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RESEARCH ARTICLE

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# Analysis of COVID-19 Prevention and Control Modes and Effects

**Abstract** This study evaluates COVID-19 prevention and control policies. Based on the simulation, we compare the effects of two major policies: contact restriction and active treatment. Through regression and cluster analysis, we classified 169 countries and regions in the world into 10 groups, among which five groups accounted for the major proportion: the ones with the labels "CHN (China) mode," "SE (South Europe) mode," "ENE-SSA (East & North Europe and Sub-Saharan Africa) mode," "US (United States) mode," and "DEU (Germany) mode"). Differences in the effects of the prevention and control of COVID-19 in typical countries in each mode are comprehensively investigated. The conclusions of this study can be summarized as follows: First, contact restriction outperforms active treatment in curbing the spread of COVID-19. Second, "CHN mode" ranks the highest level of epidemic control and emphasizes epidemic prevention and control more than economic stimulus, which is the opposite of the "US mode". Regression analysis reveals that the differences in epidemics worldwide are caused by policy differences among modes.

**Keywords** COVID-19, SEIR simulation, prevention and control policies, cluster analysis, rolling regression
**JEL Classification** I18, C13, C51

## 1 Introduction

In December 2019, cases of "viral pneumonia of unknown cause" started to appear in Wuhan, Hubei Province, which were confirmed by the China National Health Commission afterward to be a new type of coronavirus (named COVID-19 by the WHO). In the following month, COVID-19 spread rapidly in

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Wuhan at an almost exponential growth rate, rendering Hubei the first place where the disease broke out. About two months after the outbreak in China, COVID-19 began to spread to other countries. The earliest countries affected were Japan and South Korea. The European epidemic followed closely and gradually spread all over the world, among which the United States showed an exponential trend after mid-March and quickly became the hardest-hit country in the world. Figure 1 shows the trends of the COVID-19 epidemic worldwide. Obviously, countries in Europe and America dominated the trend of the entire world epidemic. Although the COVID-19 epidemic initially occurred in Asian countries, the situation is under control for the past year in these countries. Other regions such as the Eastern Mediterranean and Africa, also successfully controlled COVID-19. The COVID-19 epidemic in Southeast Asia had been kept under control for a long time but began to deteriorate sharply in mid-March 2021. There is still a long way to totally control the epidemic worldwide in the future.

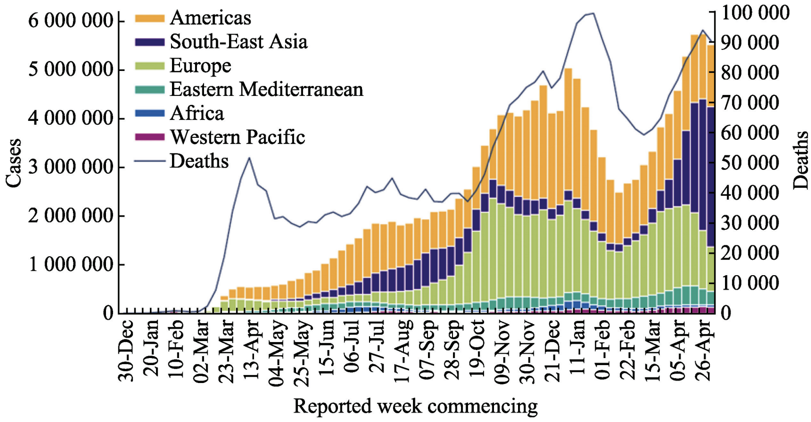



**Figure 1** Weekly World Situation of COVID-19

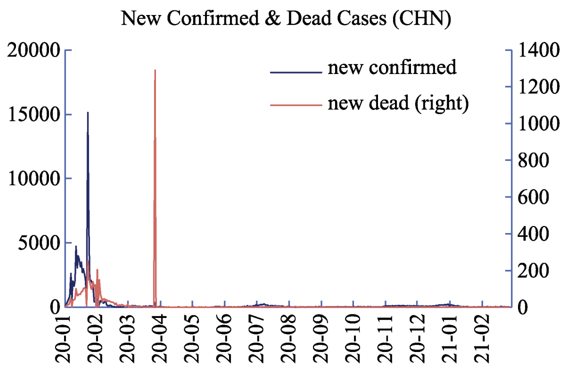
Source: WHO Situation Reports of COVID-19

In fact, in the face of the rapid spread of the COVID-19 epidemic, most countries around the world have responded positively. However, because countries have different understandings of COVID-19 and domestic systems, their specific prevention and control measures also have different characteristics (Cepaluni et al., 2020; Desson et al., 2020).

