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Supply Capacity, Supply Reliability and Precautionary Stockpiling

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Abstract: This paper examines how supply capacity and supply reliability affect precautionary stockpiling by healthcare institutions facing future supply risk. We develop a simple model in which N identical healthcare institutions choose how much medical supply to purchase in advance, while supply capacity determines current and future market prices and future supplies remain available with a given probability. The analysis yields two main results. First, an expansion of supply capacity can increase precautionary stockpiling. Although greater capacity lowers future procurement costs and thereby discourages stockpiling, it also lowers the current purchase price and makes advance purchases more attractive. When the expected loss from future supply disruption is sufficiently large relative to inventory holding costs, the latter effect dominates, so that greater supply capacity increases equilibrium stockpiling. Second, an improvement in supply reliability reduces precautionary stockpiling when the shortage loss exceeds the normal future procurement price. These results demonstrate that supply expansion and supply-risk reduction are not equivalent policies. Increasing physical supply without reducing uncertainty about future availability can unintentionally stimulate precautionary purchasing, whereas improving supply reliability directly weakens the incentive to stockpile. The analysis therefore highlights the importance of combining supply-expansion policies with measures that enhance the reliability of future procurement.

Keywords: Precautionary stockpiling, Supply capacity, Supply reliability, Supply risk, Healthcare supply chains, Inventory management

INTRODUCTION

Supply expansion is commonly viewed as a natural remedy for shortages. When governments anticipate potential disruptions in the supply of essential goods, they may increase production capacity, subsidize domestic manufacturing, facilitate imports or otherwise expand market supply. Such measures are particularly important for medical supplies, pharmaceuticals and other critical goods whose shortages can impose substantial social costs.

The conventional rationale for supply expansion is straightforward. Greater supply capacity increases market availability and lowers prices, thereby reducing scarcity and weakening incentives for precautionary purchasing. From this perspective, expanding supply should stabilize markets and discourage healthcare institutions from accumulating excessive inventories.

However, the relationship between supply expansion and precautionary stockpiling is more subtle when uncertainty about future supply persists. An expansion of supply capacity lowers not only the future procurement price but also the current price at which inventories can be accumulated. While a lower future price makes future procurement more attractive and therefore reduces the incentive to stockpile, a lower current price makes advance purchases less costly and encourages stockpiling. Consequently, supply expansion can paradoxically increase precautionary purchasing when concerns about future availability remain unresolved.

This possibility is closely related to the literature on inventory management and supply-chain resilience. Traditional inventory models emphasize the trade-off between inventory holding costs and shortage risks (Cachon and Terwiesch, 2019), while the broader supply-chain literature examines how firms respond to disruptions and uncertainty through inventory, sourcing, capacity and other resilience strategies (Tang, 2006; Craighead et al., 2007; Simchi-Levi et al., 2008; Ivanov and Dolgui, 2020). These studies provide important insights into how organizations manage inventories and supply risks.

These issues are particularly important in healthcare supply chains. Saha and Ray (2019) provide a comprehensive review of inventory-management models for pharmaceuticals and medical and surgical supplies, emphasizing the trade-off between inventory costs and service availability. Mathur et al. (2018) similarly review healthcare supply-chain management and highlight the importance of effective procurement and inventory management for healthcare performance. More recent studies motivated by the COVID-19 pandemic have focused explicitly on stockouts, stockpiling, and supply-chain resilience. Friday et al. (2021), for example, examine inventory and stockout risks during a pandemic and emphasize capabilities that enhance healthcare supply-chain resilience. Spieske et al. (2022) analyze strategies for improving the resilience of healthcare supply chains during severe disruptions.

The importance of supply reliability has also been emphasized from a policy perspective. The National Academies of Sciences, Engineering and Medicine (2022) highlights the vulnerability of medical-product supply chains and emphasizes the importance of resilience, reliable procurement, and preparedness in addition to physical production capacity. These studies suggest that preventing shortages requires attention not only to the quantity of goods that can be supplied but also to the reliability with which they can be obtained in the future.

