Improving food quality consistency of chain restaurants with central kitchen

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Abstract

Purpose – This study examines how chain restaurants can improve food quality consistency by employing central kitchens, while addressing operational challenges related to pricing and market coverage.

Design/methodology/approach – An analytical model is developed to analyze optimal pricing, quality decisions, and market coverage strategies under the central kitchen system. The model is further extended to incorporate customer congestion, variable costs, and kitchen location decisions.

Findings – Results indicate that full market coverage is optimal when customer sensitivity to quality inconsistency is either low or high, while moderate sensitivity leads to partial coverage. Conditions under which investing in a central kitchen is beneficial are also identified.

Originality/value – This research introduces a formal analytical framework revealing the strategic implications of central kitchen investment and quality control for chain restaurants. The findings provide actionable guidance for restaurateurs on designing pricing strategies and managing quality consistency.

Keywords Central kitchen, Quality consistency, Pricing, Market coverage

Paper type Research article

1. Introduction

Chain restaurants have been an extensively used business model in the modern restaurant and foodservice industry. In the United States, chain restaurant revenue expanded at a 3.9% CAGR to $227.6billion from 2019 to 2024 (IBISWorld, 2024). Compared to independent (or standalone) restaurants, running chain restaurants in multiple locations can benefit restaurateurs by increasing their brand recognition/value, economies of scale, and market share. However, restaurateurs also face operational challenges when running their chain restaurants, and one of the representative challenges is inconsistent food quality. More specifically, food quality inconsistency has two dimensions. First, the food quality in a location is not consistent with customer expectation (or the food quality is not at the standard level promised by the chain restaurants), which is referred to as negative quality inconsistency in the literature (Ferenčić and Wölfling, 2015). Second, food quality and taste in different locations are not uniform, meaning that a customer enjoying one meal in one location may find that meal tastes completely different at another branch, which is known as quality discrepancy (Es-Said, 2024). Food quality inconsistency is known to have detrimental effects on chain restaurants by losing customer satisfaction/trust, brand loyalty and market share (Chou *et al*., 2024).

In practice, food (or meals) is often prepared and cooked in decentralized manner by (storefront) local kitchens in different locations. As a result, food quality inconsistency is inevitable, as these local kitchens have non-standard ingredients, recipes, cooking procedures and equipment. Conventional initiatives of circumventing food quality inconsistency including staff training, quality control and equipment upgrade in storefront kitchens, which, however, exhibit limited effectiveness. In recent years, a few restaurateurs have begun to further improve food quality consistency by investing in central kitchens. The key idea of using central kitchens is to move major cooking procedures that are originally performed in decentralized local kitchens, like

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material procurement, cleaning, cutting, seasoning, baking/cooking, to a centralized food production facility and finish them. Then, these fully processed (or semi-processed) foods are shipped from central kitchens to different restaurant branches to serve customers (with necessary follow-up processing). Unlike conventional initiatives, the deployment of a central kitchen can effectively improve food quality consistency by ensuring the food (or the core part at least) is processed and cooked in centralized and standardized manners.

Despite the potential of central kitchens, restaurateurs can be hesitant in adopting them to maintain food quality consistency. On one hand, a restaurateur needs to carefully design his/her central kitchen, like choosing the location of the central kitchen, to avoid the substantial cost of building the facilities. On the other hand, restaurateurs also need to adjust their operations to maximize the economic benefit of using central kitchens in improving food quality consistency. This study is partially motivated by a case of a popular chain restaurant, Aminia (www.aminia.co.in), in India, who invested much in building a central kitchen to improve food quality consistency. More importantly, Aminia was interested in optimizing its operational strategies/decisions (e.g. pricing decisions) to exploit the value of improving food quality consistency under central kitchens.

However, to our knowledge, there is limited research on restaurant operations in the presence of central kitchens. To fill this research gap, we develop an analytical model to study the economic value of using central kitchens in managing food quality inconsistency. In particular, we want to explore the following questions.

(1) How can restaurants adjust their pricing and market coverage strategies under central kitchens?

(2) How can we quantify the value of adopting central kitchens in maintaining food quality consistency for chain restaurants?

In this analytical model, a continuum of customers are evenly distributed over a Hotelling line. A brand chain of two (symmetric) local restaurants provides the main food to these customers, which are located at two ends of the Hotelling line, respectively. In particular, every customer decides (1) whether to consume the food and (2) which local restaurant to choose by considering the disutility from the effects of negative quality inconsistency and quality discrepancy. A restaurateur ("she") can improve the quality consistency by investing in building a central kitchen. Specifically, if the restaurateur decides to invest, she first decides the level of quality consistency and second decides the uniform retail price of the food.

1.1 Key findings and contributions

This study presents several key findings regarding the strategic use of central kitchens in chain restaurant operations. This study establishes that consumer sensitivity to quality inconsistency consistently has a negative impact on firm profitability, highlighting the strategic importance of consistency management in restaurant operations.

In the baseline setting without a central kitchen, when consumers are relatively tolerant of quality variation, firms tend to lower prices and pursue full market coverage to achieve economies of scale. Conversely, when consumers demand high consistency, firms adopt partial market coverage and charge premium prices to serve only high-value segments. As customer travel cost increases, it becomes more difficult for firms to fully reach all customer groups, prompting a shift toward focused, high-price strategies.

After introducing a central kitchen, firms can improve quality consistency across outlets. However, the optimal strategy still heavily depends on how sensitive consumers are to inconsistency. When sensitivity is moderate, firms prefer to serve only a portion of the market with higher consistency investment and premium pricing. When sensitivity is either very low or very high, full market coverage becomes more appropriate, with adjusted investment and pricing levels. Meanwhile, higher travel costs and larger fixed investment burdens narrow the feasible range for adopting a central kitchen, reducing its profitability in cost-constrained or low-accessibility regions.

Furthermore, this study incorporates the effect of customer congestion, which moderates the relationship between consumer sensitivity and profitability. In certain ranges, congestion can actually buffer the negative effects of inconsistency and improve overall profit. However, when quality discrepancies between outlets are large, congestion amplifies dissatisfaction. Firms operating in crowded service environments must therefore implement both flow management and quality stabilization measures.

Finally, two practical operational realities are explored. (1) The distance between the central kitchen and restaurant locations affects freshness and the cost of maintaining consistency. (2) Improving consistency can lower unit costs, reflecting the benefits of standardization. The model shows that when cost sensitivity is high, firms tend to adopt partial market coverage to control investment. When cost sensitivity is low, full coverage becomes optimal, enabling firms to simultaneously benefit from consistency and cost efficiency.

This study makes several contributions to the literature in the following ways. First, we explore the managerial implications of the emerging central kitchen business model for the restaurant industry from an academic perspective. To the best of our knowledge, no existing literature systematically examines the issue of pricing optimization in restaurants after the application of central kitchens. Furthermore, our modeling framework complements the study of service quality optimization (Mejia *et al.*, 2021; Buell *et al.*, 2016; Guo *et al.*, 2023). Unlike most models that merely group or classify quality (Soteriou and Chase, 2000; Choudhary *et al.*, 2005; Davis *et al.*, 2017; Hsiao *et al.*, 2024), we delve into the impact of quality consistency on operational management. Additionally, instead of directly classifying customers (Liu and Cooper, 2015), our model incorporates customers' patience levels and quantifies both customer congestion and waiting times. Moreover, compared with the literature that considers product quality as the primary dimension of differentiation (Chambers *et al.*, 2006), we further incorporate quality consistency as a continuous decision variable and systematically analyze its nonlinear relationship with cost as well as its strategic role in service-oriented markets. Finally, in contrast to existing studies focusing on facility layout (Fujii *et al.*, 2013), this paper incorporates freshness decay into a spatially dependent cost function, revealing how central kitchen location systematically affects service consistency and operational cost.

2. Literature review

This work is relevant to two subareas in restaurant service management: (1) innovation-driven restaurant operation optimization and (2) service quality operations. Next, we review relevant studies in each subarea and clarify our differences.