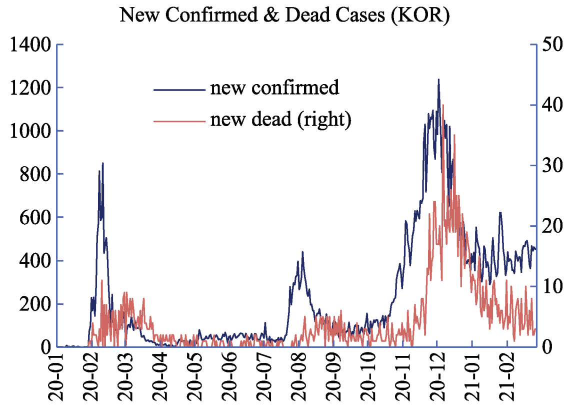
China is a special case in the world. Due to the SARS epidemic from 2002 to

2003, China has gained rich experience in fighting against public health events. Therefore, upon the outbreak of COVID-19, China immediately made a strong response, such as locking down Wuhan, closing public transportation, schools and offices across the country, quickly collecting medical resources nationally to support the hardest-hit areas, and temporarily shutting down the economy. All these measures were proved to be highly effective and helped China rapidly reduce the number of domestic cases. Countries such as South Korea and Singapore have adopted similar strategies, which focused on blocking the transmission path and isolating and treating confirmed patients in the early stages of the epidemic. Singapore imposed a one-month workplace closure and travel restriction in April 2020. South Korea conducted a large-scale nucleic acid test within a short period of time after the outbreak besides closing public places.

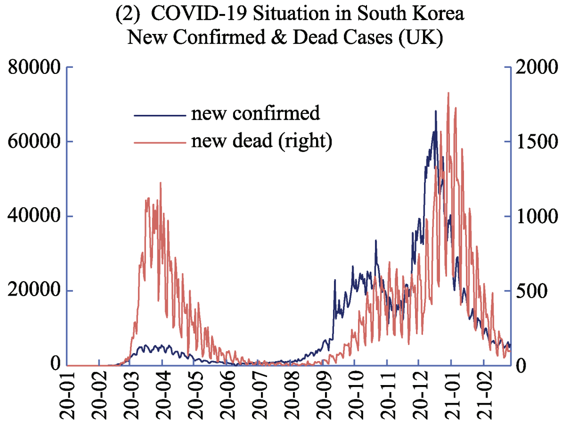
Many other countries, such as the United States, Japan, and the United Kingdom, have adopted different strategies. Most of them believed that the fatality rate of COVID-19 was low and that the vast majority of the patients were only mildly infected. Therefore, the economy far more outweighed the epidemic control. They put the focus on the treatment of severe cases to reduce the fatality rate and advocated home quarantine for mild patients. However, as the number of confirmed cases and deaths kept rising, some countries resorted to drastic measures such as curfews and city closures. For example, an emergency state was declared in the United States, while a total blockade was imposed in Italy.



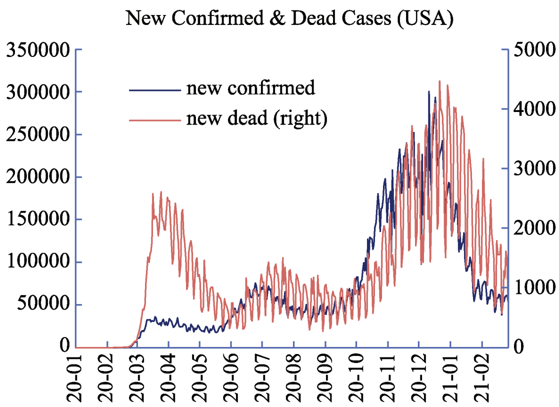
(1) COVID-19 Situation in China




(2) COVID-19 Situation in South Korea




(3) COVID-19 Situation in the UK




(4) COVID-19 Situation in the US

**Figure 2** COVID-19 Situation in Four Typical Countries

Source: China Data Institute (Hu et al., 2020)

Figure 2 shows the numbers of newly added confirmed and death cases in China, South Korea, the United Kingdom, and the United States since January 2020. It can be seen that countries with similar overall prevention and control strategies still reflect their own characteristics in the development of the epidemic. Generally, the policy style of China and South Korea, which focused on the control of infection sources, outperformed that of the United Kingdom and the United States, which mainly focused on critically ill patients, rather than on both newly confirmed and death cases. However, the development trend of the epidemic situation in China and South Korea still differed over time. China basically controlled the local epidemic after the initial outbreak, after which no large-scale outbreak has occurred again (the increase in the number of newly added death cases on April 17, 2020, is an official revision of the previous data). South Korea experienced two more peaks, and the scale of the third peak was much larger than before. Compared with the United Kingdom with a slightly larger population (67 million in the UK and 52 million in South Korea), which also experienced rebounds during the epidemic, South Korea's performance was still better, as the scale of its third epidemic peak was only about 1/50 the scale of peaks of the epidemic in the United Kingdom.

The time trends of the epidemic in the United Kingdom and the United States are roughly similar. Although they both focus on the treatment of severe cases, the number of newly added death cases in these two countries reached a high level soon after the first wave of the epidemic, showing that when the virus spreads on a large scale, this strategy is ineffective. The difference between the United Kingdom and the United States is that the United Kingdom once contained the epidemic in the summer of 2020 and controlled the number of newly added confirmed and death cases below 1,000 and 50, respectively. However, the epidemic in the United States has never been controlled temporarily. There may be several reasons. First, the United States has a significantly larger land area and population than the United Kingdom, making prevention and control in the United States more difficult. Second, the United States is a federal country. Its states have great autonomy in epidemic prevention and control, resulting in a lack of unified command and coordination. It is difficult for the states to form a joint force.

