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Don't waste that free lettuce! Impact of BOGOF promotions on retail profit and food waste

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Abstract

Buy-one-get-one-free (BOGOF), a ubiquitous sales promotion scheme by which consumers get two items for the price of one, encourages consumers to buy and waste food. An alternative promotional scheme is one where consumers receive a coupon for a second item available for free at a later time. Our work is motivated by British supermarkets which, facing criticism from lawmakers for running BOGOF promotions on perishables, started a "BOGOF Later" campaign with the claim that it would reduce the amount of waste. Food waste is indeed a very pressing issue, which has not yet been explored in connection to sales promotions. We compare the impact of these promotion schemes on a retailer's profit as well as on the amount of product wasted at the retail and household levels. We consider two possible applications: unexpected high inventory of a fresh product with a short shelflife and excess leftover inventory for an item at the end of its season or product life.

We propose a two-period newsvendor model which captures the sales-boosting effect of promotions, the postpromotion sales drop due to satiation, the coupon-redemption behavior, and the increased consumer wastage rate from BOGOF promotions. We obtain analytical comparisons of order quantity, profit, and waste across the different promotion schemes and use numerical experiments to generate further insights. We find that, in general, BOGOF promotions are profitable ways to liquidate inventory. In many instances, the increase in waste at the consumers' homes is offset by the decrease in waste at the retail store. As a result, BOGOF promotions often constitute "win-win propositions" by simultaneously increasing the retailer's profit and decreasing total waste. Overall, our results paint a more favorable picture of the BOGOF promotion scheme than commonly perceived and suggest that its environmental criticism emanates from a too narrow and too consumer-centric view of the waste problem.

KEYWORDS
buy-one-get-one-free, coupons, food waste, sales promotions, sustainability, waste

1 | INTRODUCTION

Buy-one-get-one-free (BOGOF) promotions are highly popular with consumers and are ubiquitous in today's retail world: from smoothies to pizzas, from T-shirts to cellphones, consumers love (the illusion of) a good deal, especially when it involves getting something "for free" (Ariely, 2010). A survey-based study by the AMG Strategic Advisors Shopper Panel reports that 66% of shoppers prefer BOGOF promotions to other promotions and 93% of the survey respondents report taking advantage of such a promotion in the past (AMG, 2012). Similarly, Fogel and Thornton (2008) report that consumers prefer promotions that require no effort such as BOGOF to promotions which require action such as coupons or mail-in rebates. BOGOF promotions are especially common in British supermarkets where in 2008 it was estimated that "more than 80% of all promotion activity within supermarkets is a BOGOF or three-for-two" (Wallop, 2008). Academic studies of BOGOF promotions on nonperishables have shown them to be most effective at inducing stockpiling and purchase acceleration but less effective in inducing additional spending (Farrag, 2010; Shi et al., 2004).

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For food items, BOGOF and other similar sales promotions are said to encourage consumers to eat more (Hawkes, 2009) and waste more (Aschemann-Witzel et al., 2016, 2017). In 2014, a report by the House of Lords European Committee reported that 222 million tons of food is wasted each year by the West, including 15 million tons in the United Kingdom, pointing the finger specifically at retailers who "pass on food waste from the store to the household by the use of special offers such as BOGOF" and encouraging them to move away from this type of promotion and other "morally repugnant" practices (BBC News, 2014). Cutting back on or eliminating multibuy promotions (like BOGOF) is regularly cited as a way to limit food waste at the consumer level (Calvo-Porral et al., 2017; Halloran et al., 2014; Mondéjar-Jiménez et al., 2016; Principato, 2018).

Food waste is indeed a very pressing and important issue at a time when 811 million people in the world lack access to food (FAO, 2021), including one out of eight Americans who are food insecure (Gunders, 2012). Somewhere between one third and 40% of all food produced globally goes uneaten, which amounts to about 1.3 billion tons per year (FAO, 2011; Gunders, 2012). Food is lost or wasted throughout the entire supply chain, from agricultural production down to household consumption. In high-income countries, much of the wastage happens at the final stages: 10% at the retail level and 21% at the consumer level (Buzby et al., 2014). Rotting wasted food in landfills accounts for 16% of US methane emissions, which have been linked to climate change (USDA, 2022). After much outcry from environmental activists in recent years, developed nations around the world are finally pledging to reduce food loss and food waste: the United States has set a goal of 50% less waste by 2030 (EPA, 2015), and the United Nations has established the Sustainable Development Goal to halve food waste by 2030 (United Nations, 2021).

Retailers can take an active role in the fight against food waste. Hanson and Mitchell (2017) report there is a 14:1 return on investment for businesses which integrate reduction of food loss and waste in their operations. In 2009, UK's leading retailer Tesco responded to a government criticism of BOGOF promotions by launching a "buy-one-get-one-free… later" campaign marketed as a way to help reduce household waste: consumers buying one of the featured products on this promotion are given a coupon at check-out which can be redeemed for the same item the following week (BBC News, 2010). Coupons (a.k.a, vouchers) form another popular type of promotional vehicle. According to a 2019 Coupon Intelligence Report, 87% of consumers reported using coupons received in a store (Valassis, 2019) yet, at the same time, coupon redemption rates are typically very low, that is, less than 1% for offline paper coupons (Ives, 2003; Jung & Lee, 2010; Reibstein & Traver, 1982).

In this paper, we consider the problem of a retailer selling a perishable product to consumers using a BOGOF-type promotion scheme. Motivated by the Tesco story above, we consider two types of promotion: (i) under the traditional BOGOF scheme, which we refer to as `BOGOF-Now`, consumers receive two units of the product for the price of one and they take both units home immediately; (ii) under the `BOGOF-Later` scheme, consumers pay for one item and take it home along with a coupon to be redeemed for a free identical item starting at some date in the future (no additional purchase necessary). We study the two promotion schemes applied to two types of products for which a retailer may want to use a BOGOF-type promotion. In our *fresh* model, we consider highly perishable products (with short shelf life) which are ordered regularly (e.g., produce, dairy, etc.) but for which the retailer is facing an unusually high inventory situation at the start of the planning horizon. This can be due to an exogenous shock such as the resolution of earlier disruptions in the supply chain or the result of an especially high-yield seasonal crop. In our *liquidation* model, we consider seasonal items which are approaching the end of their selling season (e.g., Halloween candy, Christmas decorations, etc.) or items approaching the end of their product life cycle (e.g., obsolete technology, discontinued products).

Under both models, we compare the promotional schemes in terms of the retailer's profit and the amount of product waste, both at the retailer's store (unsold items) and at the consumers' homes (unconsumed purchased items) over a planning horizon of two periods. We measure waste both in absolute terms (i.e., number of units unsold or unconsumed) and in relative terms (i.e., percentage of total inventory which was unsold or unconsumed).

In the *fresh* model, we compare three promotion strategies for the retailer: offering `BOGOF-Now` in Period 1, offering `BOGOF-Later` in Period 1, or offering `No-promotion`. We obtain threshold results on the retailer's profit as a function of the level of initial inventory: for moderate high inventory, offering `BOGOF-Later` in the first period is the most profitable strategy while, for very high inventory, the `BOGOF-Now` strategy should be used. Regarding waste, we prove that, for all values of the initial inventory in Period 1, offering `BOGOF-Now` in Period 1 minimizes the amount of waste at the retail store over the two-period planning horizon thanks to a combination of increased sales in Period 1 and decreased sales variability in Period 2. At the consumers' homes, we find that offering a `BOGOF-Later` promotion leads to less waste in Period 1 and more waste in Period 2 compared to `BOGOF-Now`. We also obtain threshold results regarding the total amount of waste (i.e., retail store + consumers' homes); in particular, we show that, if the initial inventory is very excessive, offering `BOGOF-Now` achieves the lowest total waste. Numerical experiments confirm that both types of `BOGOF` promotion can be *win-win propositions*, that is, they can simultaneously increase the retailer's profit and reduce waste: it was the case in the majority (58.8%) of the problem instances we studied and especially likely to be the case when the initial inventory is very excessive or when it is only slightly excessive and the selling price is low.

In the *liquidation* model, we compare the following three promotion strategies for the retailer: offering `BOGOF-Now` in Period 1, offering `BOGOF-Later` in Period 1, or offering no promotion in Period 1 and waiting until Period 2 to decide whether or not to offer a `BOGOF-Now` promotion, which we refer to as the `Postpone` strategy. We first establish a threshold result under the `Postpone` strategy: the retailer runs a `BOGOF-Now` promotion in Period 2 if and only if the amount of leftover inventory at the end of Period 1 is above a certain level. We also establish conditions under which the retailer always benefits from postponing the `BOGOF-Now` promotion to Period 2 and prove that, similarly to the *Fresh* model, the `BOGOF-Now` (`BOGOF-Later`) promotion provides higher profit when the level of initial inventory is high (low). Our waste results confirm those in the *fresh* model: offering `BOGOF-Now` in Period 1 leads to more waste than `BOGOF-Later` at the consumers' homes but less waste at the retail store. Under the assumption of an equal household wastage rate, we prove that `BOGOF-Now` minimizes total waste. Our numerical experiments complement these results by indicating that the `Postpone` strategy provides the highest profit when the level of initial inventory is low and moderate to high, offering `BOGOF-Later` in Period 1 is best when it is low-to-moderate and offering `BOGOF-Now` in Period 1 is best when it is high (provided there is a positive holding cost and/or a drop in the base demand rate in Period 2). We also see numerically that *win-win propositions* are significantly more likely to arise in the *liquidation* model (69.3% of the instances) than in the *fresh* model.

Our work contributes to the burgeoning literature on food waste reduction in operations management and the literature on sales promotion in marketing by considering the novel angle of the impact of `BOGOF` promotions on product waste both at the retail and household levels. To the best of our knowledge, we are the first authors to analytically compare the traditional `BOGOF` promotion scheme to the `BOGOF-Later` scheme and study the impact of the two `BOGOF` promotion schemes on total product waste at the retail store and the consumers' homes.

Our paper provides the following important managerial insights. First, we show that, when a retailer finds themselves with high inventory of a product, whether it is fresh with a short shelf life or nearing the end of its product life cycle or season, BOGOF-type promotions can be very effective at liquidating the inventory. If the level of initial inventory is very high, offering `BOGOF-Now` in Period 1 is the most profitable way to do so; if the level of initial inventory is moderate, the retailer is better off running a `BOGOF-Later` promotion. For items which are nearing the end of their product life cycle of season, the retailer should postpone the decision to run the `BOGOF-Now` promotion to Period 2 if the demand in that period does not drop too sharply and the holding cost is negligible.

Our results also suggest that the characterization of the `BOGOF` promotion as "morally repugnant" (as in the Tesco story) may not be fully warranted. While we find that in many cases, a `BOGOF-Now` promotion increases waste at the consumers' home (which, granted, was the focus of the criticism in the Tesco story above), it generally also decreases waste at the retail store due to a combination of increased sales and reduced demand variability. Overall, the effect is often a decrease in total waste. In other words, our analysis suggests that the environmental criticism of the `BOGOF` promotion scheme for perishables may be based on too narrow a view of the waste problem: when looking at the overall impact across both retailer and consumer levels, a more nuanced picture emerges where in some cases, offering such a promotion can lead to less waste and more profit than offering no promotion, making it a "*win-win proposition*."

2 | LITERATURE REVIEW

BOGOF promotion schemes have been studied extensively in the marketing literature. According to Gilbert and Jackaria (2002), packs with BOGOF offers facilitate brand recognition and increase future purchases. M. Mittal and Sethi (2011) investigate the effectiveness of various sales promotion techniques, including BOGOF, at inducing the desired sales response on Indian consumers, and Salvi (2013) found BOGOF promotions in the Indian apparel retail industry to be very effective at attracting consumers to the store and boosting sales. Jayaraman et al. (2012) report high satisfaction and repurchase intentions from consumers making purchases from a BOGOF scheme. Hawkes (2009) considers the impact on the dietary behavior of consumers from sale promotions, including BOGOF, on food items and finds significant increases in consumption over the short term. Psychological and behavioral aspects of sales promotions are considered by Sinha and Smith (2000) and Smith and Sinha (2000) who study consumer perceptions from equivalent deals framed either as BOGOF or as 50% off in terms of store preferences and transaction value and by S. Li et al. (2007) who compare the impact of the promotion for perishable versus nonperishable items. Boland et al. (2012) find that children preferred BOGOF promotion to the dominant 60% price cut on two units. By tracking eye movement, Gordon-Hecker et al. (2020) conclude that consumers prefer BOGOF deals to an equivalent price reduction. In summary, prior research has established that BOGOF promotions are well-liked by consumers and effective at attracting consumers and increasing sales. Our paper draws from the above-mentioned research for the justification of our modeling assumptions, and we calibrate the parameters in our numerical study based on empirical findings from these papers.

On the analytical side, BOGOF is a form of nonlinear discount pricing (Levin et al., 2014). Kim et al. (2016) consider a dynamic revenue management problem where a seller can adopt quantity discount schemes including BOGOF. Y. Li et al. (2021), Khouja and Zhou (2022), and Khouja et al. (Forthcoming) analytically compare BOGOF promotions to other marketing promotional schemes in terms of demand, profit, average price, and consumer surplus in various settings including, in the presence of strategic consumers and in a manufacturer–retailer supply chain. Thomas and Chrystal (2013) propose the theory of "relative utility pricing" to model the reaction of consumers to supermarket promotional offers including BOGOF, and Howell et al. (2015)

develop a direct utility model for price promotions which can be extended to include BOGOF promotions. Our work contributes to this stream of research as we are (to our knowledge) the first to draw analytical comparisons between a BOGOF promotion and a coupon-based promotion, and we are also the first to consider the waste angle of the problem.

Promotional coupons have also been the focus of numerous studies. Unlike immediate-incentive promotions like BOGOF, coupons require some effort on the part of consumers (Chen et al., 2005; Dogan, 2010). Reibstein and Traver (1982) and B. Mittal (1994) study the factors influencing coupon redemption rates such as product and consumer demographics. Taylor (2001) examines coupon use for services and finds similar redemption rates than for packaged good studies. Jung and Lee (2010) compare online and offline coupons and report much higher redemption rates for online coupons. Argo and Main (2008) study the social stigma of redeeming coupons. In all, the consensus on coupon promotions is that they are less effective than effort-less promotions at increasing sales and that redemption rates are generally very low. These studies support our modeling assumptions and guide our choice for the parameter ranges in the numerical study.

