Firms proactively search for low-cost production locations to enjoy cost-based advantages. In this paper, we develop a two-stage stochastic program to study a firm’s capacity investment and production decisions about the exploration of new production locations. In the first stage, the firm determines how much capacity to build at the new location, and in the second stage, after the product demand and the production cost at the new location have been observed, the firm determines the optimal production quantities. We first characterize the firm’s optimal decisions and then examine how the optimal capacity level and firm profit are affected by the key parameters. We find that the firm may be better off when either the production cost or the demand is more variable. Using numerical analyses, we also investigate the value of retaining the existing location, and our results demonstrate that retaining the existing location obtains the highest value when the market size is large, the consumers are insensitive to price, the market demand is highly uncertain, or the variability of the production cost at the new location is either sufficiently high or sufficiently low. Finally, we extend our baseline setting in two directions: one in which the firm makes the production decision prior to demand realization, and the other in which there is a finite capacity at the existing location. For both extensions, we demonstrate the robustness of the results obtained for the baseline setting.

Key words: Capacity investment, demand uncertainty, cost uncertainty, price-dependent demand, new production location

1. Introduction

Companies large and small have increasingly and proactively moved their production facilities to low-cost locations in search of a cost based comparative advantage. While Japan took up much of the manufacturing capacity in the 1970s and 1980s, and Korea and Taiwan followed soon after, China became “the world’s factory” some 20 years ago and continues to be a major source of manufactured goods (Gereffi and Lee 2012). However, as large as it is, even China is becoming less cost competitive as its economy develops and wages rise, so we see factories moving from China to other Southeast Asian countries, such as Bangladesh, Vietnam and Myanmar (OECD 2014).

Indeed, the lower wages and growing labor supply in Southeast Asia are attracting companies to shift their production from China. Examples abound. H&M, a European fashion retailer, recently moved its sweater production from China to Myanmar (The Economist 2015). Microsoft plans to shift some of its Nokia production to Vietnam (Nakamura 2015). Even some Chinese manufacturers are moving their production
to their Asian neighbors. Lever Style Inc., for instance, began moving apparel production for Japanese retail chain Uniqlo from Shenzhen, China to Vietnam (Chu 2013).

A critical challenge of producing in a new location is that there are various uncertain factors, which make it difficult to estimate the overall production cost. Much empirical evidence suggests that the true cost of production in Southeast Asia is unclear. The McKinsey Global Institute reported that the import/export costs are 24% higher in ASEAN (Association of Southeast Asian Nations) countries than in China and that the region’s customs procedures are 66% longer than the OECD average (Woetzel, Tonby, Thompson, Burtt, and Lee 2014). The mediocrity of the infrastructure (e.g., roads and power supplies), compared with that of China, also adds costs. All of these issues, when factored into the production cost formula of the new region, result in a great degree of cost uncertainty.

There are several other challenges facing firms at the verge of reorganizing their production resources. Most notably, there are multiple intertwined decisions to be considered in the firm’s decision-making process: the capacity has to be installed prior to production, and the installed capacity poses a limit on the production volume. In addition, uncertain market conditions and changing consumer preferences have led to increasingly volatile demand. As capacity choice is a strategic, long term decision, firms must make capacity investment decisions before they have a good understanding of the market demand (Goyal and Netessine 2007, Anupindi and Jiang 2008).

When exploring new production locations, a high-level question facing the firm is whether to retain the existing locations. Retaining an existing location may incur a cost, but on the other hand, it benefits the firm as it offers an alternative option for production. Therefore, firms must strike a balance between the costs and benefits of retaining the existing location. Such a trade-off can be complicated given the complex intertwined decisions and the highly uncertain market and operating conditions. In practice, firms have adopted different strategies. Some firms choose to retain their existing locations, while others decide to move the entire production to the new location. For example, Goertek, Apple’s assembler for AirPods, used the non-retaining strategy and moved the entire production of the wireless earphones from China to Vietnam. Taiwanese officials revealed that almost 30 enterprises had abandoned China and relocated to Taiwan (Cheng and Li 2018). Other companies use the retaining strategy. For example, the Japanese motor supplier Nidec will move some production out of China, joining Panasonic and other companies in an exodus to Southeast Asia and Mexico (Nikkei 2018).

In this paper, we study a firm’s decisions about the exploration of new production locations. Specifically, we are interested in the following research questions that are frequently encountered by firms operating on cost-based advantages: (i) What are the firm’s optimal capacity and production decisions when exploring new production locations? (ii) How are the firm’s optimal capacity and profitability affected by the cost and demand uncertainty? (iii) What is the value of retaining the existing production location, and how does this value depend on the product price elasticity, market size, demand uncertainty, and cost uncertainty?
To answer the above questions, we build a stylized two-stage stochastic programming model for our baseline setting in which the firm first determines how much capacity to build in the new location, and after the production cost and demand are observed, the firm then determines how much to produce in the available location(s). We first consider a benchmark model, where the firm relies on the new location only, and then study our focal model (i.e., the retaining model), where the firm retains its existing location and can thus use both the new and existing locations for production purposes. This paper considers a price-dependent demand, which enables us to study the impacts of the market conditions on the firm’s operational decisions. We begin by characterizing the optimal capacity and production decisions and proceed to study how the optimal decisions and the firm profits are affected by the demand and cost uncertainty. We then compare the firm’s profits under the two scenarios to quantify the value of retaining the existing facility, and further conduct a sensitivity analysis of this value with respect to the market size, price elasticity, demand uncertainty and cost uncertainty.

The main results of this paper are summarized as follows. First, both the firm’s profit and capacity investment at the new location increase when either the demand or production cost becomes more variable. The intuition of this result is that the firm can adapt its production decisions to the realized demand and production cost. As a result, the firm can enjoy the benefits from low-cost and high-demand scenarios and simultaneously mitigate the disadvantages arising from high-cost and low-demand scenarios. Second, the value of retaining the existing location increases as the market size increases or as the price elasticity decreases. Furthermore, the value increases with an increase in the demand variability, and first decreases and then increases with an increase in the cost variability. These results suggest that retaining the existing location obtains the highest value in an environment characterized by a large market size, low price elasticity, high demand uncertainty, and either stable or volatile production costs.

In our baseline setting, the firm makes the production decisions after observing the market demand. This is in line with the capacity investment literature (Fine and Freund 1990, Harrison and Van Mieghem 1999, Bish and Wang 2004, Goyal and Netessine 2007), and is appropriate when the production time is relatively short so that the firm is well-informed about the demand at the time of production. In addition, the baseline model considers a sufficiently large (or infinite) capacity at the existing location. To examine the robustness of our results, we study two extensions. In the first extension, we consider an alternative setting where the firm first determines the capacity at the new location, then after knowing the production cost, the firm determines the production decision, and finally when the product demand is known, the firm determines the optimal price charged to the consumers. In the second, we consider a finite capacity at the existing location. In both extensions, we show that our key results remain structurally unchanged, demonstrating the robustness of the results obtained for the baseline setting.

We make two main contributions to the literature. First, to the best of our knowledge, this paper is among the first to study a firm’s decisions about the exploration of new production locations. In doing so, we incorporate several key features of the problem, including the cost and demand uncertainty and price-dependent
demand. Our model represents an extension of the existing models in capacity management that tend to focus on the demand uncertainty only (see the literature review in Section 2). We analytically characterize the firm’s optimal production and capacity strategies, thereby providing an optimal course of actions for the firms seeking to explore new production locations. Second, our results reveal several insights that can be useful for managers. For example, we identify the market and operational conditions under which retaining the existing production facilities obtains the highest value. In addition, our sensitivity analysis provides some insights into how firms should adjust their capacity decisions when the market demand becomes more uncertain (given the fast-changing consumer preferences) or when the production costs at the new location become more transparent to the firms.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature, and Section 3 presents the research questions and formulates the model. We analyze the benchmark model and the retaining model in Section 4. In Section 5, we substantiate our analytical findings with numerical studies. Section 6 analyzes two extensions of our baseline model. Finally, in Section 7 we conclude the study and note the limitations of our model. All the proofs can be found in the Online Supplementary Document.

2. Literature Review

Our model is concerned with the capacity investment at a new production location, which involves the cost uncertainty and demand uncertainty. There is a large body of literature on capacity investment; see Van Mieghem (2003) for a comprehensive survey. Early papers in this area focus on the classic cost-flexibility tradeoff in flexible capacity investments. Fine and Freund (1990) study a single-product problem by formulating the manufacturing capacity investment decision as a two-stage stochastic program. In the first stage, the firm must make its investment decision for the manufacturing capacity before the uncertainty in the product demand is resolved. In the second stage, after the demand for the product is known, the firm implements its production decisions, which are constrained by the first stage investments. Harrison and Van Mieghem (1999) consider a multiproduct model that incorporates both the capacity investment and production decisions. Goyal and Netessine (2007) study the impact of competition on a firm’s choice of technology (product-flexible or product-dedicated). In their model, the firms make three decisions in the following sequence: choice of technology (the technology game), level of capacity investment (the capacity game), and amount of production (the production game).

In the context of capacity investment, firms may strategically delay the timing of the operational decisions. Several papers in the literature have analyzed the impacts of these operational strategies on a firm’s capacity investment decision. Van Mieghem and Dada (1999) study the value of the price and production postponement in a two-stage model in which the firm makes three decisions: capacity investment, production (inventory) quantity, and price. In a similar vein, Biller, Muriel, and Zhang (2006) study the effect of price decision postponement on the optimal investment in dedicated and flexible capacity when the flexible capacity can be shared among multiple products. Anupindi and Jiang (2008) extend the analysis to
a duopoly setting where the firms make decisions on the capacity, production, and price under demand uncertainty.

