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Study on the Impacts of the COVID-19 Pandemic on the Temporal and Spatial Pattern of Cross-Border E-Commerce Logistics Efficiency from a Temporal Distance Perspective

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Abstract: The COVID-19 pandemic has brought unprecedented disruptions to international logistics. It resulted in supply shortages which affected many aspects of the economy and society and were exacerbated by the increase in e-commerce consumption. Temporal distance is an important angle for economic geographers to understand logistics efficiency. This concept aims to show the changes in space-time compression and logistics efficiency from the result-oriented and reality-oriented perspectives. By calculating the logistics efficiency index from the temporal distance perspective, this study analyses the changes in its temporal and spatial patterns as well as the influencing factors reflected from typical samples. A quantitative analysis of the significant level of the identified factors found that both the cross-border e-commerce logistics efficiency and the pandemic experienced consistent cyclical fluctuations, but with a spiral increase; The pattern of the lowest logistics efficiency index shows large regional differences and aggregational effects, while the regional differences and aggregation effect of the highest logistics efficiency index are weaker in comparison. The progressive impact of the pandemic can be divided into three stages: (1) difficult recovery, (2) repeated shocks and (3) systematic improvement. The spatial and temporal pattern of logistics efficiency is influenced by multiple factors, and the spatial network is the most significant factor. This study provides some theoretical improvements by verifying first the effects of spatial attributes on economic activities through "relationship" coupling, and second the importance of exogenous global-scale factors. At the same time, the identification of key influencing factors can help to withstand unexpected challenges, and the analysis of regional differences can provide recommendations for space planning and land use decisions.

Keywords: COVID-19; Cross-border E-commerce logistics; Logistics efficiency; Temporal distance

1 Literature Review

Given the unprecedented disruption of the international flow of goods and services due to the COVID-19 pandemic, the level of reduction in the international logistics efficiency and the new patterns of the “flows” of goods are, therefore, some of the new research interests of economic geographers. While the pandemic reduced regional and international mobility and caused a shortage of production materials, etc., it accelerated the transformation of people’s habits from in-store to online shopping. In 2020, the U.S. ranked top for cross-border e-commerce purchases with a total of \$270 billion, but 49% of the U.S. purchases came from China-based merchants (Kayfitz, 2021). A survey by Worldpay indicated that 55% of online shoppers worldwide have purchased from another country in 2020 (Kuschel, 2020). However, the global logistics system faced travel restrictions, lockdown measures, shortage of workers, increased delivery cost, etc., which led to excessive delays in delivery time, stockpiling of goods, and thus a significant reduction in efficiency. According to the 2020 annual report by China Logistics and Procurement, nearly 40% of China’s logistics enterprises have seen their business shrunk by more than 50% during the epidemic period. Thus, investigating and visualizing the extent of disruption of the international logistics system is in need.

1.1 Research on the Impact of the COVID-19 Pandemic on E-Commerce and Logistics

Researchers have gained much attention to the issues and challenges caused by the pandemic and how it reshaped the global social and economic networks. Among these new studies, investigations on the impact of the COVID-19 pandemic on e-commerce and logistics mainly focuses on three aspects. More specifically:

(1) Analyzing the reactions and the impact of the buyer. Villa & Monzon (2021) examined how the pandemic lead to an explosion in e-commerce orders (almost doubled from Q4 2019 to Q2 2020) such that the e-commerce logistics system was under pressure and in need of improvement and expansion. Another study by Unnikrishanan & Figliozzi (2020) concluded that high-income buyers are more inclined to buy online and spend more money and demand higher levels of technology during and after the pandemic. They then discussed product accessibility equity, which can also be reflected in this paper after the national differences in logistics efficiency are calculated. Gao et al. (2020) made an interesting investigation into consumers’ behavior for online food purchases. It uses instrumental variable methods and data from Wuhan to show that the number of online purchases increases with infection numbers and it raised the question of how to ensure people from remote areas have food security. Thus, increasing regional or international logistics efficiency is the key to answering this question. By accessing each nation’s logistics systems’ responsiveness to outside shocks, can give a rough idea of a nation’s ability to have a secure product supply or food security.

(2) Analyzing the reactions and impacts of sellers or a certain industry. For example, Ding & Zhao (2021), proposed cost control methods for e-commerce logistics that can achieve better economic gains under the COVID-19 pandemic. In addition, Han et al. (2020) used city-day panel data from Alibaba to show that lockdown and other government containment measures caused a decrease in sales by 5%-11%. They also show that constraints in logistics capacities are a significant factor in the decline and recovery of e-commerce sales (Han et al., 2020). Also, Agus et al. (2021) found that customers' perceived supply chain capability is positively correlated with e-commerce capability. Seasonal logistic outsourcing is also not an important factor in the "relationship between perceived logistics capability and e-commerce platform performance" (Agus et al., 2021).

(3) Analyzing challenges or future development optimal strategies of e-commerce. Some past researches such as Xu (2021) and Wang & Xiao (2021) suggest that cross-border e-commerce faces cash flow problems, lack of supporting infrastructures, trade protectionism, technological competition, substitutive goods competition, travel restrictions, and most importantly, disruption of supply chains which causes supply shortages. Some solution suggestions include government risk monitoring, financial support, tax reduction, expand the construction of overseas warehouses, etc. (Wang & Xiao, 2021).

However, there has not been much investigation into the changes in the geographical pattern and in the efficiency of the flow of goods across the globe as one of the impacts of the pandemic. Also, past researches are mainly regionally based, this is not enough to provide a big picture of the global impacts of the pandemic on cross-border e-commerce logistics.

This study selects cross-border e-commerce logistics as the research object because 1) compared with the traditional international trade logistics, cross-border e-commerce logistics is more flexible, more sensitive to delivery time, and better able to represent the impact of the pandemic impact; 2) the waybill tracking system of cross-border e-commerce logistics is accurate and data acquisition is easier as well; 3) cross-border e-commerce is an evolution of traditional international trade. In recent years, countries have invested a significant amount of resources to promote the development of this system, to compete for economic benefits, big data resources, cultural influence, and international discourse power. Especially during the pandemic, cross-border e-commerce continues to grow against the trend of the overall global economy. Logistics plays a key role in the rise of cross-border e-commerce and is also becoming the main battlefield among the superpowers, which puts forward higher requirements, capacity, and effectiveness. At present, the research on economic geography is concentrated in the field of economics and management, so it is urgent to research the extent of reliance and responsiveness of each country's logistic network so as to assess and evaluate each country's flexibility and ability to cope with external shocks.

1.2 Research on the cross-border e-commerce logistics efficiency

Scholars who are interested in logistics efficiency, economics, and management have investigated logistics efficiency mainly from practical and operational perspectives such as its performance, risk, sustainability, and innovations. Chen, X. (2019) used the analytic hierarchy process to evaluate marine transport efficiency which shows that port efficiency is subjective to “berth shoreline length, berth depth, number of bridge cranes and yard area”. Whereas factors that affect shipping efficiency include “cargo ship tonnage, unit freight haul distance, port convergence and coordination” (Chen, 2019). These findings provide some valuable insights for later analysis of national differences in logistics efficiency. Furthermore, Zhou et al. (2008) conducted a similar study as we did for the SARS outbreak in 2002-2003 by using data envelopment analysis to measure the decline in third-party logistics providers (3PLs) decline in efficiency. Although the 3PL industry in China has changed drastically in the past twenty years, their findings may still be applicable in today’s situation. They found that Chinese 3PLs usually focus on traditional services rather than an integrator or service provider, which therefore hinders operational efficiency due to limited opportunities (Zhou et al., 2008). Additionally, Andrejic (2013) also used data envelopment analysis to solve various problems in the measurement of logistic efficiency. “Supply chain efficiency, logistics systems efficiency, logistics subsystem efficiency, logistics activity efficiency” are all the components of measurement. Thus, measuring logistics efficiency is a complicated process that need to consider all the “subsystems and activities” which can be subject to various social factors (Andrejic, 2013). In essence, these studies evaluate the development level and efficiency of the logistics industry from an endogenous perspective.

