Sustainability Strategies of Equipment Introduction and Overcapacity Risk Sharing in Mask Emergency Supply Chains during Pandemics

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Abstract: The sustainability of the mask emergency supply chain faces two problems during the current COVID-19 pandemic. First, mask manufacturers are mainly small and mid-size enterprises, resulting in a lack of funds and credit lines for the introduction of equipment. Second, the periodicity and uncertainty of pandemics create overcapacity risk for the mask emergency supply chain. To solve these problems, this study incorporates financial leasing institutions and the government into the mask emergency supply chain. Based on a questionnaire survey of practitioners of financial leasing institutions, the relationship between mask manufacturers, financial leasing institutions, and the government in the mask supply chain is analyzed through a game model, and the behavior of mask manufacturers to reduce the scale of mask production after the occurrence of overcapacity is investigated using the cusp catastrophe theory. We find that in the case of masks’ overcapacity, mask manufacturers tend to continue production. Finally, we propose that financial leasing institutions should lease mask production equipment to mask manufacturers under the guarantee of the government and develop a mechanism for the three parties to jointly share the risk of mask overcapacity, aiming at ensuring the sustainable manufacturing of masks during the pandemic.

Keywords: mask emergency supply chain; risk of mask overcapacity; financial leasing; mask production equipment

1. Introduction

Masks represent important personal protective equipment (PPE) [1] and are empirically proven to help prevent the spread of viruses and protect the health of the public [2]. The COVID-19 pandemic that emerged at the end of 2019 has the characteristics of rapid spread, long duration, and strong destructive power. As of 5 August 2021, the cumulative number of patients diagnosed with COVID-19 worldwide has exceeded 200 million, of which the cumulative number of deaths has reached 4.25 million [3]. Since the main transmission route of COVID-19 virus is respiratory droplet transmission and contact transmission [4], wearing a mask is the most important and cost-effective protective measure for the public to prevent and cut off the source of infection. Thus, during the COVID-19 pandemic, governments worldwide have issued recommendations or orders to their citizens to wear masks in public [5]. As an important PPE during the COVID-19 pandemic, the production capacity expansion of masks, the introduction of equipment, and related overcapacity issues have gained the attention of the government and academia.

Owing to the rapid growth in demand for masks and the insufficient capacity of already produced masks, there has been a global shortage of masks [6]. To overcome the shortage of masks and combat the COVID-19 pandemic, mask manufacturers in various countries have expanded their mask production capacity. Additionally, some manufacturers who were not originally engaged in mask production have also invested in mask...
production, thus forming a mask emergency supply chain [7], which has been an important part of the PPE emergency supply chain [8]. For example, after the outbreak of the COVID-19 pandemic in China in January 2020, many Chinese manufacturers invested in the production of masks. By August 2020, the number of companies engaged in the production of medical masks in mainland China increased to 2716 [9]. The annual output of masks in China in 2020 is estimated to exceed 200 billion, which is 20 times the annual output of masks in 2019 [10].

Building a mask emergency supply chain and expanding the production capacity of masks requires manufacturers to obtain more funds to introduce mask production equipment, technology, raw materials, and labor. However, the mask industry is a meager industry [11]. For example, in China in 2019, there were about 200 companies engaged in mask production, producing about 5 billion masks and accounting for more than 50% of the global mask production capacity; however, the total output value was only USD 1.56 billion [12]. Most mask manufacturers are small and mid-size enterprises (SMEs), with low sales, low credit lines, and weak anti-risk capabilities [13]. Therefore, governments and financial institutions of some countries have provided credit guarantees or financial subsidies for the mask emergency supply chains to fully release the production potential of masks and ensure the continuous supply of masks [14].

In addition to the problem of insufficient funds to introduce equipment, mask emergency supply chains during pandemics face the risk of potential overcapacity, as the demand for masks is cyclical and uncertain. It is very likely that, after the current pandemic ends, the market demand for masks will return to the pre-pandemic levels, resulting in a backlog of masks and idle mask production equipment. For example, the COVID-19 pandemic in mainland China was effectively controlled after April 2020, leading to a decline in demand, backlog, and price collapse in the Chinese mask market after May 2020. To minimize the losses caused by mask overcapacity, some mask manufacturers were forced to sell mask production equipment and raw materials at low prices [15]. Therefore, if the risk of overcapacity cannot be effectively mitigated, manufacturers who invest in mask production during a pandemic will suffer economic losses, thus discouraging them from investing in the production of PPE in future pandemics, which is not conducive to maintaining the sustainable manufacturing of masks.

To avoid the risk of overcapacity and to compensate for the losses caused by the unsellability of masks after the end of the current pandemic, mask manufacturers can increase the price of masks while expanding their production capacity to obtain considerable profits. However, the increase in the price of masks will lead to an increase in the public cost of controlling pandemics, causing some low-income mask consumers to reduce or even stop buying masks, thereby weakening the ability of communities to resist the virus. Therefore, some countries have formulated laws and policies during the COVID-19 pandemic to control the price increase of masks. If mask manufacturers use price increases to shift the risk of overcapacity, they may violate such policies [16]. The increase in the price of masks also puts many low-income countries under the pressure of lacking the production capacity for masks [17]. Therefore, the mask emergency supply chains should provide masks to the public at a relatively low price [18]. This study analyzes how to introduce equipment into the mask emergency supply chains and effectively prevent the risk of overcapacity under the premise that mask prices do not increase during pandemics.