Our work is also related to the literature on food waste. Parfitt et al. (2010) review and define the concepts of food waste and food loss in supply chains and lays out the challenges ahead for feeding a population of nine billion people by 2050. Silvennoinen et al. (2014) measure food waste in Finnish households and identify its main causes, and Oledinma and Aktas (2017) study the drivers of food waste in Qatar. Akkas et al. (2019) empirically investigate the drivers of product expiration in the consumer packaged goods industry, and Akkas and Saho (2020) focus on the impact of sales force compensation schemes on such expiration. Teller et al. (2018) and Lebersorger and Schneider (2014) study the root causes of food waste at the retail store across product categories and store formats. Broekmeulen and van Donselaar (2019) look at ways for retail stores to reduce food waste and increase freshness and sales. In our work, we combine both perspectives and study waste at the consumers' homes as well as at the retail store.

On the modeling side, Belavina (2021) looks at the impact of grocery market concentration and grocery store density on food waste in a two-echelon supply chain for a perishable item. Akkas (2019) connects product expiration and waste to shelf space allocation. Akkas and Honhon (2022) study inventory issuing policies in a two-tier supply chain for products with a fixed shelf life in the presence of reverse logistics costs. Belavina et al. (2017) and Astashkina et al. (2019) study the environmental impact of online grocery retail by modeling the impact on food waste and transportation throughout a supply chain. Kirci et al. (2021) analyze consumer waste caused by a retailer's package size decisions and the possibility of offering loose products alongside prepackaged options. Atan et al. (2019) look at how discounts on soon-to-expire perishables, and product display can reduce waste and increase profits for a retailer. Ata et al. (2012) consider how regulatory mechanisms can impact the recycling of organic waste into energy. There is also a broad set of papers focusing on inventory management for perishables which often includes a waste angle on the problem (see, e.g., van Donselaar et al., 2006; Nahmias, 1982, 2011; Haijema & Minner, 2019). Our paper complements this stream of research as we are the first (to our knowledge) to look at the impact of BOGOF and coupon-based sales promotions on perishable product waste.

The rest of our paper is organized as follows. We present three promotion strategies for the *fresh* and *liquidation* model respectively in Section 3. Our analytical results are shown in Section 4, and Section 5 is our numerical study. In Section 6, we consider two extensions of our model. We conclude and discuss further research in Section 7.

3 | MODEL

A retailer is selling an item at a fixed selling price p. The planning horizon is divided into two periods. At the start of Period 1, there are I_1 units of the product in inventory, which is an exogenous quantity. We consider two cases, corresponding to two models. In the *fresh* model, the product has a shelf life of one period, so that unsold units at the end of each period must be disposed of at a waste cost of r, and, at the start of Period 2, the retailer orders I_2 units from a supplier at a unit variable cost c and the order quantity is delivered reliably and immediately (no lead time). The *fresh* model applies to perishable items which are regularly ordered and sold by the retailer (e.g., produce or dairy). However, at the start of Period 1, the retailer finds himself with a larger-than-usual quantity of the product in inventory. One can think of Period 1 as an external "shock" to the replenishment system to which the retailer may respond with a BOGOF-type promotion. For example, it could be that the supplier has delivered more products than usual due to some surprisingly high yield for a local produce at the peak of the season. The shock could also be due to the resolution of earlier supply chain disruption: in the early months of the COVID-19 pandemic, much of the food which was destined for the food service industry could no longer be sold due to restaurants and schools closing. As a result, some of the excess food (much of it perishable) was diverted to grocery stores which had found themselves confronted with a surge in demand (Felix et al., 2020). Later in the pandemic, disruptions to the global supply chain impacted retail with shortages of many items while shipping containers from overseas were stuck at US ports, followed by excess deliveries once some of the bottlenecks cleared (New York Times, 2021).

In the *liquidation* model, the product has a remaining shelf life of two periods and the retailer cannot order more units in Period 2 so that all unsold units at the end of Period 1 are carried over to Period 2 at a holding cost of h and all unsold units at the end of Period 2 are disposed of at a waste cost of r. The *liquidation* model applies to seasonal products such as Halloween candy or Christmas decorations as well as to products which are discontinued, for example, because they are becoming obsolete, with demand for the product fading over time. The inventory I_1 at the start of Period 1 can be what is left after much of the selling season has passed, and the retailer now has only two more periods to *liquidate* the product.

In both the *fresh* and *liquidation* models, the retailer can offer two types of promotions. First, he can offer a traditional `BOGOF-Now` promotion whereby consumers pay the selling price p once to acquire two units of the product, which they bring home at once. Second, he can offer a `BOGOF-Later` promotion, whereby consumers pay the selling price p to take home one unit of the product immediately, along with a coupon to be redeemed in Period 2 for a free identical unit (without additional purchase necessary). If there is not enough inventory of the products for all the coupon-holding consumers in Period 2, coupon-holding consumers are given a refund of $\eta \in [0, p]$.

Our model is meant to study situations where the retailer finds himself with a larger-than-usual inventory quantity of the product and therefore considers using a `BOGOF`-type promotion. To make the problem interesting, we focus on cases where the promotion would not already be the optimal course of action in the absence of this high inventory. Hence, we make the following assumption:

Assumption 1. We assume that the parameters are such that, under optimized inventory conditions, it is not optimal for the retailer to run a `BOGOF` promotion.

Under the *fresh* model, this implies that it is not optimal to offer a `BOGOF-Now` promotion in Period 2 since the retailer can optimize the inventory level at the start of the period. We provide a mathematical formulation for Assumption 1 in Section 3.4 after having introduced our profit notation.

In both the *fresh* and *liquidation* models, the retailer must choose between three possible promotion strategies. The following two promotion strategies are available to the retailer in both models: (i) the `Immediate-Now` strategy: offer a `BOGOF-Now` promotion in Period 1 and no promotion in Period 2; (ii) the `Later` strategy: offer a `BOGOF-Later` in Period 1 and no promotion in Period 2. In the *fresh* model, the retailer can also choose (iii) the `No-promotion` strategy: offer no promotion in either period. In the *liquidation* model, the third possible strategy is (iii) the `Postpone` strategy: the retailer offers no promotion in Period 1, then, based on the amount of leftover inventory at the start of Period 2, decides whether to offer a `BOGOF-Now` promotion or no promotion in Period 2. The `Postpone` strategy does not apply in the *fresh* model since the retailer is able to optimize the inventory level at the start of Period 2.

Table 1 summarizes the possible strategies under each model. In what follows, we use the notation (as superscripts) Ø, N, L, and P to denote, respectively, the `No Promotion`, `Immediate-Now`, `Later`, and `Postpone` promotional strategies.

3.1 | Demand

We now explain how to calculate consumer demand in each period given the promotional strategy followed by the retailer. In all cases, let $\bar{D}$ denote the number of consumers who visit the retail store in a given period, which we refer to as *store traffic*. Most well-established grocery stores have a steady consumer base of shoppers who come regularly for their main grocery purchases (Lam, 2021) so we assume that $\bar{D}$ is the same in both periods.

Let $\lambda_t \in (0, 1)$ represent the probability that a consumer would buy the product in the absence of any promotional activity in Period t. In the *Fresh* model, we assume that the base rate of demand (in the absence of a promotion) is the same in Periods 1 and 2, which is consistent with the fact that this is a product which is regularly ordered by the retailer (e.g., produce and dairy). In the *liquidation* model, we assume that the base demand rate is smaller in Period 2 than in Period 1, representing the demand for the product fading over time, which makes sense for a seasonal product at the end of its selling season or an item approaching the end of its product life cycle. In sum, we have

Assumption 2. In the *fresh* model, $\lambda_1 = \lambda_2 = \lambda$; in the *liquidation* model, $\lambda_1 \geq \lambda_2$.

We use the normal distribution approximation to a binomial distribution to model the demand for the product under all different strategies.

No promotion strategy

Under the `No promotion` strategy, the demand in Period $t \in \{1, 2\}$ is denoted by $D_t^{\emptyset}$ and has a normal distribution with mean $\bar{D} \cdot \lambda_t$ and variance $\bar{D} \cdot \lambda_t(1 - \lambda_t)$. Note that the demand in Period 2 is independent of the demand in Period 1.

Immediate-now strategy

Under the `Immediate-Now` strategy, the retailer runs a `BOGOF-Now` promotion in Period 1 and as a result, compared to no promotion, a greater proportion of consumers who visit the store choose to buy the product as they are tempted by the promotion. Specifically, we assume that a fraction $\lambda_1 \alpha^N$ of consumers chooses to buy the product in Period 1, where $\alpha^N > 1$ is the `BOGOF-Now` *sales boost parameter*. As a result, the demand for the product in Period 1, D_1^N, has a normal distribution with mean $\bar{D} \cdot (\lambda_1 \alpha^N)$ and variance $\bar{D} \cdot (\lambda_1 \alpha^N)(1 - \lambda_1 \alpha^N)$. Note that by "demand" we mean the number of consumers looking to buy the product and given the `BOGOF-Now` promotion, each one who buys takes home two units.

In Period 2, consumers who brought home two units of the products in Period 1 are less likely to want to buy them again as many studies have documented a postpromotion sales drop (see, e.g., Hendel and Nevo, 2003; Neslin and Stone, 1996). In our *liquidation* model, the sales drop can be explained by

TABLE 1 Possible strategies

Strategy	Notation	Period 1 action	Period 2 action	Model(s)
`Immediate-Now`	N	`BOGOF-Now`	`No promotion`	*Fresh* and *liquidation*
`Later`	L	`BOGOF-Later`	`No promotion`	*Fresh* and *liquidation*
`No-Promotion`	Ø	`No promotion`	`No promotion`	*Fresh*
`Postpone`	P	`No promotion`	`BOGOF-Now` or `No promotion`	*Liquidation*

delayed consumption and stockpiling behavior (Farrag, 2010; Shi et al., 2004). In our *fresh* model, the product is assumed to be highly perishable (i.e., shelf life of one period) so delayed consumption is not an option; however, the decrease in consumption in Period 2 can be driven by a satiation phenomenon (McAlister & Pessemier, 1989; Neslin & Stone, 1996; Hendel & Nevo, 2003). Specifically, we assume only a fraction $\lambda_2\beta^N$ of consumers who bought in Period 1 choose to buy the product in Period 2, where β^N is the `BOGOF-Now` *postpromotion sales drop parameter*.

Assumption 3. $\beta^N \leq 1$.

Of the consumers who did not buy the product in Period 1, we assume that a fraction λ_2 will buy in Period 2. As a result, the demand for the product in Period 2 D_2^N has a normal distribution with mean $(\bar{D} - \min\{I_1/2, D_1^N\}) \cdot \lambda_2 + \min\{I_1/2, D_1^N\} \cdot \lambda_2\beta^N$ and variance $(\bar{D} - \min\{I_1/2, D_1^N\}) \cdot \lambda_2(1-\lambda_2) + \min\{I_1/2, D_1^N\} \cdot \lambda_2\beta^N(1-\lambda_2\beta^N)$.

Later strategy
Under the `Later` strategy, the retailer runs a `BOGOF-Later` promotion in Period 1 and, as a result, the proportion of consumers visiting the store who buys the products is more than under the no promotion but less than under a `BOGOF-Now` promotion. This is because, unlike `BOGOF-Now`, the `BOGOF-Later` promotion is not effort-less, so that fewer consumers buy the product as they anticipate not remembering to bring their coupon in the next period (Fogel & Thornton, 2008). Specifically, we assume that a fraction $\lambda_1\alpha^L$ of consumers chooses to buy the product in Period 1, where α^L is the `BOGOF-Later` *sales boost parameter*.

Assumption 4. $\alpha^N \geq \alpha^L \geq 1$.

As a result, the demand for the product in Period 1 D_1^L has a normal distribution with mean $\bar{D} \cdot (\lambda_1\alpha^L)$ and variance $\bar{D} \cdot (\lambda_1\alpha^L)(1-\lambda_1\alpha^L)$.

In Period 2, we distinguish between two types of consumers taking home the product: (i) the coupon-holding consumers, that is, those who bought the product in Period 1 and attempt to redeem their coupon to obtain the product for free in Period 2 and (ii) those who did not buy the product in Period 1 but buy it in Period 2. Specifically, we assume that Period 1 consumers have a probability γ of attempting to redeem their coupon in order to obtain the product in Period 2 for free. Further, this parameter satisfies the following condition:

Assumption 5. $\gamma \in (\lambda_2, \frac{1}{2})$

In other words, coupon-holding consumers are more likely to obtain the product (for free) in Period 2 than those who did not buy the product in Period 1 are to pay to buy the product. The technical condition $\gamma < \frac{1}{2}$ is required to simplify our analysis but is also justified by the many studies of coupon usage which suggest that redemption rates are typically very low (Ives, 2003; Jung & Lee, 2010; Reibstein & Traver, 1982). Let D_2^{Lc} and D_2^{Ln}, respectively, denote the demand from coupon-holding (repeat) consumers and paying (new) consumers. The demand from repeat consumers D_2^{Lc} has a normal distribution with mean $\min\{I_1, D_1^L\} \cdot \gamma$ and variance $\min\{I_1, D_1^L\} \cdot \gamma(1-\gamma)$. Similarly, the demand from new consumers has a normal distribution with mean $(\bar{D} - \min\{I_1, D_1^L\}) \cdot \lambda_2$ and variance $(\bar{D} - \min\{I_1, D_1^L\}) \cdot \lambda_2(1-\lambda_2)$. Hence, the total demand in Period 2 is $D_2^L = D_2^{Lc} + D_2^{Ln}$ has a normal distribution with mean $\min\{I_1, D_1^L\} \cdot \gamma + (\bar{D} - \min\{I_1, D_1^L\}) \cdot \lambda_2$ and variance $\min\{I_1, D_1^L\} \cdot \gamma(1-\gamma) + (\bar{D} - \min\{I_1, D_1^L\}) \cdot \lambda_2(1-\lambda_2)$. Note our model could be easily extended to consider a proportion of repeat consumers who lost their coupon and, therefore, pay to acquire the product in both periods.