In terms of logistics efficiency of e-commerce, recent studies regarding cross-border e-commerce mainly focus on the driving factors and challenges faced by these companies, different logistics models used, and how they relate to firms’ performances, its nature, development processes and implications of global supply chain and trade policies, etc. For example, Yu et al. (2016) made a thorough review of the international logistics models of typical e-commerce logistics companies such as Home Depot, Amazon, JingDong, etc. There are many similarities among companies from the U.S., Europe, and China (Yu et al., 2016). They use centralized distribution and use an in-store and online shopping combined business model, but Chinese companies have a greater emphasis on delivery efficiency, and some such as JingDong does not have in-store retail services (Yu et al. 2016). The similarities between logistics companies make global logistics systems competitive and thus companies have to seek a way to reduce costs and increase efficiency.

Different from the above studies, the analysis of this study starts from the logistics efficiency represented by “time distance”. It is an important perspective for economic geographers to analyze e-commerce and logistics. When analyzing the influence of informatization on geographic space, Liu

et al. (2004) proposed that “time cost” and time reliance are the natural causes of the spatial changes of enterprises under new information technologies. Based on this idea, Yu et al. (2013) further used “delivery time” to measure the “temporal distance” between e-commerce activities and use a “temporal distance map” to visualize the spatial relationships. Based on this perspective, scholars have further enriched relevant research (Hilmola O P and Tolli A 2018; Zhen F et al. 2018; Yang C et al. 2021) and expression methods (Peng 2017, Wang 2018), making “time distance”, like institutional distance, cultural distance, psychological distance, and other concepts, an important perspective to describe the relative relationship of the “flow” space. It can be seen that, compared with the complex measurement of logistics efficiency in economic and management studies, the representation of logistics efficiency by time distance is result-oriented and reality-oriented, and can directly show the real characteristics of logistics operation with core indicators. Especially when faced with the impact of the COVID-19 pandemic, the change of logistics efficiency is obvious and can represent how each nation’s business environment is less risky and less vulnerable to outside shocks.

This study aims to 1) assess the impacts of the pandemic on the international logistic system on a global scale, use big data to calculate and analyze each nation’s cross-border e-commerce logistic efficiency reduction and the changes in the temporal distance before and after the pandemic; 2) Analyze the important factors affecting logistics efficiency to provide a reference for improving the stability of supply chains; 3) Provide guidance for the government and enterprises to optimize the layout and dispatch resources from the perspective of space.

2 Methodology

2.1 Data source and processing

The core data of this study comes from the logistics waybill, which is obtained by tracking the logistics waybill in batches with the help of big data mining and cleaning technology. The specific method is to sort out the waybill numbering rules of cross-border e-commerce logistics around the world, use Python to mass generate waybill numbers. Then, use the API interface of 51tracking.com website to obtain tracking data and screen the real and effective order numbers. Figure 1 shows the key information extracted from the waybill tracking data, which includes the main extraction channels, origin, destination, shipment time and delivery time, etc. According to this information, the required information such as the number of logistics channels, the number of packages, and the delivery time can be calculated.

channel: Pos Malaysia; order number: EV953368587CN		
date	time	progress (Processing location/station code in square brackets)
2021.02.15	10:47	[Pos Laju Kota Kinabalu]Item out for delivery
2021.02.10	08:02	[Pos Laju Kota Kinabalu]Arrive at delivery facility at
2021.02.05	08:01	[Pos Laju Kota Kinabalu]Arrive at delivery facility at
2021.02.01	10:35	[DCSA Lok Kawi]Arrive at delivery facility at
2021.01.30	11:11	[Pos Laju Kota Kinabalu]Held by customs (Import)
2021.01.23	11:31	[MYKULA]Item departed to domestic location Pos Laju Kota Kinabalu
2021.01.23	11:29	[MYKULA]Release from customs clearance (Import)
2021.01.23	9:50	[MYKULA]Clearance by Postal for customs inspection (Import)
2021.01.23	09:49	[MYKULA]Item arrived at
2021.01.12	12:52	[CHINA]Item en route to MALAYSIA
2021.01.12	12:50	[GZGJZX]Customs Released (Export)
2021.01.11	01:47	[GZGJZX]Detained by Customs (Export)
2021.01.10	10:04	[CHINA]Consignment Arrived

Figure 1: Key information extraction of waybill tracking data

The data collection process began in June 2020. Since most logistics companies only allow tracking waybills within one year, thus period we selected is from July 2019 to January 2021. A total of 459,867,704 waybills were collected from 368 logistics channels, involving 213 countries and regions around the world. This data can completely cover the list of the world’s top 100 international express delivery companies (<http://www.aioexpress.com/news312>). The amount of data is large enough, and the delivery time calculated based on it is relatively accurate, which has a strong explanatory power to the change of international cross-border e-commerce logistics efficiency. However, it should be noted that due to the limitation of sampling methods, the data of the total volume of parcels for each sample country has not been compared with authoritative statistical data, so the data in this paper can only reflect the relative quantity to a certain extent.

Then, the delivery time of a successful order is calculated and classified according to the country, region, and monthly time. A total of 159 countries and regions with more than 1,000 total order numbers and monthly data are selected as samples for data analysis in this paper (including Hong Kong, Macau, and Taiwan Province as separate statistical samples). In terms of the regional distribution of the samples, those excluded in this study are the countries and regions with less developed economies and fewer international parcels, such as central and northern Africa.

In addition to logistics package data, other data in this study are mostly from statistical yearbooks and authoritative reports, and data sources and explanations are marked in specific analysis.

2.2 Measurement of logistics efficiency

Because of the differences in the development level of logistics industries and geographical distance between samples. This study starts from the perspective of time distance, measures the changes in logistics efficiency based on the changes in delivery time. Its basic expression is:

$$E_t = \frac{\overline{D}_t}{\overline{D}_{t_0}} = \frac{\sum_{i=1}^{n_t} d_i}{n_t} / \frac{\sum_{i=1}^{n_{t_0}} d_i}{n_{t_0}} \dots\dots\dots (1)$$

In formula I, E is the logistics efficiency index, is the average delivery time, t is the time period, t0 is the benchmark time period for efficiency comparison, n is the parcel quantity, i represents a certain parcel, and d is the delivery time of a certain parcel. 0<E<1 indicates that the logistics efficiency has decreased compared with the reference period, while E>1 indicates that it has improved. The greater the E value, the higher the logistics efficiency.

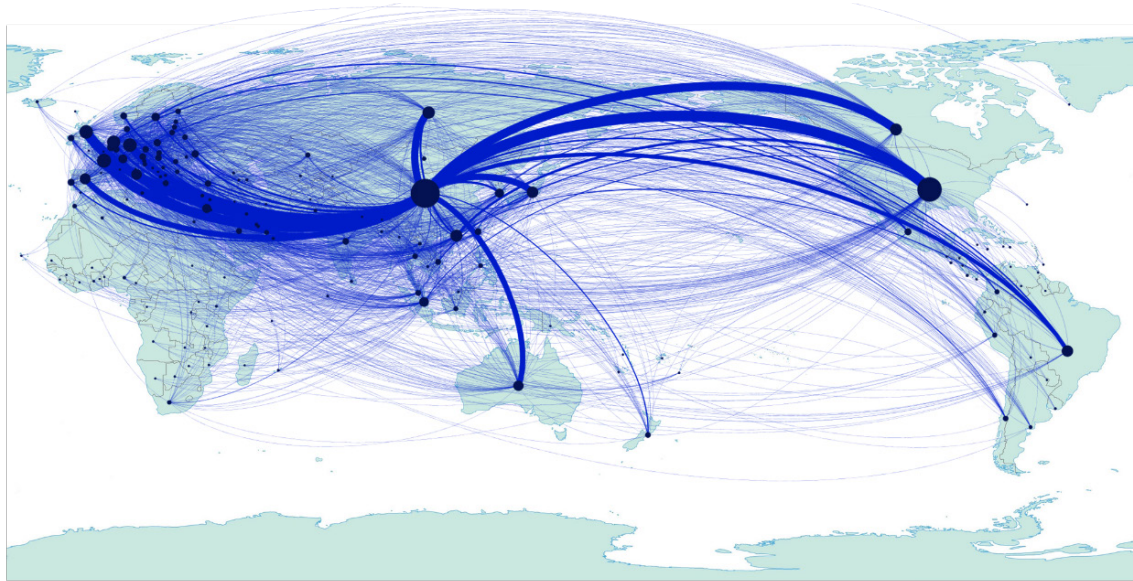
In this study, t0 is the six months before the epidemic, that is, from July 2019 to December 2019, and the average logistics delivery time in these six months is the benchmark for logistics efficiency comparison. The value of t represents the monthly time section, that is, the logistics efficiency index for 13 months from January 2020 to January 2021 is calculated respectively. For each sample, the maximum of 13 logistics efficiency indexes is the highest logistics efficiency. The minimum value is the lowest logistics efficiency, and the average value is the overall logistics efficiency.