The present paper builds on these insights but focuses on a distinction that has received less attention: the difference between expanding supply capacity and improving supply reliability. Although both may be interpreted as improvements in supply conditions, they operate through different economic mechanisms and need not have the same effect on precautionary stockpiling. Supply expansion primarily changes market prices, whereas improved supply reliability changes the risk associated with relying on future procurement. Distinguishing these two channels is particularly important when institutions can purchase inventories in advance.

To investigate this distinction, we develop a simple model in which N identical healthcare institutions choose how much medical supply to purchase in advance. Each institution requires one unit of the good in each period and chooses its initial inventory while facing inventory holding costs and the possibility of future supply disruption. Supply capacity determines current and future market prices through market-clearing conditions, while future supplies remain available with a given probability. The model therefore captures the trade-off between purchasing and holding inventory today and relying on uncertain future procurement opportunities.

The analysis yields two main results. First, an expansion of supply capacity can increase precautionary stockpiling. Greater supply capacity generates two opposing effects. By lowering the future procurement price, it makes future purchases less costly and discourages stockpiling. At the same time, it lowers the current procurement price, making advance purchases cheaper and encouraging stockpiling. We show that when the expected loss associated with future supply disruption is sufficiently large relative to inventory holding costs, the latter effect dominates. Consequently, an increase in supply capacity raises the equilibrium stockpiling level. This result demonstrates that a policy intended to alleviate shortages through greater physical supply can, under persistent supply risk, unintentionally stimulate precautionary purchasing.

Second, an improvement in supply reliability has a fundamentally different effect. When the shortage loss exceeds the normal future procurement price, an increase in the probability that future supplies remain available reduces equilibrium stockpiling. Greater supply reliability lowers the expected cost of relying on future procurement and therefore directly weakens the incentive to accumulate inventories in advance. Unlike supply expansion, which can either increase or decrease stockpiling because of its opposing price effects, greater supply reliability reduces precautionary purchasing under this economically natural condition.

Taken together, these results establish the central distinction of the paper: supply expansion and supply-risk reduction are not equivalent policies. Increasing supply capacity may lower current prices sufficiently to encourage healthcare institutions to purchase more today, particularly when concerns about future shortages remain strong. Improving supply reliability, by contrast, addresses the underlying uncertainty that motivates precautionary stockpiling. Thus, increasing the amount that can be supplied without increasing confidence in future availability may fail to discourage stockpiling and may even intensify it.

This distinction has important implications for policies aimed at securing essential medical supplies. During public-health emergencies, geopolitical disruptions or other periods of heightened supply uncertainty, increasing production capacity or current market supply may be necessary but may not be sufficient to stabilize purchasing behavior. If healthcare institutions remain concerned about future availability, lower current prices may encourage them to accumulate additional inventories. Policies that improve the reliability and credibility of future supply, such as diversifying supply sources, strengthening supply-chain resilience, establishing reliable procurement arrangements, and providing credible information about future availability, can therefore complement policies aimed at expanding physical supply.

The contribution of the paper is thus to identify a simple price mechanism through which an apparent improvement in supply conditions can have an unintended effect on precautionary purchasing and to distinguish this mechanism from the effect of improved supply reliability. The model shows that the policy question is not simply how much supply capacity is available, but also how reliably institutions expect supplies to remain available in the future. This distinction provides a simple theoretical explanation for why supply-expansion policies may fail to eliminate precautionary stockpiling when supply risk persists.

The remainder of the paper is organized as follows. Section 2 presents the basic model with multiple identical healthcare institutions. Section 3 derives the symmetric equilibrium stockpiling decision, to examine the effect of supply expansion and the effect of improved supply reliability. Section 4 provides numerical examples, and Section 5 concludes the paper.

BASIC MODEL

Consider N identical healthcare institution that requires one unit of medical supplies in every period. The planning horizon consists of T periods. Healthcare institution i purchases n_i units in period 1. Inventory holding costs are given by

$$H(n_i) = \frac{c}{2}(n_i)^2, \tag{1}$$

where $c > 0$. The supply function in period 1 is

$$Z = sp, \tag{2}$$

where $s > 0$ denotes supply capacity. Since healthcare institution i purchases n_i units in period 1, market clearing requires

$$Z = \sum_{i=1}^{N} n_i\,. \tag{3}$$

Therefore, the period-1 price is

$$p_1 = \frac{\sum_{i=1}^{N} n_i}{s}, \tag{4}$$

which means that a larger supply capacity reduces the current market price.