Postpone strategy
Under the `Postpone` strategy (only possible in the *liquidation* model), the retailer offers `No promotion` in Period 1 then, based on the amount of leftover inventory, decides whether offering a `BOGOF-Now` promotion or `No promotion` in Period 2. In this case, the demand in Period 1 has the same distribution as $D_1^{\emptyset}$ that is, it has a normal distribution with mean $\bar{D} \cdot \lambda_1$ and variance $\bar{D} \cdot \lambda_1(1-\lambda_1)$. If the retailer decides to run a `BOGOF-Now` promotion in Period 2, the demand is denoted by D_2^{PN} and it has a normal distribution with mean $\bar{D} \cdot (\lambda_2\alpha^N)$ and variance $\bar{D} \cdot (\lambda_2\alpha^N)(1-\lambda_2\alpha^N)$; otherwise, if he decides not to run a promotion in Period 2, the demand in Period 2 is denoted by $D_2^{P\emptyset}$ and it has the same distribution as $D_2^{\emptyset}$, that is, a normal distribution with mean $\bar{D} \cdot \lambda_2$ and variance $\bar{D} \cdot \lambda_2(1-\lambda_2)$.

3.2 | Retailer's profit function

In this section, we provide expressions for the retailer's profit functions for each possible strategy under the two models. Note that, in all cases, since the inventory I_1 in Period 1 is exogenous, we do not include the sunk cost of acquiring these units in the profit expressions below.

First, we consider the *fresh* model and the three possible promotion strategies: `No Promotion`, `Immediate-Now`, and `Later`. Under the `No promotion` strategy, the retailer's expected profit function is given by

$$\pi^{\emptyset}_{Fresh}(I_1) = p\mathbb{E}\left[\min\left\{I_1, D^{\emptyset}_1\right\}\right] - r\mathbb{E}\left[I_1 - D^{\emptyset}_1\right]^+ + \max_{I_2 \geq 0}\left[p\mathbb{E}\left[\min\left\{I_2, D^{\emptyset}_2\right\}\right] - r\mathbb{E}\left[I_2 - D^{\emptyset}_2\right]^+ - cI_2\right]. \tag{1}$$

In each period, the first term is the sales revenue and the second term is the disposal cost for the unsold quantity (i.e., waste). In Period 2, the last term is the variable cost of acquiring the inventory in Period 2. Note that the expression includes a maximization of the inventory level in Period 2, since the demand in Period 2 is independent of the demand in Period 1 under the `No promotion` strategy, the optimal inventory value in Period 2 does not depend on the realization of $D^{\emptyset}_1$.

Under the `Immediate-Now` strategy, the retailer's expected profit function is given by

$$\pi^{N}_{Fresh}(I_1) = p\mathbb{E}\left[\min\left\{\frac{I_1}{2}, D^{N}_1\right\}\right] - r\mathbb{E}\left[I_1 - 2D^{N}_1\right]^+ + \max_{I_2 \geq 0}\left[p\mathbb{E}\left[\min\left\{I_2, D^{N}_2\right\}\right] - r\mathbb{E}\left[I_2 - D^{N}_2\right]^+ - cI_2\right]. \tag{2}$$

In Period 1, revenue is calculated based on the minimum of the demand and *half* the inventory quantity since each consumer receives two units of the product but pays only for one. Note that the value of I_2 is chosen after observing the realization of the demand in Period 1 as it impacts the value of the demand in Period 2.

Under the `Later` strategy, the retailer's expected profit function is given by

$$\pi^{L}_{Fresh}(I_1) = p\mathbb{E}\left[\min\left\{I_1, D^{L}_1\right\}\right] - r\mathbb{E}\left[I_1 - D^{L}_1\right]^+ + \max_{I_2 \geq 0}\left[p\mathbb{E}\left[\min\left\{\left(I_2 - D^{Lc}_2\right)^+, D^{Ln}_2\right\}\right] - r\mathbb{E}\left[I_2 - D^{L}_2\right]^+ - \eta\mathbb{E}\left[D^{Lc}_2 - I_2\right]^+ - cI_2\right]. \tag{3}$$

The sales revenue in Period 2 is only earned on the paying consumers, that is, not on the coupon-holding consumers. Here again, the value of I_2 is chosen after observing the realization of the demand in Period 1 as it impacts the value of the demand in Period 2. The expressions above assume that priority is given to coupon-holding consumers over paying consumers; this is, a conservative/pessimistic assumption from the point of view of the retailer.

In the *liquidation* model, the retailer's expected profit under the three possible promotion strategies, that is, `Immediate-Now`, `Later,` and `Postpone`, is as follows:

Under the `Immediate-Now` and `Later` strategies, the retailer's expected profit functions are given by

$$\pi^{N}_{Liquid}(I_1) = p\mathbb{E}\left[\min\left\{\frac{I_1}{2}, D^{N}_1\right\}\right] - h\mathbb{E}[I_1 - 2D^{N}_1]^+ + p\mathbb{E}[\min\{(I_1 - 2D^{N}_1)^+, D^{N}_2\}] - r\mathbb{E}[I_1 - 2D^{N}_1 - D^{N}_2]^+$$

$$\pi^{L}_{Liquid}(I_1) = p\mathbb{E}\left[\min\left\{I_1, D^{L}_1\right\}\right] - h\mathbb{E}\left[I_1 - D^{L}_1\right]^+ + p\mathbb{E}[\min\{(I_1 - D^{L}_1 - D^{Lc}_2)^+, D^{Ln}_2\}] - r\mathbb{E}\left[I_1 - D^{L}_1 - D^{L}_2\right]^+ - \eta\mathbb{E}\left[D^{Lc}_2 - (I_1 - D^{L}_1)^+\right]^+. \tag{4}$$

Compared to the same strategy under the *fresh* model, the disposal cost in Period 1 is replaced by a holding cost and there is no optimization of inventory level for Period 2, therefore is no purchase cost in Period 2. Instead, the leftover inventory from Period 1 is carried over to Period 2.

Under the `Postpone` strategy, the retailer's expected profit function is given by

$$\pi^{P}_{Liquid}(I_1) = p\mathbb{E}\left[\min\left\{I_1, D^{\emptyset}_1\right\}\right] - h\mathbb{E}\left[I_1 - D^{\emptyset}_1\right]^+ + \max\left\{p\mathbb{E}\left[\min\left\{\frac{\left(I_1 - D^{\emptyset}_1\right)^+}{2}, D^{PN}_2\right\}\right] - r\mathbb{E}\left[I_1 - D^{\emptyset}_1 - 2D^{PN}_2\right]^+,\ p\mathbb{E}\left[\min\left\{I_1 - D^{\emptyset}_1, D^{P\emptyset}_2\right\}\right] - r\mathbb{E}\left[I_1 - D^{\emptyset}_1 - D^{P\emptyset}_2\right]^+\right\}. \tag{5}$$

Here, the maximum is taken over the expected profit generated in Period 2, from selling the product under a `BOGOF-Now` promotion or under `No promotion`. Note that the decision of whether or not to run the promotion in Period 2 is made after observing how many units are leftover, that is, the value of $(I_1 - D^{\emptyset}_1)^+$.

There is an interesting trade-off which contrasts the `BOGOF-Now` and `BOGOF-Later` promotions. `BOGOF-Now` leads to a larger boost in demand due to the immediacy of the reward for the consumer; however, it requires a more heavy sponsoring of their purchase since every consumer who buys the product in Period 1 receives a free unit. In contrast, with `BOGOF-Later` there is a smaller boost in consumer demand but not all participating consumers eventually receive the free unit; hence, the promotion is less costly for the retailer.

3.3 | Waste calculations

We are also interested in measuring the amount of waste which results from the retailer's promotion decision. We define *expected absolute waste at the retail store* $W^X_{Fresh,R}$ and $W^X_{Liquid,R}$ as the total unsold (and therefore disposed of) quantity of the product over the two periods, under strategy $X \in \{\emptyset, N, L\}$ for the *fresh* model and under the strategy $X \in \{N, L, P\}$ for the *liquidation* model, respectively. Similarly, we define *expected absolute waste at the consumers' homes*, $W^X_{Fresh,C}$ and $W^X_{Liquid,C}$, as the total quantity of product acquired by consumers which they do not consume under the *fresh* and *liquidation* models, respectively. Finally, we refer to the sum of these two quantities as the *total expected absolute waste*. In the *fresh* model, the optimal order quantity in Period 2 is denoted by I_2^{X*} under promotion strategy X.

Under the *fresh* model, the expected absolute waste at the retail store is the sum of the unsold inventory over the two periods:

$$W^X_{Fresh,R}(I_1) = \begin{cases} \mathbb{E}\left[I_1 - D_1^{\emptyset}\right]^+ + \mathbb{E}\left[I_2^{\emptyset*} - D_2^{\emptyset}\right]^+ & \text{if } X = \emptyset \\ \mathbb{E}\left[I_1 - 2D_1^{N}\right]^+ + \mathbb{E}\left[I_2^{N*} - D_2^{N}\right]^+ & \text{if } X = N. \\ \mathbb{E}\left[I_1 - D_1^{L}\right]^+ + \mathbb{E}\left[I_2^{L*} - D_2^{Lc} - D_2^{Ln}\right]^+ & \text{if } X = L \end{cases} \quad (6)$$

Under the *liquidation* model, the expected absolute waste at the retail store is the unsold quantity after two periods:

$$W^X_{Liquid,R}(I_1) = \begin{cases} \mathbb{E}\left[I_1 - 2D_1^{N} - D_2^{N}\right]^+ & \text{if } X = N \\ \mathbb{E}\left[I_1 - D_1^{L} - D_2^{L}\right]^+ & \text{if } X = L \end{cases}. \quad (7)$$

Under the `Postpone` strategy, the waste value depends on whether the retailer decides to run a promotion in Period 2 or not:

$$W^P_{Liquid,R}(I_1) = \begin{cases} \mathbb{E}\left[I_1 - D_1^{\emptyset} - 2D_2^{PN}\right]^+ & \text{if BOGOF-Now in P2} \\ \mathbb{E}\left[I_1 - D_1^{\emptyset} - D_2^{P\emptyset}\right]^+ & \text{if Nopromotion in P2} \end{cases}. \quad (8)$$

When the retailer runs a `BOGOF-Now` promotion, the expected absolute waste at the retail store accounts for the fact that consumers take home two units for the price of one.

The expected absolute waste at the consumers' homes is equal to a fraction of the quantity they acquire in each period. Let ρ be the base rate for consumer wastage. Studies have shown that in most developed countries, households waste about 12–33% of the food they buy, with overall up to 40% of the food produced that goes uneaten due to losses and waste at the various stages of the supply chain (Gunders, 2012). However, the wastage rate can be even higher when the retailer runs a `BOGOF-Now` promotion, as consumers bring home quantities of the product in excess of their usual consumption needs (Mondéjar-Jiménez et al., 2016). Hence, we allow for the possibility of a higher wastage rate following a `BOGOF-Now` promotion, which is denoted by ρ^N.

Assumption 6. $\rho^N \geq \rho$.

Under the *fresh* model, we have

$$W^X_{Fresh,C}(I_1) = \begin{cases} \rho\mathbb{E}\left[\min\{I_1, D_1^{\emptyset}\}\right] + \rho\mathbb{E}\left[\min\{I_2^{\emptyset*}, D_2^{\emptyset}\}\right] & \text{if } X = \emptyset \\ \rho^N\mathbb{E}\left[\min\{I_1, 2D_1^{N}\}\right] + \rho\mathbb{E}\left[\min\{I_2^{N*}, D_2^{N}\}\right] & \text{if } X = N. \\ \rho\mathbb{E}\left[\min\{I_1, D_1^{L}\}\right] + \rho\mathbb{E}\left[\min\{I_2^{L*}, D_2^{L}\}\right] & \text{if } X = L \end{cases} \quad (9)$$

Under the *liquidation* model, we have

$$W^X_{Liquid,C}(I_1) = \begin{cases} \rho^N\mathbb{E}\left[\min\{I_1, 2D_1^{N}\}\right] + \rho\mathbb{E}\left[\min\{[I_1 - 2D_1^{N}]^+, D_2^{N}\}\right] & \text{if } X = N \\ \rho\mathbb{E}\left[\min\{I_1, D_1^{L} + D_2^{L}\}\right] & \text{if } X = L \end{cases}. \quad (10)$$

In both models, when the retailer runs a `BOGOF-Later` promotion, we use the same base rate for consumer waste as when there is `No promotion`, as the consumers bring at most one unit of the product home in each period.

Under the `Postpone` strategy, the waste value depends on whether the retailer decides to run a promotion in Period 2 or not:

$$W^P_{Liquid,C}(I_1) = \begin{cases} \rho\mathbb{E}\left[\min\left\{I_1, D_1^{\emptyset}\right\}\right] + \rho^N\mathbb{E}\left[\min\left\{\left[I_1 - D_1^{\emptyset}\right]^+, 2D_2^{PN}\right\}\right] & \text{if BOGOF-Now in P2} \\ \rho\mathbb{E}\left[\min\left\{I_1, D_1^{\emptyset} + D_2^{P\emptyset}\right\}\right] & \text{if No promotion in P2} \end{cases}. \quad (11)$$

Besides absolute waste, we also measure *expected relative waste*. At the retail store, it is defined as the proportion of total product inventory put on the shelves by the retailer which is not acquired by consumers. It is calculated as $\frac{W_{Liquid,R}(I_1)}{I_1}$ in the *liquidation* model and as $\frac{W_{Fresh,R}(I_1)}{I_1 + \mathbb{E}[I_2^*]}$ in the *fresh* model, where I_2^* is the optimized order quantity in Period 2 (which, when a `BOGOF` promotion is applied, depends on the realization of demand in Period 1). Similarly, we define the expected relative waste at the consumers' home as $\frac{W_{Liquid,C}(I_1)}{I_1}$ and $\frac{W_{Fresh,C}(I_1)}{I_1 + \mathbb{E}[I_2^*]}$, which correspond to the proportion of products ordered by the retailer which is unconsumed by the consumers in the *liquidation* and *fresh* models, respectively. Note that this measure differs from the proportion of product acquired by the consumers which is wasted by them, which is equal to ρ by definition and is a constant in our

TABLE 2 Notation table

Notations	Parameters/variables
$\bar{D}$	Store traffic
λ_t	Probability of a consumer buying the product at the regular price in period $t \in \{1,2\}$
I_t	Inventory at the start of period $t \in \{1,2\}$
α^N	Sales boosting factor of `BOGOF-Now` promotion
α^L	Sales boosting factor of `BOGOF-Later` promotion
β^N	Satiation factor for `BOGOF-Now` consumer in Period 2
γ	Probability of coupon-redemption under `BOGOF-Later`
ρ	Base value of consumer waste percentage
ρ^N	Amplified consumer waste percentage under `BOGOF-Now` in Period 1
p	Retail price
c	Wholesale price
r	Disposal cost of unsold units
h	Holding cost (liquidation model only)
η	Refund value in case of stock-out under `BOGOF-Later`

All parameters are exogenous except for I_2 in the *fresh* model.

setup. We argue that our expected relative waste measures are meaningful especially in the *fresh* model, where the order quantity in Period 2, and therefore the total inventory quantity on the retailer's shelves, typically varies across promotion strategies, so that comparing absolute waste numbers could be misleading. A summary of our notation is provided in Table 2.