2.3 Logistics spatial network

By abstracting the spatial elements of cross-border e-commerce logistics, a logistics spatial network can be established. Taking 159 research samples as nodes and the relationship between the place of origin and the destination of logistics as connections, the connections can be divided into a centripetal flow and a centrifugal flow according to the connection direction, and an asymmetric directed weighted network can be established, as shown in Fig. 2. Each node size measures its centrality (i.e., the total inflow and outflow volume), the thickness of connecting line corresponds to the quantity of parcels. Logistics spatial network attributes can reflect the status of each node in the overall network. See 3.1 for specific analysis.

3 Spatial-Temporal Changes of Cross-Border E-Commerce Logistics Efficiency Under the COVID-19 Pandemic

3.1 Logistics spatial network pattern



Note: This map is based on the standard map no. GS (2016)1666 downloaded from the standard map service website of the Ministry of Natural Resources of China. The base map has not been modified, the same for figures below.

Figure 2: Overall spatial pattern of global cross-border logistics network

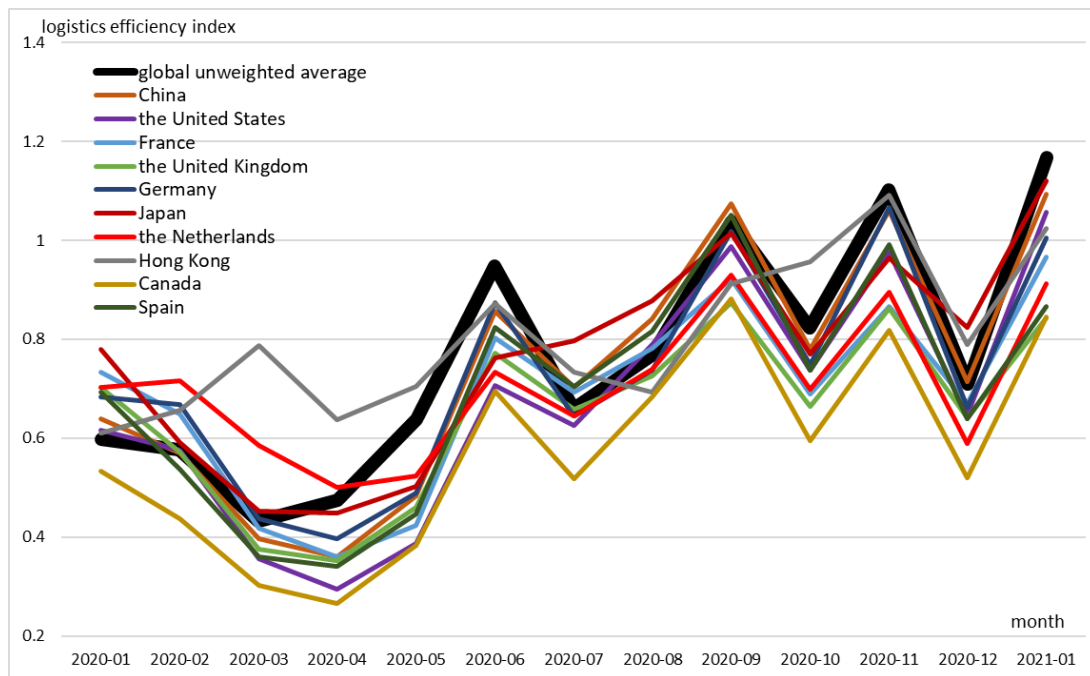
The logistics spatial network pattern is an important spatial basis for understanding the change of logistics efficiency. As shown in Figure 2, the global cross-border e-commerce logistics are closely connected, with the overall network density reaching 53.6%. On average, each country has established links with at least 84 countries, but the logistics network connections are extremely uneven. In terms of countries' parcel volumes and regional connections, China and the United States are the two countries with the largest number of connected countries and regions and the largest amount of sending and receiving parcels, respectively accounting for about 39% and 16% of the world's total parcels. France, Britain, Germany and other European countries, Japan, Hong Kong, China, South Korea, Singapore, and other Asian countries and regions, as well as Canada, Brazil, Russia, cross-border logistics package quantity is higher, but still well below the two countries, accounting for 1%- 4% of the total package. These countries also engaged in logistics partnerships with more countries. In contrast, most countries in Africa, island countries, etc.

rarely receive and receive parcels, and for other countries, such as Mongolia, logistics links are less than 10 countries and regions. In terms of the logistics flow, about 76% of the parcels were shipped in China, and about 31% were received in the United States. The volume of packages sent to the US from China accounts for about 28% of the global total, forming a very obvious spatial pattern with China as the outflow center and the US as the inflow center. The obvious direction of connectivity between regions is that there are a lot of connections from all over the world to North America, from South America to Europe, from China to all over the world, and from Africa to all over the world.

3.2 Characteristics of the changes in logistics efficiency indexes

We first calculated the unweighted average of the world's logistics index to give a big picture of the global trends of e-commerce logistics efficiency. We used unweighted index because the top ten countries had much higher parcel volumes than the rest of the world, thus a weighted average is very biased and cannot equally take every country's responses into account. Then we first present and discuss the trends for the top ten samples with the highest parcel volume and later select six other large samples that show different trends in order to show country-level differences in their resilience responses.

(1) Under the impact of the pandemic, the logistics efficiency of cross-border e-commerce fluctuates in accordance with the pandemic cycle, and the overall logistics efficiency shows a spiral increase. In 2020, The world experienced four waves of upsurges in infections which were during March-April, July-August, October, and December. These periods coincide with the fluctuations shown in Fig. 3. Fig. 3 shows the changes in the logistics efficiency of the top ten countries ranked by parcel volume. Take the world's unweighted average curve as an example, it shows a significant decrease in global logistics efficiency from 0.59 in January 2020 to 0.43 in March. This is in accordance with the first upsurge of global infections. However, the global logistics industry on average showed a strong recovery to an index number of 0.95 in June 2020, which is the first peak of the cycle. A 0.1 increase in the logistics index means 1/10 of the new delivery time is reduced on average. Thus, a 0.52 increase in the index means 52% of the new delivery time is reduced from the previous average, which is indeed a significant change. This is particularly due to the smoothing of the COVID-19 infections and the gradual recovery of systems, economies, and social orders.



Note: The global logistics efficiency index is the arithmetic mean of the logistics efficiency index of each sample (unweighted package volume, arithmetic mean can better reflect the characteristics of the country scale), same for fig. 4.