The differences in the prevention and control modes of various countries worldwide have made the effects of their respective prevention and control strategies appear to be quite different. Therefore, the effects of prevention and control are closely related to the modes. The first question this study seeks to answer is, in the face of the prevention and control of COVID-19, which characteristics can accurately and scientifically describe the prevention and control mode and status of various countries. The second question is, under different prevention and control modes, how the differences of effects are presented. This study attempts to identify the advantages and disadvantages of various prevention and control modes through the analysis of historical data, to further improve China's prevention and control ability. This is not only to improve China's emergency system but also to fully prepare for the occurrence of public health events in the future.

Although the existing literature indicates that government interventions have significant impacts on the process of epidemic outbreaks and have important implications for the current epidemic prevention and control, the high infectiousness of the COVID-19 epidemic and its global outbreak are still challenging. Different countries have different responses and measures to prevent and control epidemics. How many modes are there for COVID-19 prevention and control? What are the differences in the effectiveness of different modes? These questions have not yet been addressed or answered in the current literature. Based on the above two questions, this study uses the latest data on COVID-19 policies and cases to obtain more realistic policy implications for the prevention and control of the current epidemic.

This study first simulates two important prevention and control concepts and summarizes the differences in the dynamic development of the epidemic under different policy interventions, so as to lay a foundation for the construction of policy indicators and the exploration, classification, and evaluation of different epidemic prevention and control modes. Subsequently, this study selects epidemic-related data from 169 countries and regions around the world and divides the epidemic prevention and control modes of the sample countries into 31 categories from a scientific point of view through regression and cluster analysis methods. Finally, this study evaluates the prevention and control effects of each mode. This study makes three main contributions to the literature. First, in the analysis process, this study relies on several major databases that track epidemics in various countries, cross-references, cleans the sample data comprehensively, and handles the measurement error caused by the statistical time difference, statistical caliber adjustment, and statistical data lag, ensuring the reliability of the subsequent mathematical analysis. Second, this study relies on the digital policy database of the Oxford University's Epidemic Policy Research Team (OxCGRT), combined with two important prevention and control concepts, and constructs two new, more reasonable comprehensive policy indicators for more scientific research on epidemic prevention and control. Third, this study innovatively uses regression and cluster analysis methods to classify the prevention and control modes of key countries and uses rolling regression to capture the time-varying epidemic prevention and control effects. It shows the differences in epidemic characteristics and prevention and control modes and effects of various countries from a more scientific and accurate perspective.

The structure of this paper is as follows. The second part reviews related literature. The third part uses the SEIR model to explain the two major concepts of the prevention and control of epidemics. In the fourth part, policy indicators related to the two major prevention and control concepts are established, and epidemic policy indices are constructed. By matching the epidemic dynamic data of the corresponding countries, regression and cluster analysis methods are used to identify different prevention and control modes. In the fifth part, the classification results of the prevention and control modes of epidemics mentioned in the fourth part are used to analyze the prevention and control characteristics and their effects in typical countries under different modes. The sixth part summarizes the conclusions of this study and proposes relevant policy recommendations.

## 2 Literature Review

Relevant institutions and scholars have constructed various models to characterize the propagation dynamics model of COVID-19. The results and policy recommendations are also different due to the discrepancies in the assumptions, parameter selection, and datasets of different models. Chen et al. (2020) constructed a Bats-Hosts-Reservoir-People transmission network model to simulate the transmission mode of COVID-19. Riou et al. (2020) focused on the human-to-human transmission model in the early stages of the COVID-19 epidemic, which showed a fast contagion speed of COVID-19 among humans and emphasized the effectiveness of screening and control. Shen et al. (2020) simulated and predicted the epidemic trend of COVID-19 in the context of the

Spring Festival travel in China, uncovered COVID-19's temporal and spatial transmission mode, and underlined the importance of strong intervention measures. These models explain the contagion of the COVID-19 epidemic from different perspectives and evaluate the effectiveness of different prevention and control measures. Tang et al. (2020) constructed a dynamic SEIR model to estimate the basic reproduction number of COVID-19. Their sensitivity analysis showed that containment measures (such as close contact tracing, quarantine, travel restrictions) on Beijing's COVID-19 infection rates are almost equivalent to increasing quarantine by 100,000 baseline points, which can effectively control virus reproduction. The infection rate, morbidity, and diagnosis rate of COVID-19 change over time owing to human interventions. Therefore, Tang et al. (2020) introduced a time-varying contact rate to construct a dynamic SEIR model, which is more in line with the actual development of the epidemic and can better quantify the effectiveness of containment measures.

Regarding research on the effectiveness of the prevention and control of epidemics, numerous studies on China's COVID-19 epidemic have shown that measures such as quarantine and medical tracking are conducive to slowing down the evolution of the epidemic and suppressing its spread in a large area. Centralized reception, stratified treatment, and other measures can reduce the peak number of people infected or in the latent period (Cai et al., 2020; Cao et al., 2020; Geng et al., 2020; Hou, 2020). Additionally, the simulation results of Ming et al. (2020) indicate that timely public health interventions are essential for the prevention and control of the COVID-19 epidemic. Among public interventions, wearing masks is the most feasible and effective measure, while health education such as medical knowledge publicity and raising personal awareness of prevention can curb the increase in the number of infections and prevent secondary infections. Fang et al. (2020) showed that the strength of government interventions is related to the growth rate of the number of infections. As the number of infected people increases, the effectiveness of quarantine and protection is likely to decline, and the requirements for optimizing treatment plans and developing specific drugs become more urgent. Therefore, it is important to adopt strict intervention measures early. Regarding policy research on the prevention and control of epidemics overseas, Ngonghala et al. (2020) constructed a new type of Kermack-McKendrick model, which uses COVID-19 data from New York State and the United States for parameterization, and evaluated four main intervention measures: social distance, isolation, contact tracing, and mask use. The results show that non-pharmaceutical interventions (especially social isolation and mask use) are effective for the prevention and control of COVID-19, especially in the early stages. The above studies show that non-pharmaceutical interventions play a vital role in the prevention and control of COVID-19 and that the government's choice and formulation of policies determine the effectiveness of COVID-19 prevention and control.