Another important consideration in this literature is the timing of the capacity investment. Dangl (1999) extends the real options literature to study an investment problem where a firm has to simultaneously determine the optimal investment timing and optimal capacity level. Wang, Ferguson, Hu, and Souza (2013) develop a dynamic capacity investment model in which a firm has access to two competing heterogeneous technologies. Motivated by the pharmaceutical industry, Kaminsky and Yuen (2014) study a multiperiod capacity investment problem where the future demand for a drug exhibits an all-or-nothing feature and the demand information is updated over time. Huisman and Kort (2015) consider investment decisions within a duopolistic framework and study both the capacity level and the timing of the capacity investment.

Notably, the above studies focus on the demand uncertainty only. In our context, however, the cost uncertainty is one of the key features of the new location exploration problem. There are several papers in the literature that consider the cost uncertainty (possibly among other uncertainties) such as Shum, Tong, and Xiao (2017) and Christen (2005). However, they consider quite different problems: Shum, Tong, and Xiao (2017) study the impact of an uncertain cost reduction on a firm’s pricing decision when selling to strategic customers; and Christen (2005) examines the optimal acquisition of information about a common uncertain cost factor by two competing firms seeking to price a new product. As a result, the insights derived in these papers can hardly provide useful insights into a firm’s capacity and production strategies in the context of new location exploration.

Our paper is also loosely related to the extensive literature on sourcing/outsourcing strategies (see, e.g., Treleven and Schweikhart 1988, Kouvelis 1999, Kouvelis and Milner 2002, Burke, Carrillo, and Vakharia 2007, 2009). An excellent survey of this literature is given by Tsay, Gray, Noh, and Mahoney (2018). A closely related paper is the study by Shunko, Debo, and Gavirneni (2014). In their model, the inhouse production cost is fixed while the outsourcing cost incurred for the supplier is random. Although this is similar to our model as we also consider a random cost at the new location and a deterministic cost at the existing location, their focus is on the role of transfer pricing in a firm’s outsourcing strategy. In general, this literature does not consider the firm’s capacity investment decision, and we make a contribution by adding one more stage where the firm must determine how much capacity to build at the new location and this capacity imposes an upper limit on the production quantity.

3. Problem Description and Model Formulation

Throughout this paper, we use the following notation system. A realization of a random variable, \( \tilde{\xi} \), is denoted by \( \xi \), and its expectation and standard deviation are denoted by \( \mu_\xi \) and \( \sigma_\xi \), respectively. The notation \((z)^+\) denotes \( \max(z, 0) \), and \( \mathbb{E}[f(\cdot)]\) denotes the expectation of function \( f(\cdot) \) over the underlying random variables. The terms ‘increase’ and ‘decrease’ are used in a weak sense.
We consider a situation in which a firm plans to manufacture a product for future sale in a consumer market. The firm has some production capacity at the existing location (e.g., China) that can be used to make the product, but would also like to explore new production locations and build some new capacity there (e.g., Southeast Asia). In our baseline setting we focus on situations where the capacity at the existing location is large enough so that the firm does not face a supply shortage problem even when not building any new capacity. In Section 6, we relax this assumption by considering a finite capacity at the existing location.

Since the firm has been operating at the existing location, it is well informed about the operational environment there and thus knows the production cost (denoted by \( c_e \geq 0 \)). In contrast, a facility is not yet built at the new location, and as discussed in the Introduction, there are a number of uncertain factors that may influence the overall production cost there (Woetzel et al. 2014). Thus, it is prudent to assume that there is uncertainty about the production cost at the new location. Similar assumptions have been made in various contexts, such as for technology investments (Van Mieghem 1998) and dual-sourcing (Shunko, Debo, and Gavirneni 2014, Jain and Hazra 2017). Let \( \tilde{c} \) denote the production cost at the new location, which follows a probability distribution with a pdf of \( g(c) \) and a cdf of \( G(c) \) over the finite support \([\underline{c}, \bar{c}]\) where \( \underline{c} < \bar{c} \). We also assume that \( \mu_c < c_e \) to reflect the lower (average) production cost at the new location. Let \( c_m \) be the unit capacity cost. The firm needs to determine how much capacity to build at the new location. We denote by \( K \) the installed capacity at the new location. This capacity imposes a maximum limit on the production quantity.

On the demand side, we consider a price-dependent demand to capture the consumer response to the firm’s price. Specifically, at a price \( p \) of the product, the demand function is given by \( D(p) = d(p) + \tilde{\epsilon} \), where \( d(p) = a - \gamma p \) is the deterministic component of the demand and \( \tilde{\epsilon} \) denotes the additive random demand shock. We can interpret \( a > 0 \) as the market size and \( \gamma > 0 \) as the price elasticity. This demand function has been widely adopted in the operations and economics literature (see, e.g., Biller, Muriel, and Zhang 2006, Popescu and Seshadri 2013). The demand shock reflects the fact that at the time of the capacity investment, the firm does not know the actual product demand because capacity choice must be made well in advance (Anupindi and Jiang 2008). While the firm has some knowledge about the demand in a short term, it may face significant uncertainty in the long term when the new capacity becomes available for use. Suppose that \( \tilde{\epsilon} \) follows a distribution with pdf \( f(\epsilon) \) and cdf \( F(\epsilon) \) over the finite support \([\underline{\epsilon}, \bar{\epsilon}]\), where \( \underline{\epsilon} < \bar{\epsilon} \). Given a realized demand shock, \( \epsilon \), the inverse demand function is given by \( p = \frac{1}{\gamma}(a - \epsilon + \epsilon) \). Therefore, there is a one-to-one mapping between the price and the demand. It is convenient to work with quantities, so we will optimize the firm’s production quantity, and the price will be determined accordingly once a production quantity is chosen.

The firm faces uncertain demand and uncertain production cost when making the capacity decision at the new location, but it knows the demand and production cost when making the production decision. This
is a reasonable assumption in the capacity management literature because the capacity investment tends to be a strategic decision, while the production quantity tends to be an operational decision that is made once the operating environment is relatively familiar (Fine and Freund 1990, Harrison and Van Mieghem 1999, Bish and Wang 2004, Goyal and Netessine 2007). This fits a setting where the production time is relatively short so that the firm does not face any uncertainty in demand at the time of production. Section 6 considers an alternative setting in which the firm first determines the capacity level in the new location, then after observing the production cost of the new location, the firm determines the production quantities in the new and existing locations, and finally after the market demand is realized, the firm determines the price charged to the consumers. We also consider that the demand and production cost are independent because their contributing factors seem to be unrelated; the production cost is usually determined by various inputs such as labor costs, machine operating costs, electricity prices and overheads, while the demand for the product is mainly determined by consumer preferences, competition from rivals, production upgrades, etc. We note that the characterization of the optimal capacity and production quantity does not require this assumption of independence.

Consistent with the practical observations, we examine two scenarios of the firm’s problem. In the benchmark model, the firm does not retain the existing location and uses the new location only. In the retaining model, the firm retains the existing location while exploring a new one. The sequence of events for the benchmark model is as follows. First, the firm determines how much capacity to build at the new location. Second, the demand and production cost at the new location are realized. Third, the firm determines how much to produce at the new location. Fourth, the new production facilities start production. Finally, the firm sells the products in the consumer market. The sequence of events for the retaining model differs only in the third step, where the firm needs to determine how many products to produce at both the new and existing locations.

To avoid triviality, we make the following technical assumptions throughout the paper.

**Assumption 1.** We assume: (i) \( a + \varepsilon > \gamma \max(c_e, c_m + \bar{c}) \); (ii) \( \bar{c} < c_e < \bar{c} \); and (iii) \( \bar{c} - \varepsilon > \gamma (\bar{c} - c) \).

The first assumption ensures that the profit margin of the firm is always positive regardless of the firm’s production and capacity strategies. The second assumption is that the highest (resp. lowest) cost at the new location is greater (resp. smaller) than that of the existing location. The third assumption is that the range of \( \bar{c} \) is greater than that of \( \bar{c} \) after the adjustment based on \( \gamma \). The latter two conditions together imply that \( \bar{c} - \varepsilon > \gamma (\bar{c} - c) \).\(^1\)

\(^1\) We have examined an alternative case where \( \bar{c} - \varepsilon < \gamma (c_e - c) \). For this case, we find that only the conditions for two of the five cases in the proofs of Lemma 1 and Lemma 2 are different, but this difference does not change the properties of the objective functions that are used to characterize the optimal capacity levels and profits. Thus, this assumption is inconsequential to our findings.
4. Model Analysis
In this section, we first characterize the optimal capacity and production decisions under each model and then study the effects of key parameters on the optimal capacity and profit.

4.1. The Benchmark Model
In the benchmark model the firm does not retain the existing production location. Following the standard backward induction approach, we start with the firm’s production problem and then examine the firm’s capacity investment strategy.

4.1.1. The Production Strategy
Given a fixed capacity, $K$, at the new location, the firm’s production problem is to maximize its profit by choosing the optimal production quantity, $q_n$, subject to the capacity constraint. Note that at the production stage, the capacity investment cost is sunk. For a realized demand shock, $\epsilon$, and production cost, $c$, we formulate the firm’s production optimization problem as follows:

$$\max_{0 \leq q_n \leq K} \pi_2^n(q_n) = \frac{1}{\gamma} (a + \epsilon - q_n)q_n - cq_n.$$  

The first term of the objective function is the firm’s revenue and the second term is the production cost. Solving the above problem yields the following result.