Figure 3: Logistics efficiency index for top 10 countries ranked by parcel volume

Most importantly, as the world experienced the second, third and fourth waves of the pandemic, the logistics efficiency index became more stabilized. A plausible explanation for this phenomenon is that as logistics companies faced a larger volume of parcels and more restrictions imposed on customer delivery, they learning-by-doing. Initially, time is needed for them to find ways to increase their delivery process, but a better-organized system will benefit later. The global logistics efficiency index decreased to 0.66 in July 2020 and increased to 1.03 in September, but in the third cycle, the index became 0.82 (greater than 0.66 which is the last tough) and the second peak reached 1.10 (an index number greater than 1 means the delivery time of the single month during the pandemic is even shorter than the average delivery time before 2020). The reason why its index number reached over 1 can be partly explained by each nations’ logistics systems’ restructuring, adapting, and coordinating new ways to cope with the new norm of cross-border e-commerce. From this point of view, the COVID-19 pandemic, as a major outside shock, has benefitted global logistics systems by forcing them to increase delivery speed and have better distribution and greater capacity. More details on how some sample countries increased their logistics efficiencies will be discussed later in the study.

(2) The top ten samples (except HK) showed an incredibly similar trend as the world’s unweighted

index, but most of the timelower than the global average. It is not difficult to understand that the world’s major players in the cross-border e-commerce industry are closely linked to the global business environment. These samples show huge volatility at the beginning, but gradually become smoother later in the year. Most importantly, eight countries in Fig. 3 have an initial reduction in the efficiency index lower than the world’s average, and that even in the later waves of upsurges the majority of these countries underperformed the world’s average. For example, Canada’s index continuously decreased to 0.30 (world’s average 0.43) in March from 0.53 in January. Also, the US had the greatest reduction during the first wave of the pandemic having 0.61 in January, but 0.29 (world’s average 0.474) in April, which was because of the surging infection rates that suddenly forced people to get used to purchasing online. For these large countries, a greater amount of reduction in logistics efficiency is inevitable because first, they all experienced a dramatic sudden increase in parcel volume, and second, they have to coordinate with hundreds of partners which is thus a diseconomy of scale.

Unlike other top countries, Hongkong is an anomaly with an increase in efficiency index from 0.61 in January to 0.78 in March. This is because Hongkong is closely related to China, but had much lesser parcel quantity and more effective pandemic control methods compare to the rest of the world. These factors caused a limited impact on its logistics systems and even provide a catalyst to increase logistics efficiency.

(3) Although the trends of most countries are highly similar to the global average, there are some samples that show individual characteristics. The analysis of these typical cases can explore country-level influencing factors of logistics efficiency.

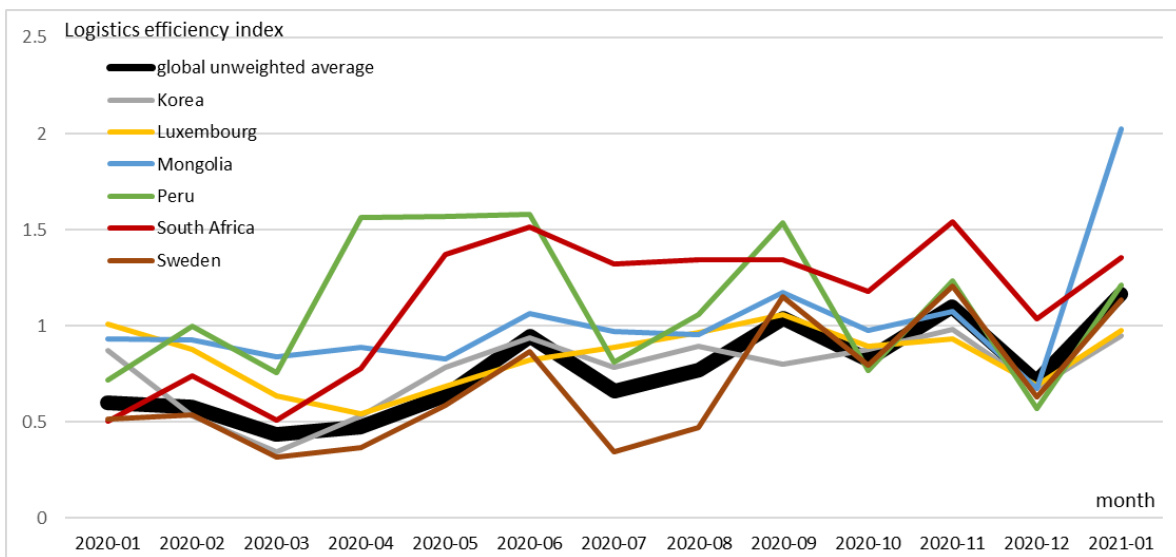


Figure 4: Logistics efficiency index for sample countries with a parcel volume greater than 200,000

These sample countries are particularly chosen to show different efficiency trends different from the norm. For example, Peru recovered right after the first wave and reached its highest level of 1.56 in April which suggests a 56% decrease in delivery time. It has maintained at a high-efficiency level for two months to June. This is because it has very developed maritime transportation and that its source and destination countries are mainly China and Singapore. However, it later decreases to nearly its original level and then followed the global average trends. South Africa also shows a quick recovery after March and first peaks at 1.51 in June. This is because South Africa paid much effort to strengthen infrastructure and the digital economy which played an important role in the recovery of the logistics industry. However, Sweden, as one of the European developed countries, was hit the most and its index lowered to 0.31 in March from 0.52 in January and then to the second-lowest point at 0.35 in July. 2020, anomalously higher than other countries. Its slow recovery is particularly due to its herd immunity policy which had major disruption to the economy and society.

Interestingly, Mongolia as a landlocked developing country has an index that is considerably high and stable. This is because 94% of the parcels were sent or received from Russia. Having only one neighbor country, that is powerful and resilient, as their only major partnership is much more efficient than countries having a hundred partners. Another reason why Mongolia has a smooth transition even during the first wave (mildly fluctuated around 1 from Jan. 2020 to Nov. 2020) is that it has not been much affected by pandemic (only 1215 cases were confirmed by the end of 2020). However, with the aggravation of the outbreak in Russia, logistics in Mongolia also experienced significant delays in November. Nevertheless, it quickly recovered to 2.02 in January 2021 from a trough of 0.67 in December.

Reasons regarding why e-commerce logistics companies in each country performed differently have to consider various factors such as national anti-pandemic measures, warehouse capacity, workers available, etc., not limited to the number of infections itself. For example, South Korea and Luxembourg show a significant reduction in the first wave of the pandemic but show much smoother fluctuations during later waves. This may be due to the South Korean government's rapid intervention, enhanced virus detection, reduced restrictive measures. Luxembourg which is an important cargo air hub in Europe has a very developed logistics industry and thus its systems are flexible, resilient, and strong in coping with emergency shocks. Nevertheless, Luxembourg's e-commerce logistics companies still have not recovered to the normal level (with an index of 0.97 in Jan. 2021).