3.4 | Discussion of the modeling assumptions

Our stylized model was built in an effort to strike the right balance between representing reality, assuring tractability, and capturing the relevant trade-offs between the different promotion strategies. In this section, we provide further justification for the assumptions we make.

We have chosen a macro-level approach to modeling consumer demand, that is, we do not model individual decision-making but rather work directly with aggregate demand functions given some reasonable and well-supported assumptions on the parameters. This aggregate modeling approach is very common in the economics literature and presents the advantages of facilitating the derivations and allowing for the parametrization based on well-established studies regarding promotion-related consumer behavior.

We assume that the retailer offers a promotion in at most one of the two periods. In our *fresh* model, this is justified under Assumption 1 (which mathematically can be stated as $\max_I \pi^{\emptyset}(I) \geq \max\{\max_I \pi^L(I), \max_I \pi^N(I)\}$) as the retailer optimizes the inventory in Period 2. For the *liquidation* model, we justify this by arguing that offering a double promotion would lead to promotion fatigue among consumers so that the effectiveness of the promotion would be significantly reduced in Period 2. Further, `BOGOF` promotions are known to create "a sense of urgency, pushing consumers to make a purchase"; therefore, it is best to use them sparingly (Mage Solution, 2021).

In our modeling of the `BOGOF-Now` promotion, we have assumed that all the consumers who buy the product engage in the promotion, that is, they all accept to take two units for the price of one. In practice, there may exist a small fraction of waste-conscious consumers who may turn down the free second unit. We have chosen not to include this possibility for two reasons. First, research shows that very few consumers are able to resist the attraction of free products (Ariely, 2010), even the most environmentally conscious ones. Second, in Section 6.1, we consider "buy-one-get-one-x-off"-type promotions where the second unit is offered at a discount, and there, we introduce a parameter (θ) to capture the fact that not all consumers take part in the promotion, that is, some take home only one unit of the product at full price. We show numerically that, in that context, the results are directionally equivalent across different values of the parameter θ.

We assume that the wastage rate at the consumers' homes may be higher under a `BOGOF-Now` promotion (Assumption 6) compared to `BOGOF-Later`. This assumption implies an increasing convex relationship between the quantity purchased and the wastage rate. Under normal circumstances, Gunders (2012) estimates that about 30% of food produced for human consumption goes uneaten. If the store runs a `BOGOF-Now` promotion, each consumer goes home with two units of the product. The first unit is likely to be wasted at a percentage similar to 30%, but the second one is probably wasted at a much higher percentage. This translates to more than 30% of the sold products ending up wasted. While a strict convex relationship is practically very reasonable, importantly, all of our results continue to hold even if Assumption 6 is met as an equality, that is, if $\rho^N = \rho$.

Our models also ignore an important benefit of the `BOGOF-Later` promotion, which is that it encourages returned patronage by consumers who want to redeem their coupon and the associated cross-selling opportunities: consumers who visit the store to redeem their coupon generally purchase other items as well. Hence, our modeling of the `Later` strategy is conservative, that is, our calculations of the retailer's expected profit under this strategy should be viewed as a lower bound on its potential performance.

In our analytical results, we assume that coupon-holding consumers who find the product stocked out in Period 2 under `the BOGOF-Later` promotion are given a full refund.

Assumption 7. $\eta = p$.

This assumption is made mainly for analytical tractability. We show in Proposition EC.1 in the Supporting Information Appendix that, under the assumption of full refunds, the value of expected profit is the same irrespective of the sequence of consumer arrivals, that is, which of the coupon-holding versus paying consumers are served first in Period 2. We also argue that it is important for firms offering

TABLE 3 Optimal values under the `No promotion` strategy in the *fresh* model.

	`No promotion`
Retailer exp. profit	$(p+r)\mathbb{E}[\min\{I_1, D_1^{\emptyset}\}] - rI_1 + [(p-c)\overline{D}\lambda - (p+r)\sqrt{\bar{D}\lambda(1-\lambda)}\phi(\Phi^{-1}(\delta))]$
Retailer Exp. Abs. Waste ($W_R^{\emptyset}$)	$\sqrt{\bar{D}\lambda(1-\lambda)}[\phi(\Phi^{-1}(\delta_1^{\emptyset})) + \delta_1^{\emptyset} \cdot \Phi^{-1}(\delta_1^{\emptyset})] + \sqrt{\bar{D}\lambda(1-\lambda)}[\phi(\Phi^{-1}(\delta)) + \delta \cdot \Phi^{-1}(\delta)]$
Consumer Exp. Abs. Waste ($W_C^{\emptyset}$)	$\rho[2\overline{D}\lambda + \sqrt{\overline{D}\lambda(1-\lambda)}(((1-\delta_1^{\emptyset}) \cdot \Phi^{-1}(\delta_1^{\emptyset}) - \phi(\Phi^{-1}(\delta_1^{\emptyset})) + ((1-\delta) \cdot \Phi^{-1}(\delta) - \phi(\Phi^{-1}(\delta))))]$

[a]where $\delta_1^{\emptyset} = \Phi(\frac{I_1 - \bar{D}\lambda}{\sqrt{\bar{D}\lambda(1-\lambda)}})$, $\delta = \frac{p-c}{p+r}$.

TABLE 4 Optimal values under the `Immediate-Now` strategy in the *fresh* model.

	`Immediate-Now`
Retailer exp. profit	$(p-c) \cdot \bar{D}\lambda + [(p+2r) - (p-c)(1-\beta^N)\lambda] \cdot \mathbb{E}[\min\{I_1/2, D_1^N\}] - rI_1 - (p+r)\mathbb{E}[\sigma_2^N]\phi(\Phi^{-1}(\delta))$
Retailer exp. abs. waste (W_R^N)	$2 \cdot (\sqrt{\bar{D}\alpha^N\lambda(1-\alpha^N\lambda)}\phi(\Phi^{-1}(\delta_1^N)) + \delta_1^N \cdot \Phi^{-1}(\delta_1^N)) + \mathbb{E}[\sigma_2^N] \cdot (\delta \cdot \Phi^{-1}(\delta) + \phi(\Phi^{-1}(\delta)))$
Consumer exp. abs. waste (W_C^N)	$\rho\overline{D}\lambda + (2\rho^N - \rho\lambda(1-\beta^N)) \cdot (\alpha^N\bar{D}\lambda + \sqrt{\bar{D}\alpha^N\lambda(1-\alpha^N\lambda)}((1-\delta_1^N) \cdot \Phi^{-1}(\delta_1^N) - \phi(\Phi^{-1}(\delta_1^N))))$
	$+\rho\mathbb{E}[\sigma_2^N]((1-\delta) \cdot \Phi^{-1}(\delta) - \phi(\Phi^{-1}(\delta)))$

[a]where $\delta_1^N = \Phi(\frac{I_1/2 - \bar{D}\lambda\alpha^N}{\sqrt{\bar{D}\lambda\alpha^N(1-\lambda\alpha^N)}})$, $\delta = \frac{p-c}{p+r}$, $\sigma_2^N = \sqrt{[\bar{D} - \min\{I_1/2, D_1^N\}] \cdot \lambda(1-\lambda) + \min\{I_1/2, D_1^N\} \cdot \beta^N\lambda(1-\beta^N\lambda)}$.

coupon deals to keep coupon-holding consumers happy and returning to their stores. Running out of the promised free product without compensation would lead to a high goodwill cost and a decrease in the effectiveness of similar future promotions. Nevertheless, in practice, some retailers advertise their coupon promotion with a small character mention of "while supplies last" or "subject to availability," in which case, consumers who want to redeem their coupon but do not find the product in inventory would not be entitled to a refund, that is, $\eta = 0$. In Section 6.2, we numerically investigate the case of $\eta \in [0, p]$ and also compare the impact of the arrival sequence on expected profit under partial or no refund.

4 | RESULTS

4.1 | Results under the fresh model

In what follows, let Φ and ϕ denote the cdf and pdf of a standard normal distribution, respectively. Also let $\delta = \frac{p-c}{p+r}$ denote the newsvendor model critical fractile.

Under the *fresh* model, the retailer is facing high initial inventory I_1 of a perishable product in Period 1. All unsold units at the end of the period are disposed of, and the retailer places an order for inventory at the start of Period 2. The retailer has three possible promotional strategies: `Immediate-Now`, `Later`, and `Postpone`.

Next, we present expressions for the retailer's expected profit and the expected absolute waste values for each promotional strategy when the order quantity in Period 2 is optimized. The values for retailer profit and waste and consumer waste are given in Table 3 for the `no-promotion` strategy, Table 4 for the `Immediate-Now` strategy, and Table 5 for the `Later` strategy.

When there is no promotion, the retailer optimizes the order quantity in Period 2 by optimizing a classical newsvendor problem under a normally distributed demand. Under the `Immediate-Now` and `Later` promotional strategies, the retailer sets the order quantity for Period 2 using the classical newsvendor formula, anticipating the impact it will have on Period 2 demand, given the realized sales in Period 1.

When a `BOGOF-Now` promotion is used, consumers who engage in the promotion take home two units of the product; therefore, this creates a difference between the *product sales*, that is, the total number of products sold, and the *paying market size*, that is, the total number of paying consumers, with the former being equal to twice the later. The *sales revenues* are always equal to the selling price p multiplied by the paying market size. Proposition 1 provides comparisons of the two metrics in expectation.

Proposition 1. *Expected product sales in Period* 1 *are larger under the* `Immediate-Now` *strategy, followed by the* `Later` *strategy then the* `No promotion` *strategies, that is,* $\mathbb{E}[\min\{I_1, 2D_1^N\}] \geq \mathbb{E}[\min\{I_1, D_1^L\}] \geq \mathbb{E}[\min\{I_1, D_1^{\emptyset}\}]$.

There is a threshold $\bar{I}$, *such that the paying market size is larger under* `Immediate-Now` *than* `Later`, *that is,* $\mathbb{E}[\min\{\frac{I_1}{2}, D_1^N\}] > \mathbb{E}[\min\{I_1, D_1^L\}]$ *if and only if* $I_1 > \bar{I}$.

We find that product sales in Period 1 are always higher with a promotion and highest under the `BOGOF-Now`. However, the paying market size, and therefore the sales revenues, can be higher or lower under either type of promotion depending on the starting inventory level: for low values of I_1, the `BOGOF-Later` promotion gives higher sales revenues but for

TABLE 5 Optimal values under the `Later` strategy in the *fresh* model

	`Later`
Retailer exp. profit	$(p-c)\bar{D}\lambda - rI_1 + [(p+r)-(p-c)\lambda - c\gamma]\mathbb{E}[\min\{I_1, D_1^L\}] - (p+r)\cdot\mathbb{E}[\sigma_2^L]\phi(\Phi^{-1}(\delta))$
Retailer exp. abs. waste ‡ (W_R^L)	$\sqrt{\bar{D}\alpha^L\lambda(1-\alpha^L\lambda)}[\phi(\Phi^{-1}(\delta_1^L)+\delta_1^L\cdot\Phi^{-1}(\delta_1^L)]\ \sigma_2^L\cdot(\delta\cdot\Phi^{-1}(\delta)+\phi(\Phi^{-1}(\delta)))$
Consumer exp. abs. waste (W_C^L)	$\rho((1+\alpha^L(1+\gamma-\lambda))\lambda\bar{D}+(1+\gamma-\lambda)\sqrt{\bar{D}\alpha^L\lambda(1-\alpha^L\lambda)}((1-\delta_1^L)\cdot\Phi^{-1}(\delta_1^L)-\phi(\Phi^{-1}(\delta_1^L)))$ $+\mathbb{E}[\sigma_2^L]((1-\delta)\cdot\Phi^{-1}(\delta)-\phi(\Phi^{-1}(\delta))))$

[a]where $\delta_1^L = \Phi(\frac{I_1-\bar{D}\lambda\alpha^L}{\sqrt{\bar{D}\lambda\alpha^L(1-\lambda\alpha^L)}})$, $\delta = \frac{p-c}{p+r}$, $\sigma_2^L = \sqrt{(\bar{D}-[\min\{I_1, D_1^L\}])\cdot\lambda(1-\lambda)+[\min\{I_1, D_1^L\}]\cdot\gamma(1-\gamma)}$.

sufficient large I_1, the `BOGOF-Now` promotion does. Further, in that case, the product sales under `BOGOF-Now` are more than double that of `BOGOF-Later`, that is, $\mathbb{E}[\min\{I_1, 2D_1^N\}] \geq 2\mathbb{E}[\min\{I_1, D_1^L\}]$.

Next, we compare the retailer's profits under the three promotional strategies.

