a "no discount" policy; different strategies can be used for different package sizes for perishable foods, which can assist them in reducing inventory aging and food waste.	
Chung, J., Li, D.	A simulation of the impacts of dynamic price management for perishable foods on retailer performance in the presence of need-driven purchasing consumers	2014	Journal of the Operational Research Society	65, 1177–1188	Fresh products in general	Retailer	1	Yes	Interview with Food Reatilers in South Korea and UK Data used to develop a simulation model and conduct numerical experiments to evaluate the impact of the frequency of discounting the price on the retailer's profit, sales volume and disposal rate.	Multi-period DP reduces waste and maximizes profit. More dynamic pricing or proactive discounting for perishables may not generate significant benefits for small retail stores. Food retailers who frequently have excess stock due to insufficient demand, a more dynamic pricing or a proactive discounting strategy will improve their business performance. The results show that the every day discount strategy leads to a profit increase of, depending on the length of the sales period, 6.25 percent to 20.32 percent. The waste is also reduced if the demand is accurately estimated, and the stock is managed in accordance with the demand prediction. The findings also indicate that the every day discount strategy is especially suitable for products with a short shelf-life, if the inventory level is higher than the demand and for products with a high sales volume.	

Table 5: Classification of all papers about DP in FSC – Other methods (own figure)

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