Article

The Impact of Sustainable Development of Cold Chain Logistics on China's COVID-19 Pandemic

Xia Li [1], Yifang Liu [1] and Huijuan Wang [2,*]

1   School of Economics, Central University of Finance and Economics, Beijing 102206, China
2   School of Statistics and Mathematics, Central University of Finance and Economics, Beijing 102206, China
*   Correspondence: wanghuijuan@cufe.edu.cn

Abstract: Currently, there are multiple COVID-19 outbreaks in China's imported cold chain product logistics. Cold chain logistics (CCL) have become an important source and weak link of China's epidemic risk. This article discusses the differential effect of CCL on COVID-19 epidemic risk in different regions of China from an econometric analysis perspective. By comparing the development level of China and foreign countries, it can be observed that the sustainability of CCL may be a key factor affecting the risks of the epidemic. This article confirms the inverse correlation between the level of sustainability of CCL and the risk of epidemics from both mechanism analysis and empirical tests. Developing sustainability is not only beneficial to the development of the CCL industry itself but also an effective way to mitigate the risk of epidemics.

Keywords: cold chain logistics; sustainability; COVID-19 pandemic; risk management

1. Introduction

The novel coronavirus 2019 (COVID-19) has caused a huge negative effect on human production and life, which has attracted great attention from governments and scholars at all levels around the world [1]. COVID-19 is highly contagious and dangerous [2]. As of 10 August 2022, the number of deaths has exceeded 6.41 million. To control the spread of the outbreak, governments worldwide have implemented measures to restrict the movement of people, gatherings and travel, and even enforced quarantines. It has affected over 90% of the world's population [3] and caused severe economic recession in many countries [4].

The identification of factors influencing the risk of new crown epidemics has become the current focus of many government departments and scholars. Many scholars have carried out related research using various mathematical models, big data information from multiple sources, etc. [5]. Among them, population mobility has become the currently recognized influencing factor [6,7]. Scholars have used different data information to study the impact of population movement on epidemic risk, such as Baidu population migration data [8], air ticket ordering data [9–11], mobile phone displacement data [12], traffic data [13], survey data [14] and other data [15]. In addition, some scholars point out that the social environment, such as urbanization level [16], medical level [17,18], population age [19], population density [19], government awareness of prevention and control [20] and transportation system [21], as well as the natural environment, including air pollution [22] and temperature [23], all have an impact on the risk of epidemics.

However, with the regularization of domestic outbreak control in China, measures such as border restrictions and isolation have effectively stopped the virus from spreading through infected persons [24,25]. Instead, the recent frequency of cold chain logistics (CCL)-related outbreaks has caused widespread public concern [26,27]. Several studies have shown that the frozen state is more conducive to the survival of novel coronaviruses [27,28]. CCL has become a new way of spreading the coronavirus disease [29,30]. Throughout

the epidemic events in China, as of July 2022, CCL-related cases have involved Beijing, Tianjin, Liaoning, Heilongjiang, Hubei, Zhejiang, Shandong, Anhui, Henan and many other provinces. This has resulted in a multi-point sporadic distribution and localized aggregated outbreaks overlapping in China (Figure 1).
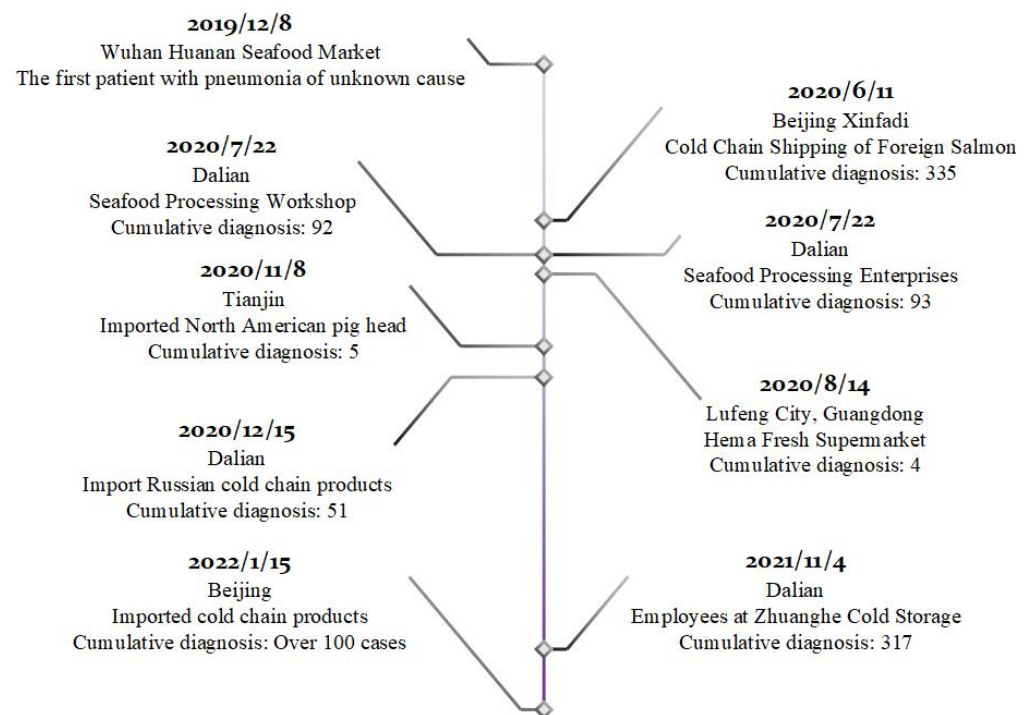