**Proposition 1 (Optimal production).** Under the benchmark model, for a given $K$, we obtain:

(i) The firm’s optimal production amount at the new location is $q_n^*(K, c, \epsilon) = \min \left( \frac{a + \epsilon - \gamma c}{2}, K \right)$.

(ii) The firm’s optimal profit (excluding capacity cost) is

$$\Pi_2^n(K, c, \epsilon) = \begin{cases} \frac{(a+\epsilon-\gamma c)^2}{2}, & \text{if } a + \epsilon - \gamma c \leq 2K, \\ \frac{K(a+\epsilon-\gamma c)}{\gamma}, & \text{if } a + \epsilon - \gamma c > 2K. \end{cases}$$

Proposition 2 characterizes the optimal production quantity and profit for the production stage. The optimal production quantity is the minimum of the stationary point and the installed capacity. It can be readily shown that the optimal production quantity and profit increase with an increase in the market size and realized demand but decrease with an increase in the price elasticity and production cost.

Based on the optimal production quantity, we obtain the corresponding price in the following corollary.

**Corollary 1.** Under the benchmark model, for a given $K$, the firm’s optimal pricing decision is given by $p^n(K, c, \epsilon) = \frac{1}{\gamma} \max \left( \frac{a+\epsilon+\gamma c}{2}, a + \epsilon - K \right)$.

The overall message of the above proposition and corollary is that the firm responds to the demand and the production cost at the new location by choosing an appropriate production quantity or price. This finding, despite being intuitive and simple, reveals an important insight: the firm has production/price flexibility in response to the realized market and operational conditions, which proves to be beneficial to the firm, as we will show in Section 5.
4.1.2. The Capacity Investment at the New Location

We now analyze the firm’s capacity investment problem. Anticipating the optimal production decision for a given capacity level, the firm aims to maximize its expected profit by choosing an optimal capacity investment level. The firm’s capacity optimization problem is formulated as follows:

$$\max_{K \geq 0} \pi_1^n(K) = \mathbb{E}[\Pi_2^n(K, \tilde{c}, \tilde{\epsilon})] - c_m K, \quad (2)$$

where the expectation is taken over $\tilde{c}$ and $\tilde{\epsilon}$ and $\Pi_2^n(K, \tilde{c}, \tilde{\epsilon})$ is given in Proposition 1. The first term of $\pi_1^n(K)$ represents the firm’s optimal expected profit in the production stage, and the second term represents the capacity cost.

We start by examining the property of the objective function.

**Lemma 1.** Under the benchmark model, the firm’s objective function $\pi_1^n(K)$ is strictly concave in $K$ for $K \leq \frac{a + \tilde{\epsilon} - \gamma c}{2}$ and is linearly decreasing in $K$ for $K > \frac{a + \tilde{\epsilon} - \gamma c}{2}$. Further, $\pi_1^n(K)$ is smooth and globally concave.

The above lemma shows that the optimization problem is well-behaved, which enables us to use the first order condition to characterize the optimal capacity. Solving the problem in (2), we obtain the following result.

**Proposition 2 (Optimal capacity).** Under the benchmark model, the firm’s optimal capacity at the new production location is $K^n = 0$ if $\mathbb{E}[(a + \tilde{\epsilon} - \gamma \tilde{c})^+] < \gamma c_m$ and $K^n = \bar{K}$ otherwise, where $\bar{K} \in [0, \frac{a + \tilde{\epsilon} - \gamma c}{2})$ is the unique solution to the following equation

$$\mathbb{E}[(a + \tilde{\epsilon} - 2K - \gamma \tilde{c})^+] - \gamma c_m = 0. \quad (3)$$

The firm’s optimal profit is given by $\Pi^n = \pi_1^n(K^n)$.

Proposition 2 characterizes the optimal capacity choice and profit under the benchmark model. We show that when the capacity cost is high, the firm does not build any capacity at the new location, but when the capacity cost is not prohibitively high, the firm chooses a capacity level that equates the marginal benefit of the capacity investment and the marginal cost. The proposition also shows that the optimal capacity level does not exceed $\frac{a + \tilde{\epsilon} - \gamma c}{2}$, which is the optimal capacity for the best possible scenario with the highest demand realization and lowest cost realization.

While the explicit expression of optimal capacity is not available, we can carry out the sensitivity analysis with respect to some of the key parameters. The next result concerns how the optimal capacity, the profit and production quantity evaluated at the optimal capacity change with the market size, price elasticity and capacity cost.
Corollary 2 (Effects of $a$, $\gamma$ and $c_m$). $K^n$, $\Pi^n$, and $q^n_m(K^n)$ all increase in $a$ but decrease in $\gamma$ and $c_m$.

Corollary 2 shows that both the optimal capacity and the firm’s optimal profit increase as the market size increases, but decrease as either the price elasticity or the capacity cost increases. The same effects of these parameters are also true for the optimal production quantity evaluated at the optimal capacity. The intuition is that there are a direct effect of these parameters on the production quantity (for any given capacity) and an indirect effect through the influence of these parameters on the optimal capacity. Since the direct and indirect effects are aligned, the production quantity increases as the market size increases, the consumers are less price sensitive, or the capacity cost decreases.

Next we draw on the stochastic order theory to examine how the optimal capacity level changes with the demand and cost uncertainties. For convenience, let us first define some notation. Let $\xi_1$ and $\xi_2$ be a pair of random variables following different distributions and the corresponding optimal capacity levels are denoted by $K^n_{\xi_1}$ and $K^n_{\xi_2}$, where $\xi_1$ and $\xi_2$ represent the demand or cost variables. In addition, we write $\xi_1 \leq_{st} \xi_2$ to indicate that $\xi_1$ is smaller than $\xi_2$ in the stochastic order sense, and write $\xi_1 \leq_{cx} \xi_2$ to indicate that $\xi_1$ is smaller than $\xi_2$ in the convex order sense.

Corollary 3 (Effects of demand and cost uncertainties). Suppose the demand and production cost are independent. We obtain: (i) If $\bar{\epsilon}_1 \leq_{st} \bar{\epsilon}_2$, then $K^n_{\epsilon_1} \leq K^n_{\epsilon_2}$; (ii) if $\bar{\epsilon}_1 \leq_{st} \bar{\epsilon}_2$, then $K^n_{\epsilon_1} \geq K^n_{\epsilon_2}$; (iii) if $\bar{\epsilon}_1 \leq_{cx} \bar{\epsilon}_2$, then $K^n_{\epsilon_1} \leq K^n_{\epsilon_2}$; and (iv) if $\bar{\epsilon}_1 \leq_{cx} \bar{\epsilon}_2$, then $K^n_{\epsilon_1} \leq K^n_{\epsilon_2}$.

The above corollary establishes the monotonicity properties of the optimal capacity with respect to the demand and cost uncertainty. To make the comparison results more concrete, we consider two specific types of distribution: uniform distribution and normal distribution. If two uniform variables have different supports but their supports have the same length, or if two normal variables have different means but the same variance, then we can conclude that one variable is smaller than the other in the stochastic order sense; similarly, if two uniform variables have the same mean but their supports have different lengths, or two normal variables have the same mean but different variances, then we can conclude that one variable is smaller than the other in the convex order sense (Müller and Stoyan 2002, p. 62-63). This, together with Corollary 3, implies that if the average demand increases or the average cost decreases (with the variability unchanged), the firm will build more capacity in the new location. Also, if the demand or cost variability increases (with the average unchanged), the firm will build more capacity in the new production location.

4.2. The Retaining Model

For the retaining model, the firm can use both the existing and new locations for production. We start with the second stage’s production problem, and then, anticipating the optimal production decision in the second stage, we examine the firm’s capacity investment decision at the new location.
4.2.1. The Production Strategy
In this stage, the firm’s capacity investment is sunk, and the firm knows the product demand and production cost at the new location. For a given capacity $K$ at the new location and for a realized demand $\epsilon$ and cost $c$, the firm aims to maximize its total profit by determining how much to produce at each location.

Denote by $q_n$ and $q_e$ the production quantities at the new and existing locations, respectively. We formulate the firm’s production optimization problem as follows:

$$\max_{0 \leq q_n \leq K, q_e \geq 0} \pi^r_2(q_n, q_e) = \frac{1}{\gamma} (a - (q_n + q_e) + \epsilon) (q_n + q_e) - c_e q_e - cq_n. \quad (4)$$

The first term of the objective function is the firm’s revenue, and the second and third terms are the production costs at the existing and new locations, respectively. Solving the above problem yields the following results.