Proposition 2. *Assume $\bar{D}$ is sufficiently large.*

1. *There exists a threshold $I_{L\phi}$ such that $\pi_{Fresh}^{\emptyset}(I_1) \geq \pi_{Fresh}^{L}(I_1)$, if and only if $I_1 \leq I_{L\phi}$;*
2. *There exists a threshold I_{NL}, such that $\pi_{Fresh}^{L}(I_1) \geq \pi_{Fresh}^{N}(I_1)$, if and only if $I_1 \leq I_{NL}$.*
3. *There exists a threshold $I_{N\phi}$, such that $\pi_{Fresh}^{\emptyset}(I_1) \geq \pi_{Fresh}^{N}(I_1)$, if and only if $I_1 \leq I_{N\phi}$.*

Further, we have $\bar{I} > I_{NL}$, where $\bar{I}$ is defined in Proposition 1 and $\pi_{Fresh}^{N}(I_1) - \pi_{Fresh}^{L}(I_1)$ is increasing in p for $I_1 \geq \bar{I}$.

According to Proposition 2, the retailer is better off not running any promotion if the level of initial inventory is not very high. If there is a lot of inventory, then running a `BOGOF-Now` promotion is optimal. In between, that is, when the level of initial inventory is moderate, the retailer should run a `BOGOF-Later` promotion.

Next, we compare the amount of absolute waste at the consumers' homes under the three promotional strategies. Let $W_{Fresh,C}^{X,t}$ denote expected absolute waste at the consumers' homes in Period $t \in \{1, 2\}$ under promotional strategy $X \in \{\emptyset, L, N\}$.

Proposition 3. *For any $I_1 \geq 0$, we have $W_{Fresh,C}^{N,1}(I_1) \geq W_{Fresh,C}^{L,1}(I_1) \geq W_{Fresh,C}^{\emptyset,1}(I_1)$ and $W_{Fresh,C}^{L,2}(I_1) \geq W_{Fresh,C}^{\emptyset,2}(I_1) \geq W_{Fresh,C}^{N,2}(I_1)$. Further, if $I_1 \geq \bar{I}$ then $W_{Fresh,C}^{N,1} \geq 2W_{Fresh,C}^{L,1}$, where $\bar{I}$ is defined in Proposition 1.*

The `Immediate-Now` strategy leads to the highest amount of consumer waste in Period 1, but the lowest amount in Period 2. When the initial inventory is sufficiently large, consumers waste *more than twice* as much at home under a `BOGOF-Now` promotion than under a `BOGOF-Later` promotion in Period 1. This is for two reasons: the expected quantity sold to consumers more than doubles (as per Proposition 1) and a greater proportion of the products brought home is wasted (as per Assumption 6). At the same time, the `Later` strategy further increases waste in Period 1 compared to the `No promotion` baseline, due to the boost in sales. In Period 2, the `Later` strategy leads to the most amount of waste at the consumers' homes because it has the highest sales due to the sales-boosting effect of the coupons and `Immediate-Now` leads to the least amount of waste at the consumers' homes because of the postpromotion drop in sales. As a result of these two opposing forces, the effect on overall consumer waste is unclear.

Now let us compare absolute waste at the retail store. Let $W_{Fresh,R}^{X,t}$ denote the retailer's expected absolute waste in Period $t \in \{1, 2\}$ under promotional strategy $X \in \{\emptyset, L, N\}$.

Proposition 4. *For any $I_1 \geq 0$, we have $W_{Fresh,R}^{\emptyset,1}(I_1) \geq W_{Fresh,R}^{L,1}(I_1) \geq W_{Fresh,R}^{N,1}(I_1)$ and $W_{Fresh,R}^{L,2}(I_1) \geq W_{Fresh,R}^{\emptyset,2}(I_1) \geq W_{Fresh,R}^{N,2}(I_1)$. As a result, $\min\{W_{Fresh,R}^{L}(I_1), W_{Fresh,R}^{\emptyset}(I_1)\} \geq W_{Fresh,R}^{N}(I_1)$, that is,* `Immediate-Now` *has the lowest expected absolute waste at the retail level over the two periods.*

In Period 1, expected absolute waste at the retail store is inversely related to sales so is the highest under a `No promotion` strategy and lowest under an `Immediate-Now` strategy. In Period 2, expected waste is the highest under a `BOGOF-Later` promotion because the variability of the demand is the largest due to the boost from coupon-holding consumers and it is the lowest under a `BOGOF-Now` promotion due to the postpromotion sales drop. It is quite interesting that expected absolute waste at the retail store over the two periods is minimized under an `Immediate-Now` strategy thanks to the combination of increased sales in Period 1 and decreased sales variability in Period 2.

Propositions 3 and 4 show differences in the ranking of expected waste at the consumer and retail levels and across the two periods. Hence, a priori, it is not clear what effect dominates when considering total expected absolute waste $W_{Fresh}^{X}(I_1) \equiv W_{Fresh,R}^{X}(I_1) + W_{Fresh,C}^{X}(I_1)$ for $X \in \{\emptyset, L, N\}$. In the next proposition, we show that different orderings of the expected waste quantities can emerge:

Proposition 5. *Assume $\bar{D}$ is sufficiently large.*

1. *When $\frac{\rho^N}{\rho} \leq 1 + (\gamma - \lambda) + \frac{\lambda(1-\beta^N)}{2}$, $W^N_{Fresh}(I_1) \leq W^L_{Fresh}(I_1)$ for all $I_1 \geq 0$. When $\frac{\rho^N}{\rho} > 1 + (\gamma - \lambda) + \frac{\lambda(1-\beta^N)}{2}$, there exists a threshold I^W_{LN}, such that $W^N_{Fresh}(I_1) \geq W^L_{Fresh}(I_1)$ if and only if $I_1 \leq I^W_{LN}$.*
2. *When $\frac{\rho^N}{\rho} \leq 1 + \frac{\lambda(1-\beta^N)}{2}$, $W^N_{Fresh}(I_1) \leq W^{\emptyset}_{Fresh}(I_1)$ for all $I_1 \geq 0$. When $\frac{\rho^N}{\rho} > 1 + \frac{\lambda(1-\beta^N)}{2}$, there exists a threshold $I^W_{\emptyset N}$, such that $W^N_{Fresh}(I_1) \geq W^{\emptyset}_{Fresh}(I_1)$ if and only if $I_1 \leq I^W_{\emptyset N}$.*
3. *There exists a threshold $I^W_{\emptyset L}$, such that, $W^L_{Fresh}(I_1) \geq W^{\emptyset}_{Fresh}(I_1)$, if and only if $I_1 \leq I^W_{\emptyset L}$.*

Moreover, $W^N_{Fresh}(I_1) - W^L_{Fresh}(I_1)$, $W^N_{Fresh}(I_1) - W^{\emptyset}_{Fresh}(I_1)$, and $W^{\emptyset}_{Fresh}(I_1) - W^L_{Fresh}(I_1)$ decrease in p.

Proposition 4 establishes that `BOGOF-Now` has the lowest waste at the retail level, and Proposition 3 shows that it has the highest waste at the customer level in the first period but lowest in the second. From Proposition 5, we see that the key factor in determining the direction of total waste is the amplified consumer wastage percentage under `BOGOF-Now` (i.e., ρ^N). When it is much higher than the baseline consumer wastage percentage (ρ), Period 1 waste at the customer level becomes the dominant factor, because consumers buy large quantities in the first period. In other cases, we find that `BOGOF-Now` can minimize total expected absolute waste, especially when the initial inventory is very large. We feel that this aspect of the `BOGOF-Now` promotion was missing in the discussions around the Tesco implementation of the promotion (see Introduction)—the "morally repugnant" characterization of the promotion scheme was centered around the waste in consumers' homes and mostly ignored the possible reduction of waste at the retail store.

4.2 | The liquidation model

In the *liquidation* model, the retailer is left with inventory I_1 of a product at the end of its selling season or life cycle. Unlike in the fresh model, there is no opportunity to reorder the product in Period 2, and unsold units from Period 1 are carried over to Period 2 at a holding cost. The retailer has three possible promotional strategies: `Immediate-Now`, `Later`, and `Postpone`.

For the `Postpone` strategy, we show that, under a mild technical condition, the decision whether or not to run a `BOGOF-Now` promotion in Period 2 amounts to comparing the leftover inventory at the end of Period 1 to a threshold value.

Proposition 6. *Under the `Postpone` strategy, when $\lambda_2(1 + \alpha^N) < 1$, there exists a threshold $\hat{I}_2$ such that, it is optimal to run a `BOGOF-Now` promotion in Period 2 if and only if the quantity left unsold at the end of Period 1 is above $\hat{I}_2$.*

In other words, under the `Postpone` strategy, the retailer will use the `BOGOF-Now` promotion in Period 2 if and only if there is still high inventory which must be liquidated. The inequality $\lambda_2(1 + \alpha^N) < 1$ is a technical condition, which allows us to prove the result using a single-crossing property for two normal distributions (see Lemma EC.2 in the Supporting Information Appendix). We believe that the result continues to hold if the inequality is not satisfied; however, it would require a more elaborate proof. For example, when $p = 3$, $r = 0.2$, $\alpha^N = 9.5$, $\lambda_1 = \lambda_2 = 0.1$, and $\bar{D} = 1000$, the condition is not satisfied, but the threshold policy still holds with $\hat{I}_2 = 188.24$. In most cases, we argue that the inequality is satisfied since λ_2, which measures the proportion of incoming consumers who buy the product in Period 2, is generally significantly lower than 1.

The derivations in the *liquidation* model are more complicated than under the *fresh* model because unsold inventory is carried over from Period 1 to Period 2, so that the profit and waste expressions can no longer be simplified using properties of a newsvendor model with normal demand. Nevertheless, we derive some results on profit and waste.

Next, we obtain limiting results on the profit comparison between `BOGOF-Now` than `BOGOF-Later` and establish conditions under which the `Postpone` strategy dominates `BOGOF-Now`.

Proposition 7. *When $I_1 \to 0$, $\pi^L_{Liquid}(I_1) \geq \pi^N_{Liquid}(I_1)$. And when $I_1 \to \infty$, $\pi^L_{Liquid}(I_1) \leq \pi^N_{Liquid}(I_1)$. If $h = 0$ and $\lambda_1 = \lambda_2$, then $\pi^P_{Liquid}(I_1) \geq \pi^N_{Liquid}(I_1)$ for all $I_1 \geq 0$.*

Proposition 7 suggests that the `Immediate-Now` strategy achieves a higher expected profit than the `Later` strategy when the starting inventory I_1 is high, but the reverse is true when it is low. Also, the proposition establishes that the `Postpone` strategy always provides a higher expected profit than the `Immediate-Now` strategy when there is no holding cost and no drop in the demand rate in Period 2; in this case, postponing the promotion comes at no cost since carrying more unsold units to Period 2 is free and the promotion would continue to be as effective in Period 2. However, if there is a positive holding cost or demand fades in Period 2, it may be optimal for the retailer to run the `BOGOF` promotion in Period 1.

Next, we provide the following result on the ranking of the expected absolute waste values.

Proposition 8. *For any $I_1 \geq 0$, we have $W^N_{Liquid,R}(I_1) \leq W^L_{Liquid,R}(I_1)$ and $W^N_{Liquid,C}(I_1) \geq W^L_{Liquid,C}(I_1)$. Further, if $\rho^N = \rho$ then, $W^N_{Liquid,R}(I_1) + W^N_{Liquid,C}(I_1) \leq W^L_{Liquid,R}(I_1) + W^L_{Liquid,C}(I_1)$.*

Proposition 8 states that the `Immediate-Now` strategy leads to more waste at the consumer's home but less waste at the retail store compared to the `Later` strategy. Under the conservative scenario where consumers do not waste a greater proportion of the products, they purchase at home (i.e., Assumption 6 is satisfied as an equality), then the `Immediate-Now` strategy leads to the lowest overall waste.

5 | NUMERICAL RESULTS

The goals of our numerical study are as follows: (i) compare the impact on the retailer's profit and on the level of product waste of `BOGOF` promotion schemes compared to the baseline of no promotion, (ii) analyze the breakdown of the waste between the retail store and the consumers' homes under the possible strategies, (iii) identify cases where one promotion strategy is a *win-win proposition*, which means that it provides the highest profit value *and* the lowest amount of waste.

We calibrated our parameter set carefully based on previous empirical studies. Specifically, we set γ in such a way that the coupon redemption rates would fall in the traditionally observed range of 5–25% as in Ives (2003), Jung and Lee (2010), and Reibstein and Traver (1982). We set the sales to boost parameters from the `BOGOF` promotions α^N and α^L between 1.1 and 3 in accordance with a report from the United Kingdom's Competition Commission (Competition Commission, 1999) which quotes typical sales increases of 200% for promotions in British supermarkets. We set the postpromotion sales drop factor β^N after a `BOGOF-Now` promotion between 0.5 and 1 (where 1 corresponds to no sales drop) as most studies (on nonperishable products) report little to no discernable drop in sales postpromotion (DelVecchio et al., 2006; Hendel & Nevo, 2003; Neslin & Stone, 1996; Neslin & Shoemaker, 1989; Sun, 2005) (yet, we suspect that a study that would focus on perishable may find more of a decline due to the well-documented satiation effect and variety-seeking behavior (McAlister & Pessemier, 1989)). Finally, we set the parameters on the percentage waste at the consumers' homes ρ and ρ^N in the 10–40% range based on Gunders (2012).

More specifically, for both the *fresh* model and the *liquidation* model, we vary the parameters as follows: $\bar{D} = 1000$, $\lambda \in \{0.05, 0.1\}$, $p \in \{2, 3, 4, 5\}$, $c = 1$, $r \in \{0, 0.25, 0.5\}$, $\alpha^N \in \{1.2, 1.3, 1.4, 1.5, 2, 3\}$, $\alpha^L \in \{1.1, 1.2, 1.5, 2\}$, $\gamma \in \{1.5\lambda, 2\lambda, 2.5\lambda\}$, $\beta^N \in \{0.5, 0.8, 1\}$, $\rho \in \{0.1, 0.2, 0.3\}$, and $\rho^N \in \{1.5\rho, 2\rho\}$. For the *liquidation* model, we also set $\lambda_1 = \lambda$ and $\lambda_2 = \{0.5\lambda, 0.8\lambda, \lambda\}$ and the holding cost as $h = \{0, 0.25\}$. We make sure that all of Assumptions 1–7 are satisfied in all the problem instances we consider.