To tackle the problem of equipment introduction and overcapacity in mask emergency supply chains during pandemics, scholars have carried out in-depth research. Among them, Wang proposed the horizontal and vertical integration of emergency supply chains and constructed a resilient emergency supply chain operation system for the material collection, transportation, distribution, and recycling processes [19]. Jiang et al. summarized the development process of emergency supply chains, analyzed the existing problems in the guarantee of emergency supplies, and constructed a government-led business continuity management (BCM) emergency supply chain system, consisting of three parts: an operation continuity plan, a business continuity plan, and a data collection and analysis system [20].
Liang and Liu used the evolutionary game method to analyze the evolution of main stakeholders’ behavior in PPE emergency supply chains under the market supervision environment and proposed the introduction of a nonlinear dynamic penalty–subsidy mechanism to effectively ensure the continuous and stable operation of emergency supply chains [21]. Dai et al. suggested that the main data of PPE supply chains should be publicly disclosed so that the government and hospitals can accurately assess the supply chain interruption risk of each PPE manufacturer [22]. To identify the risk aversion characteristics of suppliers in emergency supply chains, Liu et al. have constructed a model for the government and enterprises to jointly reserve emergency supplies and share the cost of material storage [23].

In response to emergency mask supply chains during the COVID-19 pandemic, Cheng proposed encouraging mask manufacturers to export their products to other countries under severe pandemic situations and to establish a reserve library of masks and mask production equipment to improve the storage capacity [10]. Liu proposed that stored masks should be put on the market during public health emergencies to help meet the people’s demand for masks and mitigate the social impact caused by the surge in demand [24]. Manero suggested adopting 3D printing technology in a flexible PPE production system in response to the surge in mask demand due to the pandemic [25]. Ni et al. designed a KN95 mask production line oriented to modular design to meet the functional equipment requirements of different production methods [26]. Similarly, Lin designed a two-dimensional pneumatic servomechanism-based mask sewing platform [27], while Chen et al. proposed to establish a financial system for emergency supply chains to provide financial support to enterprises engaged in the production [28]. In response to the challenges brought by the pandemic to enterprises, Schepers et al. empirically examined how entrepreneurs build entrepreneurial resilience during the COVID-19 crisis based on the research framework of the “challenge-response-learning cycle” [29]; Secinaro et al. studied the changes in the financial statements of European SMEs before and after the SARS outbreak, and analyzed the degree of SARS’s impact on the financial status of SMEs [30]; Campra and Brescia combed through the research literature during the COVID-19 pandemic and found that the COVID-19 pandemic has led to a transformation in the business model of tourism, medical tourism, and food management [31]. Paolo et al. constructed a tourism restart model based on the value chain theory and proposed the main factors affecting the restart of the tourism industry in the context of the new crown pandemic [32].

In response to the introduction of equipment and overcapacity in mask emergency supply chains, Kok and Woo investigated a case where the Taiwanese government established a special committee to support the production of mask production equipment to expand the supply of masks during the COVID-19 pandemic [33]. Li et al. pointed out that, during pandemics, the government’s reduction of taxes levied on mask manufacturers can help the latter introduce mask production equipment and expand the scale of mask production [34]. Jiang and Zhao analyzed how mask manufacturers should avoid financial risks caused by mask overcapacity from the perspective of financial management [16]. Wang proposed that, after the occurrence of mask overcapacity, mask manufacturers should continue production to make up for the fixed costs that have been invested and reduce losses [35]. Zheng suggested that financial institutions should leverage the risk of overcapacity [36]. Kenderdine and Ling analyzed how central banks and sovereign wealth funds can support manufacturing exports to overcome the problem of overcapacity [37]. Zhu et al. introduced a differential game model, established a dynamic coordination mechanism for mask emergency supply chains, optimized emergency supply chains through cost sharing and transfer payments, and analyzed how to reduce the risks faced by emergency supply chains [38].

Although the extant literature has studied the problems related to mask emergency supply chains during pandemics, there are still some shortcomings. First, there is a lack of research on the introduction and disposal of mask production equipment, which is the core part of a mask emergency supply chain. Second, there is a gap in the literature with respect
to the conditions and critical points of the risk of mask overcapacity during pandemics. Third, there are no dynamic analyses of the evolutionary path of the behavior of the main participants in mask emergency supply chains. Thus, to fill the aforementioned gaps in the literature, based on the evolution process and characteristics of mask manufacturers when facing overcapacity, this study proposed the use of financial leasing, which specializes in the leasing of production equipment, as a financial tool to support mask emergency supply chains and utilizes a combination of evolutionary game modeling and the cusp catastrophe model to analyze the conditions and critical points of the mask overcapacity risk during pandemics. Finally, we design a plan for the introduction of equipment in mask emergency supply chains and the guarantee of risk sharing of overcapacity during pandemics.

This study combines qualitative analysis (questionnaire survey) and quantitative analysis (game model, cusp catastrophe model) to examine the mask emergency supply chain during the pandemic. Through the questionnaire survey, we understand the attitude of financial leasing institutions on the mask emergency supply chain. Based on this information, we used the game model to analyze the game behavior between the government, financing institutions, and mask manufacturers in the mask emergency supply chain, and employed the cusp catastrophe model to analyze the process and conditions of mask overcapacity.