## 3 Simulation of Control and Prevention Policy

Although the time of the outbreak of COVID-19 differs in each country, all governments have implemented a series of prevention and control measures to minimize human migration and curb the spread of new infections in the population. For example, after the outbreak in Wuhan, China first imposed a strict city-wide lockdown. Simultaneously, strict restrictions on public transportation were imposed in other provinces of China. Many other countries have introduced control policies. Hale et al. (2020) evaluated policies of containment, economic stimulus, health care, and other fields that had been issued since the outbreak of COVID-19 in most countries around the world. These policies have proven necessary and effective for epidemic control.

For epidemic control, two types of measures have proved to be the most effective: suppressing personal contact and preventing the contact of infected people and susceptible people to avoid infection by imposing a city-wide lockdown and implementing an isolation policy. Among them, the most stringent is the isolation policy, which prevents close contact between the infected and susceptible groups. Additionally, closing schools, maintaining social distancing, and wearing masks are also effective measures to prevent close contact among people and reduce the probability of infection. The second is striving to treat all infected people and conduct epidemiological investigations in time. If the infected person cannot receive effective and timely treatment, they will surely spread the virus through various contacts. Close contacts of confirmed patients should also be isolated and observed in time, to prevent further spread of the virus by infected persons during the incubation period. To understand these two prevention and control measures more intuitively, we performed a simulation using the SEIR model of COVID-19 to examine the trend of the epidemic over time under different contact and treatment policies while keeping the pathological characteristics of COVID-19 unchanged.

The classic model to describe the development of a certain infectious disease, given the scale of population (N), is the SIR model. The model generally divides the entire population into three categories: susceptible (S), infected (I), and recovered (R). Both the susceptible and the recovered are healthy. However, the recovered have memory antibodies in their bodies. Therefore, generally, they will not contract infectious diseases anymore. However, susceptible people are more likely to get infected through being in contact with infected people. The SIR model is not sufficient to describe the transmission path of COVID-19 perfectly because the incubation period for COVID-19 is about a week, and people in this period can still spread the virus. The SEIR model adds the incubation period population (E) into the SIR model and performs better in simulations (Chen et al., 2020; He et al., 2020; Tang, et al., 2020). A typical SEIR model of COVID-19 can be expressed through the following set of differential equations:

$$\begin{cases} \dot{S} = -\frac{S}{N} r(\beta_0 I + \beta_1 E) \\ \dot{E} = \frac{S}{N} r(\beta_0 I + \beta_1 E) - \alpha E \\ \dot{I} = \alpha E - \gamma I \\ \dot{R} = -\gamma I \end{cases} \tag{1}$$

Specifically, in each period, the infected and people in the latent period are assumed to be in contact with r individuals. Such contact results in a probability of $\beta_0$ and $\beta_1$ to be infected. Furthermore, people exposed to the infection enter the incubation period, and are then confirmed as infected after several days. Under the intervention of positive treatment, the infected individuals have a probability of $\gamma$ to recover. Although it has been reported that several recovered test positive again, it is most likely to be the genetic material of the virus during the treatment, and the recovered persons still have antibodies in the body, so that they are no longer susceptible. The evolutionary relationship between the four groups in the SEIR model is shown in Figure 3.

To fit the model to the situation of COVID-19, typical parameters were calibrated according to existing literature. It is worth noting that the parameters in the model can be divided into two categories. One is related to the pathological characteristics of COVID-19 and will not be affected by external policies. These parameters included the probability of exposure to infection $\beta_0$, $\beta_1$ and the number of days in the incubation period 1/α. According to Hou et al. (2020), the probability of two types of contact infection is set to be equal, $\beta_0 = \beta_1 = 0.0269$. According to the "New Coronavirus Pneumonia Diagnosis and Treatment Plan (Trial Eighth Edition),"[1] the period lasts between three and seven days; in this study, the period is set as 7, that is, α=1/7.