To set the value of the initial inventory level I_1, we first compute the initial optimal inventory ordering quantity in the absence of promotion, denoted by $I^{\emptyset *}$, which we refer to as the *no-promotion inventory level*, and set $I_1 = IR \times I^{\emptyset *}$, where $IR \in \{1.1, 1.5, 2, 3\}$ is the *inventory excess ratio* (IR).

In total, we generated 88,128 and 528,768 problem instances for the *fresh* and *liquidation* models, respectively.

TABLE 6 Percentage difference in expected profit relative to `No promotion` in the *fresh* model (100% means no impact)

IR		Min	Max	Mean
1.1	`Im-Now`	68.7%	78.2%	74.1%
	`Later`	91.8%	109.2%	100.7%
1.5	`Im-Now`	81.7%	92.6%	88.2%
	`Later`	93.5%	135.4%	109.3%
2	`Im-Now`	98.3%	117.6%	107.4%
	`Later`	93.5%	182.1%	113.2%
3	`Im-Now`	108.6%	197.3%	142.0%
	`Later`	92.8%	217.1%	114.5%

Abbreviation: IR, inventory excess ratio.

5.1 | Numerical results with the fresh model

First, we consider the impact on the retailer's profit from offering a `BOGOF` promotion relative to the `No promotion` baseline by computing the percentage difference in expected profit, specifically $\pi^{X*}_{Fresh}(I_1)/\pi^{\emptyset *}_{Fresh}(I_1)$ for $X \in \{N, L\}$ and $I_1 \geq 0$. The results are presented in Table 6 as a function of the IR.

We see that offering a `BOGOF` promotion can increase or decrease the retailer's expected profit depending on the initial inventory level I_1. When the IR is low, the retailer can actually lose money from running an `Immediate-Now` promotion compared to no promotion—this is, in fact, always the case when IR is 1.1 and 1.5. However, when $IR = 3$, using the `Immediate-Now` strategy is always more profitable than running no promotion. In contrast, the `Later` strategy can be more or less profitable than the `No promotion` benchmark across all values of IR and overall, has a much wider range of possible values compared to `Immediate-Now`.

In Figure 1 (left panel), we show the regions where each strategy achieves the highest value of the retailer's expected profit as a function of the product's price and the IR for a representative problem instance. Consistently with Proposition 2, the initial inventory should be sufficiently high for the `BOGOF` promotions to be profitable and the `Immediate-Now` strategy dominates the `Later` strategy past a certain threshold on the inventory level. Further, higher prices make offering `BOGOF` promotions more profitable.

In Figure 2 (left panel), we show the same regions as a function of the sales boost parameter α^L. In this figure, we fix $\alpha^N = 1.8$ and vary α^L in $[1, \alpha^N]$ to satisfy Assumption 4. We see that, when α^L is small, there may not exist values of the IR such that the `Later` strategy maximizes expected profit,

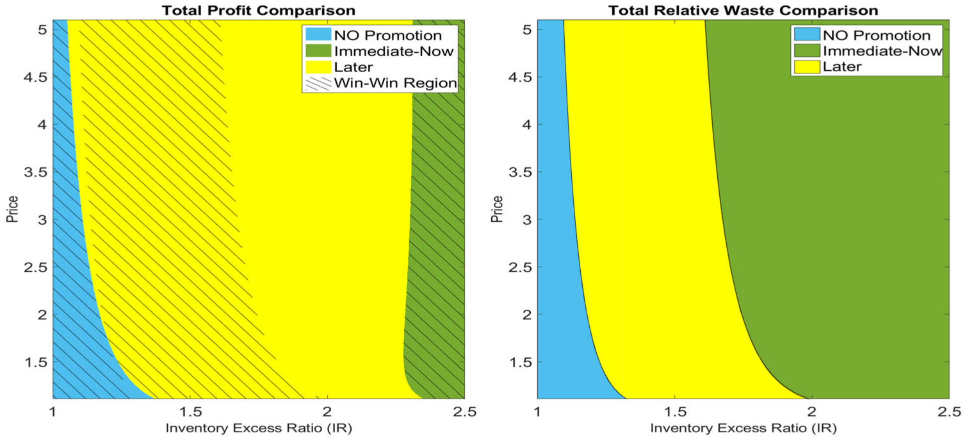

FIGURE 1 Profit and relative waste comparison as a function of price and the IR in the *fresh* model. The left panel shows the strategy with the highest profit, while the right panel shows the strategy with the lowest relative waste. The shaded areas represent win-win propositions. The other parameters are set as follows: $c = 1, r = 0.2, \bar{D} = 1000, \lambda = 0.1, \alpha^N = 1.8, \alpha^L = 1.4, \beta^N = 0.5, \gamma = 0.2, \rho = 0.15$, and $\rho^N = 0.3$. [Color figure can be viewed at wileyonlinelibrary.com]

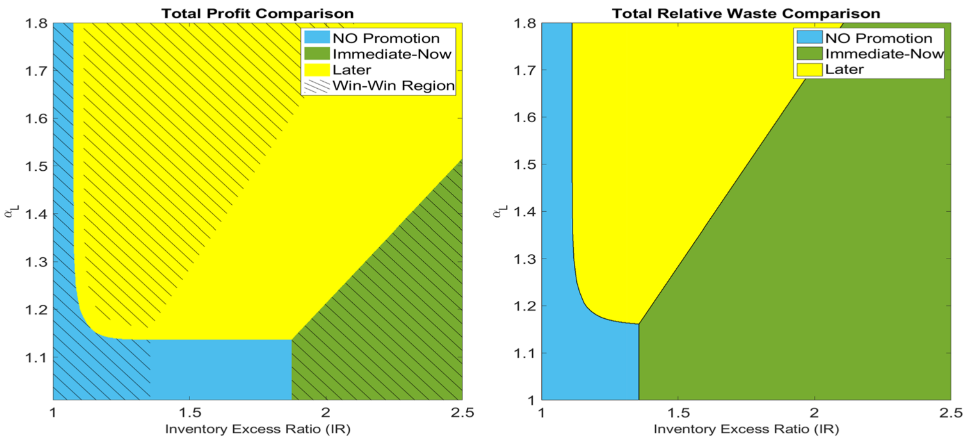

FIGURE 2 Profit and relative waste comparison as a function of the `Later` sales boost parameter and the IR in the *fresh* model. The left panel shows the strategy with the highest profit, while the right panel shows the strategy with the lowest relative waste. The shaded areas represent win-win propositions. The other parameters are set as follows: $c = 1, r = 0.2, \bar{D} = 1000, \lambda = 0.1, \alpha^N = 1.8, p = 3, \beta^N = 0.5, \gamma = 0.2, \rho = 0.15$, and $\rho^N = 0.3$. [Color figure can be viewed at wileyonlinelibrary.com]

but past a minimum threshold value, the region where `Later` is optimal expands with α^L.

In Figure 1 (right panel) and Figure 2 (right panel), we compare the relative waste of the three strategies. We observe that `Immediate-Now` leads to the lowest total expected relative waste when the IR is relatively high. For intermediate values, `Later` leads to less relative waste and for small *IR* values, `No promotion` yields the lowest relative waste. Similar conclusions are drawn regarding the impact of the sales boost parameter, except that there exists a minimum threshold value of α_L below which `Later` is never the lowest relative waste strategy.

Figure 3 compares expected relative waste across the three strategies for different values of the IR, broken down between the retail store and the consumers' homes. We see that, compared to `No Promotion`, offering a `BOGOF` promotion always increases waste at the consumers' homes but always decreases waste at the retail store, so that, overall total relative waste may go up or down. Comparing `Immediate-Now` and `Later`, we see that the `Immediate-Now` strategy increases waste at the consumers' homes by the most amount but also reduces the amount of waste at the retail store by the most amount, so that the overall impact depends on the value of the IR: for low values, `Later` leads to less waste; but for higher values, it is `Immediate-Now`. Figure 3 is consistent with Proposition 4, which states that the `Immediate-Now` strategy always leads to the lowest absolute waste at the retail store.

Next, we look into the cases where one strategy represents a win-win proposition, which we define as giving the highest expected profit value for the retailer and the least relative waste (which, as we argue in Section 3.3 is the most relevant

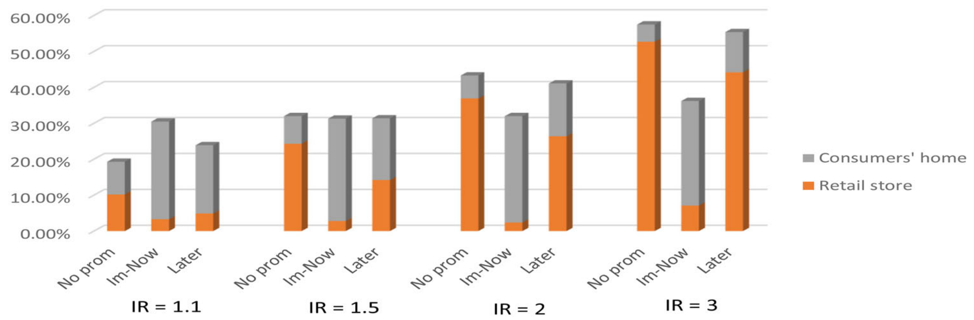

FIGURE 3 Expected relative waste comparison in the *fresh* model [Color figure can be viewed at wileyonlinelibrary.com]

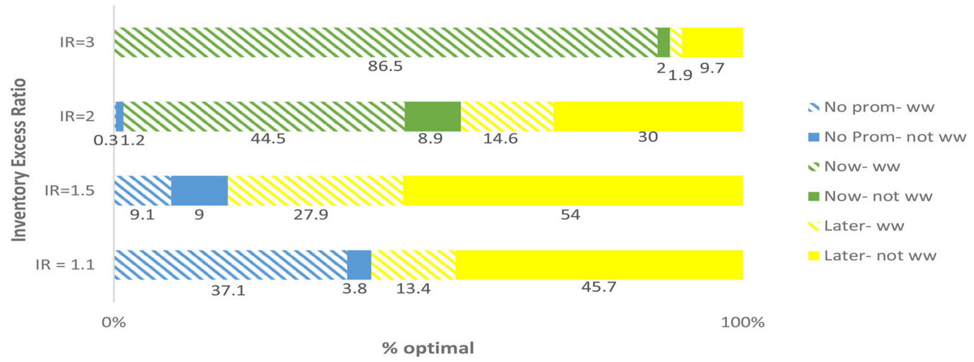

FIGURE 4 Percentage of the instances where each strategy is optimal and win-win ("ww") propositions as a function of the IR in the *fresh* model [Color figure can be viewed at wileyonlinelibrary.com]

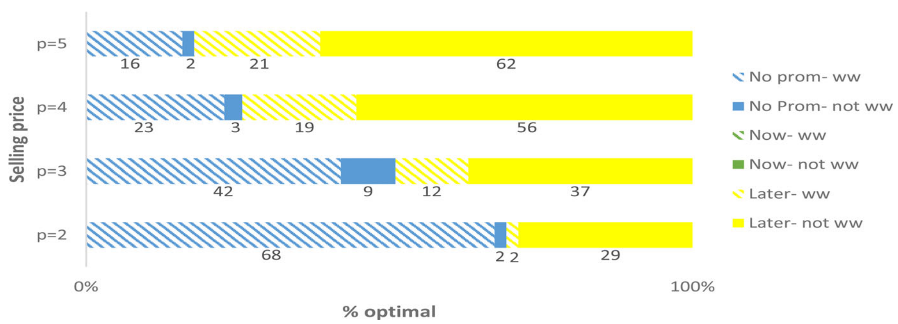

FIGURE 5 Percentage of the instances with $IR = 1.1$ where each strategy is optimal and win-win ("ww") propositions as a function of the selling price in the *fresh* model [Color figure can be viewed at wileyonlinelibrary.com]

waste metric), across all three strategies (i.e., `No-Promotion`, `Immediate-Now`, and `Later`).

On left panels of Figures 1 and 2, we use shading to illustrate the regions where a *win-win proposition* occurs for the representative problem instance. We see that a *win-win proposition* arises with `Immediate-Now` when the initial inventory is very excessive, that is, when $IR = 2.3$ or higher, and with `Later` or `No promotion` when the initial inventory is not very high.

In Figures 4 and 5, we represent the percentage of instances where each strategy is optimal and mark with shading those instances where that strategy achieves the lowest waste, making it a *win-win proposition*. Figure 4 presents the percentages as a function of the IR, and Figure 5 presents the percentages as a function of the selling price given an IR of 1.1. For other values of the IR, the differences across selling price values are less salient. The main reason for this effect is that the retailer's profit depends on two factors: the sales quantity and the price. When the IR is low, the comparison of profits is driven mostly by the price. On the other hand, when the IR is very high, the comparison of profits is driven mostly by the sales quantity.

We see that in the majority of problem instances (exactly 58.8%), the optimal strategy is a *win-win proposition*. This is especially true if the IR is high (for any selling price value) or if the IR is low and the selling price is high (Table 7).

TABLE 7 Frequency of win-win propositions in the *fresh* model

IR	Price		Percentage of best profit	Percentage of least waste	Percentage of cases win win	Total percentage of win-win
1.1	Lower	`No prom`	60.3%	87.1%	54.7%	
		`Im-Now`	0.0%	0.5%	0.0%	61.8%
		`Later`	39.7%	12.4%	7.0%	
	Higher	`No prom`	21.6%	74.7%	19.4%	
		`Im-Now`	0.0%	4.2%	0.0%	39.2%
		`Later`	78.4%	21.1%	19.8%	
1.5	Lower	`No prom`	18.6%	35.3%	9.3%	
		`Im-Now`	0.0%	35.8%	0.0%	38.2%
		`Later`	81.4%	28.9%	28.9%	
	Higher	`No prom`	17.6%	34.3%	8.8%	
		`Im-Now`	0.0%	38.9%	0.0%	35.6%
		`Later`	82.4%	26.8%	26.8%	
2	Lower	`No prom`	3.1%	11.8%	0.5%	
		`Im-Now`	48.2%	72.1%	40.2%	56.8%
		`Later`	47.9%	16.1%	16.1%	
	Higher	`No prom`	0.0%	11.8%	0.0%	
		`Im-Now`	58.7%	75.1%	48.9%	62.0%
		`Later`	41.3%	13.1%	13.1%	
3	Lower	`No prom`	0.0%	2.0%	0.0%	
		`Im-Now`	88.7%	96.1%	86.6%	88.5%
		`Later`	11.3%	2.0%	1.9%	
	Higher	`No prom`	0.0%	2.0%	0.0%	
		`Im-Now`	88.2%	96.1%	86.3%	88.2%
		`Later`	11.8%	2.0%	2.0%	

In summary, we find that when a retailer finds himself with large inventory of a fresh product, `BOGOF` promotions generally constitute a good way to increase profits, especially when the product price is high and when the sales-boosting effect of the promotions is large. More interesting is the impact these promotions have on product waste: although `BOGOF` promotions generally increase the amount of waste at the consumers' homes, they may reduce total relative waste and as such, provide a *win-win proposition*. When the amount of initial inventory is large, the `Immediate-Now` strategy very often provides a *win-win proposition*, that is, it achieves the highest profit and the lowest waste; when it is moderate, it can happen with the `Later` strategy. This is because fewer product units are wasted at the retail store, due to the combined effect of overall inventory levels going up and the reduced demand uncertainty in the second period, which can offset the increase in the waste at the consumers' homes. This is especially true with the `Immediate-Now` strategy, but also, to a lower extent, with the `Later` strategy.