3.3 Global spatial patterns of the logistics efficiency index

3.3.1 Each country's lowest logistics efficiency index

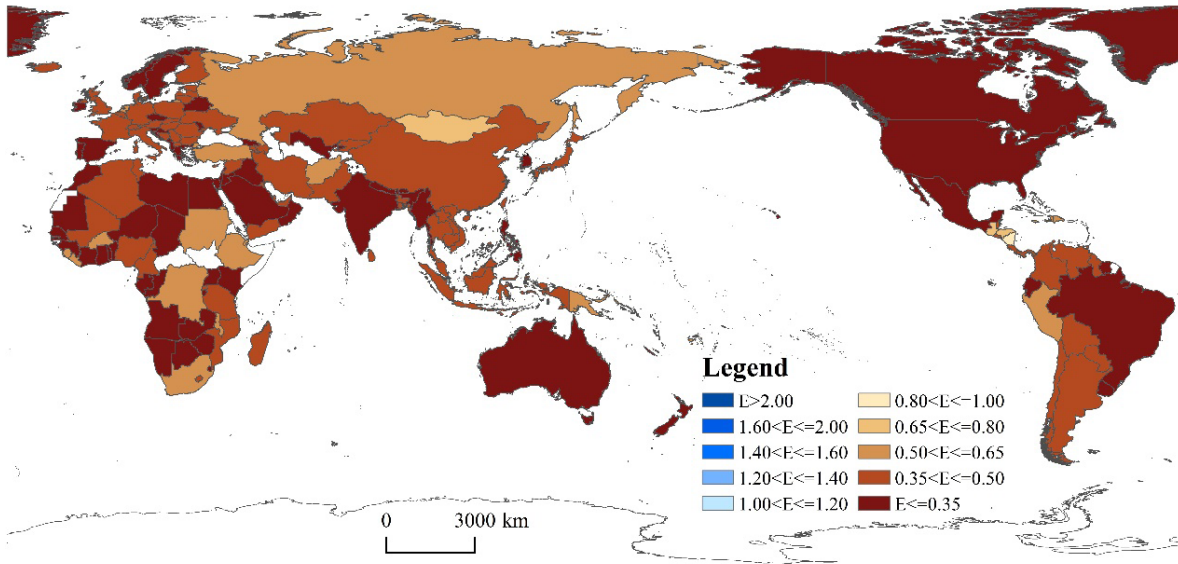


Figure 5: The spatial pattern of each countries' lowest logistics efficiency index

As shown from Fig. 3 and Fig. 4 already, during the first wave of COVID-19 infections, the shortcomings of cross-border e-commerce logistics systems were revealed and thus most key player countries had their most severe shock in early 2020. However, since COVID-19 spread at different speeds in different countries, we extract the least efficiency index for each country from Jan. 2020 to Jan. 2021 regardless of the month when the worst shock happened to that country. In this way, we can compare which country had the most severe disruption and which had the least influence. In early 2020, all nations did not have well-established strategies to code with the new virus, thus citizen's awareness, control methods, medical systems, hospital capacities as well as political factors played important roles in the process. These differences between countries resulted in the uneven disruption pattern shown in Fig. 5. Fig. 5 illustrates the lowest logistics efficiency for each country. Several key observations can be made that:

(1) all countries in the world (i.e., both the developed and developing countries) have suffered a reduction in cross-border e-commerce logistics efficiency to a certain extent. In Fig 5, all countries had their lowest indexes below 1. Most importantly, it is not the usual case that generally developed countries performed better under outside shocks. There are, however, both developed and underdeveloped countries in the 0.21-0.29 range as well as the 0.50 to 0.90 range. The lowest global unweighted average

index is 0.43 (Mar. 2020) which means on average the delivery time had increased more than doubled than pre-pandemic levels.

(2) Worst affected samples with parcel volume greater than 200,000: Canada, India, New Zealand, America, US, Mexico, Belarus, Australia, etc. In fact, most of the worst affected countries are underdeveloped countries, that are vulnerable to outside shocks because of the lack of infrastructure and economic robustness. However, as listed above there are also many highly developed countries that suffered huge losses during the pandemic. For Canada, one of the only two large distributing centers was closed, all goods have to be transferred to Vancouver for processing, which seriously delaying the delivery time. New Zealand was very strict in prevention and control, cities were in lockdown several times, and its index dropped to 0.25 in April. The spread of COVID-19 in these countries has not been controlled in a timely manner. For example, the US has the lowest index of 0.29, which shows weak resilience, and flexibility. Similar to the US, where political instability and poor public administrations exacerbated the impact of the pandemic, in Belarus, the pandemic was also compounded by political turmoil. The efficiency index dropped to the lowest of 0.33. In Mexico, the logistics infrastructure is relatively poorly established. In remote areas, only postal services can deliver goods. It was more difficult to ensure timeliness under the impact of the pandemic and the efficiency index dropped to the minimum of 0.33.

(3) Mildly affected samples that have a parcel volume greater than 200,000: China, Southeast Asian countries, Mongolia, Russia, Indonesia, the middle-east countries, etc. Parcel volume is a key factor in logistics efficiency predictions. Among the mildly affected samples, there are 20 of them have a parcel volume less than 10,000. Thus, the reason why they show a high resilience is because of less number of parcels. However, reasons for high volume countries to have limited impact different from another. For example, China and Southeast Asian countries did not have huge surges in infection cases compare to the rest of the world. Also, governments' fast response to the virus resulted in the least amount of supply chain disruption. For Russia, about 90% of parcels came from China. In 2020, the China-Europe freight trains were running regularly, which has greatly reduced the impact of the pandemic on cross-border logistics. Middle-east countries, in general, were not much affected, because of their robust economy and the continued rapid expansion of international logistics.

(4) There is a clear aggregation effect in neighboring countries. According to Fig. 5, we propose the hypothesis that one country's logistics performance is closely related to neighboring countries, especially for less globalized countries. An aggregation effect is explained as the further intensification of delivery inefficiency due to the negative externalities from neighborhood countries. The spatial connectedness between Canada-US-Mexico, Australia-New Zealand, Mongolia-Russia, Southeast Asia, and Europe creates an aggregation effect. Since neighboring countries are normally the country with the closest socio-economic ties, a shock happened to one country will ripple to the neighbors. Mongolia-Russia

reveals a positive ripple effect, whereas Canada-US-Mexico experiences a negative effect. Countries' changes in their logistics efficiency index reveal the nature of the country as a node in the global logistics network. Countries who play an important role in the network will therefore be more influential to neighboring countries, but also subject to more risks that can lower efficiencies.

(5) Although, the level of infections rates is a major cause of most delivery delays, social-economical, geographical, and political factors all played a role in exacerbating the delivery delays. It is important to note that, countries that have the highest infection rates need not be the least inefficient country. It is true that India (594728 cases), the US (6291268 cases), and Brazil (1876641 cases) have a very high number of cases and thus resulted in the lowest two index ranges. However, Canada has only 18342 cases but has a minimum index of 0.27 which is one of the lowest even among developing countries. Also, Russia which was heavily hit by the pandemic has not seen a very significant decrease in efficiency as well. Since highly developed countries also can be badly hit by the pandemic, just considering the economic development level is also not enough in predicting the level of reduction in the e-commerce logistics industry.

3.3.2 Each countries' highest logistics efficiency index

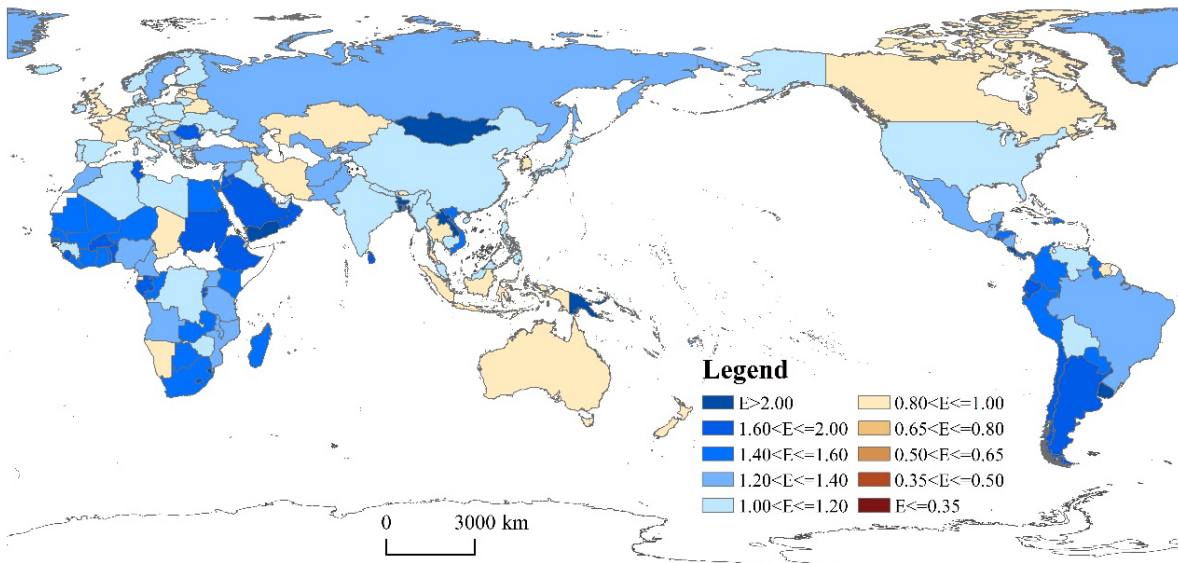


Figure 6: The spatial pattern of each countries' highest logistics efficiency index