2.1 Innovation-driven restaurant operation optimization

Restaurant operations are one of the most frequently discussed subfields in operations management. Over the past few decades, academic research has mainly focused on typical operational issues in offline, standalone restaurants, such as service capacity (Bae *et al.*, 2022), table allocation (Tan and Staats, 2020) and worker productivity (Kamalahmadi *et al.*, 2021; Akhundov *et al.*, 2022). In recent years, however, the rise of digital technologies has reshaped how restaurants operate. For instance, Tan and Netessine (2020) demonstrated that tabletop ordering technologies improve operational efficiency by reducing dining duration and slightly increasing revenue per customer. Alongside dine-in improvements, the emergence of online delivery platforms has further transformed the industry. Studies such as Feldman *et al.* (2023) and Chen *et al.* (2022) examined how restaurants and platforms coordinate dine-in and delivery services through price and fee design, while Niu *et al.* (2021) explored logistics strategy selection in third-party delivery collaboration. Li and Wang (2025) shows that on-demand delivery platforms boost restaurant sales but benefit chains through takeout and independents through increased dine-in traffic. Additionally, Shi and Xu (2024) highlighted the evolving dynamics of dine-in versus delivery demand during the COVID-19 pandemic. These studies emphasize the operational complexity arising from multi-channel service delivery and the strategic importance of integrating new technologies. Despite the rapid digitization of the restaurant industry, academic research on emerging business models – such as central kitchens, cloud kitchens and ghost kitchens – remains relatively scarce. Most of these studies focus on technical aspects such as scheduling, location planning or IT system architecture. For example, Neria *et al*. (2025) developed a sequential decision model for ghost kitchens that jointly optimizes cooking and delivery schedules using large neighborhood search and value function approximation, highlighting the trade-off between food freshness and delivery efficiency. A study on central kitchen location planning integrates optimization and simulation to evaluate the impact of facility placement on service consistency and cost control, offering insights for large-scale restaurant chains (Švancár *et al*., 2024). In addition, a systematic review on cloud kitchen operations (Harini *et al*., 2025) emphasizes the difficulty virtual brands face in maintaining consistent service quality in the absence of a physical environment. However, few explicitly model quality consistency as a central operational decision variable or do they provide an integrated framework linking quality consistency with cost, pricing and geographic structure.

Furthermore, the decision to adopt and locate a central kitchen also relates to research on channel competition and omnichannel strategies. Gao *et al*. (2022) find that higher return rates in online channels encourage retailers to operate fewer but larger physical stores. Tang *et al*. (2023) examine how firms strategically choose between online, offline and omnichannel retailing in the context of new retail models. Sapra and Kumar (2024) show that omnichannel retailers should balance customized and universal product assortments based on customer channel preferences. Hao and Kumar (2024) find that consumer showrooming reshapes supplier–retailer dynamics and emphasize the importance of contract structure in mitigating its impact. Collectively, these studies highlight the multifaceted nature of decision-making in multi-channel operations, with a focus on assortment planning, channel configuration and vertical coordination. However, most of this literature centers on retail settings and pays limited attention to service-oriented industries where product quality consistency, pricing strategy and centralized production must be jointly managed. Addressing this gap, our study develops an integrated analytical framework that centers on the strategic application of central kitchens. We examine how central kitchen adoption interacts with pricing and location decisions and analyze its role in improving quality consistency and operational efficiency for multi-location restaurant chains.

2.2 Service quality operations

Service quality management is a vital stream within operations management, with a longstanding emphasis on enhancing customer satisfaction and firm performance under resource constraints (Hogreve *et al*., 2024). Recent foundational studies, such as Pawanr *et al*. (2025) and Mukherjee *et al*. (2024), reinforce its strategic importance by integrating quality frameworks like total quality management (TQM) and risk-based modeling. More recent studies confirm that high service quality not only improves satisfaction and loyalty (Yum and Yoo, 2023; Silalahi *et al*., 2024), but also boosts downstream performance such as repurchase rates and revenue (Hui *et al*., 2025). In parallel, researchers have begun leveraging digital platforms for service evaluation: for example, Mejia *et al*. (2021) utilize social media data to assess provider quality, while Ananthakrishnan *et al*. (2023) investigate firms' reactions to online feedback. In addition, Guo *et al*. (2023) highlight the signaling value of operational cues such as queue lengths in shaping customer perceptions. However, much of this literature focuses on average service quality or feedback mechanisms within single-firm contexts. Recent work has drawn attention to service quality variability as a key driver of churn and firm performance. For instance, Sriram *et al*. (2015) show that high variability – even with strong mean quality – can lead to customer defection, and DeCroix *et al*. (2021) propose personalized pricing to offset its effects. Keskin and Li (2024) further explore dynamic pricing under evolving and uncertain quality preferences. Yet, these studies often overlook competitive dynamics and congestion effects, which are critical in service-intensive industries such as restaurants. Our study addresses this gap by developing a competitive framework that integrates quality consistency, pricing, and customer congestion. We explicitly model how customer congestion effect influence customer utility and examine how firms can strategically manage consistency to enhance competitiveness.

The COVID-19 pandemic has further underscored the strategic role of service quality consistency. According to Karniouchina *et al*. (2022), restaurants with stable service standards and strong customer loyalty exhibited greater resilience during the crisis. Recent empirical studies reinforce this view: Villanueva *et al*. (2023) demonstrate that consistent service quality improved customer satisfaction and loyalty during the pandemic; and the case study by Cottrell and Bokunewicz (2024) explores how crisis management and organizational culture contribute to restaurant resilience and long-term viability. These findings show that quality consistency is not merely an operational metric but a key driver of brand equity, especially for chain restaurants. However, existing work lacks analytical models linking consistency with pricing and spatial strategies. In response, we extend a quality consistency model by incorporating customer congestion, variable costs and central kitchen location. Our results offer actionable guidance on quality control and kitchen investment, enabling restaurants to optimize pricing, improve customer utility and sustain performance across distributed outlets.

3. The model

Consider a system of two symmetric chain restaurants, indexed by 1 and 2, providing a main food to a continuum of customers uniformly distributing over a Hotelling line [0,1]. The two restaurants, 1 and 2 are located at the ends “0” and “1,” respectively. Each restaurant has a local storefront kitchen that prepares (cooks) the food for customers. However, due to factors such as nonstandard ingredients, recipes and cooking procedures, each restaurant $i \in \{0, 1\}$ faces the problem of food quality inconsistency. Previous empirical studies (e.g. Ferenčić and Wölfling (2015)) have shown that food quality inconsistency leads to some variation in a restaurant’s food quality. To capture the possible variation in food quality, we follow the operations management literature on quality control (e.g. Gerchak and Mossman (1992)) and use a mean-preserving way to model the quality level of restaurant i:

$$q_i = \lambda_i \overline{q} + (1 - \lambda_i)\xi = \overline{q} + (1 - \lambda_i)\xi, \tag{1}$$

in which $\overline{q}$ is the standard food quality (which customers normally expect or the restaurants promise) and ξ is a normally distributed random variable with mean $\overline{q}$ and variance σ^2. From (1) we can see that the parameter λ is an indicator of variation in food quality. Specifically, when $\lambda = 1$, there is no variation at all (meaning that food quality inconsistency vanishes); when $\lambda = 0$, there is the largest variation in food quality with $\mathrm{var}[q_i] = \sigma^2$ (meaning that food quality inconsistency is severe).

Given the variable food quality, a customer who locates at $x \in [0, 1]$ and chooses restaurant i would have the following utility:

$$U_i(x) = V - u\,\mathbb{E}[(\overline{q} - q_i)^+] - p - t_s\, l_i(x). \tag{2}$$

In (2), V represents a basic utility, p is the retail price of the food and $l_i(x)$ ($l_1(x) = x$ and $l_2(x) = 1 - x$) represents the distance between customer x and restaurant i, and t_s is the customer traveling cost rate. The terms $u\,\mathbb{E}[(\overline{q} - q_i)^+]$ captures the expected customer disutilities because of the negative quality inconsistency. It is evidenced (e.g. Ferenčić and Wölfling (2015), Es-Said (2024)) that a customer is sensitive to the (average) shortfall $\mathbb{E}[(\overline{q} - q_i)^+]$ in food quality at restaurant i relative to her expectation, and the coefficient u in (2) captures the marginal disutility with respect to the shortfall.