After the stockpiled inventory is exhausted, each healthcare institution purchases one unit in each subsequent period. Therefore, future market clearing implies

$$Z = N. \tag{5}$$

Since the supply function remains

$$Z = sp, \tag{6}$$

the future equilibrium price is

$$p_F = \frac{N}{s}. \tag{7}$$

Let q_0 denote the probability that supplies remain available in the future. If supplies are available, each healthcare institution purchases at price $p_F = \frac{1}{s}.$; if supplies are unavailable, each healthcare institution incurs a shortage loss L. Therefore, the expected procurement cost per future unit is

$$E = q_0\frac{N}{s} + (1 - q_0)L, \tag{8}$$

which determines healthcare institution *i*'s expected total cost as

$$C_i(n_i) = p_1 n_i + \frac{c}{2} n_i^2 + (T - n_i)E. \tag{9}$$

Substituting (4) and (8) into (9), we obtain

$$C_i(n_i) = \frac{n_i\left(n_i + \sum_{j \neq i} n_j\right)}{s} + \frac{c}{2} n_i^2 + (T - n_i)\left[\frac{q_0 N}{s} + (1 - q_0)L\right]. \tag{10}$$

OPTIMAL STOCKPILING

The first-order condition for healthcare institution *i* is

$$\frac{dC_i(n_i)}{dn_i} = 0. \tag{11}$$

Therefore, we have

$$\frac{2n_i + n_{-i}}{s} + cn_i - \frac{q_0 N}{s} + (1 - q_0)L = 0. \tag{12}$$

Since

$$n_1 = \cdots = n_N = n^*. \tag{13}$$

follows in the symmetric equilibrium, we have the interior optimum as

$$n^* = \frac{q_0 N + (1 - q_0)Ls}{cs + N + 1}. \tag{14}$$

To examine how supply capacity affects stockpiling, differentiate (14) with respect to s. We obtain

$$\frac{\partial n^*}{\partial s} = \frac{(1 - q_0)L(N + 1) - cq_0 N}{(cs + N + 1)^2}. \tag{15}$$

Therefore,

$$\frac{\partial n^*}{\partial s} > 0 \tag{16}$$

if and only if

$$(1 - q_0)L(N + 1) > cq_0 N. \tag{17}$$

Proposition 1: (Supply Expansion and Precautionary Stockpiling with Multiple Healthcare Institutions)

In a symmetric equilibrium with N identical healthcare institutions, an increase in supply capacity s increases each institution's optimal stockpiling whenever $(1 - q_0)L(N + 1) > cq_0 N$.

Supply expansion generates the following two opposing effects.

Future-Cost Effect: Since $p_F = \frac{N}{s}$, as in (7), an increase in s reduces future procurement costs. This effect discourages stockpiling.

Current-Price Effect: Since $p_1 = \frac{\sum_{j=1}^{N} n_j}{s}$, as in (4), an increase in s reduces the cost of purchasing inventory today. This effect encourages stockpiling.

When shortage losses L are sufficiently large, (17) holds. In this case, the current-price effect dominates the future-cost effect. Consequently, supply expansion increases stockpiling.

This result is paradoxical because supply expansion is usually expected to reduce precautionary purchasing. Instead, when future supply risk remains unresolved, greater supply capacity may induce healthcare institutions to stockpile even more aggressively.

Similarly, to examine how supply reliability affects stockpiling, differentiate (14) with respect to q_0. We obtain

$$\frac{\partial n^*}{\partial q_0} = \frac{N - Ls}{cs + N + 1}. \tag{18}$$

Therefore,

$$\frac{\partial n^*}{\partial q_0} < 0 \tag{19}$$

if and only if

$$L > \frac{N}{s} = p_F. \tag{20}$$

Proposition 2: Supply Reliability and Precautionary Stockpiling

Suppose that the shortage loss exceeds the future procurement price, that is, $L > p_F$. Then, an increase in the probability that future supplies remain available, (q_0), reduces optimal stockpiling:$\frac{N-Ls}{cs+N+1} < 0$

Thus, greater supply reliability reduces precautionary stockpiling. This result contrasts with Proposition 1, which shows that an expansion of supply capacity may increase stockpiling. Hence, increasing supply capacity and improving supply reliability can have fundamentally different effects on precautionary purchasing.