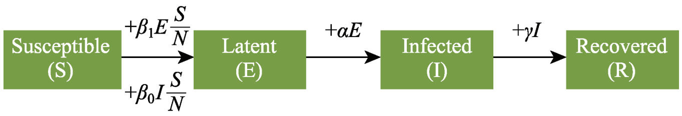



**Figure 3** Evolutionary Relationship of the SEIR Model of COVID-19

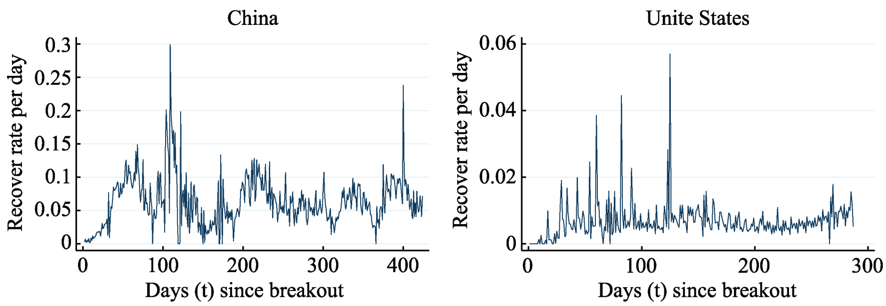



**Figure 4** Daily Cure Rate in China and the US

Note: The cure rate here is computed as # (daily recovery cases) divided by # (stock confirm cases). The data source is the China Data Institute (Hu et al., 2020).

Other types of parameters that will be significantly affected by prevention and control policies include $r$, the number of contacts during the diagnosis and incubation period, and $\gamma$, the probability of cure for the confirmed patient. When implementing contact restriction policies, such as keeping residents at home, maintaining social distance, and restricting public transportation and business during the outbreak of the epidemic, the parameter $r$ will be much lower than when these policies are absent. Therefore, we assume that a confirmed case and a case in the incubation period have the same contact rate to susceptible people by $r = 20$. Simultaneously, if the

[1]《新型冠状病毒肺炎诊疗方案（试行第八版）》

government adopts active personnel contact restriction measures, it is assumed that $r$ will be reduced by 10% every two days. Additionally, if the government actively supports the treatment of confirmed people, the cure rate will also change significantly. For example, under the active intervention of the government, parameter $\gamma$ in China is at a relatively high level globally, with an average of 0.049. As shown in Figure 4, during the critical phase of epidemic control in March, the daily cure rate was stable at approximately 0.1. However, the United States, which is in sharp contrast with China, has a significantly lower cure rate. The average cure rate during the epidemic was only 0.0117, with a relatively long period of less than 0.01. Therefore, in the simulation, we adopted three values for the cure rate, namely the normal level of 0.05, the high level of 0.1, and the low level of 0.01. The table below shows the important policy parameter settings with a group population of 300,000. Figure 5 shows the simulation results under six scenarios with the initial condition I(0)=10, R(0)= E(0)=0.

**Table 1** Parameter Setting of Six Policy Scenarios

| Scenario | Policy situation | Policy parameters |
|---|---|---|
| 1 | Normal | $r = 20, \gamma = 0.05$ |
| 2 | Contact restriction | $r(0) = 20, r_t = \max(1, 0.9 \times r_{t-1}), \gamma = 0.05$ |
| 3 | Positive treatment | $r = 20, \gamma = 0.1$ |
| 4 | Negative treatment | $r = 20, \gamma = 0.01$ |
| 5 | Contact restriction + positive treatment | $r(0) = 20, r_t = \max(1, 0.9 \times r_{t-1}), \gamma = 0.1$ |
| 6 | Contact restriction + negative treatment | $r(0) = 20, r_t = \max(1, 0.9 \times r_{t-1}), \gamma = 0.01$ |

From the above simulation results, the main findings can be summarized as follows.

First, the policy of contact restriction had a significant effect on the control of the epidemic. Comparing Scenarios 1 and 2, in the early outbreak of the epidemic, contact restriction can quickly restrain the epidemic, and the stock of infectious cases remains at a low level until the epidemic disappears. Comparing Scenarios 4 and 6, even when the treatment policy is relatively negative, the peak number of infected cases under the contact restriction policy in Scenario 6 is significantly less than half the number in Scenario 4, which significantly slows down the spread of the epidemic and sets aside the necessary time for the generation of medical resources. Simultaneously, comparing Scenarios 1 and 6, the peak of the spread of the epidemic under the policy of contact restriction is also significantly lower than that without