**Proposition 3 (Optimal production).** Under the retaining model, for a given $K$, we obtain:

(i) The firm’s optimal production amounts at the new and existing production locations are

$$ (q^*_n, q^*_e) = \begin{cases} (K, \frac{a + \epsilon - \gamma c_e}{2} - K), & \text{if } (c, \epsilon) \in \Omega_1, \\ (K, 0), & \text{if } (c, \epsilon) \in \Omega_2, \\ \left(\frac{a + \epsilon - \gamma c_e}{2}, 0\right), & \text{if } (c, \epsilon) \in \Omega_3, \\ \left(0, \frac{a + \epsilon - \gamma c_e}{2}\right), & \text{if } (c, \epsilon) \in \Omega_4, \end{cases}$$

where

$$\Omega_1 = \{(c, \epsilon) : c_e \geq c, -a + \gamma c_e + 2K < \epsilon \leq \bar{\epsilon}\},$$
$$\Omega_2 = \{(c, \epsilon) : c_e \geq c, -a + \gamma c + 2K < \epsilon \leq -a + \gamma c_e + 2K\},$$
$$\Omega_3 = \{(c, \epsilon) : c_e \geq c, \epsilon \leq \epsilon \leq -a + \gamma c + 2K\},$$
$$\Omega_4 = \{(c, \epsilon) : c_e < c, \epsilon \leq \epsilon \leq \bar{\epsilon}\}.$$  

(ii) The firm’s optimal profit (excluding capacity cost) is

$$\Pi^r_2(K, c, \epsilon) = \begin{cases} \frac{(a + \epsilon - \gamma c_e)^2}{(a - \frac{\epsilon - \gamma c}{\gamma}) K} + (c_e - c) K, & \text{if } (c, \epsilon) \in \Omega_1, \\ \frac{(a + \epsilon - \gamma c)^2}{a - \frac{\epsilon - \gamma c}{\gamma} K}, & \text{if } (c, \epsilon) \in \Omega_2, \\ \frac{(a + \epsilon - \gamma c)^2}{a - \frac{\epsilon - \gamma c}{\gamma}}, & \text{if } (c, \epsilon) \in \Omega_3, \\ \frac{(a + \epsilon - \gamma c_e)^2}{a - \frac{\epsilon - \gamma c_e}{\gamma}}, & \text{if } (c, \epsilon) \in \Omega_4. \end{cases}$$

Proposition 3 characterizes the firm’s optimal production quantities and optimal profit when the existing location is retained. When the production cost at the new location is higher than that at the existing location (i.e., $\Omega_4$), the firm will only use the existing location because there is no capacity limit. Otherwise, the firm may only use the new location or use both locations. Specifically, depending on the realized demand, there are three possible production strategies. When the realized demand is high (i.e., $\Omega_1$), the firm may not have enough capacity at the new location and hence must produce some products at the existing location as well.
In this case, the firm will produce an amount $K$ at the new location and an amount $\frac{a+\epsilon-\gamma c_e}{2} - K$ at the existing location. When the realized demand is medium (i.e., $\Omega_2$), the firm produces an amount $K$ at the new location and does not engage in any production at the existing location. When the realized demand is small (i.e., $\Omega_3$), the firm produces an amount $\frac{a+\epsilon-\gamma c}{2}$ at the new location only, which is less than the capacity $K$.

The above results reveal that the existing location is used for production when the realized production cost at the new location is high (i.e., $\Omega_4$), or when the realized demand is high even if the production cost at the new location is low (i.e., $\Omega_1$). As such, retaining the existing location provides a distinctive advantage to the firm: it not only helps to reduce production costs but also fills some demand that would otherwise be left unmet. In Subsection 5.2 we will quantify the magnitude of this advantage, and study how it is affected by various parameters.

The following corollary follows directly from Proposition 3, which gives the total production quantity and the optimal price charged to consumers.

**Corollary 4.** Under the retaining model, for a given $K$, the firm’s total production quantity is given by

$$Q(K) = \max \left( \frac{a+\epsilon-\gamma c_e}{2}, \min \left( \frac{a+\epsilon-\gamma c}{2}, K \right) \right),$$

and the optimal price is given by

$$p^r = \frac{1}{\gamma} \min \left( \frac{a+\epsilon+\gamma c_e}{2}, \max \left( \frac{a+\epsilon+\gamma c}{2}, a+\epsilon - K \right) \right).$$

Using the results in the above corollary, we can write the firm’s optimal profit compactly:

$$\Pi_2^r(K) = \frac{1}{\gamma}(a - Q + \epsilon - c_e)Q + (c_e - c)^+ \cdot \min \left( \frac{a+\epsilon-\gamma c_e}{2}, K \right),$$

where the expression of $Q$ is given in Equation (5). This enables us to dissect two components of the firm’s profit. The first term is the firm’s profit if it were to only use the existing production location to produce the total amount of $Q$ products. Note that $Q$ is a function of $K$, so the new capacity installed at the new location may affect the total production quantity. The second term is cost saved due to the availability of production capacity at the new location, which also depends on the new capacity. These represent two distinctive effects of the capacity at the new location on the firm’s profit, which we will discuss in the next subsection.

**4.2.2. The Capacity Investment at the New Location** Now we consider the firm’s capacity investment decision for the retaining model, which is formulated as follows:

$$\max_{K \geq 0} \pi_1^r(K) = \mathbb{E} [\Pi_2^r(K, \bar{c}, \bar{\epsilon})] - c_m K,$$

where the expectation is taken over $\bar{c}$ and $\bar{\epsilon}$ and $\Pi_2^r(K, \bar{c}, \bar{\epsilon})$ is given in Proposition 3. The first term of the objective function is the expected profit in the production stage (excluding the capacity cost), and the second term gives the capacity cost incurred at the new production location.

Before determining the optimal capacity, we first examine the property of $\pi_1^r(K)$. 
Lemma 2. Under the retaining model, the firm’s objective function $\pi^r_1(K)$ is linear in $K$ for $K \in [0, \frac{a+\bar{e}-\gamma c}{2}]$, strictly concave in $K$ for $K \in (\frac{a+\bar{e}-\gamma c}{2}, \frac{a+\bar{e}-\gamma c}{2}]$, and linearly decreasing in $K$ for $K \in (\frac{a+\bar{e}-\gamma c}{2}, +\infty)$. Further, $\pi^r_1(K)$ is smooth and globally concave.

Similar to Lemma 1, this lemma establishes the concavity of the objective function, which allows us to use the first order condition to characterize the optimal capacity under the retaining model. Define $\mathbb{I}\{\cdot\}$ as an indicator function, which takes the value of 1 if the conditions in the bracket are satisfied and zero otherwise. Solving the capacity investment problem in Equation (20), we obtain the following result.

Proposition 4 (Optimal capacity). Under the retaining model, the firm’s optimal capacity is $K^r = 0$ if $\mathbb{E}[(c_e - \bar{c})^+] < \gamma c_m$ and $K^r = \hat{K}$ otherwise, where $\hat{K} \in (\frac{a+\bar{e}-\gamma c}{2}, \frac{a+\bar{e}-\gamma c}{2})$ is the unique solution to the following equation

$$
\mathbb{E}[(a + \bar{e} - 2K - \gamma \bar{c})^+ \cdot \mathbb{I}\{\bar{c} \leq c_e, \bar{c} \leq -a + \gamma c_e + 2K\} + \gamma (c_e - \bar{c})^+ \cdot \mathbb{I}\{\bar{c} \geq -a + \gamma c_e + 2K\}] - \gamma c_m = 0. \quad (9)
$$

The firm’s optimal profit is given by $\Pi^r = \pi^r_1(K^r)$.

Proposition 4 characterizes the optimal capacity choice at the new location. We know that the optimal capacity depends on the marginal benefit and the marginal cost of the capacity. Based on Equation (7), the marginal benefit of investing in capacity at the new location is as follows:

$$
\frac{d\pi^r_1(K)}{dK} = \frac{1}{\gamma} \mathbb{E}\left[\begin{array}{c}
(a + \bar{e} - 2K - \gamma \bar{c})^+ \cdot \mathbb{I}\{\bar{c} \leq c_e, \bar{c} \leq -a + \gamma c_e + 2K\} + \\
\gamma (c_e - \bar{c})^+ \cdot \mathbb{I}\{\bar{c} \geq -a + \gamma c_e + 2K\}\end{array}\right].
$$

The above equation shows that there are two positive effects of capacity investment at the new location. First, capacity investment at the new location may lead to an increase in demand (termed the demand enhancement effect); when the realized cost at the new location is lower, this lower cost translates into a lower price, which in turn leads to a higher demand. Second, the capacity investment may save production costs in terms of the production that would otherwise take place at the existing location (termed the cost saving effect). To determine the optimal capacity level, the firm compares the overall benefit with the capacity cost. When the capacity cost is high, the firm will not build any capacity at the new location; otherwise, the firm will build the amount of capacity that equates the marginal benefit with the capacity cost. When it is economically justifiable to build some capacity, the firm will choose a capacity level that lies in the interval $[\frac{a+\bar{e}-\gamma c}{2}, \frac{a+\bar{e}-\gamma c}{2}]$. Note also that, unlike the benchmark model, the condition for not building any capacity does not depend on the market size under the retaining model. This is because the production is postponed until the demand is realized and the firm can always use the existing location for production (so the new location can be regarded as an additional source of production). In Section 6, we show that when the production decision must be made before demand realization, the condition for not building any capacity does depend on the market size.
Similar to Proposition 2, we cannot give an explicit form of the optimal capacity under the retaining model. Despite this challenge, we can perform some sensitivity analysis, and the following corollary shows how the optimal capacity, the optimal profit and the total production quantity evaluated at the optimal capacity change with the market size, price elasticity and capacity cost.

**Corollary 5** (Effects of \(a, \gamma\) and \(c_m\)). \(K^r\), \(\Pi^r\) and \(Q(K^r)\) all increase in \(a\), but decrease in \(\gamma\) and \(c_m\).