2019/12/8
Wuhan Huanan Seafood Market
The first patient with pneumonia of unknown cause

2020/6/11
Beijing Xinfadi
Cold Chain Shipping of Foreign Salmon
Cumulative diagnosis: 335

2020/7/22
Dalian
Seafood Processing Workshop
Cumulative diagnosis: 92

2020/7/22
Dalian
Seafood Processing Enterprises
Cumulative diagnosis: 93

2020/11/8
Tianjin
Imported North American pig head
Cumulative diagnosis: 5

2020/8/14
Lufeng City, Guangdong
Hema Fresh Supermarket
Cumulative diagnosis: 4

2020/12/15
Dalian
Import Russian cold chain products
Cumulative diagnosis: 51

2022/1/15
Beijing
Imported cold chain products
Cumulative diagnosis: Over 100 cases

2021/11/4
Dalian
Employees at Zhuanghe Cold Storage
Cumulative diagnosis: 317

Figure 1. Statistics on major cold chain-related COVID-19 outbreak events in China. Sources: Chinese Center for Disease Control and Prevention (www.chinacdc.cn, accessed on 10 August 2022).

CCL has become the main factor affecting the current risk of new crown epidemics. Given that the outbreaks of epidemic events in CCL vary from region to region, if the reasons for this variability can be derived, the risk of epidemic can be effectively reduced through risk management in CCL. However, most of the current academic studies on CCL are based on medical perspectives or descriptive studies [30,31]. There is a lack of corresponding empirical studies on whether there is any link between CCL and epidemic risk. By comparing the development level of China and foreign countries, it is observed that the sustainability level of CCL may be a key factor affecting the risk of epidemics. Further, this article confirms the inverse correlation between the level of sustainability of CCL and the risk of epidemics from both mechanism analysis and empirical tests. The research results show that improving the sustainability of CCL is not only beneficial to the development of the CCL industry itself but also an effective way to mitigate the risk of epidemics. This has important theoretical and practical implications for preventing the spread of the new crown epidemic along the CCL and improving the development level of CCL in China. This also provides a theoretical basis for the relevant departments to carry out epidemic control measures in the future, thus effectively reducing the risk of epidemics.

The remainder of the paper is as follows. Section 2 provides the mechanistic analysis of the effect of the sustainable development of CCL on the risk of a new crown epidemic. Section 3 provides the empirical analysis. Section 4 represents research results and analysis. Section 5 reports the discussion, and Section 6 reports the conclusions.

2. Mechanistic Analysis of the Effect of Sustainable Development of CCL on the Risk of New Crown Epidemics

At present, China's COVID-19 epidemic prevention and control has entered a normalized stage [32]; however, the situation outside epidemic prevention and control is still

serious [33], the cross-border movement of people and trade flows caused by the risk of foreign import of the new crown pneumonia epidemic is increasing [32]. Currently, scholars have conducted research on risk assessment [33] and policies for prevention and control [34] of inbound persons. With the implementation of policy measures such as closed-loop transit and segregation control [35], the risk of inbound personnel has been effectively managed [36]. Instead, the frequency of imported local outbreaks triggered by the imported cold chain is causing wide concern [27]. Several studies have shown that the cold environment is more suitable for virus survival [37,38]. Imported frozen products have become one of the important transmission routes for the virus of the new crown pneumonia outbreak [39,40]. Since June 2020, many imported epidemics in China have originated from refrigerated goods imported from abroad, and CCL has now become the subject of strict control in China [37]. The frequent occurrence of cold chain epidemics has exposed many shortcomings in the management of China's CCL.

Therefore, this paper explores the reasons for the frequent occurrence of epidemics in China's CCL by comparing the development situation in China and abroad, and then provides theoretical basis and policy suggestions for future epidemic prevention and control in CCL.