Nevertheless, the cross-border e-commerce logistics efficiency indexes in most samples show strong recovery and resilience. In fact, the global e-commerce logistics system, on the one hand, has suffered

from the disruption of productivity and the pressure on shipments caused by the growth of cross-border e-commerce. On the other hand, it has recovered through improved logistics management, transportation modes and routes, and labor deployment. The two effects of “destruction” and “recovery” are carried out at the same time. When the destruction effect is stronger, the delivery time keeps decreasing, but when the recovery effect is stronger, the delivery time begins to improve, showing resilience. Combing the findings from Fig. 3 and Fig. 4, as the world was being hit by the second wave of infections, global logistics systems had enough experience and capacity to respond to later upsurges in online orders. Fig. 6, therefore, illustrates each country’s best performance index during this period. Some key observations are that:

(1) 37 countries are having a period maximum index that is still lesser than 1. These countries involve developed countries such as the UK, Canada, Australia, New Zealand, Singapore, France and developing countries such as Tanga, Malta, and Indonesia, etc. Among these countries, the UK and France ranked 3rd and 4th in parcel volume). Thus, their slow recovery can be attributed to the large volume of parcels. Also, the UK and France had the highest infection rates in Europe (6.15 million and 6.37 million respectively). They were in lockdowns and there were great disruptions in social orders. Australia in the south also extended the closure of its international borders many times, seriously affecting the normal operation and recovery of cross-border logistics, with the highest index of only 0.88 suggesting that it never recovered back to the pre-pandemic level.

(2) 16 countries have a period maximum index greater than 2. Except for Bangladesh, Laos, Lebanon, and Mongolia, most of these countries only have hundreds of parcels. Since the sample size is too small, we do not further discuss this in this study. These islands or landlock counties had the increase in efficiency because it has a limited number of parcels, in the meanwhile had much less road traffic. Laos (parcel volume 555289) and Mongolia (parcel volume 950850) are the two samples with considerable e-commerce goods processing capacities. Laos’s situation was similar to Mongolia so we omit further discussion here.

(3) The spatial pattern of the lowest logistics efficiency index shows large regional differences and aggregation, while the regional differences and aggregation effect of the highest logistics efficiency index are relatively less obvious. The global average lowest logistics efficiency index was 0.43, and the highest average logistics efficiency index was 1.17. The worst affected countries had the lowest index of 0.20 which is 5 times slower than the normal delivery time. However, countries could not achieve 5 times faster speed of delivery after recovery and the highest efficiency index that was achieved is 2.78. This is true because countries can have unlimited losses, but improvements can be very limited especially during lockdown periods. Also, the aggregation effect within regions is also less obvious in Fig. 6.

(4) The aggregation effect is shown in Australia-New Zealand-Indonesia-Malaysia, Argenti-

na-Chile-Ecuador-Peru, and China-India-Myanmar regions. A nation's logistics delays can easily spread to neighboring countries which can intensify regional inefficiencies. Countries neighboring Australia show the least improvement in logistics efficiency. This region has a long trading history and has integrated transportation and logistics networks. Thus, these countries tend to have similar trends in their infections rates, delivery time, recovery ability, and parcel volume. This partly explains why these samples have similar lowest and highest levels of efficiencies. The aggregation effect intensifies regional impacts that either cause greater damage or benefit to a country. The Persian Gulf is another place that shows a spatially concentrated improvement. In 2019, Saudi Arabia launched a national industrial and logistics development program that drawn huge resources into this industry which greatly limited the impact of the pandemic on logistics and even outperformed the previous level before the end of the first wave of COVID-19 infections. Additionally, Argentina has seen a booming market where companies took up more warehousing space and land to build huge e-fulfillment centers. Investment in smart technology management surged as well. Thus, due to the aggregation effect, global logistics network locational advantages should now consider proximity to integrated and high-standard transportation networks, large markets, and external benefits from neighboring countries.

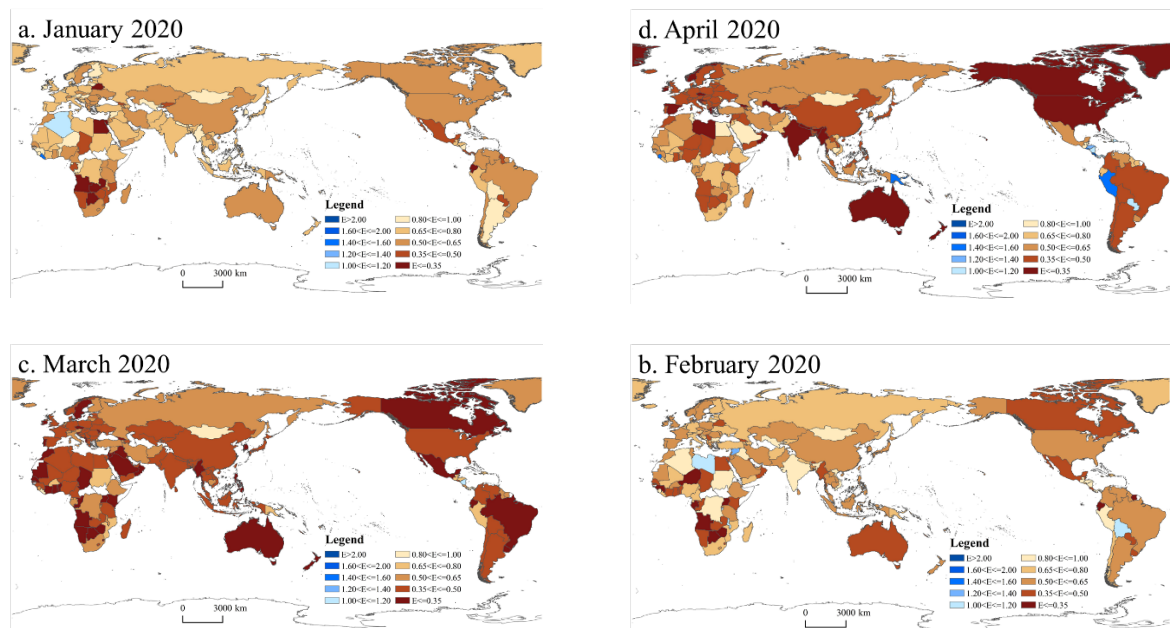
(5) A comparison between China and the US as the largest two countries in the global logistics industry. China, which was the first country that successfully controlled the spread of COVID-19, had an index of 1.09 during the most efficient month (Jan. 2021). Compared with the world's highest index of 1.17 (Jan. 2021). the lower logistic resilience in China may be due to larger parcel volume (18 times that of Hong Kong) and stricter traffic (especially air transport) control policies. China had the largest number of cross-border e-commerce parcels which is 2.5 times more than the US. However, China's efficiency index still ranked second among the top ten countries (Japan ranked first). The resilience of China's logistics is mainly due to the effective prevention and control of the pandemic, as well as the substitution of China-Europe freight trains for air transport, and the diversification of logistics transportation improves its ability to resist outside shocks. Thus, its neighboring countries, benefitting from China's stable, resilient, and powerful logistics systems and market, also made improvements after the outbreak. On the other hand, the US which had the highest index of 1.05 (Jan. 2021) is similar to China and also below the global average. As shown in Fig 4, it is considerably lower than China for most of the time. The main reason is of course the drastic difference in infection rates and severity. The US had very poor anti-pandemic policies and the number of COVID cases is 394 times higher than China's number. The extent of social and supply chain disruption is coupled with political instability. The surge of orders in the US led to increased operational pressure at freight stations and a serious cargo backlog at ports, making it more difficult to ensure the timeliness of logistics. In the US, the outbreak was early and severe. The number of infected employees surged during the first and second waves of the pandemic,

and a large number of parcels were stockpiled for transshipment processing.