The results in Corollary 5 are consistent with those in Corollary 2. We note that the analytical analysis is not amenable for the effects of the demand and cost uncertainty due to the complexity of Equation (9). Thus, we will resort to numerical studies to address this problem in Section 5.

Finally, it is useful to make some comparisons between the optimal capacity and profit under the benchmark model and those under the retaining model.

**Corollary 6.** \(K^r \leq K^n\) and \(\Pi^r \geq \Pi^n\).

As expected, the firm builds more capacity in the new location when the existing location is not retained. Additionally, the firm’s profit is higher when the existing location is retained.

### 5. The Numerical Study

In this section, we complement the analytical results with an extensive numerical study. The focus of the numerical study is two-fold. First, we conduct a sensitivity analysis of the firm’s optimal capacity and profit with respect to the demand and cost uncertainty. Second, we study how the value of retaining the existing location changes with respect to key parameters. As a convention, all the numerically derived results in this section are stated as observations.

For the numerical analyses, we assume that the demand and the production cost at the new location each follow a doubly truncated normal distribution. The truncation is needed because the cost and demand values are drawn from an interval, and in particular, the cost values cannot be negative. A truncated normal distribution is commonly used to represent a positive random variable (see, e.g., Jordan and Graves 1995, Perakis and Roels 2008).

Suppose the production cost at the new location, \(\tilde{c}\), follows a doubly truncated normal distribution where the base normal distribution with a mean \(\mu_c\) and a standard deviation \(\sigma_c\) is truncated symmetrically at \(\underline{c} := \mu_c - \delta_c\) and \(\bar{c} := \mu_c + \delta_c\). Therefore, the distribution of \(\tilde{c}\) is characterized by the parameters \(\mu_c\), \(\sigma_c\) and \(\delta_c\). Formally, the pdf of the truncated normal distribution is given by

\[
g(c) = \frac{g_o(c)}{\int_{\underline{c}}^{\bar{c}} g_o(z) \, dz},
\]

where \(g_o(\cdot)\) is the pdf of the base normal distribution \(\mathcal{N}(\mu_c, \sigma_c^2)\). Similarly, the demand shock \(\tilde{\epsilon}\) follows a doubly truncated normal distribution where the base normal distribution with a mean \(\mu_e\) and a standard
deviation $\sigma_c$ is truncated symmetrically at $\epsilon := \mu_c - \delta_c$ and $\bar{\epsilon} := \mu_c + \delta_c$. The pdf of the truncated normal distribution is given by

$$f(\epsilon) = \frac{f_o(\epsilon)}{\int_{\bar{\epsilon}}^{\epsilon} f_o(z) \, dz},$$

where $f_o(\cdot)$ is the pdf of the base normal distribution $\mathcal{N}(\mu_c, \sigma_c^2)$. According to Khasawneh, Bowling, Kaewkuekool, and Cho (2005), the variance of the doubly truncated normal distribution increases with the deviation of the upper/lower bound from the mean as well as with the standard deviation of the base normal distribution. Thus, we use both $\delta_c$ and $\sigma_c$ to represent the variability of $\bar{c}$. Similarly, we use $\delta_{\bar{\epsilon}}$ and $\sigma_{\bar{\epsilon}}$ to represent the variability of $\bar{\epsilon}$.

Although this section reports the findings based on truncated normal distributions, we have also tested the findings using uniform distributions and found that the results remain the same structurally. To avoid repetition we do not include the results for the uniform distributions but will make them available upon request.

5.1. The Effects of the Demand and Cost Uncertainty on Capacity and Profit

We now examine how the optimal capacity and profit change with the demand and cost uncertainty under each model. To examine the effect of the cost uncertainty (measured by $\delta_c$ and $\sigma_c$), we use the following parameter values for our base scenario: $a = 100$, $\gamma = 1$, $c_e = 40$, $c_m = 5$, $\mu_c = 30$, $\mu_e = 0$, $\sigma_c = 40$, and $\delta_c = 30$.$^2$ Additionally, when measuring cost variability using $\delta_c$, we set $\sigma_c = 30$ and vary the value of $\delta_c$ from 1 to 30, that is, $\delta_c \in \{1, 2, \ldots, 29, 30\}$; when measuring cost variability using $\sigma_c$, we set $\delta_c = 20$ and vary the value of $\sigma_c$ from 1 to 30, that is, $\sigma_c \in \{1, 2, \ldots, 29, 30\}$. For each value of $\delta_c$ or $\sigma_c$ we solve for the optimal capacity and optimal profit under each model. The results are shown in Figures 1 and 2, from which we make some observations below.

**Observation 1 (Effects of Cost Variability).** $K^n$, $\Pi^n$, $K^r$ and $\Pi^r$ all increase in $\delta_c$ and $\sigma_c$.

As can be seen from Figures 1 and 2, the optimal capacity and profit increase in cost variability regardless of the measure used to represent cost variability. The reason why a greater variability of cost leads to a higher profit is because the firm can set the production quantity or price after the cost is realized. When the realized cost turns out to be high at the new location, the firm can choose to cut down production (under both the benchmark and retaining models), and/or uses the existing production facilities for production (under the retaining model). As a result, the firm can mitigate the negative effects of high-cost realizations, but at the same time, enjoys the benefits of low-cost realizations. As a side note, we also observe from the figure that the firm’s optimal capacity is higher but the firm’s profit is lower under the benchmark model, which is consistent with Corollary 6.

$^2$ We have examined a number of other scenarios under which different values of these parameters are used. We make a remark on this at the end of this subsection.
As firms gradually move their production to new locations (e.g., Southeast Asia), the operational environments are expected to be increasingly transparent in these locations. Thus, the firms will have a better knowledge of the production costs there. Observation 1 implies that the firms will build less capacity in the new locations and may become worse off when the cost uncertainty diminishes. A caveat of this implication though is that the firms need to take into consideration other factors which may be evolving as well. For example, as the infrastructure develops or labor productivity improves, the production cost efficiency in these new locations will be increased, which may outweigh the negative effect of decreasing cost uncertainty.

To examine the effect of the demand uncertainty (measured by $\delta_e$ and $\sigma_e$), we use the following parameter values for our base scenario: $a = 100, \gamma = 1, c_e = 40, c_m = 5, \mu_e = 0, \mu_c = 30, \sigma_e = 30$, and $\delta_e = 15$. Additionally, when measuring demand variability using $\delta_e$, we set $\sigma_e = 60$ and vary the value of $\delta_e$ from 15.
to 44 with a step size of 1. When using $\sigma_c$ to measure the demand variability, we set $\delta_c = 25$ and vary the value of $\sigma_c$ from 1 to 30 with a step size of 1. For each value of $\delta_c$ or $\sigma_c$, we solve for the optimal capacity and optimal profit under each model. The results are shown in Figure 3 and Figure 4. Based on these figures, we make some observations below.

Observation 2 (Effects of demand variability). $K^n$, $\Pi^n$, $K^r$ and $\Pi^r$ all increase in $\delta_c$ and $\sigma_c$.

Similar to the results for $\delta_c$ and $\sigma_c$, an increasing demand variability benefits the firm. This is because the firm can adjust its production quantity or price after the actual demand is realized. Under both the benchmark and retaining models, the firm may cut down production when the realized demand is low. Such operational flexibility provides a lever for the firm so that it can enjoy the benefits from high demand realizations but mitigate the negative impacts of low demand realizations. Similar to Figures 1 and 2, Figures 3 and 4 also reveal that the firm builds more capacity and makes less profit when the existing location is not retained.
An implication of the above observation is that, when the market demand becomes more uncertain given the fast-changing consumer tastes, the firm may find it beneficial to expand the capacity investment in new locations and in so doing makes more profit. Again, with the increasingly volatile market, firms need to maintain their sanity when it comes to reconfiguring production resources especially in a highly competitive market. In this situation, competition from rivals may play an important role in their decision making about the explanation of new production destinations.

Finally, we remark that we have tested a number of numerical scenarios by varying the values of other parameters (i.e., \( a, \gamma, c_e, c_m, \mu_c \)). Since \( \bar{\epsilon} \) represents the random demand shock, we fix its mean to be zero (i.e., \( \mu_\epsilon = 0 \)). For each of the other parameters, we consider three possible values; that is, \( a \in \{ 70, 100, 130 \} \), \( \gamma \in \{ 0.6, 0.8, 1 \} \), \( c_e \in \{ 30, 40, 50 \} \), \( c_m \in \{ 3, 5, 7 \} \), and \( \mu_c \in \{ 25, 30, 35 \} \). For each scenario, we vary the value of each of the demand and cost variabilities (i.e., \( \delta_c, \sigma_c, \delta_\epsilon, \sigma_\epsilon \)) and rerun the optimization model as in our base scenario. For all the numerical scenarios considered, we find the same patterns as summarized in Observations 1 and 2.

5.2. The Value of Retaining the Existing Location

Corollary 6 shows that the firm always benefits from retaining the existing location. We feel that a more relevant question is how much value retaining the existing location brings to the firm, and how this value is affected by key parameters. We use the following measure to quantify the magnitude of the value of retaining the existing location:

\[
\Delta = \Pi^r - \Pi^n. \tag{10}
\]

One may alternatively interpret this value as the potential loss if the firm does not retain the existing location. In practice, retaining the existing location may involve a cost. Thus, the firm’s decision about whether to retain the existing location depends on the relative sizes of its value and cost. Clearly, if the value is greater than the cost, then it is worth retaining the location; otherwise it is not worthwhile to do so.