Note that *win-win propositions* can occur even in instances where the disposal cost r is equal to zero, so the mechanism behind their occurrence is not solely driven by the negative relationship between profit and waste in the retailer's objective function. The overall waste benefits come from the extra sales which, even at the amplified waste percentage of the `BOGOF-Now` promotion, mean that more products are consumed; instead of ending up unsold on the retailer's shelves, promoted sold units at least get a chance of being consumed by consumers. This effect, combined with the fact that it is in the retailer's best interest to take a hit on the per-unit revenue (due to the promotion) in order to sell more, leads them to the occurrence of *win-win propositions*.

5.2 | Numerical results with the liquidation model

As in the previous subsection, we first consider the impact on the retailer's profit from running one of the three strategies relative to the baseline of `No promotion`, by computing the percentage difference in expected profit, specifically $\pi^{X*}_{Liquid}(I_1)/\Pi^{\emptyset*}_{Liquid}(I_1)$ for $X \in \{P, N, L\}$ and $I_1 \geq 0$. The results are presented in Table 8 as a function of the IR.

By construction, the `Postpone` strategy always gives more profit than the `No-Promotion` baseline, since the retailer can

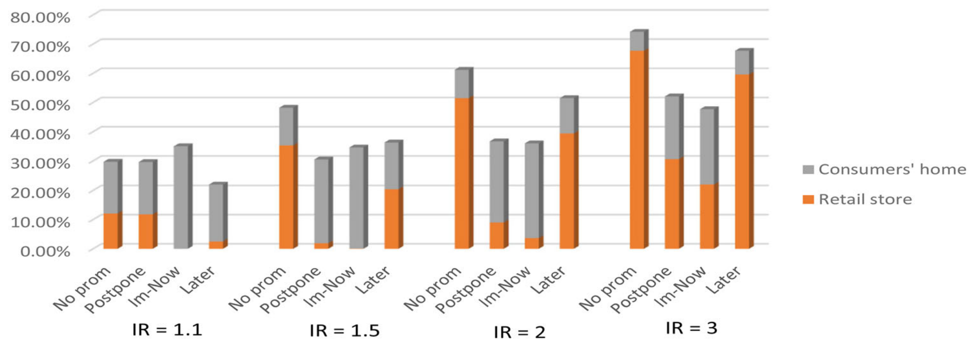

FIGURE 6 Expected relative waste comparison in the *liquidation* model [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 8 Percentage difference in expected profit relative to `No promotion` in the *liquidation* model (100% means no impact)

IR		Minimum	Maximum	Mean
1.1	`Postpone`	100.0%	100.4%	100.0%
	`Im-Now`	55.1%	64.3%	58.9%
	`Later`	90.0%	121.5%	102.5%
1.5	`Postpone`	100.9%	123.8%	110.6%
	`Im-Now`	75.0%	110.5%	87.0%
	`Later`	99.5%	172.2%	115.9%
2	`Postpone`	106.7%	192.5%	135.6%
	`Im-Now`	100.0%	193.9%	126.9%
	`Later`	99.5%	248.2%	119.7%
3	`Postpone`	106.7%	686.5%	172.9%
	`Im-Now`	107.0%	720.1%	189.6%
	`Later`	99.5%	497.5%	126.3%

Abbreviation: IR, inventory excess ratio.

decide not to run a promotion in Period 2. As with the *fresh* model, we see that offering a `BOGOF` promotion in Period 1 can increase or decrease the retailer's expected profit. The highest improvements occur when the initial inventory is very excessive.

In Figure 6, we represent the expected relative waste across strategies as a function of the IR, broken down between the retail store and the consumers' homes. As expected, when the amount of initial inventory increases, the relative waste percentages from all strategies increase since the gap between baseline demand and initial inventory gets larger. More interestingly, we observe that the promotions cause the waste to shift from the retail store to the consumers' homes, and the effect is particularly strong with the `Immediate-Now` and `Postpone` strategies. When the initial inventory is very excessive, we find that `BOGOF-Now` and `Postpone` lead to lower relative waste than `BOGOF-Later` and the reverse is true when the initial inventory is not much larger than the no-promotion inventory level.

In Figure 7, we compare profit and total relative waste under the three strategies. As we did in Figures 1 and 2, the shaded areas correspond to parameter values such that one strategy is a *win-win proposition*, as defined in the previous subsection. When the initial inventory is just slightly over the no-promotion inventory level, the `Postpone` strategy achieves the highest expected profit; in this region, it is most likely optimal for the retailer not to offer the `BOGOF-Now` promotion in Period 2, making it equivalent to a `No-Promotion` strategy. As the amount of initial inventory increases, the `BOGOF-Later` case becomes the best strategy up to a point where it is taken over by the `Postpone` strategy—in this region, it is most likely optimal for the retailer to run a `BOGOF-Now` promotion in Period 2. Finally, when the amount of initial inventory is very excessive, the `Immediate-Now` becomes the best strategy. Figure 8 shows a similar pattern except that, when the sales boost parameter α^L for `Later` is very low, the `Later` strategy is never optimal; and when it is very high, the `Postpone` strategy is never optimal.

We also notice that, when the initial inventory level is near the no-promotion inventory level (i.e., low *IR*), the `Postpone` strategy never achieves the lowest relative waste—this is because, in that region, the retailer likely does not run any promotion, and therefore sells fewer units off the initial inventory I_1 compared to running a `BOGOF` promotion.

In Figure 9, we represent the percentage of instances where each strategy is optimal as a function of the IR and mark with shading those instances where that strategy achieves the lowest waste, making it a *win-win proposition*. We see that in many problem instances (overall 69.3%), the optimal strategy is a *win-win proposition*, and this can happen with all three strategies. Also, comparing Figures 4 and 9, we find that, in general, the *liquidation* model has a higher percentage of instances which are *win-win propositions* than the *fresh* model.

In summary, we find that when a retailer finds himself with high inventory of a seasonal or about-to-be-discontinued product, `BOGOF` promotions generally constitute a good way to increase profits, especially when the price is high and the sales-boosting effect of the promotions is large. Depending on the amount of inventory level, it may be best to follow different promotional strategies. More often than with fresh products, the optimal strategy also minimizes the amount of relative waste, making it a *win-win proposition*.

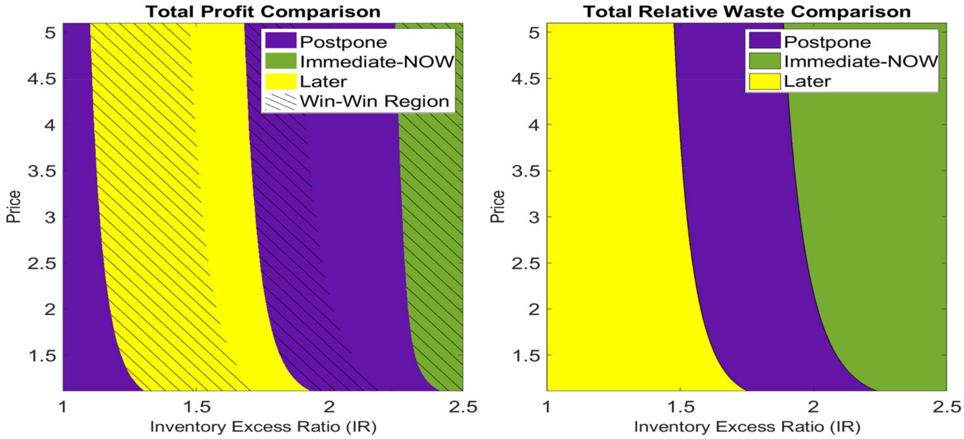

FIGURE 7 Profit and relative waste comparison as a function of price and the IR in the *liquidation* model. The left panel shows the promotion strategy with the highest profit, while the right panel shows the one with the lowest relative waste. The shaded areas represent win-win propositions. The other parameters are set as follows: $c = 1, r = 0.2, \bar{D} = 1000, \lambda_1 = 0.1, \lambda_2 = 0.05, \alpha^N = 1.8, \alpha^L = 1.2, \beta^N = 0.5, \gamma = 0.2, h = 0.1, \rho = 0.15$, and $\rho^N = 0.3$. [Color figure can be viewed at wileyonlinelibrary.com]

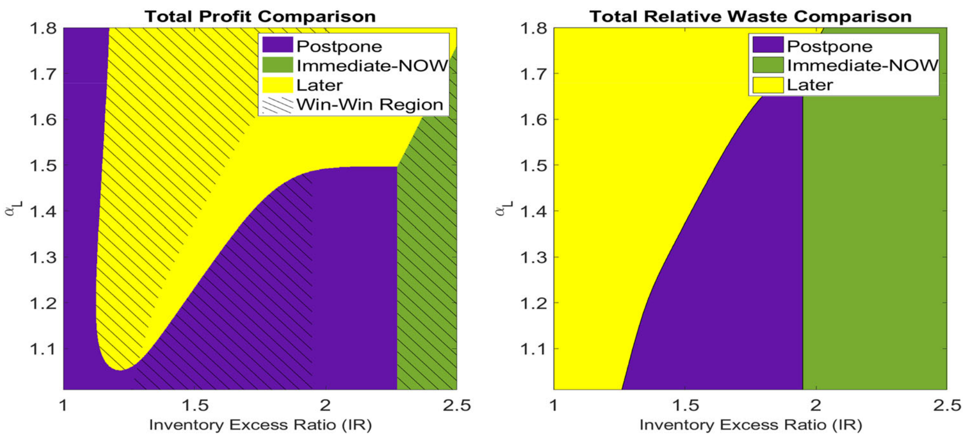

FIGURE 8 Profit and relative waste comparison as a function of the `Later` sales boost parameter and the IR in the *liquidation* model. The left panel shows the promotion strategy with the highest profit, while the right panel shows the one with the lowest relative waste. The shaded areas represent win-win propositions. The other parameters are set as follows: $c = 1, r = 0.2, \bar{D} = 1000, \lambda_1 = 0.1, \lambda_2 = 0.05, p = 3, \alpha^N = 1.8, \beta^N = 0.5, \gamma = 0.2, h = 0.1, \rho = 0.15$, and $\rho^N = 0.3$. [Color figure can be viewed at wileyonlinelibrary.com]

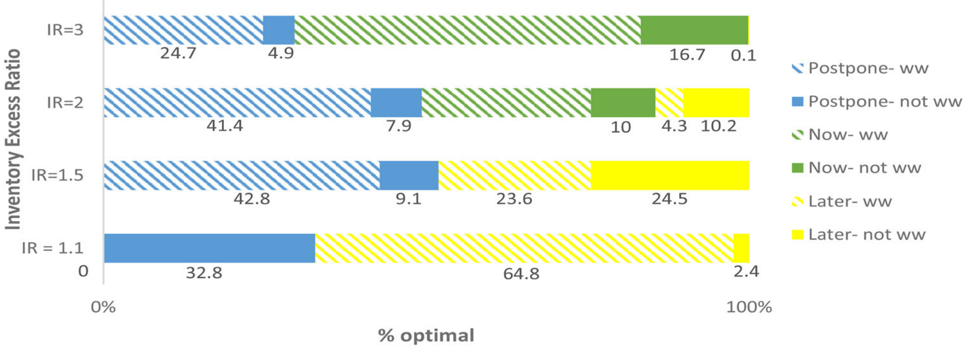

FIGURE 9 Percentage of the instances where each strategy is optimal and win-win ("ww") propositions as a function of the IR in the *liquidation* model [Color figure can be viewed at wileyonlinelibrary.com]

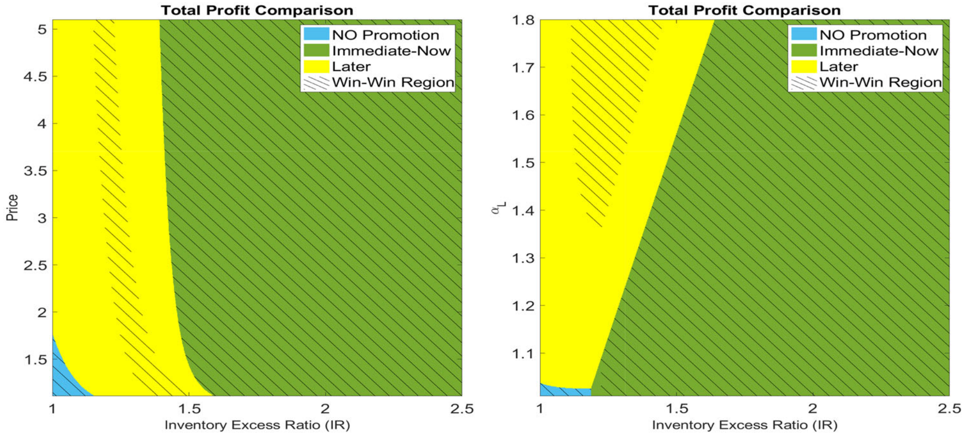

FIGURE 10 Profit comparison as a function of price and the `Later` sales boost parameter in the *fresh* model under `BOGOX` promotion with $x = \theta = 0.5$. Both panels show the selling scheme with the highest profit. The shaded area represents win-win propositions. The remaining parameters: $c = 1$, $r = 0.2$, $\bar{D} = 1000$, $\lambda = 0.1$, $\alpha^N = 1.8$, $\beta^N = 0.5$, $\gamma = 0.2$, $\rho = 0.15$, $\rho^N = 0.3$. On the left panel, $\alpha^L = 1.4$; on the right panel, $p = 3$. [Color figure can be viewed at wileyonlinelibrary.com]

6 | EXTENSIONS

In this section, we present two extensions to our base model (1) offering a discount on the second product rather than it being free, that is, a "buy-one-get-one-x%off" type of promotion and (2) offering a partial refund in case of a stock-out for the `BOGOF-Later` promotion scheme.