Apparently, a customer would choose restaurant i, rather than restaurant $j(\neq i)$, only when her utility $U_i(x)$ is not negative and not less than the utility $U_j(x)$ of choosing restaurant j, i.e.

$$U_i(x) \geq 0, U_i(x) \geq U_j(x).$$

To avoid the negative effect of food quality inconsistency, the restaurateur can invest in building a central kitchen. As mentioned earlier, by moving some procedures to the central kitchen, the chain restaurants can effectively improve the food consistency. Specifically, with the central kitchen, each restaurant i's food consistency level is given by:

$$\lambda = \tau + \theta, \tag{3}$$

in which τ is the consistency from the storefront operation, and θ is the consistency controlled by the central kitchen operation. The cost function $K(\theta)$ captures the effort of maintaining the consistency of food quality, which is convexly increasing in θ. Specifically, we consider the quadratic form of $K(\theta)$ as follows:

$$K(\theta) = b\frac{\theta^2}{2}, \tag{4}$$

where $b > 0$. The quadratic cost function is widely used in the literature (Choudhary *et al.*, 2005) to capture the increasing marginal cost when improving the food quality. The fixed investment cost of building a central kitchen is F_k.

The sequence of events is as follows. First, on a strategic level, the restaurateur decides whether to build a central kitchen and the level of process standardization (i.e. the quality consistency variable θ). Second, the restaurateur charges a uniform retail price p of the food for two restaurants. The assumption on uniform retail price is aligned with the practice of the chain restaurant in practice.

Assumption 1. We need the following assumption:

$$V \geq c + \frac{\delta\gamma}{2}(nonnegative\ demand), \tag{5}$$

$$V \geq \frac{t_s}{2} + \frac{\delta\gamma}{2}(nonnegative\ variable), \tag{6}$$

$$V \leq c + \frac{\delta\gamma}{2} + \frac{bt_s}{\delta} - \delta(constraint\ for\ \theta), \tag{7}$$

$$b \geq \delta(constraint\ for\ \theta), \tag{8}$$

$$b \geq \frac{\delta^2}{t_s}(concavity) \tag{9}$$

According to the non-negative form of the demand function and variable and the constraint for θ, the range of the consumer's base utility V can be determined, where we assume that the retail price is higher than the cost parameter (i.e. $p \geq c$). Meanwhile, according to the concavity and constraint for θ, the range of cost parameter b can be determined.

For ease of composition, we define $\delta := \frac{u\sigma}{\sqrt{2\pi}}$ and $\gamma := 2 - \tau_1 - \tau_2$ in the following presentation.

In our model, we define $\delta := \frac{u\sigma}{\sqrt{2\pi}}$, where u reflects the customer's marginal disutility from a shortfall in expected quality, and σ captures the standard deviation of quality across outlets. In practice, σ can be estimated from quality inspection scores or customer rating dispersion, while u may be inferred from the sensitivity of customer churn or complaints to changes in consistency. For instance, a drop in SOP compliance might lead to a measurable rise in negative reviews, which can be used to estimate u. This aligns with operational practices in leading chain restaurants such as Haidilao or McDonald's, where SOP audit results and consistency assessments are directly tied to customer satisfaction metrics and service evaluation systems. Moreover, similar behavioral sensitivity parameters have been modeled in the literature (Buell *et al.*, 2016; Guo *et al.*, 2023), validating the economic relevance of δ.

4. Analysis of the game

Let D_i denote customer demand for two chain restaurants. We start with deriving the expression for $D_i(\cdot)$ based on customer utility as follows. Recall that the utility function for a customer who chooses restaurant 1 and is located at x, is given by:

$$U_1 = V - p - \delta(1-\lambda_1) - xt_s \tag{10}$$

Meanwhile, the utility function for this customer, who chooses restaurant 2 and is located at x, is given by:

$$U_2 = V - p - \delta(1-\lambda_2) - (1-x)t_s \tag{11}$$

Then, this customer would choose restaurant 1 only when $U_1 \geq 0$ and $U_1 \geq U_2$, and she would choose restaurant 2 only when $U_2 \geq 0$ and $U_2 \geq U_1$. Based on these observations, we have the following result.

Lemma 1. Given the uniform meal price p and consistency levels (λ_1, λ_2) of chain restaurants,

(1) *When $p > V - \delta - \frac{1}{2}t_s + \delta\frac{\lambda_1+\lambda_2}{2}$, the customer demands for two restaurants are expressed by:*

$$D_1(p) = \frac{V - p - \delta(1-\lambda_1)}{t_s}, \quad D_2(p) = \frac{V - p - \delta(1-\lambda_2)}{t_s}, \tag{12}$$

which satisfy $D_1(p) + D_2(p) < 1$.

(2) *When $p \leq V - \delta - \frac{1}{2}t_s + \delta\frac{\lambda_1+\lambda_2}{2}$, the demands for two restaurants are given by:*

$$D_1(p) = \frac{1}{2} + \frac{\delta(\lambda_1-\lambda_2)}{2t_s}, \quad D_2(p) = \frac{1}{2} - \frac{\delta(\lambda_1-\lambda_2)}{2t_s}, \tag{13}$$

which satisfy $D_1(p) + D_2(p) = 1$.

(3) *As such, the total demands for chain restaurants, denoted as $\widehat{D}(p) = D_1(p) + D_2(p)$, are given by:*

$$\widehat{D}(p,\lambda_1,\lambda_2) = \begin{cases} 1 & \text{if } p \leq V - \delta - \dfrac{1}{2}t_s + \delta\dfrac{\lambda_1+\lambda_2}{2}, \\ \dfrac{\delta(\lambda_1+\lambda_2) - 2(\delta + p - V)}{t_s} & \text{if } p > V - \delta - \dfrac{1}{2}t_s + \delta\dfrac{\lambda_1+\lambda_2}{2}. \end{cases} \tag{14}$$

Proof. See Supplementary Material.

Lemma 1 shows the expressions for the customer demands for two restaurants, depending on the meal price p. Specifically, when the retail price p is sufficiently large (that is, $p > V - \delta - \frac{t_s}{2} + \frac{\delta(\lambda_1+\lambda_2)}{2}$), not all customers in the market will choose one of the restaurants (in other words, $D_1(p) + D_2(p) < 1$), which means that the market is partially covered by the chain restaurants (see Figure 1). This case is called "partial coverage strategy".

On the other hand, when p is small (i.e. $p < V - \delta - \frac{t_s}{2} + \frac{\delta(\lambda_1+\lambda_2)}{2}$), all the customers in the market will choose at least one of the restaurants (i.e. $D_1(p) + D_2(p) = 1$), which means that the market is fully covered by the chain restaurants (see Figure 2). The second case is called "full coverage strategy."

4.1 Baseline setting without central kitchen

Using the demand function shown in Lemma 1, we formulate the problem of maximizing the total profits of chain restaurants in the baseline setting without a central kitchen. Note that in the baseline setting, without the intervention of the central kitchen, that is, $\theta = 0$, the level of quality consistency is simplified to $\lambda_i = \tau_i$. According to Lemma 1, we have:

$$\widehat{D}(p) = \begin{cases} 1 & \text{if } p \leq V - \frac{1}{2}t_s - \delta\frac{\gamma}{2}, \\ \frac{2V - 2p - \delta\gamma}{t_s} & \text{if } p > V - \frac{1}{2}t_s - \delta\frac{\gamma}{2}. \end{cases} \tag{15}$$

Therefore, the problem of maximizing total profits from two restaurants can be written as follows:

$$\max_{p\geq 0}\{\Pi^B(p)\} = \max_{p\geq 0}\left\{(p-c)\widehat{D}(p)\right\},$$

in which $\Pi^B(p)$ is the profit function. Further define $\Pi_F^B(p) := p - c$ and. $\Pi_P^B(p) := (p-c)\left(\frac{2V-2p-\delta\gamma}{t_s}\right)$

We next solve the problem of maximizing total profits as follows:

Proposition 1. *In the baseline setting, under* Assumption 1,

(1) *when* $\delta > \frac{2(V-c-t_s)}{\gamma}$, $\Pi^B(p)$ *is quasi-concave with maximum price:*

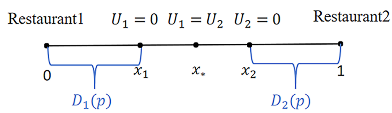

Figure 1. Partial market coverage. Source: Authors' own work

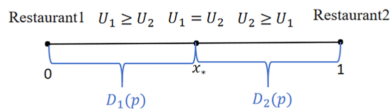

Figure 2. Full market coverage. Source: Authors' own work

$$p^* = \frac{c+V}{2} - \frac{\delta\gamma}{4}, \pi^* = \frac{(-2c-\delta\gamma+2V)^2}{8t_s}$$

which leads to partial market coverage.