We now examine the effects of key parameters on the value of retaining the existing location. That is, we study how \( \Delta \) changes with market size \( a \), product price elasticity \( \gamma \), cost variability (measured by \( \delta_c \) and \( \sigma_c \)) and demand variability (measured by \( \delta_\epsilon \) and \( \sigma_\epsilon \)).

To examine the effect of \( a \) on the retaining value, we set \( c_m = 5 \), \( \gamma = 1 \), \( \mu_\epsilon = 0 \), \( \sigma_\epsilon = 40 \), \( \delta_\epsilon = 30 \), \( \mu_c = 30 \), \( \sigma_c = 30 \), \( \delta_c = 15 \) and \( c_e = 40 \). The value of \( a \) ranges from 90 to 119 with a step size of 1. Similarly, to examine the effect of \( \gamma \), we use the same set of parameter values except that we set \( a = 100 \) and vary the value of \( \gamma \) from 0.1 to 1 with a step size of 0.1. Figure 5 illustrates how the retaining value changes with the market size and the price elasticity. We make the following observations based on Figure 5.

Observation 3 (Effects of \( a \) and \( \gamma \) on the Value of Retaining). The retaining value increases in \( a \) but decreases in \( \gamma \).
The intuition of this result is straightforward. As discussed earlier for Proposition 3, the firm uses the existing location for production purposes when the realized production cost at the new location is high (i.e., $\Omega_4$), or when the realized demand is high even if the production cost at the new location is low (i.e., $\Omega_1$). We observe from Proposition 3 that the production quantity at the existing location increases in the market size but decreases in the price elasticity, which implies that the value of retaining also increases as the product market grows or the consumers are less price sensitive.

Next we examine the effects of demand and cost variabilities on the value of retaining. For this analysis, we fix the values of the other parameters for our base scenario: $a = 100, \gamma = 1, c_c = 40, c_m = 5, \mu_c = 0$ and $\mu_\epsilon = 30$.\(^3\)

As discussed earlier, we use $\delta_c$ and $\sigma_c$ to measure the cost variability. To examine the effect of $\delta_c$ on the retaining value, we further set $\sigma_c = 40$, $\delta_c = 30$, $\sigma_c = 30$, and vary the value of $\delta_c$ from 1 to 30 with a step size of 1. To examine the effect of $\sigma_c$ on the retaining value, we further set $\sigma_c = 40$, $\delta_c = 30$, $\delta_c = 15$, and vary the value of $\delta_c$ from 1 to 30 with a step size of 1. Similarly, we use $\delta_\epsilon$ and $\sigma_\epsilon$ to measure the demand variability. To examine the effect of $\delta_\epsilon$, we further set $\sigma_\epsilon = 30$, $\delta_\epsilon = 15$, $\sigma_\epsilon = 40$, and vary the value of $\delta_\epsilon$ from 15 to 44 with a step size of 1. To examine the effect of $\sigma_\epsilon$, we further set $\sigma_\epsilon = 30$, $\delta_\epsilon = 15$, $\delta_\epsilon = 30$, and vary the value of $\sigma_\epsilon$ from 1 to 30 with a step size of 1. Figure 6 and Figure 7 illustrate how the retaining value changes with the cost and demand variabilities measured by $\delta_c$ and $\delta_\epsilon$, and by $\sigma_c$ and $\sigma_\epsilon$, respectively.

We make the following observations from these figures.

**Observation 4 (Effects of Cost and Demand Variabilities on the Value of Retaining).**

The retaining value first decreases and then increases in $\delta_c$ and $\sigma_c$, and always increases in $\delta_\epsilon$ and $\sigma_\epsilon$.

\(^3\) Again, we have examined a number of other scenarios under which different values of these parameters are used. We make a remark on this at the end of this subsection.
Observation 4 shows that the impact of the cost variability on the value of retaining exhibits a U-shaped pattern, and the impact of demand variability is monotone. We provide some intuition about these observations. As discussed in Proposition 3, the use of existing location occurs when the realized cost of the new location is higher than that of the existing location, or when the realized demand is high even if the realized cost of the new location is lower, thereby suggesting two possible benefits of retaining the existing location. Accordingly, there are two counteracting effects of increasing cost variability on the value of retaining. On the one hand, as cost variability increases, the firm can benefit from the higher incidence of low-cost realizations but does not necessarily hurt from the high incidence of high-cost realizations due to the availability of the existing location. This leads to a positive effect of increasing cost variability on the first benefit. On the other hand, as cost becomes more variable, which implies a smaller incidence of the cost realizations
being smaller than the cost at the existing location, the second benefit of retaining the existing location diminishes. As a result, the overall effect of increasing cost variability may not be monotone, and we find that the second effect dominates the first when the cost variability is small but the reverse is true when the cost variability is already large.

In contrast with cost variability, increasing demand variability only affects the second benefit of retaining the existing location. As the demand becomes more variable, which implies a higher likelihood of both high and low demand realizations, the firm can benefit more from high demand realizations but does not necessarily hurt from the low demand realizations because it can choose to cut down production. This suggests that the firm may benefit more from retaining the existing location when the market demand becomes more volatile.

Observations 3 and 4 have some implications for the firms who need to decide whether or not to retain existing production facilities. First, retaining the existing location is more beneficial when there is a larger market size and consumers are less price sensitive. Second, the firms benefit more from retaining the existing location when they have little or enough knowledge about the new production location but benefit less when they have moderate knowledge about the location. In addition, it is expected that the firms over time may be increasingly better informed about the operational environments in the new location. Our results suggest that the firms will profit from this additional information only when they already have enough information. Third, as the market demand becomes increasingly uncertain, the firm is expected to more likely keep the existing facilities to better respond to the volatile consumer market. Overall, retaining the existing location obtains the highest value when the market size is large, the consumers are insensitive to price, the market demand is highly uncertain, or the variability of the production cost at the new location is either sufficiently high or sufficiently low.

As a final remark, to examine the effects of cost and demand variabilities on the value of retaining, we have considered a number of scenarios by using different values of other parameters; that is, \( a \in \{70, 100, 130\} \), \( \gamma \in \{0.6, 0.8, 1\} \), \( c_e \in \{30, 40, 50\} \), \( c_m \in \{3, 5, 7\} \), and \( \mu_c \in \{25, 30, 35\} \). Again, for all these scenarios, we find that the value of retaining first increases and then decreases in cost variability, and always decreases in demand variability.

6. Extensions

This section examines two extensions of our baseline setting. In the first extension, we consider an alternative setting in which the production decision is made prior to knowing the actual demand. In the second extension, we generalize our baseline model by considering a finite capacity at the existing location.

6.1. A Three-Stage Setting

In this alternative setting, the firm first determines the capacity level in the new location, then after observing the production cost of the new location, the firm determines the production quantities in the new and existing
locations, and finally after the market demand is realized, the firm determines the price charged to the consumers. Similar to the baseline setting, we first analyze the benchmark model where the existing location is not retained and then the retaining model where it is retained.

**The benchmark model.** When the existing location is not retained, the formulation of the firm’s optimization problem is as follows:

- **Stage 1:** Capacity investment. The firm aims to maximize its expected profit by choosing the optimal capacity level:

  \[
  \Pi_1^n = \left\{ \max_{K \geq 0} \mathbb{E} [\Pi_2^n (K, \tilde{c})] - c_m K \right\}, 
  \tag{11}
  \]

  where the expectation is taken over \( \tilde{c} \) and the definition of \( \Pi_2^n (K, \tilde{c}) \) is given next.

- **Stage 2:** Production. Given the realized production cost, \( c \), and the capacity level, \( K \), the firm aims to maximize its expected profit by choosing the optimal production quantity:

  \[
  \Pi_2^n (K, c) = \left\{ \max_{0 \leq q_n \leq K} \mathbb{E} [\Pi_3^n (q_n, \tilde{\epsilon})] - cq_n \right\}, \quad \forall c, \tag{12}
  \]

  where the expectation is taken over \( \tilde{\epsilon} \) and the definition of \( \Pi_3^n (q_n, \tilde{\epsilon}) \) is given next.

- **Stage 3:** Pricing. Given the realized demand shock, \( \epsilon \), and the production quantity, \( q_n \), the firm aims to maximize its profit by choosing the optimal price:

  \[
  \Pi_3^n (q_n, \epsilon) = \left\{ \max_{p \geq 0} p \cdot \min (a - \gamma p + \epsilon, q_n) \right\}, \quad \forall \epsilon, \tag{13}
  \]

  where the total selling quantity is the minimum of the demand and the production quantity.

Using the backward induction approach, we first examine the firm’s Stage 3 problem, then the firm’s Stage 2 problem, and finally the firm’s Stage 1 problem. Due to space limitation, we will directly present the firm’s optimal decisions in the three stages.