2.1. Analysis of the Gap between China and International CCL Development

As urbanization accelerates and people's awareness of food safety increases, the market size of China's CCL industry is growing rapidly [41]. First, the demand for CCL remains strong. Under the normalization of epidemic prevention and control, the total market demand exceeded 270 million tons in 2021 [42]. Second, the market size shows a stable growth trend. The research report predicts that the market scale of China's CCL industry will increase to CNY 450.5 billion in 2022 [42]. Finally, the size of CCL infrastructure construction also shows a continuous expansion trend. Cold storage capacity and the number of reefer trucks are growing rapidly. By 2020, the total amount of national food cold storage reached 70.8 million tons, with a new storage capacity of 10.275 million tons, an increase of 16.98% [42]. The national refrigerated vehicle fleet will be 275,000 units in 2020, with a year-by-year growth rate of about 28.09% [43].

The current traditional scale growth trend of China's CCL industry is more obvious, but the level of sustainable development is lacking [44]. Specifically, there are deficiencies in standardization, informatization, automation and green development (Table 1). The construction of an industry standardization system is not comprehensive [45]. At present, although more than 200 cold chain industry standards have been declared in China, the standards are repeated, and the coverage of standards needs to be further expanded [46]. The application level of information technology needs to be improved. Canada, the Netherlands and many other developed countries have adopted advanced logistics information technology within the process of CCL, which has greatly improved the transparency and traceability of product logistics information. However, China has not yet established a comprehensive information monitoring platform for CCL, which cannot realize the real-time monitoring of the whole process of CCL transportation and the traceability of information. It is impossible to implement the effective supervision and guarantee of CCL epidemic risks [47]. By the end of 2020, only around 10 provinces/cities, including Beijing, Tianjin, Shanghai, Zhejiang, Fujian and Guangdong, were able to implement cold chain food traceability [48]. This demonstrates that China has numerous technical pain points in the elimination of imported food and supervision and traceability during the epidemic [49]. The level of automation needs to be improved. Developed countries, such as Japan and Germany, have established advanced CCL warehousing facilities and equipment, such as automated cold storage, automated warehousing, etc., thus saving significant labor costs [45,50]. However, China's CCL operations are still dominated by labor, and the application of facilities and equipment, such as automated sorting, handling, loading and unloading, is insufficient, and the low level of specialization in cold chain operations restricts the improvement of overall efficiency. During the pandemic, close proximity within

working environments further increased the difficulty of epidemic prevention and control. The degree of green technology is also lacking. Of the CCL freight volume in China, 90% is completed by road cold chain transportation. The energy consumption is mainly fuel, and the carbon emission is large [51]. In addition, outdated refrigeration equipment and technology leads to high energy consumption for refrigeration [52]. However, developed countries, such as Japan and South Korea, are actively developing various infrastructure constructions, such as road, rail, sea and air transportation, required for CCL across the country [52,53].

Table 1. Comparison of the development situation of CCL in China and abroad.

	Country	Development Level Comparison
Standardization	America	In 2002, the CCL Association issued the "Cold Chain Quality Standards", covering storage, transportation, processing and other industries, providing the basis for the certification of the entire cold chain products; in 2005, the "National Transportation Science and Technology Development Strategic Plan" was formulated, with a construction period of 20 years [45]
	Japan	The Ministry of Agriculture, Forestry and Fisheries established the Food Cold Chain Promotion Association and issued the "Quality Management Methods for Frozen Food and the Improvement Direction of Frozen Circulation Facilities" and "Refrigeration Chain Guidelines" [45]
	Canada	Adopted advanced market access systems, such as Good Agricultural Practice (GAP) and Good Veterinary Practice (GVP) [54]
	China	The linking system of all links, professional certification systems and market access systems still need to be improved [45,55]
Informatization	America	The transportation vehicles are installed with tracking and information traceability systems, and the real-time supervision and location tracking of the transportation vehicles are carried out during the transportation process, so that the entire process can be traced to any link of the logistics information [56].
	Canada	Automatic temperature control and detection equipment are widely used and the Internet of Things and Global Positioning System (GPS) technology are being developed. During the logistics and transportation process, the real-time monitoring of refrigerated temperature changes, vehicle operation, fuel consumption and door opening times is performed [57]
	Netherlands	The construction of the information platform is relatively complete. During the whole logistics process, the real-time temperature and location information of products can be inquired after at any time, which greatly enhances the transparency of product logistics information [56]
	China	China has not yet established a comprehensive CCL information monitoring platform; thus cannot realize the real-time monitoring of the whole process of CCL transportation and the traceability of CCL information and cannot realize the effective supervision and guarantee of cold chain risks [47]
Automation	Germany	Adopt automated cold storage technology, such as storage technology automation, warehouse management system, etc. [50]
	Japan	Equipped with temperature control equipment that can be controlled by grades, the world's leading automated three-dimensional warehouse, a high degree of automation saves significant labor costs [45]
	China	The CCL operation is still dominated by labor, the lack of application of facilities and equipment, such as automatic sorting, handling, loading and unloading, and the low level of specialization in the cold chain operation restricts the improvement of overall efficiency