(2) *when* $\delta \leq \frac{2(V-c-t_s)}{\gamma}$, $\Pi^B(p)$ *is concave with maximum price:*

$$p^* = \frac{1}{2}(2V-\delta\gamma-t_s), \pi^* = \frac{1}{2}(2V-\delta\gamma-t_s)-c$$

which leads to full market coverage.

Proof. See Supplementary Material.

Proposition 1 highlights how firms should adapt their pricing and market coverage strategies in response to changes in customer sensitivity to quality inconsistency (δ). When δ is low, customers are more tolerant of variation in food quality across locations and the firm benefits from lowering prices and serving the full market. In contrast, as δ increases, the firm raises prices and targets only quality-sensitive customers, leading to partial market coverage.

Travel cost (t_s) also plays a key role in shaping market strategy. Higher travel costs make it harder for the firm to serve all customers profitably, further reinforcing the incentive to focus on a narrower, high-value segment.

Managerial recommendations: Firms should segment their operational strategies based on regional differences in customer quality sensitivity and travel cost. In high-density or premium urban markets, firms may justify investing in consistency and charging premium prices. Conversely, in low-sensitivity or high-mobility-friction areas, mass-market strategies with lower pricing and less consistency investment may yield higher returns.

4.2 Main model with central kitchen

Using the demand function shown in Lemma 1, we formulate the problem of maximizing the total profits of chain restaurants in the main model with a central kitchen. By introducing the central kitchen, each restaurant i's consistency level is given by: $\lambda_i = \tau_i + \theta$. In which τ_i is the consistency from storefront operation, and θ is the consistency controlled by the central kitchen operation. According to Lemma 1, we have:

$$\widehat{D}(p,\theta) = \begin{cases} 1 & \text{if } p \leq V - \frac{1}{2}t_s + \delta\frac{-\gamma+2\theta}{2}, \\ \frac{2V-2p+\delta(-\gamma+2\theta)}{t_s} & \text{if } p > V - \frac{1}{2}t_s + \delta\frac{-\gamma+2\theta}{2}. \end{cases} \tag{16}$$

The cost function $K(\theta)$ captures the effort of maintaining the consistency of food quality, which is convexly increasing in θ. Specifically, we consider the quadratic form of $K(\theta)$ as follows:

$$K(\theta) = b\frac{\theta^2}{2}, \tag{17}$$

Where $b > 0$. The fixed investment cost of building a central kitchen is F_k.

Therefore, the problem of maximizing total profits from two restaurants can be written as follows:

$$\max_{p\geq 0,\theta\in[0,1]}\{\Pi^M(p,\theta)\} = \max_{p\geq 0,\theta\in[0,1]}\left\{(p-c)\widehat{D}(p,\theta) - K(\theta) - F_k\right\},$$

in which $\Pi^M(p)$ is the profit function. Further define $\Pi_F^M(p,\theta) := p - c - b\frac{\theta^2}{2} - F_k$ and $\Pi_P^M(p,\theta) = (p-c)\left(\frac{2V-2p+\delta(-\gamma+2\theta)}{t_s}\right) - b\frac{\theta^2}{2} - F_k$.

We next solve the problem of maximizing total profits as follows:

Proposition 2. *With central kitchen, the operator's optimal pricing strategies under Assumption 1 is given by:*

(1) *when* $\delta \in \left[\frac{b\gamma - \sqrt{b^2\gamma^2 + 16b(c+t_s-V)}}{4}, \frac{b\gamma + \sqrt{b^2\gamma^2+16b(c+t_s-V)}}{4}\right)$, *the operator chooses a partial coverage strategy and the optimal decisions and profit are as follows:*

$$\begin{aligned} \theta_P^* &= \frac{\delta(2V-2c-\delta\gamma)}{2\left(b\cdot t_s - \delta^2\right)}, \\ p_P^* &= \frac{c\left(2bt_s - 4\delta^2\right) + bt_s(-\delta\gamma + 2V)}{4bt_s - 4\delta^2} \\ \pi_P^* &= \frac{b(-2c-\delta\gamma+2V)^2}{8bt_s - 8\delta^2} - F_k \end{aligned} \tag{18}$$

(2) *when* $\delta \in \left[0, \frac{b\gamma - \sqrt{b^2\gamma^2+16b(c+t_s-V)}}{4}\right) \cup \left[\frac{b\gamma+\sqrt{b^2\gamma^2+16b(c+t_s-V)}}{4}, \infty\right)$, *the operator chooses a full coverage strategy and the optimal decisions and profit are as follows:*

$$\begin{aligned} \theta_F^* &= \frac{\delta}{b}, \\ p_F^* &= \frac{1}{2}\left(-\delta\gamma + 2\delta^2/b - t_s + 2V\right) \\ \pi_F^* &= \frac{1}{2}\left(-\delta\gamma + \delta^2/b - t_s + 2V\right) - c - F_k \end{aligned} \tag{19}$$

Proof. See Supplementary Material.

Proposition 2 illustrates how, after introducing a central kitchen, the firm's optimal pricing, quality consistency investment level and market coverage strategy are influenced by consumers' sensitivity to quality inconsistency (δ). When δ falls within a moderate range, the firm chooses a partial market coverage strategy, focusing on customer segments that are highly sensitive to quality variation. In this case, the firm needs to invest in a higher level of consistency (θ_P^*) and charges a higher price to reflect the value of improved service. However, when δ is very low or very high, the firm is more inclined to adopt a full market coverage strategy, with moderate pricing and adjusted consistency investment.

Furthermore, both the travel cost (t_s) and the fixed cost associated with central kitchen investment (F_k) substantially influence the firm's strategic decisions. As t_s increases, geographic frictions make it more difficult to access customers with varying degrees of quality sensitivity. Consequently, firms tend to concentrate their efforts on serving quality-sensitive segments, reducing the relative necessity of pursuing quality consistency across the board. In parallel, higher travel costs suppress customers' willingness to pay and reduce their effective service radius, thereby tightening the pricing margin and diminishing overall profitability. On the other hand, an increase in F_k directly reduces the firm's profit potential and raises the threshold required to justify the adoption of a central kitchen.

4.2.1 Managerial recommendations. Although a central kitchen enhances quality consistency across outlets, it may not fully mitigate the demand loss induced by high travel costs (t_s). As a result, firms should calibrate their investments in consistency according to the spatial characteristics of local markets. Instead of uniformly pursuing full-market standardization, a localized strategy that targets consumer segments with high sensitivity to quality inconsistency (δ) is likely to be more effective. Furthermore, given the substantial fixed investment required, firms must carefully evaluate the necessity of central kitchen adoption. A phased or region-specific deployment strategy may help alleviate financial pressure while allowing gradual quality improvements.

Figure 3 illustrates how the firm's optimal consistency investment level (θ*) changes with consumer sensitivity to quality inconsistency (δ) in the context of a centralized kitchen strategy. The graph identifies two distinct strategic regimes:

When δ is either low or high, the firm adopts a full market coverage strategy (blue segments). In these regions, customers are either tolerant of variation or extremely sensitive and the firm chooses a linear investment strategy to deliver broad accessibility with moderate quality control.

In contrast, when δ falls in a moderate range, the firm switches to a partial market coverage strategy (orange curve). Here, customers are particularly sensitive to inconsistency. To retain this high-value segment and justify premium pricing, the firm significantly increases consistency investment.

The two dashed vertical lines denote the boundaries between strategy zones, reflecting how the firm's optimal coverage policy shifts systematically with consumer sensitivity.

4.2.2 Managerial recommendations. Firms should align their quality investment and pricing strategies with the distribution of quality sensitivity across customer segments. In moderately sensitive markets, a "high consistency + premium pricing + focused coverage" approach delivers stronger performance. Conversely, in markets with either very low or very high sensitivity, firms benefit more from a "low consistency + low price + full coverage" strategy that emphasizes scale and cost efficiency. The figure also highlights the existence of strategic thresholds, encouraging firms to monitor market shifts and adjust consistency investments dynamically.