The remaining part of this paper consists of the following parts: The second part conducts a questionnaire survey of the practitioners of financial leasing institutions, and then uses a combination of a two-party game model and a cusp catastrophe model to analyze how financial leasing institutions intervene in the mask emergency supply chain and play a role therein. The third part uses a tripartite game model to analyze how the government, financial leasing institutions, and mask manufacturers can cooperate to establish a risk sharing mechanism for mask overcapacity to ensure the sustainable operation of the mask emergency supply chain during the pandemic. The fourth and fifth parts discuss, summarize, and prospect the research results.

2. Intervention of Financial Leasing Institutions in Mask Emergency Supply Chains

2.1. Advantages of Financial Leasing

This study sets up financial leasing as a financial tool to provide mask manufacturers with mask production equipment for three reasons.

First, financial leasing can help solve the problems of overcapacity and inventory backlog faced by manufacturers [39]. Since the increase in demand for masks during pandemics is cyclical, once the pandemic is over, the demand for masks will decline. Therefore, mask manufacturers do not need to purchase mask production equipment, but only need to lease mask production equipment from financial leasing institutions until the end of the pandemic. In other words, through cooperation with financial leasing institutions, manufacturers can cut the cost of purchasing and the long-term maintenance of mask production equipment and reduce the impact of the mask backlog.

Second, financial leasing institutions have professional equipment asset management capabilities, as they can provide manufacturers with professional services such as production equipment leasing, repair, maintenance, and insurance. Additionally, the equipment disposal capacity of financial leasing institutions, as the lessor meets the lessee’s demand for introducing equipment, can also reduce the residual value risk premium in the rent, which is conducive to reducing the financing cost of the lessee [40].

Third, financial leasing has less credit discrimination against SMEs. The reason for this is that a financial leasing company has ownership of the leased property, and the lessee only has the right to use the equipment; thus, when the lessee breaches or goes bankrupt, the lessor can take back the equipment and reduce losses. Therefore, financial leasing transactions often do not require the lessee to provide mortgage assets, which helps to alleviate the financing constraints on enterprises that need to introduce equipment and meet the needs of mask manufacturers, mainly SMEs, in mask emergency supply chains [41].
Next, this study used a questionnaire survey, a two-party game model, and a cusp catastrophe model for the analysis, in that order.

2.2. Questionnaire

To understand the attitude of practitioners in the financial leasing industry toward mask emergency supply chains, we designed a questionnaire and distributed it to practitioners in the field of financial leasing (Questionnaires were distributed in the five financial leasing WeChat groups of China). A total of 128 online questionnaires were distributed; of these, 122 were valid and filled in by the employees of 63 financial leasing institutions in Mainland China.

Regarding job descriptions, as shown in Figure 1, 15.57% of the respondents were company executives, 28.69% were leaders of business or risk control departments, and 38.52% were ordinary managers of business or risk control departments. In addition, 14.75% of the respondents had worked in the financial leasing industry for more than 10 years, 32.79% for 5–10 years, and 40.16% for 2 to 5 years.

![Figure 1](image1.png)

**Figure 1.** Job description of the respondents.

Figure 2 shows the level of understanding of financial leasing by practitioners in the field of masks. Under the five-point system, the respondents’ scores for the mask industry, mask manufacturers, mask production technology/equipment, and the mask market were 2.33, 2.16, 2.14, and 2.43, respectively (“1” means completely unknown, “5” means complete understanding).

![Figure 2](image2.png)

**Figure 2.** The degree of understanding of financial leasing by practitioners in the field of masks.
In order to test whether the data in this paper’s questionnaire is valid, this paper performs a *t*-test on the data of the four answers involving the degree of understanding of financial leasing by practitioners in the field of masks. The test results are shown in Table 1:

| Table 1. *t*-test of the degree of understanding of financial leasing by practitioners in the field of masks. |
|---------------------------------------------------------------|
| **t-Test Result**                                             |
| **Test Value = 3**                                           |
| **95% Confidence Interval**                                  |
| **Mean Difference**                                          |
| **Lower Limit**                                              |
| **Upper Limit**                                              |
| Understanding of mask industry                               |
| Understanding of mask manufacturers                          |
| Understanding of mask production equipment                   |
| Understanding of mask market                                 |
| −7.775                                                      |
| 121                                                         |
| 0.000                                                       |
| −0.844                                                      |
| −1.06                                                       |
| −0.63                                                       |
| −7.457                                                      |
| 121                                                         |
| 0.000                                                       |
| −0.861                                                      |
| −1.09                                                       |
| −0.63                                                       |
| −4.788                                                      |
| 121                                                         |
| 0.000                                                       |
| −0.566                                                      |
| −0.80                                                       |
| −0.33                                                       |
| −5.820                                                      |
| 121                                                         |
| 0.000                                                       |
| −0.672                                                      |
| −0.90                                                       |
| −0.44                                                       |

It can be seen from Table 1 that the *t*-test results for the data of the four responses are statistically significant.

Regarding the attitude of financial leasing practitioners toward mask manufacturers introducing equipment and expanding production capacity during a pandemic, 61.48% of the respondents believed that financial leasing institutions should support mask manufacturers to introduce mask production equipment to combat pandemics; 57.38% believed that insufficient disclosure of relevant information in the field of masks will weaken their willingness to provide financing support; 50.82% believed that their willingness to provide financial support will weaken if mask manufacturers lack collateral and credit lines; 71.31% believed that the government should provide a credit guarantee for mask manufacturers financing actions for the introduction of mask production equipment; 61.48% believed that the government should provide financial subsidies for mask manufacturers; and 60.66% selected “direct leasing” as the financial leasing industry to support the leasing method of equipment introduced by the mask industry.