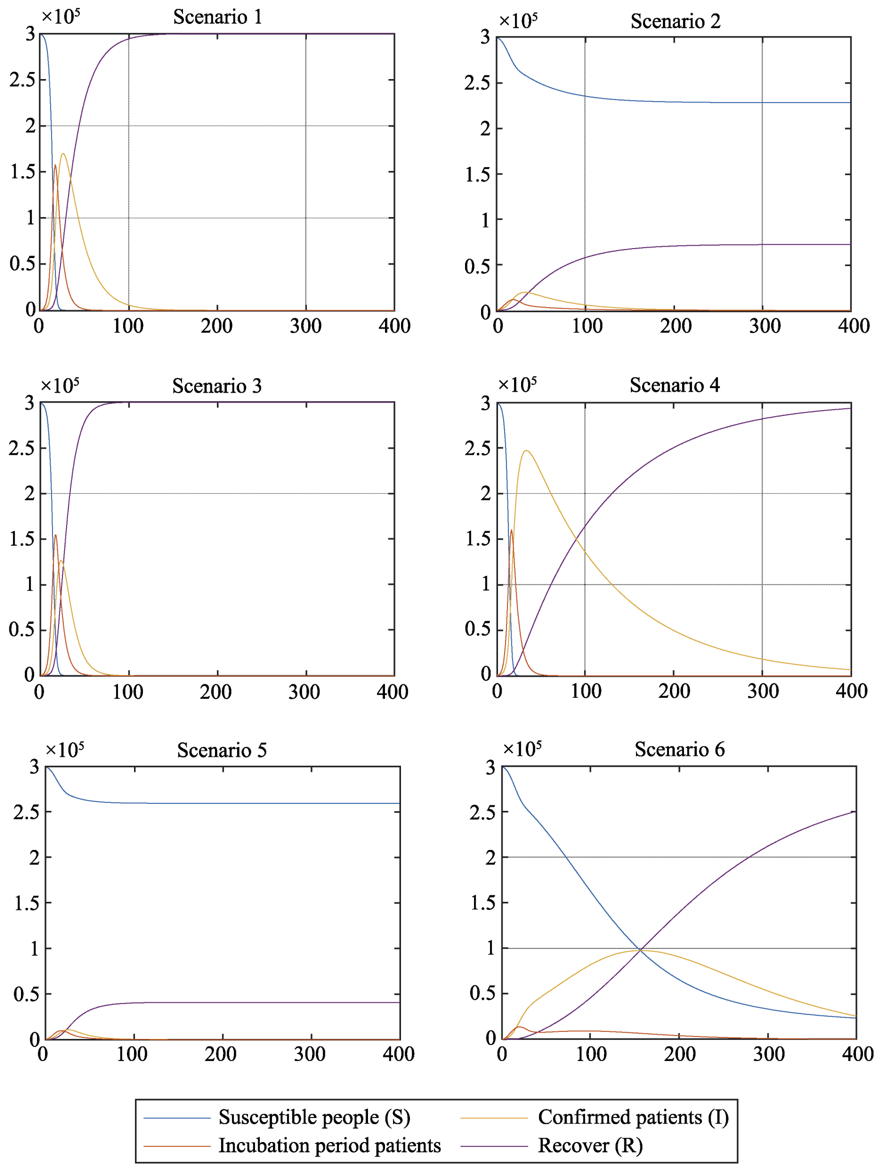



**Figure 5** Simulation of the SEIR Model of COVID-19 under Six Policy Scenarios

contact restriction. Therefore, regardless of the level of medical care in a country, contact restriction is the most important policy for controlling infection.

Second, an active treatment policy has a certain but limited effect on the control of the epidemic. Comparing Scenarios 1 and 3, the cure rate in the latter is twice that in the former, which results in a lower peak of the epidemic in Scenario 3 than in Scenario 1. However, compared with Scenario 2, the control effect in Scenario 3 is significantly worse. From the perspective of the outbreak process, the peak time points in Scenarios 3 and 1 are very close, and the end of the epidemic in Scenario 3 is earlier than that in Scenario 1. Comparing Scenarios 2 and 5, under the implementation of the contact restriction policy, increasing the cure rate can significantly reduce the total scale of the epidemic (the cumulative number of infected people), but has a limited impact on the process of the outbreak.

Based on the above analysis, although the classic SEIR model is different from the actual situation, the conclusions obtained are generally consistent with previous studies (Fang et al., 2020; Ming et al., 2020; Ngonghala et al., 2020): Contact restriction is essential for epidemic prevention. The control effect is the most significant, and the scale and process of the epidemic can be significantly changed. Even when the epidemic treatment policy is not compulsory, the number of infections can be reduced significantly, and its spread can be delayed. At the current medical level, an active treatment policy can increase the cure rate, which consequently shrinks the scale of the epidemic. However, this policy is not as effective as contact suppression, and it is difficult to delay the outbreak of the epidemic. The integration of the two policies is the best policy choice. Moreover, it can not only quickly control the epidemic, but also control the scale and speed of the epidemic to the maximum.

## 4 Regression and Cluster Analysis of COVID-19 Control Modes

There are many factors in epidemic prevention and control that affect the implementation of the above two prevention and control concepts. The first is a lack of experience. In China, prevention and control did not start in time, owing to the lack of understanding of the pathology of COVID-19 in the earliest stage.

After investigations conducted by the expert group, the Chinese government acted quickly and implemented a series of measures to restrain personnel contact, especially to close Wuhan, which, according to Fang et al. (2020), reduced at least 76.98% of the population inflow, 56.31% of the population outflow, and 55.91% inside the population movement of Wuhan. If there were no such measures, the number of people infected outside Wuhan would increase by 105.27%. The second is political confrontation. China, Japan, and South Korea were the first countries to experience the COVID-19 epidemic. During the epidemic, China proactively shared its prevention and control experiences with the international community. However, when the epidemic broke out in countries such as the United States, it spread on a large scale owing to ineffective prevention and control at the early stage. To shirk their responsibility for ineffective prevention and control, such governments associate COVID-19 with China and stigmatize China, further exacerbating the spread of COVID-19. The third factor is economic development. In the face of the COVID-19 epidemic, both containment and treatment require strong social production as a guarantee. When the containment policy lasts too long, social production will stagnate, making it difficult for normal life to be guaranteed, at which time the government will fall into the dilemma of epidemic prevention and control and economic development. Additionally, if social productivity (the production of basic protective materials, the capacity of hospitals, etc.) cannot keep up, the government's active intervention treatment policy will be difficult to implement effectively. Fourth, there are differences in social culture and government organizational capabilities. Epidemic prevention and control have a significant impact on the lives of individuals and families. Therefore, strong prevention and control measures need the cooperation of all sectors of society. There are a large number of grassroots organizations in China. Under the leadership of the government, while actively preventing and controlling the epidemic, they can also guarantee the basic living needs of people. With the concerted efforts of the government and the people, China's prevention and control policies have been implemented very successfully. In contrast, in some countries, when epidemic prevention and control affect personal lives, many people disregard them and believe that personal freedom is more important than home isolation and wearing masks, which significantly reduces the effectiveness of the p policies. Therefore, although containment and active treatment become the consensus of experts in epidemic prevention and control, owing to the above factors, the implementation of these two concepts in different countries is not the same, as are the results.