Table 1. *Cont.*

	Country	Development Level Comparison
Green	Europe	In terms of energy saving, refrigerated trucks increase the loading capacity by improving the heat insulation performance and sealing performance of the car body, and reduce the cooling loss during loading and unloading from the design point of view; in terms of environmental protection, environmentally friendly materials are used as much as possible in terms of materials [53]
	China	Of the CCL freight volume, 90% is completed by road cold chain transportation [51]. The refrigerated truck itself and various refrigerating equipment in the vehicle have a large carbon emission; due to the slow update of refrigeration technology in CCL enterprises and the lack of standardized standards for operation professionals, high energy consumption in warehousing and distribution processing links [51]

2.2. Defining the Concept of Sustainable Development of CCL

With the continuous improvement of people's living standards and business environment, the scale of China's CCL market and infrastructure construction are expanding [58]. However, the current development of China's CCL is relatively short, and the industry is still in the primary stage of development [59], revealing problems such as the pursuit of scale expansion, the lack of fine management system, the high dependence on labor and the service quality to be improved [60].

Against the background of the new normal of economic development, the growing demand for logistics, the regularization of epidemic prevention and control and the increasing importance of environmental protection, the traditional method of development is unsustainable [61]. The current development of CCL, especially in some developed countries, has gradually changed from the traditional development to the sustainable development mode of "four integration", i.e., standardization, informatization, automation and going green.

2.3. Mechanism Analysis of the Impact of Sustainable Development of CCL on Epidemic Risk

The lack of sustainable development of CCL has led to problems in China's epidemic prevention and control. On the one hand, because the low temperature environment is beneficial for the long-term survival of the virus [62], cold chain commodities have become a possible key medium in this new crown pneumonia pandemic [63]. The expansion of CCL will increase the risk of foreign new coronaviruses entering the country with frozen products. On the other hand, sustainable development can effectively reduce the risk of local epidemic spread through refined management, improved information traceability and reduced manual dependence.

The traditional development of CCL will increase the risk of epidemics (Figure 2). First, the uneven epidemic prevention standards make it difficult to guarantee the level of epidemic prevention and control. China's CCL market lacks unified industry standards, and the concentration of CCL enterprises is very low, so that each enterprise has its own epidemic prevention standards in CCL and transportation. Including the sanitation management of cold storage and refrigerated trucks, as well as the disinfection and sterilization of handling personnel and sorting personnel before work, the non-uniform epidemic prevention standards make it difficult to guarantee the level of epidemic prevention and control. Secondly, the artificial dependence is too high, and the physical proximity between personnel is dense, which further increases the risk of virus infection and transmission [64]. Food CCL has a certain complexity, whether it is the production and processing of food or the transportation and distribution of goods, all involve complex links and processes [65]. Compared with developed countries with a high degree of automation, China's CCL industry has a greater demand for personnel, and the personnel-intensive work environment increases the risk of worker infection [66]. Finally, it is not uncommon for many companies to have substandard temperatures, transportation specifications, and refrigerated trucks,

which makes it impossible to guarantee the quality of vaccines and other pharmaceutical products [67].