Proposition 3. (Central kitchen adoption) *In the main model, a central kitchen will be adopted by the chain restaurant only when F_k does not exceeds a threshold κ, i.e. $F_k \leq \kappa$, where κ is as follows*:

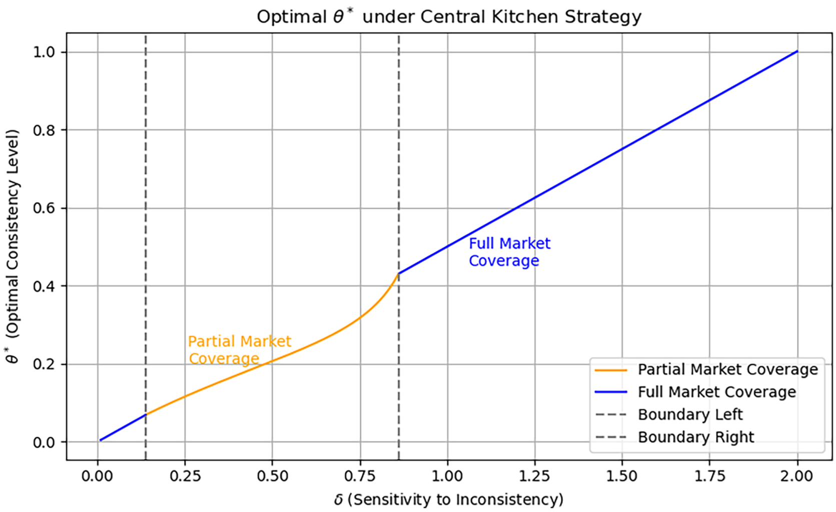

Figure 3. Optimal θ* under central kitchen strategy. Source: Authors' own work

(1) *if* $\delta \in \left[0, \frac{2(V-c-t_s)}{\gamma}\right)$, *then* $\kappa = \frac{\delta^2}{2b}$.

(2) *if* $\delta \in \left[\frac{b\gamma - \sqrt{b^2\gamma^2+16b(c+t_s-V)}}{4}, \frac{b\gamma + \sqrt{b^2\gamma^2+16b(c+t_s-V)}}{4}\right)$, *then* $\kappa = \frac{(-2c-\delta\gamma+2V)^2}{8t_s - 8\delta^2/b} - \frac{(-2c-\delta\gamma+2V)^2}{8t_s}$.

(3) *if* $\delta \in \left[\frac{2(V-c-t_s)}{\gamma}, \frac{b\gamma+\sqrt{b^2\gamma^2+16b(c+t_s-V)}}{4}\right) \cup \left[\frac{b\gamma+\sqrt{b^2\gamma^2+16b(c+t_s-V)}}{4}, \infty\right)$,
then $\kappa = \frac{1}{2}(-\delta\gamma - t_s + 2V) - c + \frac{\delta^2}{2b} - \frac{(-2c-\delta\gamma+2V)^2}{8t_s}$.

Moreover, in case (2), the adoption of the central kitchen benefits consumer utility only when $b \geq \frac{\delta^2}{2t_s}$ *and* $\frac{-4V\delta\gamma}{8V-4\delta\gamma} \leq c \leq \frac{2V-4V\delta\gamma}{-4\gamma}$*; in case (3), the adoption always benefits consumer utility; in case (1), doing so has no effect on consumer utility.*

Proof. See Supplementary Material.

Proposition 3 characterizes the threshold condition κ under which a central kitchen becomes a profitable investment for the firm. The threshold varies with the consumer's sensitivity to quality inconsistency (δ) and is piecewise defined across three regimes. In addition, the adoption of a central kitchen has no effect on consumer utility when δ is very low, yields conditional benefits in the intermediate sensitivity range and generally enhances consumer utility when δ lies outside this intermediate range.

Figure 4 provides an intuitive visualization of the proposition regarding central kitchen adoption. The blue curve $\kappa(\delta)$ illustrates the profitability threshold for central kitchen adoption under varying levels of consumer sensitivity to quality inconsistency. When the actual fixed investment cost F_k falls below this threshold – i.e. within the shaded area beneath the curve – adopting a central kitchen becomes the profit-maximizing strategy for the firm. Within this feasible region, the yellow-shaded area corresponds to scenarios where the firm opts for full market coverage alongside the use of a central kitchen, leveraging backend standardization to serve a broader customer base. The green-shaded area, in contrast, represents partial market coverage, where the central kitchen supports a more focused strategy targeting quality-sensitive consumers through enhanced consistency and control.

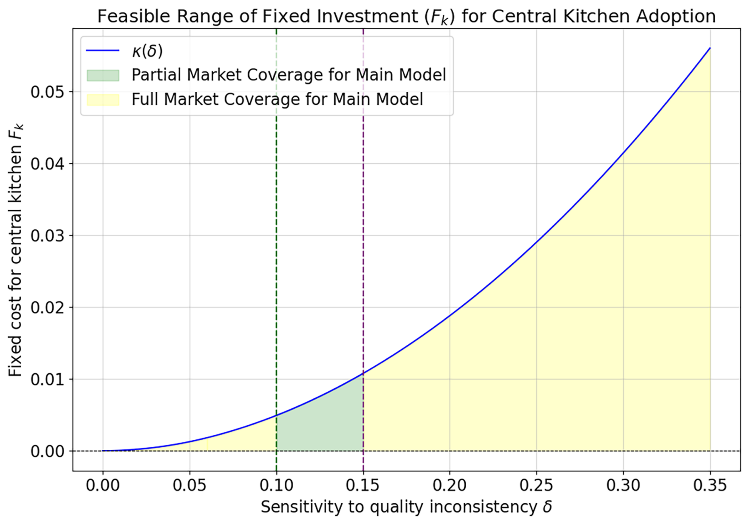

Figure 4. Feasibility of central kitchen adoption: threshold analysis of ($\kappa(\delta)$) Source: Authors' own work

As customer travel cost (t_s) increases, the economic viability of adopting a central kitchen decreases across all levels of quality sensitivity. At the same time, the range of δ values under which the firm adopts a partial market coverage strategy widens significantly, indicating a strategic shift toward serving quality-sensitive customer segments rather than aiming for full market coverage. In high travel-cost areas – such as remote locations or regions with limited customer mobility – restaurant operators should be cautious when considering central kitchen investments, especially if full market coverage is difficult to achieve. Instead, they should identify high-value, consistency-sensitive customer segments and adopt partial coverage strategies supported by targeted standardization (e.g. regional central kitchens or automated processes), thereby enhancing service quality and operational efficiency within focused markets.

5. Extension I: the effect of customer congestion

In this section, we extend the main model by considering the effect of customer congestion. Similarly, we also need some assumption in this generalized setting.

Assumption 2. We need the following assumption:

$$V \geq c + \frac{\delta\gamma}{2} (nonnegative\, demand), \tag{20}$$

$$V \geq \frac{t_s}{2} + \frac{\delta\gamma}{2} (nonnegative\, variable), \tag{21}$$

$$V \leq c + \frac{\delta\gamma}{2} + \frac{bt_s + b\beta}{\delta} - \delta (constraint\, for\, \theta), \tag{22}$$

$$b \geq \delta (constraint\, for\, \theta), \tag{23}$$

$$b \geq \frac{\delta^2}{\beta + t_s} (concavity) \tag{24}$$

According to the non-negative form of the demand function and variable and the constraint for θ, the range of the consumer's base utility V can be determined, where we assume that the retail price is higher than the cost parameter (i.e. $p \geq c$). Meanwhile, according to the concavity and constraint for θ, the range of cost parameter b can be determined.

The utility function for a customer, who chooses restaurant 1 and is located at x, is given by:

$$U_1 = V - p - \delta(1 - \lambda_1) - (x)t_s - \beta d_1^e \tag{25}$$

Meanwhile, utility function for this customer, who chooses restaurant 2 and is located at x, is given by:

$$U_2 = V - p - \delta(1 - \lambda_2) - (1 - x)t_s - \beta d_2^e \tag{26}$$

The parameter $\beta (\beta \geq 0)$ captures the disutility experienced by a customer due to congestion at a selected restaurant. A higher value of β implies that customers are more sensitive to congestion and therefore more likely to avoid overcrowded restaurants. This component plays a critical role in shaping consumer choice behavior and balancing demand between outlets.

The equilibrium demand satisfies: $\widehat{D}(p, \lambda_i) = d_i^e$.