To explore the epidemic prevention and control modes, this study selects related data from 169 countries and regions around the world and conducts research on the epidemic prevention and control policies and epidemic development trends of these countries and regions, to obtain a scientific classification of epidemic prevention and control modes. Specifically, this study categorizes epidemic prevention and control policies and indices them according to their degree of importance, and regresses them to the epidemic status. By comparing the regression coefficients, cluster analysis is used to obtain the classification results of epidemic prevention and control modes.

## 4.1 Introduction to Variable Indicators and Data Sources

### 4.1.1 Policy Indicators for Epidemic Prevention and Control

This study draws on the classification data of the policy text for the prevention and control of COVID-19 in various countries around the world by Hale et al. (2020) from the Oxford COVID-19 Government Response Tracker (OxCGRT). OxCGRT divides the epidemic prevention and control policies into four categories: containment and closure policies, economic policies, health system policies, and miscellaneous policies. Each category contains several sub-categories. Through research and professional judgment, OxCGRT evaluated the implementation and intensity of each subdivided policy, hence providing convenience and possibilities for research on the prevention and control policies of COVID-19. This study focuses on containment and closure, as well as economic and health system policies. The containment and closure policies are divided into seven sub-categories: school closing (C1), workplace closing (C2), canceling public events (C3), restricting gatherings (C4), closing public transportation (C5), stay-at-home requirements (C6), restrictions on internal movement (C7), and international travel controls (C8). Health system policies are divided into eight sub-categories: public information campaigns (H1), testing policy (H2), contact tracing (H3), emergency investment in healthcare (H4), investment in vaccines (H5), facial coverings (H6), vaccination policy (H7), and protection of elderly people (H8). Economic policies are divided into four sub-categories: income support (E1), debt/contract relief (E2), fiscal measures (E3), and international support (E4).

From the analysis of the SEIR model of the COVID-19 epidemic, the importance of containment is beyond doubt. For health system policies, facial coverings (H6) can be attributed to containment policies. Public information campaigns (H1), testing policy (H2), and contact tracing (H3) play a very important role in the detection of new COVID-19 infections and people in the latent period. Emergency investment in healthcare (H4) will have an impact on the admission of patients in the medium and long term. Investment in vaccines (H5) and vaccination policies (H7) will take more time to take effect. The protection of elderly people (H8) has a greater correlation with the control of the number of deaths. Among the economic policies, income support (E1) and debt/contract relief (E2) directly affect people's ability to withstand the impact of the epidemic and their willingness to follow stricter epidemic prevention and control measures. Fiscal measures (E3) provide a country's overall economic stimulus expenditure in response to the epidemic. International support (E4) is the assistance provided by one country to support the fight against the epidemic in other countries. Hale et al. (2020) first standardized all indicators according to the formula $I_{j,t} = 100\frac{v_{j,t} - 0.5(F_j - f_{j,t})}{N_j}$. $v_{j,t}$ is the policy indicator before the standardization of the $j$ indicator in period $t$, $F_j$ marks whether the policy has a policy implementation dummy variable. $f_{j,t}$ is the policy implementation dummy variable in period $t$, and $N_j$ is the maximum value of the $j$ indicator. Further, they used nine indicators (C1–C8 and H1) to construct a comprehensive policy stringency index with equal weight. This study also includes three subdivision policy indices constructed by OxCGRT: containment health index, economic support index, and government response index.

Simultaneously, this study considers that the development of the COVID-19 epidemic is a long-term process, and the epidemic is not static from beginning to end, but constantly changing. The relative importance of various policies at different stages is different, and the focus of the government's work will also be adjusted. For example, the focus of the work at the beginning of the epidemic was containment and patient admission, while the development and promotion of vaccines is crucial to completely end the epidemic in the middle and late stages. Therefore, a major disadvantage of the index constructed by OxCGRT is that its composition does not adjust over time. To describe the policy intensity at different stages of the epidemic more accurately, this study divides the development of the epidemic into two stages: “Up” and “Down.” These stages are defined by the sign of the increase of stock confirmed cases, and the sign is positive in the “Up” stage and negative in the “Down” stage. We define the “In Control” stage by the level stock confirmed cases being less than 50. Based on the indicators provided by OxCGRT, this study constructs two indices, the containment index and the economic index, and uses different construction methods when the epidemic is in the “Up” and “Down” stages. The specific construction methods for the above indices are shown in Table 2.