**Proposition 5 (Optimal decisions).** When the production decision is made prior to demand realization, under the benchmark model, we obtain:

(i) For a given \( \epsilon \) and \( q_n \), the firm’s optimal price in Stage 3 is

\[
\Pi_3^n(q_n, \epsilon) = \max \left( \frac{a + \epsilon}{2\gamma}, \frac{a + \epsilon - q_n}{\gamma} \right). \tag{14}
\]

(ii) For a given \( c \) and \( K \), the firm’s optimal production quantity in Stage 2 is

\[
q_n^n(K, c) = \min (K, \bar{q}_n^n),
\]

where \( \bar{q}_n^n \) is the unique solution to the equation

\[
\mathbb{E}[(a - 2\bar{q}_n^n + \tilde{\epsilon})^+] - \gamma c = 0.
\]

(iii) The firm’s optimal capacity in Stage 1, \( K^n_n \), is the unique solution to the following equation,

\[
\mathbb{E} \left( \frac{1}{\gamma} \mathbb{E} \left[ (a + \tilde{\epsilon} - 2K^n)^+ - \tilde{\epsilon} \right]^+ \right) - c_m = 0. \tag{14}
\]
The retaining model. When the existing location is retained, the formulation of the firm’s optimization problem is as follows:

- **Stage 1**: Capacity investment. The firm aims to maximize its expected profit by choosing the optimal capacity level:

\[
\Pi_1^\epsilon = \left\{ \max_{K \geq 0} E \left[ \Pi_2^\epsilon(K, \tilde{c}) \right] - c_m K \right\},
\]

where the expectation is taken over \( \tilde{c} \) and the definition of \( \Pi_2^\epsilon(K, \tilde{c}) \) is given next.

- **Stage 2**: Production. Given the realized production cost, \( c \), and the capacity level, \( K \), the firm aims to maximize its expected profit by choosing the optimal production quantities at the new and existing locations:

\[
\Pi_2^\epsilon(K, c) = \left\{ \max_{0 \leq q_n \leq K, q_e \geq 0} E \left[ \Pi_3^\epsilon(q_n, q_e, \tilde{c}) \right] - cq_n - c_e q_e \right\}, \quad \forall c,
\]

where the expectation is taken over \( \tilde{c} \) and the definition of \( \Pi_3^\epsilon(q_n, q_e, \tilde{c}) \) is given next.

- **Stage 3**: Pricing. Given the realized demand shock, \( \epsilon \), and the production quantities, \((q_n, q_e)\), the firm aims to maximize its profit by choosing the optimal price:

\[
\Pi_3^\epsilon(q_n, q_e, \epsilon) = \left\{ \max_{p \geq 0} p \cdot \min(a - \gamma p + \epsilon, q_n + q_e) \right\}, \quad \forall \epsilon,
\]

where the total selling quantity is the minimum of the realized demand and the production quantity.

Solving the above three-stage problem, we obtain the firm’s optimal decisions in the following proposition.

**Proposition 6 (Optimal decisions).** When the production decision is made prior to demand realization, under the retaining model, we obtain:

(i) For a given \( \epsilon, q_n \), and \( q_e \), the firm’s optimal price in Stage 3 is
\[
p^\epsilon(q_n, q_e, \epsilon) = \max \left( \frac{a + \epsilon}{2\gamma}, \frac{a + c_e - (q_n + q_e)}{\gamma} \right).
\]

(ii) For a given \( c \) and \( K \), the firm’s optimal production quantities in Stage 2 are
\[
(q_n^\epsilon, q_e^\epsilon) = \begin{cases} (K, q_e^\epsilon - K), & \text{if } c < c_e \leq \frac{1}{\gamma} E[(a + \tilde{c} - 2K)^+] \\ (K, 0), & \text{if } c < \frac{1}{\gamma} E[(a + \tilde{c} - 2K)^+] \leq c_e, \\ (q_n^\epsilon, 0), & \text{if } c_e \geq \frac{1}{\gamma} E[(a + \tilde{c} - 2K)^+], \\ (0, q_e^\epsilon), & \text{if } c_e \leq c, \end{cases}
\]

where \( q_n^\epsilon \) is the unique solution to equation \( \frac{1}{\gamma} E[(a + \tilde{c} - 2q_n^\epsilon)^+] - c = 0 \), and \( q_e^\epsilon \) is the unique solution to equation \( \frac{1}{\gamma} E[(a + \tilde{c} - 2q_e^\epsilon)^+] - c = 0 \).

(iii) The firm’s optimal capacity in Stage 1, \( K^\epsilon \), is the unique solution to the following equation,

\[
E \left[ \left( \frac{1}{\gamma} E[(a + \tilde{c} - 2K^\epsilon)^+] - \tilde{c} \right)^+ \right] + E[(c_e - \tilde{c})^+] - c_m = 0.
\]

Propositions 5 and 6 characterize the firm’s optimal decisions under the benchmark and retaining models, respectively. We can see that Equation (18) differs from Equation (14) only in the term \( E[(c_e - \tilde{c})^+] \), and it can be shown that the optimal capacity level is larger under the benchmark model than under the retaining model.
model, which is analogous to the result in Corollary 6 for the baseline setting. In addition, because in this three-stage setting the demand and production cost are realized in different stages, the effects of their uncertainties on the optimal capacity can be separated. This is different from our baseline setting in which the firm makes the production decision when both cost and demand are realized at the same time. Despite these differences, we can replicate our sensitivity analysis results. The following corollary summarizes the effects of key parameters on the optimal capacity levels and profits.

COROLLARY 7 (Effects of key parameters). When the production decision is made prior to demand realization, we obtain:

(i) The optimal capacity levels, \( K^n \) and \( K^r \), increase in \( a \) but decrease in \( \gamma \) and \( c_m \);
(ii) The optimal profits, \( \Pi^n \) and \( \Pi^r \), increase in \( a \) but decrease in \( \gamma \) and \( c_m \);
(iii) Suppose \( \tilde{\epsilon} \) and \( \tilde{\epsilon} \) are independent. If \( \tilde{\epsilon} \) follows either a uniform or normal distribution, the optimal capacity levels increase in \( \mu_{\epsilon} \) and \( \sigma_{\epsilon} \). When \( \tilde{\epsilon} \) follows either a uniform or normal distribution, the optimal capacity levels decrease in \( \mu_{\epsilon} \) but increase in \( \sigma_{\epsilon} \).

The results in the above corollary match those in our baseline setting. We have also conducted numerical studies to check if the effects of demand and cost variabilities on the profitability carry over to this extension. We find that the firm’s profit increases in the cost and demand variabilities. The reason is because, similar to our baseline setting, the firm can adjust its price after knowing the demand, and can also adjust the production decision after knowing the cost. In other words, even though the pricing and production decisions are separated into two stages, the firm still enjoys the benefit of operational flexibility (in terms of pricing and production).

We also find that the value of retaining the existing location first decreases and then increases in the cost variability, but increases in the demand variability. Despite the difference in model setup, the driving forces for the value of retaining remain the same: The use of existing location occurs when the realized cost of new location is higher or when the realized demand is high even if the realized cost is lower (see part (ii) of Proposition 6). As a result, the effects of cost and demand variabilities on the retaining value are structurally similar: there are two counteracting effects of increasing cost variability on the retaining value, and the existence of the existing location enables the firm to better respond to demand uncertainty and this advantage is more significant when the demand is more volatile.

Another interesting point concerns the effect of production postponement (that occurs in the baseline setting) on the value of retaining the existing facilities. Denote by \( \hat{\Delta} \) the value of retaining in this alternative setting. Then the effect of production postponement can be measured by \( \Delta - \hat{\Delta} \). Our numerical studies show that the sign of \( \Delta - \hat{\Delta} \) may be positive or negative depending on the parameter values. This suggests that production postponement may strengthen or weaken the value of retaining. In addition, we find that production postponement strengthens the value of retaining when the market size is large, the consumers are highly sensitive to the product price, the production cost is reasonably uncertain, or the demand is relatively stable.
6.2. Finite Capacity at the Existing Location

In this extension, we consider a finite capacity $K_e \geq 0$ at the existing location. Note that the benchmark model remains the same as in our baseline setting, so we will focus on the analysis of the retaining model. Following the same approach, we start with the firm’s production decision in Stage 2, and then examine the firm’s Stage 1 problem on capacity investment.

The production strategy. Given the capacity level $K$ at the new production location, and the demand and cost realizations $\epsilon$ and $c$, the firm aims to maximize its profit by choosing the optimal production quantities at both locations:

$$\max_{0 \leq q_n \leq K, 0 \leq q_e \leq K_e} \pi_2(q_n, q_e) = \frac{1}{\gamma}(a - (q_n + q_e) + \epsilon)(q_n + q_e) - c_eq_e - cq_n. \quad (19)$$

Solving the above problem yields the firm’s optimal production quantities and profit.