6.1 | Partial discount on the second product

First, we consider the "buy-one-get-one-x%off" type of promotion, in short `BOGOx`, where the consumer who participates pays full price p on the first unit of product but only $(1 - x\%)p$ on the second unit. Under `BOGOx-Now`, the consumer takes both units home in Period 1, while under `BOGOx-Later`, the consumer is given a coupon to redeem for the second unit at an $x\%$ discount in Period 2. For example, $x = 0.5$ corresponds to the common "buy-one-get-one-half-off" promotion. Unlike with `BOGOF-Now`, where it was reasonable to assume that all consumers who purchase the product would take part in the promotion (as discussed in Section 3.4, very few consumers can resist the temptation of a "free" product), we now consider that only a proportion $\theta \in [0, 1]$ of them takes part in the `BOGOx` promotion.

We first consider the *fresh* model. In Figure 10, we consider the case of $x = 0.5$ and $\theta = 0.5$, that is, a 50% discount on the second unit and half of the consumers take part in the promotion. On the two subfigures, we represent the areas where each possible strategy is optimal and mark the *win-win propositions* (as defined in Section 5) as shaded regions. The figures are drawn using the same parameter set and therefore can be directly compared to the left panel graphs of Figures 1 and 2.

The overall conclusion of this exercise is that the order relationship between the strategies is unchanged but the size of the optimality regions varies. By comparing Figure 10 with Figures 1 and 2, we see that when only half the consumers take part in the promotion, the overall pattern remains and we note that the region where the `Immediate-Now` strategy is optimal expands significantly—this is because, with fewer consumers engaging in the promotions, more units can be sold to full-price consumers and this effect is stronger for `BOGOF-Now` than for `BOGOF-Later`.

We present a similar comparison for the *liquidation* model in Figure 11 (for $x = \theta = 0.5$). Here again, we observe that the pattern is similar to the results in Section 4, with a larger region of optimality for the `Immediate-Now` promotion. The intuition is that the partial discount makes the `BOGOF` promotions less costly, and this has a greater impact on the `Immediate-Now` strategy because of the higher sales-boosting factor.

Hence, we conclude that the ordering results we obtained in Section 4 regarding profit and waste of the three promotional strategies appear to continue to hold for the more general case of `BOGOx` promotions.

6.2 | Partial refund in case of stock-out

When the retailer runs a `BOGOF-Later` promotion, we have assumed that, if a coupon-holding consumer finds the product stocked out in Period 2, the retailer gives her a refund of $\eta \in [0, p]$. For our main analytical derivations in Section 4, we have assumed that $\eta = p$ (Assumption 7), that is, the consumer gets a full refund. As discussed in Section 3.4, the main reason for this assumption is analytical tractability: as we prove in the Supporting Information Appendix (Proposition EC.1), under a full refund, the expected profit calculation does not depend on the sequence of consumer arrivals, that is, when coupon-holding consumers arrive versus (full-price)-paying consumers.

However, in practice, retailers may only offer a partial or even no refund at all to consumers who attempt to redeem a

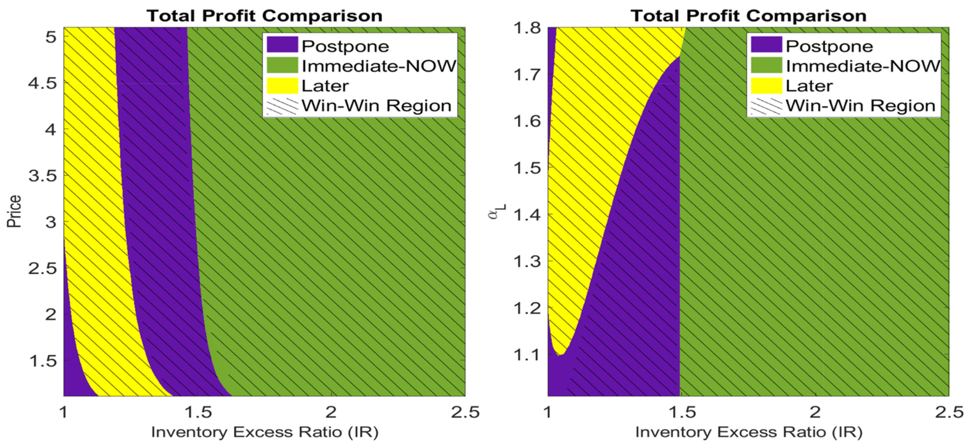

FIGURE 11 Profit comparison as a function of price and the `Later` sales boost parameter in the *liquidation* model under `BOGOx` promotion with $x = \theta = 0.5$. Both panels show the selling scheme with the highest profit. The shaded area represents win-win propositions. The remaining parameters: $c = 1$, $r = 0.2$, $\bar{D} = 1000$, $\lambda_1 = 0.1$, $\lambda_1 = 0.05$, $\alpha^N = 1.8$, $\beta^N = 0.5$, $\gamma = 0.2$, $\rho = 0.15$, and $\rho^N = 0.3$. In the left panel, $\alpha^L = 1.4$; in the right panel, $p = 3$. [Color figure can be viewed at wileyonlinelibrary.com]

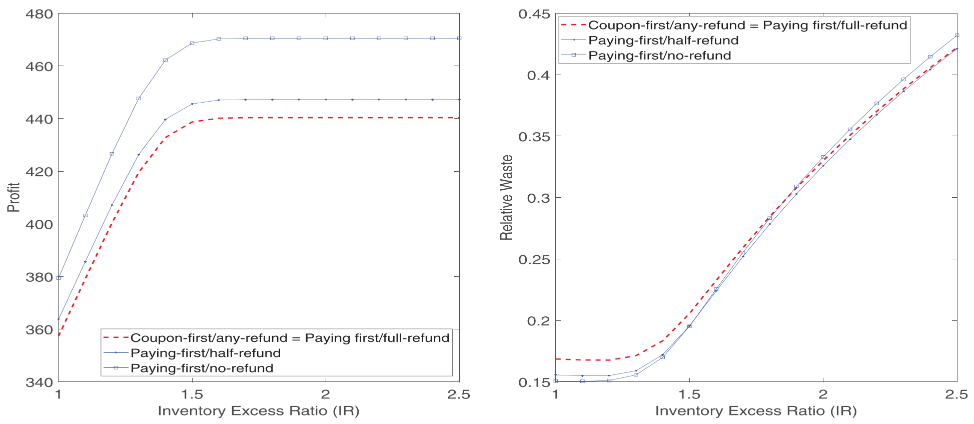

FIGURE 12 Comparison of refund schemes for `BOGOF-Later` promotions in the *fresh* model. The parameters are $c = 1$, $r = 0.2$, $p = 2.5$, $\bar{D} = 1000$, $\lambda = 0.1$, $\alpha^N = 1.8$, $\alpha^L = 1.4$, $\beta^N = 0.5$, $\gamma = 0.2$, $\rho = 0.15$, $\rho^N = 0.3$. [Color figure can be viewed at wileyonlinelibrary.com]

coupon for a stocked-out product. For example, there could be a mention of "while supplies last" in the fine print of the promotion. Analytically speaking, with a partial or no refund, the sequence of consumer arrivals matters in the calculation of expected profit. In Figures 12 and 13, we represent expected profit and expected relative waste in the *fresh* and *liquidation* models under three different refund policies: no refund ($\eta = 0$), a half-price refund ($\eta = \frac{p}{2}$), and full refund ($\eta = p$) and the two most extreme scenarios regarding the sequence of consumer arrivals: (1) all coupon-holding consumers are served first, followed by all the paying consumers and (2) all the paying consumers are served first, followed by all the coupon-holding consumers.

We find that, when the coupon-holding consumers are served before paying consumers, the expected profit and relative waste are virtually identical across all three possible refund policies in the *fresh* model. This is because in the *fresh* model, the retailer optimizes the order quantity in Period 2 and, therefore, chooses it to be high enough so that, with a very high probability, there is enough to satisfy all the coupon-holding consumers and at least some of the paying consumers. As a result, the numbers for the following four cases are virtually indistinguishable: coupon-first/full-refund, coupon-first/half-refund, coupon-first/no-refund, and paying-first/full-refund. For this reason, there are only three curves on all the plots in Figure 12.

However, in the *liquidation* model, since the retailer does not reorder the product at the start of Period 2, it is possible that some coupon-holding consumers find the product stocked-out in Period 2 and, therefore, the refund policy has an impact on the retailer's profit. This is especially true when the initial inventory is not excessive (IR is closer to 1). With partial refund or no refund, when the paying consumers are served first, the profit is higher, as the retailer spends less or no money compensating the coupon-holding consumers who find the product stocked out. On the other hand, waste in the *liquidation* model is not affected by the refund policy or the sequence of the consumer arrival, since the total inventory

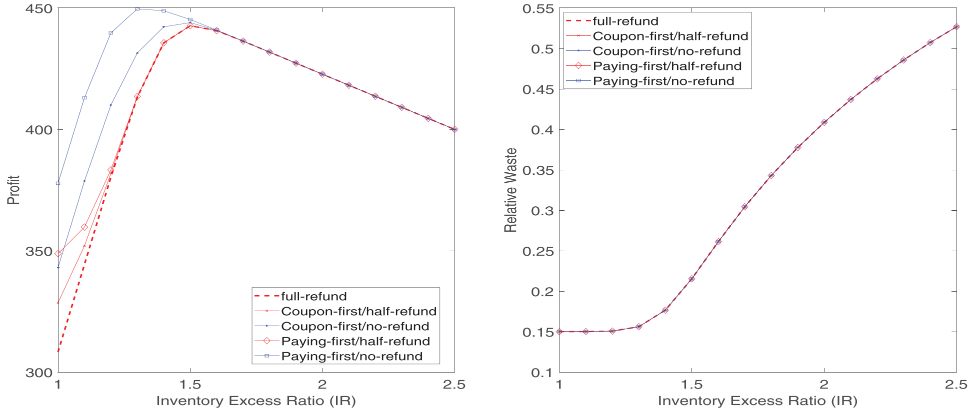

FIGURE 13 Comparison of refund schemes for BOGOF-Later promotions in the *liquidation* model. The parameters are $c = 1$, $r = 0.2$, $p = 2.5$, $h = 0.1$, $\bar{D} = 1000$, $\lambda_1 = 0.1$, $\lambda_2 = 0.05$, $\alpha^N = 1.8$, $\alpha^L = 1.4$, $\beta^N = 0.5$, $\gamma = 0.2$, $\rho = 0.15$, $\rho^N = 0.3$. [Color figure can be viewed at wileyonlinelibrary.com]

available for the two periods is fixed and demand does not depend on the refund policy.

When the paying consumers are served first, the refund policy has an impact on the magnitude of the retailer's expected profit (up to 10% and 15%, respectively, in the *fresh* and *liquidation* models). Regarding relative waste, there is a magnitude difference of about 15% between full and no refund in the *fresh* model but no difference in the *liquidation* model. However, the shape of the expected profit and relative waste functions is the same no matter what the refund policy is.

Given these observations, we expect that the threshold results we obtained for the comparison of profit and waste in Section 4 under full refund would continue to hold in the case of a partial or no refund.

7 | CONCLUSION

The *No Waste Network*, an initiative of the Dutch Ministry of Agriculture, described Tesco's BOGOF-Later promotion scheme as "an ingenious solution that still helps consumers who are cost-conscious and boosts Tesco's sustainability credentials" (No Waste Network, 2017). In this paper, we have analyzed this novel form of promotion and compared it to the traditional BOGOF promotion.

Our stylized comparison of the BOGOF promotion schemes illustrates interesting trade-offs in the promotion of a product with high inventory showing that, in many cases, a "win-win" situation arises wherein the retailer can increase profits and reduce waste at the same time. This is true for fresh products with short shelf life but, even more so, for products approaching the end of their selling season or product life cycle. Our work also suggests that the environmental criticism of the BOGOF promotion schemes for perishables may be based on too narrow a view of the waste problem: when looking at the overall impact across both the retail store and the consumers' homes, the percentage of wasted products may actually go down when a BOGOF promotion is introduced. At the same time, our results point to interesting differences between the traditional BOGOF-Now promotion scheme and the BOGOF-Later scheme: the former tends to lead to a greater shift of the waste from the retail store to the consumers' home and is optimal and waste-minimizing when the amount of inventory is very excessive, whereas the latter is best used when the amount of initial inventory is moderate.

We recognize some limitations of our analysis. Our modeling of the BOGOF-Later scheme is conservative as we focus on one product and ignore the potential repeat purchases and cross-selling benefits. Also, our waste calculations treat retail and consumer waste equally but, in practice, one may hope that unsold products from retail stores are less likely to make their way directly to landfills, especially in countries like France where a 2016 legislation makes it a requirement for grocery stores to give edible leftover food to charity (NPR News, 2016). We also recognize that ideally the problem of food waste necessitates a more comprehensive approach, considering the entire supply chain (from farm to consumer) across multiple substitutable product categories. Yet, we are confident in the value of our findings based on the last two stages of the supply chain given that, for most developed nations and many product categories, this is where most of the wastage happens.

"Food waste in industrialized countries can be reduced by raising awareness among food industries, retailers, and consumers. There is a need to find good and beneficial use for safe food that is presently thrown away" (FAO, 2011). We hope that our work can contribute to this noble goal by inspiring retailers to pursue initiatives which can help alleviate the very pressing issue of food waste. To anyone reading this article: please be mindful of tempting promotion schemes which are very likely to lead to waste, and always, remember to "*refuse, reuse, reduce and recycle*"!

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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