3.4 The temporal process characteristics of the changes in logistics efficiency

The logistics efficiency analysis based on different time sections (Figure 7), can show the time-varying logistics efficiencies on a global scale. Specifically, the progressive impact of the COVID-19 pandemic on logistics efficiency can be divided into three stages:

(1) The first stage: from January to June 2020 (corresponding to the first wave of the pandemic), the global logistics efficiency was improved after the rapid decline and difficult recovery. From January to March, the pandemic began to spread all over the world, and countries could not take quick and effective measures against the outbreak in time, and the delivery time of almost all samples was greatly delayed. Since March, the international logistics chain was severely cut off, and the logistics efficiency of various samples has dropped significantly. At first, the decline in North America and Oceania was obvious, but the decline soon spread to South America and Western Europe, and finally spread to almost all countries. This shows a spatial transmission phenomenon from low logistics efficiency samples to high logistics efficiency samples. At the same time, corresponding measures were introduced to promote the resumption of work and production, and logistics efficiency entered a difficult recovery stage. In June, the logistics efficiency indexes of most samples were greatly improved compared with the initial stage of the pandemic, and the indexes of some samples in Africa and South America has recovered to the pre-epidemic level, but the efficiency of samples in North America, Western Europe, Oceania and some North Africa was still very low.



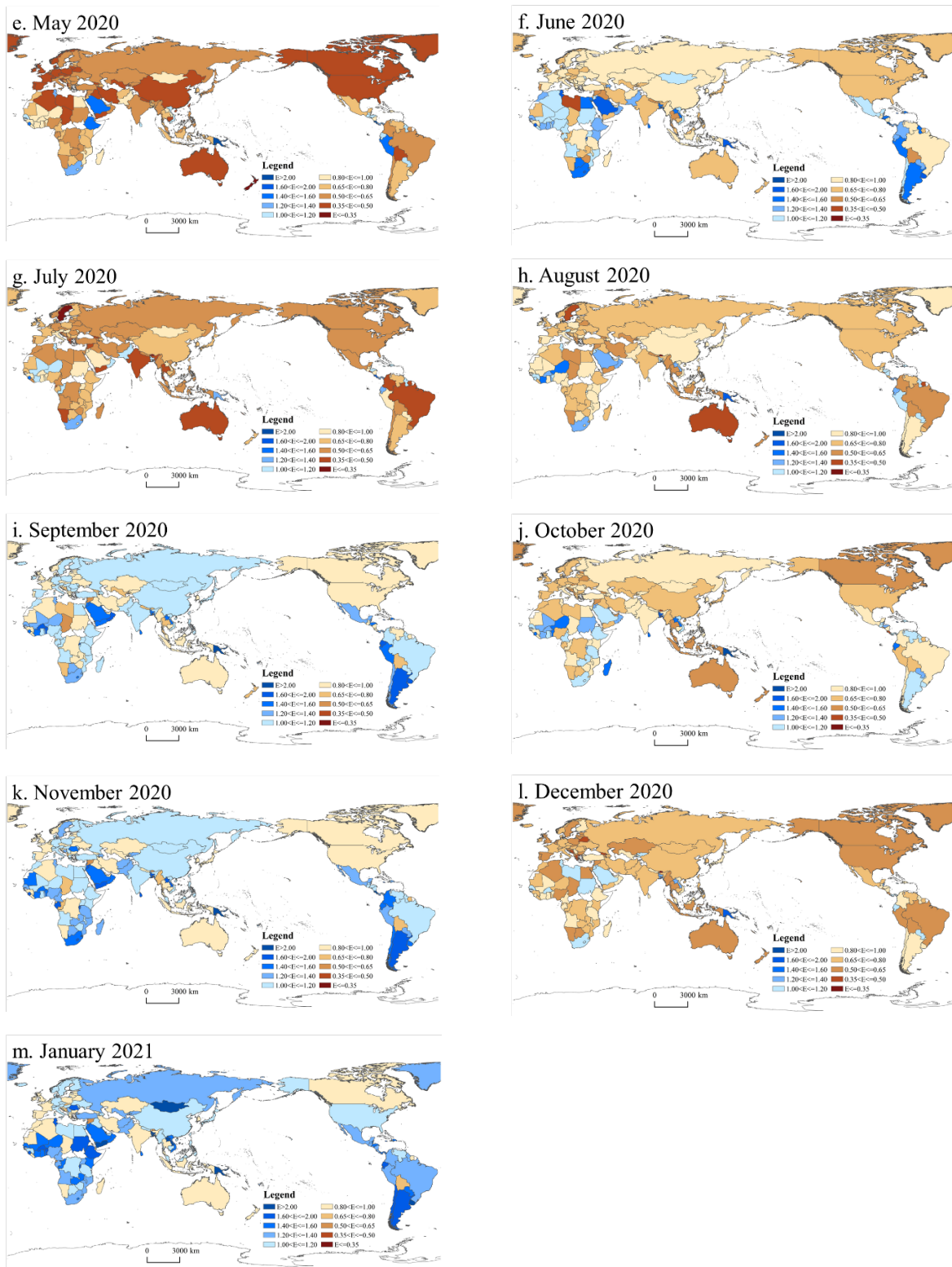


Figure 7: Changes of logistics efficiency index from Jan. 2020 to Jan. 2021

(2) The second stage: from July to November 2020 (corresponding to the second and third waves of the pandemic), the global overall logistics efficiency fluctuated repeatedly, but the recovery speed accelerated, and the global logistics efficiency recovered to the pre-epidemic level. In July 2020, affected by the second wave of the pandemic, the global average logistics efficiency declined slightly. Since August 2020, the global index improved significantly; With China as the center of improvement, a spatial transmission pattern from high logistics efficiency samples to low logistics efficiency samples is witnessed; Subsequently, the logistics efficiency in West Asia, North Africa, Western Europe, and North America increased one after another. In October 2020, the whole world was hit by the third wave of the pandemic, and the efficiency index declined once again, but the magnitude was smaller than that of the previous two waves, and it recovered quickly. By November, the efficiency index of most samples in the world had recovered to the pre-epidemic level, with a global average of 1.17, and only a few samples had an index less than 1. At this stage, the improvement of samples from the United States and Australia is relatively weak, and the logistics efficiency index is still less than 1 (0.97 and 0.84 respectively) in November, especially in Australia, where the logistics efficiency index is as low as 0.43 in July.

(3) The third stage: from December 2020 to January 2021 (corresponding to the fourth wave of the pandemic), the logistics efficiency fluctuated globally, but soon recovered and improved and exceeded the pre-pandemic level. Affected by the large-scale outbreak in winter, the global average logistics efficiency declined. But, sample countries already accumulated experiences in fighting the pandemic in the past year, thus the degree of disruption was far less severe than that of the first stage, and countries' recovery speed was faster. After the first three waves of difficult recovery, the logistics efficiency of each sample logistics system has been systematically improved. When faced with severe impacts again, countries are more resilient.