Regarding the attitude of practitioners in the financial leasing industry to the risk of mask overcapacity after the end of the current pandemic, 63.11% of the respondents believed that the market demand for masks will return to the pre-pandemic level; 81.16% were worried that mask manufacturers might face the risk of overcapacity after introducing equipment and expanding production capacity; 72.95% believed that the government should provide financial support and credit guarantees for mask manufacturers’ financial support and expanding production capacity; 72.95% believed that the government should provide financial support and credit guarantees for mask manufacturers’ financing actions to introduce equipment and expand production capacity, thus alleviating the concerns of financial leasing institutions about the risk of mask overcapacity.

### 2.3. Two-Party Game Model

Based on the results of the questionnaire survey (in Supplementary Materials) of financial leasing practitioners, we constructed a two-party game model for mask manufacturers and financial leasing institutions to choose their strategies after the emergence of mask overcapacity. The assumptions of the model are as follows:

**H1:** The market demand for masks surges during a pandemic, causing mask manufacturers to introduce mask production equipment and expand their production scale. When the pandemic is over, the market demand for masks will return to the pre-pandemic level, leading to the unsellability of masks produced after capacity expansion and making mask production equipment introduced during the pandemic idle.
H2: After the outbreak of the pandemic, a mask manufacturer and a financial leasing institution sign a lease contract in the form of a “direct lease”, in which the latter is responsible for purchasing mask production equipment and renting it to the former to expand the mask production capacity. During the lease period, there will be a mask overcapacity; thus, the strategy of the financial leasing institution will be {continue leasing, stop leasing}, while the strategy of mask manufacturers will be {continue production, stop production}.

H3: The financial leasing institution evaluates the assets of the leased mask production equipment in accordance with the fair value and adopts the method of equal principal and interest repayment. The lease period for the mask manufacturer to lease mask production equipment is calculated on a monthly basis in “n” months. The interest and rent must be paid to the financial leasing institution every month, and the price of masks during the lease period remains unchanged. The capital cost of the financing leasing institution to purchase the mask production equipment is “$C_1$”, the fair value of the mask production equipment is “$V$”, the rate of return of masks during the lease period is “E”, the monthly rate of return is the same, the lease rate is “$\lambda$”, the lease interest rate is “r”, and the cost for the financial leasing institution to investigate the mask manufacturers’ information is “$C_2$”.

H4: The mask overcapacity occurs in the “t” (t < n) month of leasing mask production equipment. If the mask manufacturer and the financial leasing institution choose to terminate the lease contract in the month when the mask overcapacity occurs, the liquidated damages that need to be paid to the other party are “$D_1$” and “$D_2$”, respectively. After the early termination of the contract, the production equipment will be returned to the financial leasing institution. Additionally, if the mask manufacturer wants to continue to maintain production, it needs to purchase mask production equipment from the financial leasing institution at the depreciation rate “$\delta$”.

H5: The probability that the financial leasing institution chooses to continue or stop leasing is “m” and “1 − m”, respectively. Similarly, the probability that the mask manufacturer chooses to continue or stop production are “n” and “1 − n”, respectively, where 0 indicates that the financial leasing institution chooses to stop leasing or the mask manufacturer chooses to stop production, whereas “1” means that the financial leasing institution chooses to continue leasing or the mask manufacturer chooses to continue production.

Based on the above assumptions, this study constructs a two-party game model including financial leasing institutions and mask manufacturers after the occurrence of mask overcapacity, in which the financial leasing institutions are the lessor and the mask manufacturers are the lessee. The profit matrix of the model is presented in Table 2.

**Table 2.** The income matrix of the two-party game model.

| Game Strategy Combination | Financial Leasing Institutions | Mask Manufacturers |
|---------------------------|--------------------------------|-------------------|
| (1, 1)                    | $\lambda(1 + r)^n - V - C_1 - C_2$ | $\lambda V(1 + E) - \lambda V(1 + r)^n - \frac{n - t}{n} \lambda V(1 + E)$ |
| (1, 0)                    | $\lambda V(1 + r)^t + D_1 - V - C_1 - C_2$ | $\frac{1}{\lambda} \lambda V(1 + E) - \lambda V(1 + r)^t - D_1$ |
| (0, 1)                    | $\lambda V(1 + r)^t - C_1 - C_2 - D_2 + \delta - 1)|V$ | $\frac{1}{\lambda} \lambda V(1 + E) + D_2 - \lambda V(1 + r)^t - \delta V$ |
| (0, 0)                    | $\lambda V(1 + r)^t - C_1 - C_2 - V$ | $\frac{1}{\lambda} \lambda V(1 + E) - \lambda V(1 + r)^t$ |