**Lemma 3 (Optimal production).** When the firm has a finite capacity at the existing location, for a given $K$, $c$ and $\epsilon$, the firm’s optimal production quantities at the new and existing locations are

$$(q_n^*, q_e^*) = \begin{cases} 
(0, a+\epsilon-\gamma c_e), & \text{if } (c, \epsilon) \in \Gamma_1, \\
(0, K_e), & \text{if } (c, \epsilon) \in \Gamma_2, \\
\left(\frac{a+\epsilon-\gamma c_e}{2} - K_e, K_e\right), & \text{if } (c, \epsilon) \in \Gamma_3, \\
(K_e, K_e), & \text{if } (c, \epsilon) \in \Gamma_4, \\
(K_e, 0), & \text{if } (c, \epsilon) \in \Gamma_5, \\
\left(K, \frac{a+\epsilon-\gamma c_e}{2} - K\right), & \text{if } (c, \epsilon) \in \Gamma_7, \\
(K, K_e), & \text{if } (c, \epsilon) \in \Gamma_8,
\end{cases}$$

where

$$\begin{align*}
\Gamma_1 &= \{(c, \epsilon) : c_e < c, \epsilon \leq \epsilon \leq -a + \gamma c_e + 2K_e\}, \\
\Gamma_2 &= \{(c, \epsilon) : c_e < c, -a + \gamma c_e + 2K_e < \epsilon \leq -a + \gamma c + 2K\}, \\
\Gamma_3 &= \{(c, \epsilon) : c_e < c, -a + \gamma c + 2K_e < \epsilon \leq -a + \gamma c + 2(K_e + K)\}, \\
\Gamma_4 &= \{(c, \epsilon) : c_e < c, -a + \gamma c + 2(K_e + K) < \epsilon \leq \bar{\epsilon}\}, \\
\Gamma_5 &= \{(c, \epsilon) : c_e \geq c, \epsilon \leq -a + \gamma c + 2K\}, \\
\Gamma_6 &= \{(c, \epsilon) : c_e \geq c, -a + \gamma c + 2K < \epsilon \leq -a + \gamma c_e + 2K\}, \\
\Gamma_7 &= \{(c, \epsilon) : c_e \geq c, -a + \gamma c_e + 2K < \epsilon \leq -a + \gamma c_e + 2(K + K_e)\}, \\
\Gamma_8 &= \{(c, \epsilon) : c_e \geq c, -a + \gamma c_e + 2(K + K_e) < \epsilon \leq \bar{\epsilon}\}.
\end{align*}$$
The firm’s optimal profit (excluding capacity cost) is

$$\Pi_2'(K, c, \epsilon) = \begin{cases} 
\frac{(a+\epsilon-\gamma c)e}{4\gamma}, & \text{if } (c, \epsilon) \in \Gamma_1, \\
\frac{(a-K_c+\epsilon-\gamma c)e}{4\gamma}, & \text{if } (c, \epsilon) \in \Gamma_2, \\
\frac{(a+\epsilon-\gamma c)^2}{\gamma} + (c - c_e)K_c, & \text{if } (c, \epsilon) \in \Gamma_3, \\
\frac{(a-K_c+\epsilon-\gamma c)^2}{\gamma} - cK - c_eK_c, & \text{if } (c, \epsilon) \in \Gamma_4, \\
\frac{(a-\gamma c)^2}{\gamma}, & \text{if } (c, \epsilon) \in \Gamma_5, \\
\frac{(a-K_c)^2}{\gamma}, & \text{if } (c, \epsilon) \in \Gamma_6, \\
\frac{(a-\gamma c)^2}{\gamma} + (c_e - c)K_e, & \text{if } (c, \epsilon) \in \Gamma_7, \\
\frac{(a-(K_c+K_e))(K_e+K)}{\gamma} - cK - c_eK_c, & \text{if } (c, \epsilon) \in \Gamma_8, 
\end{cases}$$

A general observation from the lemma is that the firm’s optimal production strategy is more complex than that in our baseline model (i.e., Proposition 1), and the optimal strategy could take one of the eight possible forms, depending on the realized cost and demand. Since the existing location has a finite capacity, there are two distinctions from the baseline setting. First, even when the realized cost at the new location is higher, the firm may still produce at the new location (i.e., \(\Gamma_3\) and \(\Gamma_4\)). Second, the firm may use the maximum capacity at the existing location but not use any capacity at the new location, which occurs when the realized cost is higher and the realized demand is not up to a level that justifies the production at the new location (i.e., \(\Gamma_2\)).

We now examine the firm’s capacity investment problem, which is formulated as follows:

$$\max_{K \geq 0} \pi_1'(K) = \mathbb{E}[\Pi_2'(K, \tilde{c}, \tilde{\epsilon})] - c_m K,$$  \hspace{1cm} (20)

where the expectation is taken over \(\tilde{c}\) and \(\tilde{\epsilon}\) and \(\Pi_2'(K, \tilde{c}, \tilde{\epsilon})\) is given in Lemma 3. Solving this problem yields the firm’s optimal capacity level.

**Proposition 7 (Optimal capacity).** When the firm has a finite capacity at the existing location, the optimal capacity \(K^*\) at the new location is the unique solution to the following equation

$$0 = -c_m + \frac{1}{\gamma} \mathbb{E} \left[ (a + \tilde{\epsilon} - 2K^* - \gamma \tilde{\epsilon})^+ \mathbb{I}_{\{\tilde{c} \leq c_e, \tilde{\epsilon} \leq -a + \gamma c_e + 2K^*\}} \right]$$

$$+ \frac{1}{\gamma} \mathbb{E} \left[ (c_e - \tilde{c})^+ \mathbb{I}_{\{\tilde{c} \leq c_e, \tilde{\epsilon} \leq -a + \gamma c_e + 2(K_e + K^*)\}} \right],$$

$$+ \frac{1}{\gamma} \mathbb{E} \left[ (a + \tilde{\epsilon} - 2(K_e + K^*) - \gamma \tilde{\epsilon})^+ \mathbb{I}_{\{\tilde{e} \leq c_e, \tilde{\epsilon} \leq -a + \gamma c_e + 2(K_e + K^*)\}} \right]$$

$$+ \frac{1}{\gamma} \mathbb{E} \left[ (a + \tilde{\epsilon} - 2(K_e + K^*) - \gamma \tilde{\epsilon})^+ \mathbb{I}_{\{\tilde{\epsilon} > c_e\}} \right].$$

We observe that this extended model covers the benchmark model (where \(K_c = 0\)) and the retaining model (when \(K_c\) is sufficiently large) as two special cases. Indeed, if \(K_c = 0\), the above equation reduces to the one in Proposition 2, and if we set \(K_c \to +\infty\), the above equation reduces to the one in Proposition 4. We have numerically checked whether the sensitivity analysis results (i.e., Observations 1-4) carry over to this extension, and find that all the results remain structurally unchanged. This is somewhat expected because
as shown in our baseline setting, the effects of market size, price elasticity, cost and demand variabilities are consistent for the two polar cases, and thus having a finite capacity would not affect these sensitivity analysis results.

7. Concluding Remarks

In this paper we have considered a firm’s capacity and production decisions when the firm would like to explore new production locations. Consistent with the practice that some firms choose to retain their existing location while others rely only on the new location, we consider two problem models: the benchmark model, where the firm does not retain the existing location; and the retaining model, where the firm does. Comparing these two models allows us to study the value of retaining the existing location.

In our baseline setting, the production decision is made after knowing the actual demand. This may fit settings where the production stage is relatively short so that the firm is well informed about the market conditions when making the production decision. However, this is less appropriate when the production lead time is long and thus the production must be conducted when the firm has little knowledge about the market demand. We have considered an alternative setting in which the firm makes the production decision prior to knowing the demand, and after knowing the actual demand the firm makes the pricing decision.

In addition, our baseline retaining model considers a sufficiently large capacity at the existing location. We have also relaxed this assumption in Section 6 by considering a finite capacity at the existing location.

Our analysis begins by characterizing the optimal capacity and production decisions and then examines how the optimal capacity and firm profit are affected by the market size, price elasticity, and the demand and cost uncertainty. We also study how the value of retaining the existing location changes with respect to the key parameters. The main analytical and numerical results are summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Benchmark model</th>
<th>Retaining model</th>
<th>Value of retaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand uncertainty</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
</tr>
<tr>
<td>Cost uncertainty</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
</tr>
<tr>
<td>Market size</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
</tr>
<tr>
<td>Product elasticity</td>
<td>decrease</td>
<td>decrease</td>
<td>decrease</td>
</tr>
</tbody>
</table>

Among other results, we find that increases in the cost and demand uncertainty may benefit the firm. This result is driven by the firm’s operational flexibility in the sense that it can adjust the production decisions after observing the production cost and market demand. We also numerically show that retaining the existing location obtains the highest value when the market size is large, the price elasticity is low, the demand uncertainty is high, and the cost uncertainty is either sufficiently high or sufficiently low. The value of retaining the existing location is reflected in the production stage when the firm may choose to produce
some products at this location. This occurs when the realized cost at the new location is higher than that of the existing location, or when the realized demand is high even if the realized cost at the new location is lower. We find that the optimal production quantity at the existing location increases in the market size and decreases in the price elasticity, which explains the result that the retaining value is larger when the market size is larger or when the consumers are less price sensitive. Regarding the effect of the cost uncertainty, we identify two countering effects of increasing cost uncertainty on the value of retaining the existing location. The overall effect depends on the status quo cost variability. In contrast, the effect of demand uncertainty on the retaining value is monotone because increasing demand uncertainty makes the firm benefit more from high demand realizations but not suffer from low demand realizations when the existing location is retained. Finally, we demonstrate that these results are robust to the two extensions.

Based on the research findings, some managerial insights may be generated for managers at the crossroad of exploring new production locations. Regarding the capacity investment strategy, the firms should move more of their production to new locations when the consumer market is more uncertain, and build less capacity as they have a better understanding of the new locations. Regarding whether or not to retain the existing location, our findings suggest that the firms may more likely keep their existing facilities when the demand is more volatile, the market is growing, or the consumers are less sensitive to the product price. We also find that an increasing transparency of the new environments leads to a stronger incentive of retaining the existing location only when the environments are already quite transparent.

We conclude by discussing several limitations of our model. First, we consider a demand model with additive random shocks. A natural extension is to consider a multiplicative demand model and study whether and how this would change the main results derived in the paper. Second, we focus on a single firm’s optimization problem. Future research may extend our model to a competitive setting where multiple firms compete in the consumer market. Third, an important consideration in global supply chains is accessibility of (upstream) supply networks and proximity of (downstream) consumer markets. We feel that an interesting research question is how firms should balance the trade-off between cost, supply accessibility and market proximity.

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