The sustainability of CCL will mitigate the risk of epidemics (Figure 2). Firstly, the standardization of CCL, including epidemic prevention standards, facility and equipment standards, technical work and management standards, etc., can better regulate the development of the industry, improve the technical level of the CCL industry and reduce the risk of import and spread of epidemics [68]. Secondly, the improvement of the informatization level of CCL will improve the level of food supervision and traceability. A key factor in epidemic prevention and control is the sharing of information and the recording of data [69]. The traceability and tracking system mechanism of CCL commodities can quickly locate relevant entities in the supply chain in the event of an epidemic, control the epidemic within a small range and achieve rapid, timely and efficient discovery and processing [70]. In addition, the use of the whole visualization of the traceability system to achieve sampling in the various nodes of fresh products can be the timely detection of potential new crown virus contamination. From post-event recovery to real-time prevention, even reaching prior control, thus minimizing public health safety problems arising from epidemics and safeguarding people's property [68]. Thirdly, the improvement of the level of automation reduces the density of personnel and further reduces the risk of the spread of the epidemic. The automatic storage of goods, automatic loading and unloading, automatic sorting and picking and other automated implementations make the entire CCL operation much more efficient. In turn, it saves a significant amount of manpower and reduces the risk of transmission, while increasing production capacity and shortening operation times [71]. Finally, the improvement of the level of green technology can provide strong support for the development of CCL. Energy conservation and emission reduction have become a global consensus, and low-carbon technology and low-carbon economy have attracted widespread attention around the world [72]. Green development can optimize the operation process of the enterprise, reduce the waste of resources and energy and ultimately achieve the lowest cost. At the same time, it can improve the green corporate image regarding energy reduction and emission reduction for enterprises, create a good public reputation and help the sustainable development of CCL [73]. For epidemic prevention and control, the efficient disinfection of CCL goods is the most effective way to interrupt the "thing-to-human" transmission of the virus. Conventional disinfectants not only produce by-products that are poisonous to human health but also pollute water and air. Compared to this, green disinfection methods that produce trace amounts or even non-toxic by-products have significant advantages, not only by reducing environmental pollution but also by improving disinfection efficiency [63].
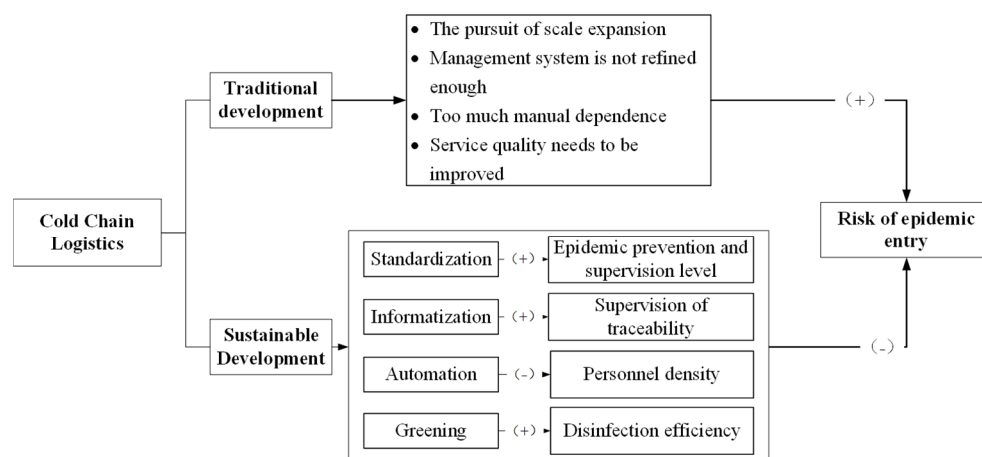

Figure 2. Impact mechanism map.

Based on the above mechanism analysis of the impact of CCL on the risk of the new crown epidemic, this paper proposes the following theoretical assumptions to be tested:

Hypothesis 1: *The scale growth of CCL will increase the epidemic risk.*

Hypothesis 2: *The level of development of sustainable cold chain logistics will reduce the epidemic risk.*

3. Empirical Analysis of the Sustainable Development of CCL on the Risk of New Crown Pneumonia Outbreak

3.1. Data Source

Theoretical analysis shows that the traditional and sustainable development of CCL will have different impacts on the risk of epidemics. To verify these analysis results, this paper conducts an empirical analysis using monthly data from 31 provinces in China in 2020. The sample data are obtained from the General Administration of Customs of China, the distribution map of Chinese cold chain logistics enterprises, China Cold Chain Logistics Development Report, China Statistical Yearbook and statistical yearbooks of various provinces.

3.2. Variable Selection

The number of new confirmed cases of neoconiosis every month. For the assessment of the risk of the new crown epidemic, the existing literature mostly selects case data, including the number of new cases and cumulative confirmed cases, to intuitively reflect the severity of the epidemic [8]. Considering that the cumulative number reflects the total size of confirmed cases in the region due to importation or spread since the onset of the epidemic, it represents the severity of past epidemics in the region to a greater extent [74]. The number of newly confirmed cases can better reflect the difference in the risk of the epidemic at different times. Newly confirmed cases indicate increased risk in the region and vice versa [8]. Combined with the data in this article, the monthly number of newly confirmed cases is selected as an intuitive measure of different epidemic risks in each province.

Monthly Frozen Product Import Quantity: The demand for imported frozen products will directly affect the risk of overseas epidemic importation [20]. Considering that the country has adopted effective prevention and control measures for overseas imported personnel, and the freezing environment is more suitable for virus survival, this article does not consider overseas-imported personnel for the time being.

CCL development scale: Considering the main equipment used in each link and the availability of data [75], this paper selects the number of enterprises, the capacity of cold storage and the number of vehicles to comprehensively measure the scale of CCL.

The level of sustainable development of CCL. At present, there is little quantitative literature on the sustainable development degree of CCL, and it is difficult to obtain direct measurement data. This paper selects the number of CCL-related policies and the number of star CCL enterprises as proxy variables for the sustainable development of CCL. The number of cold chain-related policies promulgated by each province reflects the degree of standardization in the region to a certain extent. Star CCL enterprises are the result of comprehensive selection of enterprise facilities, informatization, management and services, and their number can be used as a measure of the sustainable development of CCL.