Lemma 2. Given the uniform meal price p and quality consistency level θ,

(1) *When* $p \le V - \frac{\beta+t_s}{2} + \frac{\delta(-\gamma+2\theta)}{2}$*, the demands for two restaurants are given by:*

$$D_1(p,\theta) = \frac{1}{2} + \frac{\delta(\tau_1 - \tau_2)}{2(\beta + t_s)}, \quad D_2(p,\theta) = \frac{1}{2} - \frac{\delta(\tau_1 - \tau_2)}{2(\beta + t_s)}, \tag{27}$$

which satisfy $D_1(p, \theta) + D_2(p, \theta) = 1$.

(2) *When* $p > V - \frac{\beta+t_s}{2} + \frac{\delta(-\gamma+2\theta)}{2}$*, the demands for two restaurants are given by:*

$$D_1(p,\theta) = \frac{V - p - \delta(1 - \tau_1 - \theta)}{\beta + t_s}, \quad D_2(p,\theta) = \frac{V - p - \delta(1 - \tau_2 - \theta)}{\beta + t_s}, \tag{28}$$

which satisfy $D_1(p, \theta) + D_2(p, \theta) < 1$.

(3) *As such, the total demands for chain restaurants, denoted as* $\widehat{D}(p,\theta) = D_1(p,\theta) + D_2(p,\theta)$*, are given by:*

$$\widehat{D}(p,\theta) = \begin{cases} 1 & \text{if } p \le V - \dfrac{\beta + t_s}{2} + \dfrac{\delta(-\gamma + 2\theta)}{2}, \\ \dfrac{\delta(-\gamma + 2\theta) - 2(p - V)}{\beta + t_s} & \text{if } p > V - \dfrac{\beta + t_s}{2} + \dfrac{\delta(-\gamma + 2\theta)}{2}, \end{cases} \tag{29}$$

Proof. See Supplementary Material.

Lemma 2 shows the expressions for the customer demands for two restaurants, depending on the retail price and quality consistency. Specifically, when the retail price p is sufficiently large (i.e. $p > V - \frac{\beta+t_s}{2} + \frac{\delta(-\gamma+2\theta)}{2}$), not all the customers in the market will choose one of the restaurants (in other words, $D_1(p) + D_2(p) < 1$), which means that the market is partially covered by the chain store service (see Figure 6). This case is referred to as "partial coverage strategy."

On the other hand, when p is small (i.e. $p \le V - \frac{\beta+t_s}{2} + \frac{\delta(-\gamma+2\theta)}{2}$), all the customers in the market will choose one of the restaurants (in other words, $D_1(p) + D_2(p) = 1$), which means that the market is fully covered by the chain store service (see Figure 5). The second case is referred to as "full coverage strategy."

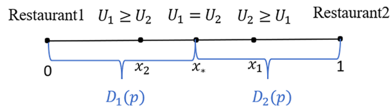

Figure 5. Full market coverage. Source: Authors' own work

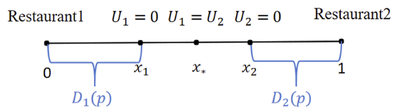

Figure 6. Partial market coverage. Source: Authors' own work

The cost function $K(\theta)$ captures the effort of maintaining the consistency of food quality, which is convexly increasing in θ. Specifically, we consider the quadratic form of $K(\theta)$ as follows:

$$K(\theta) = b\frac{\theta^2}{2}, \tag{30}$$

Where $b > 0$. The fixed investment cost of building a central kitchen is F_k.

Therefore, the problem of maximizing total profits from two restaurants can be written as follows:

$$\max_{p\geq 0,\theta\in[0,1]}\left\{\Pi^E(p,\theta)\right\} = \max_{p\geq 0,\theta\in[0,1]}\left\{(p-c)\widehat{D}(p,\theta) - K(\theta) - F_k\right\},$$

in which $\Pi^E(p, \theta)$ is the profit function. Further define $\Pi_F^E(p,\theta) := p - c - b\frac{\theta^2}{2} - F_k$ and $\Pi_P^B(p,\theta) = (p-c)\frac{\delta(-\gamma+2\theta)-2(p-V)}{\beta+t_s} - b\frac{\theta^2}{2} - F_k$.

We next solve the problem of maximizing total profits as follows.

Proposition 4. *In the baseline model with consumer congestion, under Assumption 2,*

(1) *when* $\delta > \frac{2(V-c-t_s-\beta)}{\gamma}$, $\Pi^B(p)$ *is quasi-concave with maximum price:*

$$p^* = \frac{c+V}{2} - \frac{\delta\gamma}{4}, \pi^* = \frac{(-2c-\delta\gamma+2V)^2}{8(\beta+t_s)}$$

which leads to partial market coverage.

(2) *when* $\delta \leq \frac{2(V-c-t_s-\beta)}{\gamma}$, $\Pi^B(p)$ *is concave with maximum price:*

$$p^* = \frac{1}{2}(-\delta\gamma - \beta - t_s + 2V), \pi^* = \frac{1}{2}(-\delta\gamma - \beta - t_s + 2V) - c$$

which leads to full market coverage.

In the main model with consumer congestion, under Assumption 2.

(1) *when* $\delta \in \left[\frac{b\gamma - \sqrt{b^2\gamma^2+16b(c+t_s+\beta-V)}}{4}, \frac{b\gamma + \sqrt{b^2\gamma^2+16b(c+t_s+\beta-V)}}{4}\right)$, *the operator chooses a partial coverage strategy, and the optimal decisions and profit are as follows:*

$$\begin{aligned} \theta_P^{E}* &= \frac{\delta(2V-2c-\delta\gamma)}{2\left(b\cdot t_s + b\beta - \delta^2\right)}, \\ p_P^{E}* &= \frac{b(\beta+t_s)(2c-\delta\gamma+2V) - 4c\delta^2}{4b(\beta+t_s) - 4\delta^2} \\ \pi_P^{E}* &= \frac{b(-2c-\delta\gamma+2V)^2}{8b(\beta+t_s) - 8\delta^2} - F_k \end{aligned} \tag{31}$$

(2) *when* $\delta \in \left[0, \frac{b\gamma - \sqrt{b^2\gamma^2+16b(c+t_s+\beta-V)}}{4}\right) \cup \left(\frac{b\gamma + \sqrt{b^2\gamma^2+16b(c+t_s+\beta-V)}}{4}, \infty\right)$, *the operator chooses a full coverage strategy, and the optimal decisions and profit are as follows:*

$$
\begin{aligned}
\theta_F^{E*} &= \frac{\delta}{b}, \\
p_F^{E*} &= \frac{1}{2}\left(-\delta\gamma + 2\delta^2/b - \beta - t_s + 2V\right), \\
\pi_F^{E*} &= \frac{1}{2}\left(-\delta\gamma + \delta^2/b - \beta - t_s + 2V\right) - c - F_k
\end{aligned}
\tag{32}
$$

Proof. See Supplementary Material.

Proposition 4 demonstrates that when customer congestion effects are introduced into the model, the firm's optimal pricing, consistency level and market coverage strategy still fundamentally depend on consumer sensitivity to quality inconsistency (δ). Similar to the main model, partial market coverage arises when δ lies within an intermediate range, where the firm targets quality-sensitive customers through higher consistency investment and premium pricing. Conversely, when δ is sufficiently low or high, a full market coverage strategy remains optimal, supported by moderate pricing and calibrated consistency levels.

However, the introduction of the congestion parameter (β), which captures disutility from crowding at popular outlets, introduces a moderating effect. Specifically, high values of β intensify customers' avoidance of overcrowded locations, thereby slightly reducing the firm's ability to rely solely on consistency upgrades for differentiation. Nonetheless, the overall structure of the optimal strategy remains consistent with the benchmark setting.

5.1 Managerial implications

In high-congestion environments – such as peak hours or densely populated urban markets – firms may encounter increased difficulty in serving all customers efficiently, even when quality consistency is improved. Under such conditions, consistency-enhancing strategies may need to be supplemented with decentralization or load-balancing mechanisms, such as staggered service times or the establishment of multiple outlets. Moreover, as congestion diminishes the marginal utility of quality improvements, firms must carefully assess whether the returns from investing in consistency remain justifiable in crowded service settings. This underscores the importance of aligning quality management efforts with spatial capacity planning, calling for a more nuanced approach that jointly considers service consistency and demand distribution.

Proposition 5. (Central kitchen adoption) *In the extension model, a central kitchen will be adopted by the chain restaurant only when F_k does not exceeds a threshold κ, i.e. $F_k \le \kappa$, where κ is as follows.*

(1) *if* $\delta \in \left[0, \frac{2(V-c-t_s-\beta)}{\gamma}\right)$, *then* $\kappa = \frac{\delta^2}{2b}$.