Using the assignment method, we calculated that when $\lambda = 0.5$, $V = 20$, $r = 0.5$, $n = 10$, $C_1 = 4$, $C_2 = 1$, $D_1 = 1$, $D_2 = 10$, $\delta = 0.001$, $n = 10$, $t = 8$, and $E = 0.001$, the game model reaches the equilibrium point (1, 0), indicating that the financial leasing institutions choose to continue leasing, and the mask manufacturers choose to stop production. At this time, the cooperative relationship between financial leasing institutions and mask manufacturers breaks down, and the mask emergency supply chains are at risk of interruption. The calculation results of the two-party game model show that if there is no third party to provide guarantees for the cooperation between the financial leasing institutions and the mask manufacturers, the cooperation between the two parties will be difficult to maintain after the risk of mask overcapacity appears.
The replication dynamic equation of the mask manufacturers’ response behavior when there is overcapacity is as follows:

\[
K(s) = s(1 - s)[\lambda V(1 + E) - \lambda V(1 + r)^n - D_1] + (1 - s)[\lambda V(1 + E) - \lambda V(1 + r)^n] \]
\[
- s[\lambda V(1 + E) - \lambda V(1 + r)^n - \lambda V(1 + E)] - (1 - s)[\lambda V(1 + E) + D_2 - \lambda V(1 + r)^n - \delta V]
\]
\[
= \{-\lambda V[(1 + r)^n - (1 + r)^n] + D_1 - D_2 + \delta V\}s^3 + [\lambda V[(1 + r)^n - (1 + r)^n] - D_1 + 2D_2 - 2\delta V]s^2 + (\delta V - D_2)s
\]  

(1)

The function of this replication dynamic equation is to describe the mask manufacturer’s production strategy selection behavior after the occurrence of mask overcapacity.

2.4. The Cusp Catastrophe Model

To better observe and analyze the conditions and impact of the risk of mask overcapacity on the state of the mask emergency supply chain, this study introduces the cusp catastrophe model. The basic principle of the cusp catastrophe model is that changes in two control variables cause the state variables of the system to change. As shown in Figure 3, the 3D surface map of the cusp catastrophe model is composed of the upper, lower, and folded lobes. The upper and lower layers are the safety layers, and the folded layer is the risk layer, with point O being the evolution starting point of the system. When 0 evolves from the upper lobe to the lower lobe along the O–S path, the system is always in a safe state; however, when the system evolves along the O–P–H–Z path, the folded leaves become crossed in the P–H section. At this time, the system suddenly changes to a risk state, and the trajectory becomes unstable.

![Figure 3. The 3D surface diagram of the cusp catastrophe model.](image)

This study adopts the traditional strategy of choosing to stop production in the two-party game model of mask manufacturers and financial leasing institutions when the pandemic is in the safety state, whereas mask manufacturers choose to continue production when the pandemic is in the risk state according to the cusp catastrophe model. Additionally, we translate and transform the reproduction dynamic equation of the mask manufacturers’ behavior in the two-party game model into the relevant equations, parameters, and constraints of the cusp catastrophe model under the corresponding conditions and then analyze the evolution process and conditions of the mask manufacturers’ choice behavior when facing overcapacity [42,43]. The process of translation transformation is as follows:

Let \( N_1 = -\lambda V[(1 + r)^n - (1 + r)^n] + D_1 - D_2 + \delta V, N_2 = \lambda V[(1 + r)^n - (1 + r)^n] \]
\[
- D_1 + 2D_2 - 2\delta V, N_3 = \delta V - D_2, N_2 = (N_1 + N_3),
\]

where “\( N_1 \)” is calculated as “the net income of mask manufacturers that choose to stop production when mask overcapacity occurs – the net income of mask manufacturers
that choose to continue production strategy + mask manufacturers’ purchase of mask production equipment + 2 * liquidated damages paid by mask manufacturers—liquidated damages paid by financial leasing institutions”.

Then, the replication dynamic Equation (1), which describes the strategy selection behavior of mask manufacturers in Section 2.3, can be converted to the following:

\[
K(m_1) = \frac{dn_1}{dt} = N_1m_1^3 + N_2m_1^2 + N_3m_1. \tag{2}
\]

Let \( y = m_1 + \frac{N_2}{3N_1} \), then \( \frac{dy}{dt} = y^3(t) + uy(t) + v. \tag{3} \)

Equation (3) can be changed to the balance surface equation of the standard cusp catastrophe model as:

\[
V'(t) = y^3 + uy + v = 0. \tag{4}
\]

Among them, “\( u \)” and “\( v \)” are the control variables, while “\( y \)” is the state variable. The \( u \) and \( v \) variables are calculated as follows:

\[
u = \frac{N_2^3 - N_3^2}{27N_1^3} - \frac{N_2N_3}{3N_1^2}, \]

\[v = \frac{N_3^2 - N_2^3}{3N_1^2} - \frac{N_3}{27N_1^2}. \tag{5}\]

According to the catastrophe theory, the critical surface where the risk state occurs is the projection of the curved surface, as shown in Equation (5), in the direction (\( u, v \)). Taking the derivative of Equation (4), the condition that the singular point set satisfies is:

\[
V'' = 3y^2 + u = 0. \tag{6}
\]

Simultaneously, Equations (4) and (6) can obtain the critical surface of the patient’s behavior in the risk state, that is, the set of divergence points are computed as:

\[4u^3 = -27v^2. \tag{7}\]

When \( u > 0 \), Equation (6) has no real number solution, that is, the potential function of change has no real number solution, indicating that the risk state will not appear. At this time, when \( N_1 > 0 \) and \( \delta - D_2 > 0 \), the net profit when the mask manufacturer chooses to stop the production — the net profit when the mask manufacturer chooses to continue the production + the mask manufacturer’s purchase of masks production equipment + 2 * liquidated damages paid by the mask manufacturer – the liquidated damages paid by the financial leasing institutions is more than 0, and the expenditure of the mask manufacturer on purchasing mask production equipment is greater than the liquidated damages paid by the mask manufacturer. Thus, the mask manufacturer tends to adopt the strategy of stopping production.