Control Variables: Number of beds per capita in medical and health institutions and number of practicing physicians per 10,000 population are used to measure the disease control and treatment capacity of different provinces [20]. Add the urban population density to the model for regression by referring to practices, following Surendra Hazarie et al. (2021) [76] and Li Ruiqi et al. (2018) [77]. At the same time, this paper considers that the early epidemic risk of a specific province will have an impact on the current management and control measures, which in turn will affect the subsequent epidemic risk. Therefore,

the early epidemic risk is added to the model. For descriptive analysis of specific variables, see Table 2.

Table 2. Comparison of cold chain technologies in different countries.

Variables	Variable Description	Mean	Std	Min	Max
Explained Variable					
New cases	Monthly number of new cases of new coronary pneumonia	186.50	107.53	1	372
Explanatory Variables					
Import	Monthly import quantity of frozen products (tons)	24,767.98	41,795.55	0	186,690
Company	Number of CCL companies	64.65	51.19	0	290
Capacity	Cold storage capacity (tons)	1,588,956	1,352,399	0	6,178,781
Vehicle	Number of CCL vehicles	1403.26	1651.22	0	6410
Policy	Number of Cold Chain-related policies	9.32	6.80	1	27
Star-company	Number of star CCL companies	3.42	4.49	0	21
Control Variables					
Density	Provincial population density (person/km^2)	3008.09	1104.87	1136.5	5497.84
Bed	Number of beds per capita in medical and health institutions (beds/person)	0.01	0.001	0.004	0.008
Doctor	Number of practicing physicians per 10,000 population	0.28	0.05	0.21	0.50
Early-risk	Risk of previous outbreaks (cumulative number of confirmed cases in the province as of the end of the previous month)	2518.77	11,458.67	1	68,149

3.3. The Model

We construct a fixed-effects model to test the differential impact of the degree of CCL development on the epidemics risk, and the model is set as follows:

$$\text{New} - \text{cases}_{it} = \alpha_0 + \alpha_1 \text{Import}_{it} + \alpha_2 \text{Company}_i + \alpha_3 \text{Capacity}_i + \alpha_4 \text{Vehicle}_i$$
$$+ \alpha_5 \text{Policy}_i + \alpha_6 \text{Star} - \text{company}_i + \alpha_7 X_{it} + \varphi_i + \varepsilon_{it} \tag{1}$$

where the variable subscript *it* denotes the observation of province *i* in month *t* of 2020; the explained variable New $-$ cases$_{it}$ is the number of new cases of new coronary pneumonia in province *i* in month *t* of 2020; and Import$_{it}$ is the import quantity of frozen products of province *i* in month *t*. Company$_i$, Capacity$_i$ and Vehicle$_i$, respectively, represent the number of CCL enterprises, cold storage capacity and CCL vehicles in province *i* in 2020, which are used to comprehensively evaluate the development scale of CCL in each province. Policy$_i$, Star $-$ company$_i$, respectively, represent the number of CCL-related policies and the number of star-rated CCL companies promoted by province *i* in 2020, which are used to measure the sustainable development level of CCL in each province. X_{it} is a control variable, including the number of beds in medical and health institutions per capita, the number of licensed doctors per 10,000 people, the population density at the provincial level and the risk of early epidemics. φ_i is the provincial fixed effect and ε_{it} is the error term. $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ represent the impact of the development scale of CCL on the epidemics risk. α_5, α_6, respectively, represent the impact of CCL policy and the number of star CCL enterprises on the number of newly confirmed cases in each province. In this paper, they are used to represent the impact of the sustainable development level of CCL on epidemic risk. If α_5, α_6 are less than 0, it indicates that the higher the sustainable development level of CCL, the lower the epidemic risk.

4. Results

Table 3 shows the regression results between the degree of sustainable development of CCL and the risk of the new crown epidemic. Column (1) represents the regression results of the full sample; considering the large number of infected people in Wuhan, column (2) represents the regression results of the subsample after excluding the data of January and February 2020 in Hubei Province.

Table 3. The empirical results.

	(1)	**(2)**
VARIABLES	**Full-Sample**	**Sub-Sample**
Company	−19.64 ***	−12.31 **
	(7.271)	(4.932)
Capacity	0.00187 **	0.00115 **
	(0.000782)	(0.000530)
Vehicle	−0.0431	−0.0372
	(0.174)	(0.118)
Policy	−125.3 ***	−69.45 ***
	(23.38)	(16.08)
Star-company	−298.3 ***	−174.1 **
	(109.1)	(74.05)
Import	0.00145 **	−0.000332
	(0.000599)	(0.000416)
Density	−0.927 ***	−0.532 ***
	(0.247)	(0.168)
Bed	−358,554 **	−217,565 **
	(161,673)	(109,579)
Doctor	593.6	838.3
	(1885)	(1275)
Early-risk	−0.979 ***	−0.464 ***
	(0.00212)	(0.0270)
Constant	5316 ***	2978 ***
	(1367)	(932.7)
Observations	341	330
R-squared	0.999	0.557

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$.