NUMERICAL EXAMPLE

Consider the following parameter values: $N = 1, T = 10,\ q_0 = 0.9,\ c = 1,\ L = 100$. Then, we have the optimal stockpiling level as

$$n^* = \frac{0.9 + 10s}{s + 2}. \tag{21}$$

Hence,

$$\frac{\partial n^*}{\partial s} > 0, \tag{22}$$

and supply expansion increases stockpiling.

Similarly, if we consider the following parameter values: $N = 1, T = 10,\ s = 1,\ c = 1,$ $L = 100$. Then, we have the optimal stockpiling level as

$$n^* = \frac{q_0 + 100(1 - q_0)}{3}. \tag{23}$$

Hence,

$$\frac{\partial n^*}{\partial q_0} < 0, \tag{24}$$

and increase in supply reliability reduces stockpiling.

CONCLUSION

This paper developed a simple model of precautionary stockpiling in which multiple identical healthcare institutions face uncertainty about future supply availability. The analysis focused on two policy dimensions that are often treated as closely related but may have fundamentally different effects on inventory behavior: expanding supply capacity and improving supply reliability.

The first main result is that an increase in supply capacity can increase precautionary stockpiling. Supply expansion generates two opposing effects. By lowering the future procurement price, it makes future purchases less costly and therefore reduces the incentive to accumulate inventories in advance. At the same time, however, it lowers the current procurement price, making advance purchases cheaper and encouraging stockpiling. When the expected loss from a future supply disruption is sufficiently large relative to inventory holding costs, the latter effect dominates. Consequently, greater supply capacity increases the equilibrium stockpiling level.

The second main result is that improving supply reliability has a fundamentally different effect. When the shortage loss exceeds the normal future procurement price, an increase in the probability that future supplies remain available reduces precautionary stockpiling. Greater supply reliability lowers the expected cost of relying on future procurement and therefore weakens the incentive to purchase and store supplies in advance.

Taken together, these results highlight an important distinction between supply capacity and supply reliability. Increasing physical supply does not necessarily eliminate the uncertainty that motivates precautionary purchasing. Indeed, when future supply risk remains unresolved, lower current prices resulting from supply expansion may provide healthcare institutions with an additional incentive to accumulate inventories. By contrast, improving the reliability of future supply directly addresses the underlying source of precautionary stockpiling.

This distinction has important policy implications. Policies designed to prevent shortages should not focus exclusively on expanding production capacity or increasing current market supply. If healthcare institutions remain uncertain about whether essential goods will be available in the future, supply expansion alone may fail to reduce precautionary purchasing and may even increase it. Measures that enhance the reliability and credibility of future supply, such as diversifying supply sources, strengthening supply-chain resilience, establishing reliable procurement arrangements, and providing credible information about future availability, can therefore be particularly effective in discouraging excessive inventory accumulation.

Several extensions remain for future research. First, the present model assumes identical healthcare institutions. Allowing institutions to differ in shortage losses, inventory holding costs or exposure to supply disruptions could generate heterogeneous stockpiling responses to supply policies. Second, future supply availability is represented by an exogenous probability. Endogenizing this probability would make it possible to analyze feedback effects through which aggregate stockpiling itself increases the likelihood of future shortages. Such an extension could generate self-reinforcing episodes of panic buying. Third, supply capacity is treated as exogenous. Allowing producers or governments to choose capacity in response to anticipated stockpiling behavior would provide a richer framework for analyzing optimal supply policy.

Overall, the paper demonstrates that supply expansion and supply-risk reduction are not equivalent policies. Greater supply capacity can, under certain conditions, encourage precautionary stockpiling, whereas greater supply reliability reduces it. Effective shortage-management policy should therefore address not only the quantity of goods that can be supplied, but also the reliability with which those goods will remain available in the future. This distinction provides a simple explanation for why policies that successfully expand supply can nevertheless fail to eliminate precautionary purchasing during periods of persistent supply risk.

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