When \( N_1 < 0 \) and \( \delta - D_2 < 0 \), within the set of divergent points, there is a possibility of a sudden change in the cusp, consequently entering a state of risk. At this time, the net profit when the mask manufacturer chooses to stop the production — the net profit when the mask manufacturer chooses to continue the production + the mask manufacturer’s purchase of mask production equipment + 2 * the liquidated damages paid by the mask manufacturer – the liquidated damages paid by the financial leasing institutions is less than 0, and the expenditure of the mask manufacturer on purchasing mask production equipment is less than the liquidated damages paid by the mask manufacturer. Therefore, the mask manufacturer tends to adopt the strategy of continuing production.

This study uses the assignment method to assign and transform the main parameters of the two-party game model and finds that the changes in the mask manufacturer’s behavior are within the set of divergence points, as shown in Figure 4. This means that there is a possibility of sudden changes in the behavior of mask manufacturers, that is,
mask manufacturers tend to abandon the traditional strategy of stopping production after the occurrence of mask overcapacity and choose the strategy of continuing production.

Figure 4. Diagram of the divergence point set of the cusp catastrophe model.

Under normal evolutionary game conditions, the trajectory of the mask manufacturer’s behavior does not exceed the range of the divergent point set; however, to more intuitively describe the evolution mechanism of the mask manufacturer’s behavior, we use a 3D surface diagram and a 2D projection diagram to illustrate the complete trajectory of the behavior of the mask manufacturer before and after the sudden change. Figure 5 shows the evolution mechanism of the safety state of the mask manufacturer’s behavior. When the value of “v” does not change and the value of “u” gradually decreases, the trajectory of the phase point is B2–S2, at this time, the behavior of the mask manufacturer is in a stable state. When the value of “v” gradually decreases and is finally less than 0, the value of “u” first decreases and then increases, and the phase point motion trajectory will change to S2–A2–D2, as the phase point moves along the smooth surface from the upper lobe to the lower lobe. At this time, there is no intersection point between B′2–S′2–A′2–D′2 and the divergent point set T′1O′T′2 on the 2D plane, thus making the mask manufacturer’s behavior always in a safe state during the evolution process.

Figure 6 shows the evolution mechanism of the risk state of the mask manufacturer’s behavior. When the value of “v” gradually decreases and the value of “u” does not change, the trajectory of the phase point is L1–L2. At this time, the mask manufacturer’s behavior is in a safe state, and as the value of “v” is further reduced, the trajectory of the phase point turns to L2–L3, then the phase point is close to the folded lobe, and the mask manufacturer’s behavior gradually changes from a safe state to a risky state.
A - 2D and the divergent point set 1T O 2T on the 2D plane, thus making the mask manufacturer’s behavior always in a safe state during the evolution process.

Figure 4. Diagram of the divergence point set of the cusp catastrophe model.

Figure 5. Diagram of the evolution mechanism of the safety state of the mask manufacturer’s behavior.

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With the further decrease in the “V” value and the gradual increase in the “u” value, the trajectory of the phase point turns to L3–L4. At this time, the phase point enters the folded lobe and jumps suddenly. This is manifested in a 2D plane as the projection of the trajectory of the phase point passing through the set of divergent points 7LOL, with the phase point in the folded lobe being very unstable with no fixed running track, which represents the sudden change in the mask manufacturer’s behavior.

As the value of “v” further decreases and becomes a negative value, the trajectory of the phase point turns to L5–L6, and the phase point gradually leaves the folded lobe and enters the lower lobe, which means that the mask manufacturer’s behavior changes from a risky state to a safe state.

According to the definitions of N1, N2, u, and v in the cusp catastrophe model, and the respective trajectories of the phase points in Figures 5 and 6, we can see that by increasing the liquidated damages in the mask production equipment lease contract signed by the mask manufacturers and financial leasing institutions, reducing the rental interest rate of mask production equipment, purchasing small and medium-sized mask production equipment with relatively low value, and signing flexible contracts with flexible lease terms, mask manufacturers can be more inclined to continue producing masks after over-capacity and maintain the sustainable manufacturing of masks. On the contrary, mask manufacturers are more inclined to stop producing masks, which puts the mask emergency supply chain at risk of interruption.

Figure 5. Diagram of the evolution mechanism of the safety state of the mask manufacturer’s behavior.

Figure 6. Diagram of the evolution mechanism of the risk state of the mask manufacturer’s behavior.

With the further decrease in the “V” value and the gradual increase in the “u” value, the trajectory of the phase point turns to L3–L4. At this time, the phase point enters the folded lobe and jumps suddenly. This is manifested in a 2D plane as the projection of the trajectory of the phase point passing through the set of divergent points 7LOL, with the phase point in the folded lobe being very unstable with no fixed running track, which represents the sudden change in the mask manufacturer’s behavior.

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trajectory of the phase point passing through the set of divergent points $L'_4O'L'_7$, with the phase point in the folded lobe being very unstable with no fixed running track, which represents the sudden change in the mask manufacturer’s behavior.