There are regional differences in the sustainable development of CCL in China. According to the statistical results of the sustainable development level of CCL in each province/city (Table A1), the sustainable development levels of CCL in eastern coastal cities, such as Shandong, Shanghai, Henan, Beijing and Zhejiang, are relatively high. Among them, in 2020, the number of cold chain-related policies in Shandong Province was as high as 27 and the number of star-level CCL enterprises was also as high as 21. Jiangxi, Sichuan, Hubei and other central inland provinces are at a medium level of development, while western regions, such as Xinjiang, Gansu, Ningxia and Tibet are at a low level, with only one or two policies and zero star-rated logistics companies.

The expansion of CCL will increase epidemic risk. Cold storage capacity and the number of imported frozen products are significantly positively correlated with the risk of an epidemic. The larger the regional cold storage capacity and the greater the number of imported frozen products, the greater the possibility that the imported food will carry the new coronavirus and the higher the risk of virus importation, which in turn increases the risk of cold chain epidemics. This paper does not find a correlation between the number of regional cold chain vehicles and the risk of the epidemic. Another scale variable, the number of CCL companies, has a significant negative correlation with epidemic risk.

The higher the sustainable development level of CCL, the lower the epidemic risk. First, the number of CCL-related policies has a significant negative correlation with newly confirmed cases, which indicates the importance that local government attaches to the development of CCL. The more perfect the relevant policies, the more complete the CCL standards and norms, the more conducive to promoting the high-quality development of local CCL, thereby reducing the risk of cold chain epidemics. Secondly, star CCL companies also have a negative correlation with the number of newly confirmed cases. The higher the number, the higher the level of sustainable development of CCL enterprises in the region. The regression coefficient of the Policy variable is −125.3, indicating that a province/city adds a policy related to cold chain logistics and the province/city will reduce monthly newly confirmed cases by more than 125 cases. The regression coefficient of the "Star-company" variable is −298.3, indicating that if a province/city adds a star-rated logistics company, the province/city will reduce about 298 new confirmed cases per month.

Regarding the regression results of the control variables, we also draw some conclusions. First, there is a significant negative correlation between the number of beds and newly confirmed cases, which reflects that the more adequate medical and health resources in a region, the more effectively the epidemic can be controlled and the less the risk of the epidemic will be. Second, there is a significant negative correlation between urban population density and newly confirmed cases. For respiratory infectious diseases, such as new coronary pneumonia, it is spread through droplets, contact, etc., and it is very easy to spread in densely populated and confined spaces. Finally, the risk of the early stage of the epidemic is negatively related to the newly confirmed cases of the new crown epidemic, mainly because after the local epidemic occurs, the relevant departments will strengthen the control, thereby reducing the risk of the CCL epidemic.

5. Discussion

The frequent occurrence of domestic cold chain epidemics has attracted widespread attention, but existing research is mainly based on medical perspectives or descriptive analysis of reality [30,31]. There is no empirical analysis on the relationship between CCL and epidemic risk. This paper starts from the two dimensions of mechanism analysis and empirical testing and comprehensively analyzes the impact of CCL sustainability level on the risk of China's new crown epidemic.

The scale expansion has increased the epidemic risk in the domestic cold chain. By comparing the development situation of CCL between China and developed countries, it is concluded that sustainable development of CCL in China, including standardization, informatization, automation and increasing green technology, is far behind the world's advanced level. When the epidemic situation abroad is still severe, the traditional development model of non-uniform epidemic prevention standards, untraceable commodity information and a working environment with close physical proximity between workers makes CCL a weak link in domestic epidemic prevention and control. Frozen food is an important transmission medium of the new coronavirus, and the number of imported frozen products and the capacity of cold storage will increase the risk of epidemics in the region [63]. The greater the number of enterprises, to a certain extent, indicates that the market competition in this region is more intense [78]. Promote enterprises to improve the standardization, rigor and science of management; improve the sustainability of the development of CCL; and at the same time reduce the risk of the epidemic spreading in cold chain logistics.

Improving the sustainable development level of CCL is an effective means of epidemic risk control. The empirical results show that the more cold chain-related policies and number of star-rated logistics companies in a province, the fewer new confirmed cases in the province. Sustainable development has effectively reduced the risk of local epidemics by improving epidemic prevention standards, improving supervision and traceability, reducing staff density and improving quality and efficiency.