3.5 Quantitative analysis of influencing factors

Combining the above analysis, we propose that the influencing factors of logistics efficiency include the quantity of parcels, the number of contacting countries, the level of development of the logistics industry, the severity of the pandemic, and the strength of virus prevention and control. Among them, package quantity and the number of contacting countries constitute the attributes of logistics spatial network, which corresponds to node centrality and the number of node connections after some calculations with the data mined. The logistics comprehensive score is selected as the index of the development level of the logistics industry. The data comes from the research of the World Bank and Turku School of Economics and Business Administration, "Connecting to Competition: Trade Logistics in the Global Economy, Logistics Performance Index and Index Report" (<http://worldbank.org/lpi>), the time section

is 2018. The index of pandemic severity is the cumulative number of confirmed cases in a period. The data is from the website of Johns Hopkins University Coronavirus Resource Center (<https://coronavirus.jhu.edu/>), and we select the period that corresponds to the scope of this study. The index of pandemic prevention and control is the stringency index of government response, and the data source is covid-19: String Encyclopedia Index of Oxford University (<https://ourworldindata.org/grapher/covid-stringency-index>), and we select the period that corresponds to the scope of this study. According to the above quantitative indicators, the Pearson correlation coefficient between each influencing factor and logistics efficiency was calculated and is shown in Tab. 1.

Table 1: Pearson correlation between logistics efficiency and influencing factors

Influencing factors	Overall logistics efficiency	Minimum logistics efficiency	Maximum logistics efficiency
Node Centrality	-0.104*	-0.058	-0.125*
Logistics network connections	-.149*	-0.030	-.143*
Development level index of logistics industry	-.265**	-0.094	-.362**
Severity of the Pandemic	-0.109	-0.076	-0.094
pandemic prevention and control efforts	0.051	-0.028	0.067

Note: * and ** indicate significant at 0.05 and 0.01 levels respectively (double tail).

The above result shows that 1) There is a negative correlation between the development level of the logistics industry and the overall logistics efficiency and this relationship is more significant for the highest logistics efficiencies (about 30% explanatory power, significant at 0.01 level). This is different from usual cognition, because developed countries, such as Europe and America, had a poor performance of logistics efficiency. On one hand, it reflects the current evaluation of the development level of the logistics industry only considers the advancement of technology, management level, and potential volume, but lacks evaluations regarding risk resistance; On the other hand, it also shows that there are comprehensive factors affecting logistics efficiency and cannot only consider the development level of the logistics industry. 2) The number of logistics network connections and the centrality of logistics network nodes are negatively correlated with the overall logistics efficiency and the highest logistics efficiency index (on a 15%, 10% explanatory power, 5% significant level). This indicates that logistics efficiency is sensitive to spatial network relationship factors. Large parcel volume, multi-route flow directions caused a momentum that is “too big to lose”. Resource run-off caused by warehouse explosions is also an important factor that affects logistics efficiency. 3) The severity of pandemic and

the intensity of pandemic prevention and control have no significant influence on logistics efficiency. Therefore, when facing impacts from severe crises, the focus of improving logistics resilience should be on its “network” and its “root causes”, that is, to improve the overall logistics network from a global scale, not just from itself; Under the devastating impact of the pandemic, the characteristics of the global “community of shared future” are more prominent. A country’s logistics timeliness will be affected by global transportation, policy control, upstream and downstream industrial chains, etc. Therefore, it is necessary to recognize the various influencing factors of delivery delays inside the global network. 4) The above factors have no significant influence on countries’ minimum logistics efficiencies. It is only statistically significant on countries’ overall logistics efficiencies and their highest logistics efficiencies. This may be related to the sudden outbreak of the pandemic. Since the global logistics industry never suffered such a global impact before, logistics systems in some countries were almost stagnated.

4 Conclusion and Discussion

As a sudden “quasi-natural experiment”, the pandemic provides an important condition for the empirical test of cross-border e-commerce logistics efficiency and the analysis of major influencing factors. By studying logistics efficiency from the time distance perspective, this study analyzes the temporal and spatial patterns of cross-border e-commerce logistics efficiency. The core conclusions are as follows:

(1) Under the impact of the pandemic, the logistics efficiency of cross-border e-commerce fluctuates in accordance with the pandemic cycle, and the overall logistics efficiency rises spirally. The global fluctuation trend is highly similar. From January 2020 to January 2021, four waves of ups and downs have been experienced. There are certain differences in wave peak time and change amplitude, etc. The samples with large package volumes recover relatively slowly, and some samples show typical characteristic differences. This analysis provides a reference for exploring the factors that affect logistics efficiency.

(2) The spatial pattern of the lowest logistics efficiency index shows large regional differences and aggregation, while the regional differences and aggregation of the highest logistics efficiency index are relatively weaker. The global average lowest logistics efficiency index was 0.43, and the highest average logistics efficiency index was 1.17. Compared with pre-pandemic levels, the logistics efficiency decreased by an extent that was much more than the level of improvement. In North America, Western Europe, and other regions, logistics efficiency decreased the most, recovered the slowest and showed spatial aggregation effect. Nevertheless, many countries have not recovered to the pre-epidemic level. Central Asia, Central and Eastern Europe, West Asia, and North Africa regions are relatively less affected and have recovered to a level higher than before; The efficiency index of China, the United States, and Hong Kong showed the amount of influence by factors such as virus prevention and control

capability, transportation diversification and control.

(3) The progressive impact of the COVID-19 pandemic on global logistics efficiency can be divided into three stages. 1) From January to June 2020, the global logistics efficiency declined rapidly and improved after a difficult recovery. The decline in efficiency was transmitted from low index samples to high index samples, and the process of efficiency recovery was then transmitted from high index samples to low index samples. 2) From July to November 2020, the global logistics efficiency fluctuated repeatedly, but the recovery speed accelerated and even returned to the pre-epidemic level; 3) From December 2020 to January 2021, the global logistics efficiency fluctuated slightly, but quickly recovered and exceeded the pre-pandemic level, the efficiency levels were systematically improved.

(4) The spatial-temporal difference in logistics efficiency is caused by multiple factors. Relatively, factors that affect logistics network relationships are more sensitive. Logistics node centrality and the number of connecting points bring the most significant inertia characteristics and resource run-offs; There is a negative correlation between logistics development level and logistics efficiency as a whole. It shows that the current logistics development evaluation system pays less attention to the risk resistance level; The severity of the pandemic and the prevention and control methods are not significant factors. The globalized characteristic of the logistics industry is more prominent under sudden impactful shocks.

As discussed above, this study focuses on the development needs of the cross-border e-commerce logistics industry. It enriches the research on logistics efficiency from the economic geography perspective, expands the research scope of logistics geography, and further supplements and deepens the research on supply chain efficiency on a global scale. It provides support for the issue of “reshaping a more stable global production network” proposed by Yeung H.W.C (2021) et al. At the same time, the application of “waybill data” in this study enriched the geographical big data analysis method. The conclusions of this research could provide some reference for the cross-border e-commerce logistics industry to improve efficiency and resist stresses and provide spatial guidance for the government and enterprises to optimize the organization and dispatching of resources.

In terms of the theoretical establishment progress, this study verifies the importance of the impact of logistics network relationship on logistics efficiency and the spatial dissemination effect of logistics efficiency. Once again, we prove that spatial attributes affect economic activities through “relationship” coupling, and exogenous global scale factors become more and more prominent. The theoretical research direction of economic geography should be further deepened in fields such as exogenous global scale and relational economic geography. Based on this theory, our team’s follow-up research will further explore the identification of exogenous worldwide factors and the mechanism of spatial network relations. We also plan to conduct an in-depth analysis of typical cases such as the China-Europe freight trains and overseas warehouses. We want to explore the geographical response and strategic coupling

brought about by the changes in logistics efficiency. In the current era of unprecedented changes, the globalization process keeps on moving forward (Liu Weidong, 2020). Logistics efficiency may face more influencing factors and greater challenges, which require continuous monitoring and analysis by the academic community to promote research to better serve the needs of economic and social development.

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Author Contributions

The authors acknowledge their responsibility for the following: research conception and design, data collection, results analysis and interpretation, and manuscript writing.

Availability of Data and Materials

The authors confirm that all data generated or analyzed during this study are included in the published articles in the references.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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