(2) *if* $\delta \in \left[\frac{b\gamma - \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}, \frac{b\gamma + \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}\right)$,
then $\kappa = \frac{(-2c-\delta\gamma+2V)^2}{8(\beta+t_s) - 8\delta^2/b} - \frac{(-2c-\delta\gamma+2V)^2}{8(\beta+t_s)}$.

(3) *if* $\delta \in \left[\frac{2(V-c-t_s-\beta)}{\gamma}, \frac{b\gamma + \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}\right) \cup \left[\frac{b\gamma + \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}, \infty\right)$,
then $\kappa = \frac{1}{2}\left(-\delta\gamma - \beta - t_s + 2V\right) - c + \frac{\delta^2}{2b} - \frac{(-2c-\delta\gamma+2V)^2}{8(\beta+t_s)}$.

Moreover, in case (2), the adoption of the central kitchen benefits consumer utility only when $b \geq \frac{\delta^2}{2(\beta+t_s)}$ *and* $\frac{-4V\delta\gamma}{8V-4\delta\gamma} \leq c \leq \frac{2V-4V\delta\gamma}{-4\gamma}$*; in case (3), the adoption always benefits consumer utility; in case (1), doing so has no effect on consumer utility.*

Proof. See Supplementary Material.

Proposition 5 characterizes the threshold condition κ under which a central kitchen becomes a profitable investment for the firm. The threshold varies with the consumer's sensitivity to quality inconsistency (δ) and is piecewise defined across three regimes. In addition, the adoption of a central kitchen has no effect on consumer utility when δ is very low, yields conditional benefits in the intermediate sensitivity range and generally enhances consumer utility when δ lies outside this intermediate range.

Figure 7 provides an intuitive visualization of the proposition regarding central kitchen adoption. The blue curve $\kappa(\delta)$ illustrates the profitability threshold for central kitchen adoption under varying levels of consumer sensitivity to quality inconsistency. When the actual fixed investment cost F_k falls below this threshold – i.e. within the shaded area beneath the curve – adopting a central kitchen becomes the profit-maximizing strategy for the firm. Within this feasible region, the yellow-shaded area corresponds to scenarios where the firm opts for full market coverage alongside the use of a central kitchen, leveraging backend standardization to serve a broader customer base. The purple-shaded area, in contrast, represents partial market coverage, where the central kitchen supports a more focused strategy targeting quality-sensitive consumers through enhanced consistency and control.

As customer travel cost (t_s) increases, the economic viability of adopting a central kitchen decreases across all levels of quality sensitivity. At the same time, the range of δ values under which the firm adopts a partial market coverage strategy widens significantly, indicating a strategic shift toward serving quality-sensitive customer segments rather than aiming for full market coverage. In high travel-cost areas – such as remote locations or regions with limited customer mobility – restaurant operators should be cautious when considering central kitchen investments, especially if full market coverage is difficult to achieve. Instead, they should identify high-value, consistency-sensitive customer segments and adopt partial coverage strategies supported by targeted standardization (e.g. regional central kitchens or automated processes), thereby enhancing service quality and operational efficiency within focused

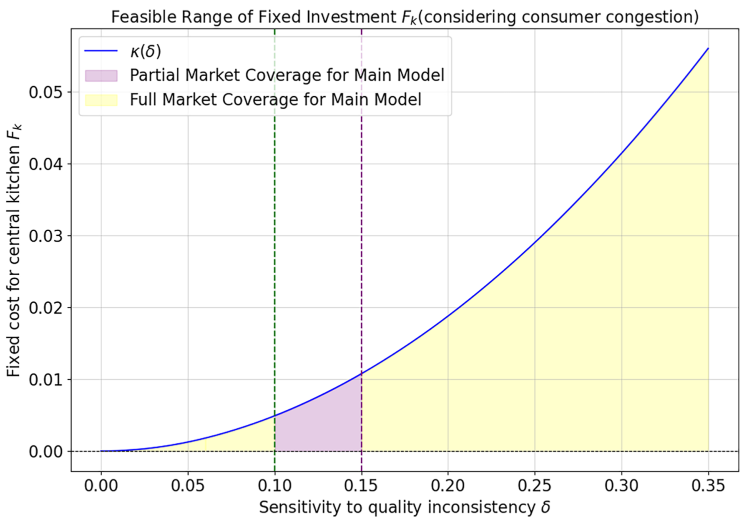

Figure 7. Feasibility of central kitchen adoption: threshold analysis of ($\kappa(\delta)$). Source: Authors' own work

markets. The result obtained in this case is consistent with the conclusion derived from the main model without considering the effect of customer congestion.

Proposition 6. (The effect of consumer congestion) *Sensitivity to quality inconsistency will always have a negative impact on restaurant profits* ($\frac{\partial \Pi^*}{\partial \delta} < 0$).

For baseline model with consumer congestion.

(1) *when* $\delta \leq \frac{2(V-c-t_s-\beta)}{\gamma}$, *the congestion effect and the negative impact of food quality inconsistency are independent (i.e.* $\frac{\partial^2 \Pi^*}{\partial \beta \partial \delta} = 0$*).*

(2) *when* $\delta > \frac{2(V-c-t_s-\beta)}{\gamma}$, *congestion effect can circumvent the negative impact of food quality inconsistency (i.e.* $\frac{\partial^2 \Pi^*}{\partial \beta \partial \delta} > 0$*) .*

For main model with consumer congestion:

When $\delta \in \left[0, \frac{b\gamma - \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}\right) \cup \left(\frac{b\gamma + \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}, \infty\right)$, *the congestion effect and the negative impact of food quality inconsistency are independent (i.e.* $\frac{\partial^2 \Pi^*}{\partial \beta \partial \delta} = 0$*).*

When $\delta \in \left[0, \frac{b\gamma - \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}\right) \cup \left(\frac{b\gamma + \sqrt{b^2\gamma^2 + 16b(c+t_s+\beta-V)}}{4}, \infty\right)$.

(1) *when* $\gamma \leq \frac{16\delta(2V-2c)}{8b(\beta+t_s+8\delta^2)}$, *congestion effect can circumvent the negative impact of food quality inconsistency (i.e.* $\frac{\partial^2 \Pi^*}{\partial \beta \partial \delta} > 0$*).*

(2) *when* $\gamma > \frac{16\delta(2V-2c)}{8b(\beta+t_s+8\delta^2)}$, *congestion effect can intensify the negative impact of food quality inconsistency (i.e.* $\frac{\partial^2 \Pi^*}{\partial \beta \partial \delta} < 0$*).*

Proof. See Supplementary Material.

5.2 Managerial implications

This proposition confirms that consumer sensitivity to quality inconsistency (δ) consistently exerts a negative impact on firm profitability, reinforcing the importance of maintaining robust quality consistency – particularly in markets characterized by high sensitivity levels. Interestingly, under certain parameter conditions, customer congestion (β) may partially offset the adverse effects of quality inconsistency. In such cases, firms can utilize service load-balancing mechanisms, such as reservation systems or staggered work shifts, to alleviate crowding and enhance perceived service reliability. However, when the inconsistency level across outlets (γ) is high, congestion tends to amplify consumer aversion to inconsistency. Under such circumstances, firms must ensure not only fast service delivery but also a high level of uniformity in service quality to retain customer satisfaction and foster loyalty.

6. Extension II: generate cost structure

The distance d between central kitchen and each restaurant is a decision variable.

$$U_i = V\eta(d) - p - u\mathbb{E}[(\overline{q} - q_i)^+] - t_s L_i(x), \tag{33}$$

in which $\eta(d)$ is a discount factor in food freshness because of the transporting time and is decreasing in d. There is a direct relationship between d and η: for any given level of freshness η, a unique delivery distance d corresponds to it, and vice versa. Therefore we can define $\eta = f(d) \Rightarrow d = f^{-1}(\eta)$.

Meanwhile, the fixed cost of establishing a central kitchen is $F_k(d)$, which is decreasing in d. Therefore, we can get $F_k(d) = F_k(f^{-1}(\eta))$.