Based on the above analysis conclusions, this paper puts forward the development measures of the CCL industry in China and similar developing countries, as well as the epidemic prevention and control measures in the CCL link from the following four perspectives.

First, the prevention and control of epidemics risk in CCL should be strengthened. On the one hand, relevant departments should strengthen supervision and require importing enterprises to reduce the import of cold chain food from areas severely affected by an epidemic. At the same time, relevant enterprises should establish and improve the early warning and reporting mechanism for preventing the importation of new coronaviruses. On the other hand, it is necessary to strengthen the health monitoring of CCL practitioners and the supervision of the source of goods.

Second, the informatization construction of CCL should be strengthened. Relevant government departments should strengthen the informatization construction of the CCL industry and improve the traceability of the imported goods. The establishment of a complete data information platform for the CCL industry should be promoted. Throughout the whole process of cold chain transportation, the transparency of product logistics information should be enhanced to ensure that customers can check the real-time temperature and location information of products at any time. At the same time, it should strengthen the construction of temperature monitoring and the traceability system to ensure the quality controllability and safety of cold chain food in all aspects of production and circulation and avoid the spread of viruses in the CCL.

Third, the automation level of the CCL industry should be improved. In the future development of the CCL industry, the automatic temperature and humidity monitoring system as well as the whole process control equipment should actively be promoted, while improving the automation of cold storage and sorting. The population dependence of the cold chain logistics industry should be reduced, which in turn reduces the risk of virus transmission in the cold chain system.

Fourth, the level of green development of the CCL industry should be promoted. Green logistics is not only an objective requirement of economic and social development but also an inevitable choice for logistics development. The application of green disinfection methods should be promoted, relevant standards and guidelines should be issued and the standardization and efficiency of cold chain commodity disinfection should be improved [63]. At the same time, enterprises should be encouraged to purchase energy-saving and environmentally friendly cold chain transportation vehicles, promote packaging waste recycling and enforce the construction of a green system.

6. Conclusions

At present, there are imported epidemics related to CCL in many places in China. Imported cold chain food has now become the center of attention for strict prevention and control in China [79]. However, most relevant studies are based on a medical perspective or descriptive event analysis. Different from existing research, this paper innovatively considers the impact of CCL development degree on epidemic risk. The impact of the sustainability level of the CCL industry on epidemic risk was also specifically explored in terms of both mechanistic analysis and empirical measurements. The results show that the scale of development of CCL increases the risk of epidemic importation. For areas with a similar development scale, the higher the sustainable development level, the lower the risk of epidemic outbreak. Improving the sustainable level of CCL will not only help the long-term development of the industry itself but also act as an important means of risk prevention and control in the post-epidemic era. Strengthening the traceability of cold chain products, improving the energy conservation and environmental protection level of cold chain equipment and promoting the standardization of cold chain processes and the improvement of hygiene standards have become important measures and controls and will improve China's COVID-19 epidemic prevention level.

There are still shortcomings in this paper in the process of empirical analysis and index system construction. Due to the limitation of data collection, the empirical regression

only uses the monthly data of each province in 2020, and the empirical results need to be further verified.

Appendix A

Table A1. The status of the sustainable development of cold chain logistics in various provinces/cities in China.

Provinces/Cities	Number of Cold Chain Related Policies	Number of Star Cold Chain Logistics Companies	Sustainability Level
Shandong	27	21	24
Shanghai	27	11	19
Henan	16	8	12
Hunan	16	8	12
Beijing	18	5	11.5
Zhejiang	19	2	10.5
Jiangxi	13	5	9
Fujian	9	8	8.5
Guangdong	14	2	8
Sichuan	13	2	7.5
Liaoning	4	10	7
Jiangsu	11	2	6.5
Hubei	7	5	6
Hebei	10	2	6
Jilin	10	2	6
Yunnan	9	2	5.5
Hainan	10	0	5
Shanxi	7	2	4.5
Anhui	7	2	4.5
Guangxi	5	4	4.5
Qinghai	8	0	4
Guizhou	5	0	2.5
Heilongjiang	2	2	2
Inner Mongolia	4	0	2

Table A1. *Cont.*

Provinces/Cities	Number of Cold Chain Related Policies	Number of Star Cold Chain Logistics Companies	Sustainability Level
Chongqing	3	1	2
Tianjin	4	0	2
Xinjiang	4	0	2
Gansu	2	0	1
Ningxia	2	0	1
Shaanxi	2	0	1
Tibet	1	0	0.5

Note: "Sustainable Development Level" is the simple weighted average of "Number of Cold Chain Related Policies" and "Number of Star Cold Chain Logistics Enterprises" with a weight of 0.5.

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