As the value of “v” further decreases and becomes a negative value, the trajectory of the phase point turns to $L_5-L_6$, and the phase point gradually leaves the folded lobe and enters the lower lobe, which means that the mask manufacturer’s behavior changes from a risky state to a safe state.

According to the definitions of $N_1$, $N_2$, u, and v in the cusp catastrophe model, and the respective trajectories of the phase points in Figures 5 and 6, we can see that by increasing the liquidated damages in the mask production equipment lease contract signed by the mask manufacturers and financial leasing institutions, reducing the rental interest rate of mask production equipment, purchasing small and medium-sized mask production equipment with relatively low value, and signing flexible contracts with flexible lease terms, mask manufacturers can be more inclined to continue producing masks after overcapacity and maintain the sustainable manufacturing of masks. On the contrary, mask manufacturers are more inclined to stop producing masks, which puts the mask emergency supply chain at risk of interruption.

The cusp catastrophe model points out how mask manufacturers choose production strategies when facing the risk of overcapacity to avoid interruption of the mask emergency supply chain. Next, this study uses a tripartite game model to analyze how the risk sharing mechanism for mask overcapacity is established after the government joins the mask emergency supply chain.

3. Government Intervention in Mask Emergency Supply Chains

In the second chapter of this paper, based on the combination of the two-party game and the cusp catastrophe models, we analyze the evolution process and conditions of mask manufacturers in the face of mask overcapacity when financial leasing institutions are involved in the mask emergency supply chain. On this basis, we introduce the government into the mask emergency supply chain, establish a tripartite game model, and design a tripartite cooperation between mask manufacturers, financial leasing institutions, and the government to jointly share the risk of mask overcapacity and achieve a stable operation of the mask emergency supply chain.

3.1. Background on Government Intervention in Mask Emergency Supply Chains

Since most mask manufacturers are SMEs, it is difficult to obtain financing support from financial institutions. Therefore, mask manufacturers need to seek government support to use government credit as a guarantee to apply to financial leasing institutions for leasing business to obtain mask production equipment. In addition, the overcapacity problem faced by mask emergency supply chains may prevent manufacturers that rent mask production equipment from fully repaying the financial lease payments on time, which may lead to the emergence of credit risks [44]. Among the financial leasing transactions announced by Chinese listed companies from 2007 to 2016, about 30% of the lessees were companies with overcapacity [45]. Therefore, Liu proposed that the government should purchase and store excess masks after the occurrence of mask overcapacity [24]. Additionally, other studies suggested that the government should prepare medical supplies for future pandemics to alleviate the inventory pressure of mask manufacturers. Li postulated that the government’s active intervention can help eliminate market concerns about the expected slow sales and overcapacity of masks [46]. For emergency supplies, such as PPE, which are highly time-sensitive and in large demand, Pi suggests that a joint administrative and enterprise reserve mechanism should be implemented, with government finances supporting enterprises to reserve emergency supplies [47].

For example, during the COVID-19 pandemic in China, due to the government’s active intervention, manufacturers were relieved from the anticipated mask overcapacity and slow sales, and they were also strongly encouraged to actively expand their mask
Some financial leasing institutions are also actively cooperating with medical equipment manufacturers with the encouragement of the government to support manufacturers in producing more medical supplies, including masks, to fight the COVID-19 pandemic. For example, in February 2020, under the promotion of the Jiangxi Provincial Government, Jiangxi Financial Leasing Co., Ltd. provided a financing support of CNY 50 million for a company engaged in the production of medical equipment to help expand the scale of production of such equipment, including masks [48].

3.2. Tripartite Game Model

Based on the research results in Section 2, we construct a tripartite game model for the strategic choices of financial leasing institutions, mask manufacturers, and the government after the occurrence of mask overcapacity. In this model, the financial leasing institutions are the lessors, the mask manufacturers are the lessees, and the government is the guarantor. The assumptions of the model are as follows.

H1: The government’s strategy set is [guaranteed, and not guaranteed]. Among them, the probabilities that the financial leasing institutions choose either the “continuing leasing” or “stopping leasing” strategy are “m” and “1 − m”, respectively. Similarly, the probabilities that the mask manufacturer chooses either the “continuing production” or the “stopping production” strategy are “s” and “1 − s”, respectively. The probabilities that the government chooses “guaranteed” or “non-guaranteed” are “x” and “1 − x”, respectively.

H2: The government uses the following two methods to perform its own guarantee function. First, it provides credit guarantees for mask manufacturers to lease mask production equipment to reduce the cost of information investigation by financial leasing institutions. Second, it establishes a joint government–enterprise reserve model. After the occurrence of mask overcapacity, if the mask manufacturer chooses to continue production, the government will purchase unsold masks and store them in preparation for the next pandemic. Conversely, if the mask manufacturer chooses to stop production and returns the mask production equipment to the financial leasing agency, the government is responsible for the cost of idle equipment, with its social benefit by sharing the risk of mask overcapacity represented as “R”.

Based on the above assumptions, we construct a tripartite game model, in which “1” means that the subject of the game adopts the strategy of “continuing leasing”, “continuing production”, or “guarantee”; whereas “0” means that the subject of the game adopts the strategy of “abandoning leasing”, “stopping production”, or “no guarantee”. The profit matrix of the model is shown in Table 3.