The cost function $F_k(d)$ captures the fixed cost of establishing a central kitchen, which is decreasing in d due to its inverse relationship with the freshness discount factor. Specifically, we consider the quadratic form of $F_k(f^{-1}(\eta))$ as follows:

$$F_k\left(f^{-1}(\eta)\right) = k\frac{\eta^2}{2}, \tag{34}$$

Where $k > 0$. k is the cost sensitivity coefficient, capturing the extent to which the fixed cost of building a central kitchen increases with the level of freshness decay. A higher k implies that the firm is more sensitive to quality inconsistency, thereby incurring higher fixed costs to mitigate freshness loss.

In our model, two distinct components reflect the cost implications of maintaining food quality consistency: We define a consistency effort cost function $K(\theta)$, which captures the increasing marginal effort required to improve quality consistency. This cost is assumed to be convex in the consistency level $\theta \in [0, 1]$ and takes a quadratic form:

$$K(\theta) = b\frac{\theta^2}{2}, \tag{35}$$

Where $b > 0$.

We further extend the model by allowing the per-unit operational cost c to decrease in consistency level θ, reflecting that more consistent processes may reduce unit cost due to standardization or learning effects. Specifically, we let

$$c(\theta) = c_0 - \alpha\theta \tag{36}$$

where $\alpha > 0$.

Therefore, the problem of maximizing total profits from two restaurants can be written as follows:

$$\max_{p\geq 0,\theta\in[0,1]}\{\Pi(p,\theta,\eta)\} = \max_{p\geq 0,\theta\in[0,1]}\left\{(p - c(\theta))\widehat{D}(p,\theta,\eta) - K(\theta) - F_k(\eta)\right\},$$

in which $\Pi(p)$ is the profit function. Further define $\Pi_F(p,\theta,\eta) := p - c_0 - \alpha\theta - b\frac{\theta^2}{2} - F_k(\eta)$ and $\Pi_P(p,\theta,\eta) = (p - c_0 - \alpha\theta)\left(\frac{2V\eta - 2p + \delta(-\gamma+2\theta)}{t_s}\right) - b\frac{\theta^2}{2} - F_k(\eta)$.

Assumption 3. We need the following assumption:

$$V \geq c_0 + \frac{\delta\gamma}{2}(nonnegative\,demand), \tag{37}$$

$$V \geq \frac{t_s}{2} + \frac{\delta\gamma}{2}(nonnegative\,variable), \tag{38}$$

$$V > \sqrt{kt_s - k(\delta+\alpha)^2/b}(nonnegative\,variable), \tag{39}$$

$$V \leq c_0 + \frac{\delta\gamma}{2} + \frac{bt_s}{\delta} - \delta(constraint\,for\,\theta), \tag{40}$$

$$V \leq k(constraint\, for\, \eta), \tag{41}$$

$$k \leq \frac{V(2V - 2c_0) - \delta\gamma)}{2t_s - 2\delta^2/b}(constraint\, for\, \eta), \tag{42}$$

$$b \geq \delta(constraint\, for\, \theta), \tag{43}$$

$$b \geq \frac{(\delta + \alpha)^2}{t_s}(concavity) \tag{44}$$

$$k \geq \frac{V^2 b}{bt_s - (\delta + \alpha)^2}(concavity) \tag{45}$$

According to the non-negative form of the demand function and variable and the constraint for θ and the constraint on η, the range of the consumer's base utility V can be determined, where we assume that the retail price is higher than the cost parameter. Meanwhile, according to the concavity and constraint for θ and η, the range of cost parameter b and k can be determined.

We next solve the problem of maximizing total profits as follows.

Proposition 7. With central kitchen, the operator's optimal pricing strategies under Assumption 3 is given by:

(1) *when* $k > \frac{V^2}{c_0 + t_s - \frac{(\delta+\alpha)^2}{b} + \frac{\delta\gamma}{2}}$, *the operator chooses a partial coverage strategy, and the optimal decisions and profit are as follows:*

$$\begin{aligned}
\eta_P^* &= \frac{V(2c_0 + \delta\gamma)}{2\left(V^2 - kt_s + \frac{k(\delta+\alpha)^2}{b}\right)}, \\
\theta_P^* &= \frac{\delta k(2c_0 + \delta\gamma)}{2\left(b\left(V^2 - kt_s\right) + (\delta + \alpha)^2 k\right)}, \\
p_P^* &= \frac{bkt_s(2c_0 + \delta\gamma)}{4\left(b\left(V^2 - kt_s\right) + (\delta + \alpha)^2 k\right)} + c_0, \\
\pi_p^* &= -\frac{bk(2c_0 + \delta\gamma)^2}{8\left(b\left(V^2 - kt_s\right) + (\delta + \alpha)^2 k\right)}
\end{aligned} \tag{46}$$

(2) *when* $k \leq \frac{V^2}{c_0 + t_s - \frac{(\delta+\alpha)^2}{b} + \frac{\delta\gamma}{2}}$, *the operator chooses a full coverage strategy, and the optimal decisions and profit are as follows:*

$$
\begin{aligned}
\eta_F^* &= \frac{V}{k}, \\
\theta_F^* &= \frac{\delta}{b}, \\
p_F^* &= \frac{1}{2}\left(-\delta\gamma + 2(\delta+\alpha)^2/b - t_s + 2V^2/k\right) \\
\pi_F^* &= \frac{1}{2}\left(-\delta\gamma + (\delta+\alpha)^2/b - t_s + V^2/k\right) - c_0
\end{aligned}
\tag{47}
$$

Proof. See Supplementary Material.

Proposition 7 explores how the firm's optimal strategy changes when two key operational realities are introduced: (i) the distance between the central kitchen and individual restaurants affects food freshness (via $\eta(d)$) and (ii) the per-unit cost of production decreases with higher consistency, reflecting cost savings from standardization ($c(\theta) = c_0 - \alpha\theta$). The model maintains the distinction between partial and full market coverage, driven by whether the fixed cost sensitivity parameter k crosses a specific threshold.

When k is large, meaning the fixed cost of achieving higher freshness increases rapidly with consistency, the firm adopts a partial market coverage strategy. It focuses on delivering high consistency levels to a subset of quality-sensitive customers, leading to higher per-unit price (p_P^*) and moderate profit levels. In contrast, when k is sufficiently small, full market coverage becomes optimal. The firm chooses a moderate consistency level and leverages both improved freshness (shorter d) and cost savings (α) to serve a broader market efficiently.

6.1 Managerial implications

Firms should carefully assess how spatial decisions – particularly the location of a central kitchen – affect product freshness and overall cost-effectiveness. A poorly chosen location may lead to faster quality decay and higher investments to maintain consistency. Moreover, the potential to reduce unit costs through operational standardization highlights the broader strategic value of consistency, not only for customer perception but also for internal process efficiency. To this end, firms should consider adopting automated production technologies, standardized operating procedures and digital systems that jointly promote consistency and reduce marginal production costs. Finally, in markets characterized by high values of k (i.e. quality decay rates) or high logistical dispersion, full market coverage may become prohibitively expensive. In such cases, firms may benefit more from localized deployment and targeted service to quality-sensitive consumer segments.

7. Conclusion

This study develops a comprehensive analytical framework to investigate how chain restaurants can strategically use central kitchens to improve food quality consistency and optimize relevant decisions in the presence of central kitchens. Our findings underscore the critical role of consumer sensitivity to quality inconsistency in shaping pricing and service decisions. In particular, by introducing a central kitchen, restaurateurs can better coordinate its pricing and quality control decisions, enabling them to better serve quality-inconsistency-sensitive customers. Our results reveal that central kitchens not only act as an effective way to reduce quality dispersion across locations but also enable firms to effectively implement partial or full market coverage strategy, depending on the level of quality sensitivity.

We further extend our analysis by incorporating customer congestion, variable cost structures and central kitchen location choices. Notably, we find that the negative impact of quality inconsistency on firm profitability persists regardless of congestion effects, reinforcing the value of investment in consistency-enhancing infrastructure. The introduction of variable cost reveals a non-monotonic relationship between cost sensitivity and central kitchen profitability, while the location-dependent cost function highlights the nuanced role of logistics planning in backend operations.

This research can be extended as follows: First, it would be interesting to generalize our model by considering multiple (more than) two outlets and examine the robustness of our findings in the general setting. Second, in practice, it is necessary to keep some inventories of semi or fully cooked dishes, procured from a central kitchen, in the storefront kitchen. Then, another interesting topic is to jointly optimize the inventory and pricing decisions and examine the corresponding market coverage strategies.

Supplementary material

The supplementary material for this article can be found online.

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