Using the assignment method, when R = 2, λ = 2e, V = 1, r = 0.01, n = 50, C_1 = 1.1, C_2 = 4.75, C_3 = 10, E = 8.85, t = 40, D_1 = 10, D_2 = 10, and δ = 0.01, the equilibrium point of the tripartite game model is (1, 1, 1), which means that after the occurrence of mask overcapacity, the financial leasing institution chooses to continue leasing, the mask manufacturer chooses to continue production, and the government chooses “guarantee”. That is, the three parties cooperate comprehensively to jointly share the risk of mask overcapacity.

The calculation results of the tripartite game model indicate that financial leasing institutions and the government should cooperate with mask manufacturers to jointly share the risk of mask overcapacity. After the occurrence of mask overcapacity, if mask manufacturers and financial leasing institutions continue to perform their contracts, the government is responsible for purchasing unsold masks and storing them in response to future pandemics. If financial leasing institutions or mask manufacturers choose to default or terminate the lease contract early, it must pay the other party liquidated damages and return the mask production equipment to the financial leasing institutions.
we proposed a plan to help mask manufacturers effectively share the risk of overcapacity through the analysis of the game and the cusp catastrophe models, we found that, afterproduction + the mask manufacturer’s purchase of mask production equipment + 2 * the leasing and disposal financing and disposal. Therefore, this study sets the financial leasing institution as the investor in the mask emergency supply chain, focuses on the leasing and disposal of mask production equipment, and contributes to the literature on emergency supply chain management.

4. Discussion

As shown in the literature review in the first chapter of this paper, the existing studies mainly examine the composition, operation mechanism, mask reserve, risk prevention, and other issues of the mask emergency supply chain during the pandemic. Based on previous research, this study refines the research on the risk of mask overcapacity and equipment leasing in the mask emergency supply chain and introduces the research method of cusp catastrophe model to analyze the conditions and processes of mask overcapacity.

According to the characteristics of the COVID-19 pandemic and mask emergency supply chains in China, this study investigated how manufacturers, financial institutions, and the government could cooperate to combat the pandemic by improving the mask emergency supply chains, helping manufacturers introduce mask production equipment and share the risk of mask overcapacity, ensuring the sustainable manufacturing of masks, and providing guidance for emergency supply chain management during future pandemics.

The traditional response of manufacturers regarding the overcapacity is to reduce capacity; however, due to the uncertainty of the pandemic, if the pandemic worsens after the mask capacity declines, the shortage of masks will threaten public health. Therefore, we proposed a plan to help mask manufacturers effectively share the risk of overcapacity and guarantee the sustainable manufacturing of masks without reducing the production capacity prematurely.

Moreover, the analysis method that combines the game and the cusp catastrophe models proposed in this study can help researchers study the emergence and control of risks in the evolution of the behavior of relevant subjects in mask emergency supply chains. Through the analysis of the game and the cusp catastrophe models, we found that, after the emergence of mask overcapacity, the net profit when the mask manufacturer chooses to stop production — the net profit when the mask manufacturer chooses to continue production + the mask manufacturer’s purchase of mask production equipment + 2 * the liquidated damages paid by the mask manufacturer — the liquidated damages paid by the financial leasing institutions is less than 0, and the expenditure of the mask manufacturer on purchasing mask production equipment is less than the liquidated damages paid by the mask manufacturer. Thus, the mask manufacturer tends to adopt the strategy of continuing production; otherwise, the mask manufacturer tends to adopt the strategy of stopping production.

Furthermore, mask production equipment is one of the core components of the mask emergency supply chain, and financial leasing is a financial tool specialized in equipment financing and disposal. Therefore, this study sets the financial leasing institution as the investor in the mask emergency supply chain, focuses on the leasing and disposal of mask production equipment, and contributes to the literature on emergency supply chain management.
5. Conclusions

This paper proposes a risk sharing mechanism for mask overcapacity during the pandemic. In the event of a pandemic, the demand for masks increases rapidly, and manufacturers need to obtain mask production equipment and expand production capacity. Therefore, financial leasing institutions should intervene in the mask emergency supply chain, purchase mask production equipment, and lease it to the mask manufacturers under the government’s credit guarantee. The mask manufacturers should return the mask production equipment to the financial leasing institutions after the lease expires. In other words, financial leasing institutions and the government should cooperate with mask manufacturers to jointly share the risk of mask overcapacity. The government–enterprise joint reserve model of financial leasing institutions and the government should be established to reserve idle masks and mask production equipment after overcapacity. In addition, the financial leasing institutions are responsible for finding other mask manufacturers from countries that are still hit by the pandemic and leasing mask production equipment to them, while the government bears the idle cost of mask production equipment. The mask industry should establish a perfect information disclosure system and regularly disclose basic information on the state of the industry to the market to reduce the information investigation cost of financial institutions.

This paper analyzes the risk of overcapacity and equipment leasing in the mask emergency supply chain. In order to solve the problem of overcapacity of masks and unstable supply of masks, a comprehensive supply chain as a complete ecosystem should be established. This comprehensive supply chain includes mask production planning, storage, distribution channels, information sharing, market research, customer behavior, public health policies, logistics, raw material supply, etc., and these are also the future research directions of the mask emergency supply chain.

Supplementary Materials: Questionnaire survey of “Attitudes of financial leasing institutions to the expansion of mask production capacity” and its data are available online at https://www.mdpi.com/article/10.3390/su131810355/s1.

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