**Table 2** Construction of Comprehensive Policy Indicators

| Index | Construction method | Formula |
|---|---|---|
| Stringency index | Equal weight | (C1+C2+C3+C4+C5+C6+C7+C8+H1)/9 |
| Containment health index | Equal weight | (C1+C2+C3+C4+C5+C6+C7+C8+H1+H2+H3+H6+H7+H8)/14 |
| Economic support index | Equal weight | (E1+E2)/2 |
| Government response index | Equal weight | (C1+C2+C3+C4+C5+C6+C7+C8+E1+E2+H1+H2+H3+H6+H7+H8)/16 |
| Containment index (Up) | Relative importance weight | (5×(C1+C2+C3+C5+C6+H6)+3×(C4+C7+C8)+2×H1+4×(H2+H3+H4))/53 |
| Containment index (Down) | Relative importance weight | (5×(H2+H3)+4×(C1+C2+C3+C5+C6+H6)+3×(C4+C7+C8)+2×(H1+H4))/47 |
| Economic index (Up) | Relative importance weight | (4E1+5E2)/9 |
| Economic index (Down) | Relative importance weight | (E1+E2)/2 |

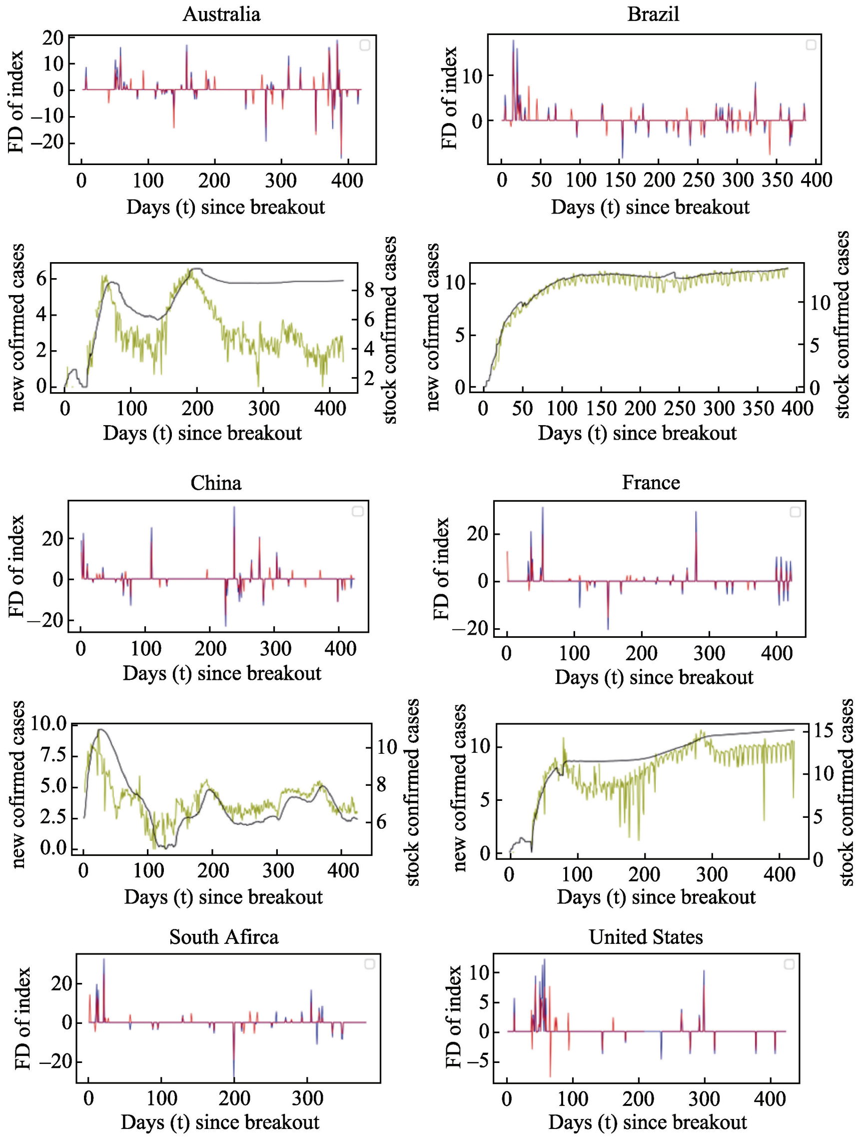
### 4.1.2 Epidemic Development Trend Indicator

The dynamic indicators of the epidemic can be divided into two categories:

cumulative and newly added, with specific statistics on the number of confirmed, cured, and death cases every day. Cumulative indicators are the result of past epidemic development and policy reactions. It is difficult for them to evaluate dynamic epidemic changes. Drawing on the conclusions and enlightenment of the previous SEIR model, the number of stock and new confirmed cases can evaluate the effectiveness of prevention and control policies in containment, while the number of death cases can reflect the effect of active intervention and treatment. Therefore, COVID-19 data of the stock and newly confirmed cases and death and new death cases are key for our analysis.

Many institutions and research teams monitor the daily development of the COVID-19 epidemic around the world, such as the World Health Organization, Hale et al. (2020), Ashofteh and Jorge (2020), and Hu et al. (2020). Chinese institutions such as Dingxiangyuan and Baidu are also tracking the global epidemic situation. The above data sources are different in the statistical results owing to time differences and errors in media reports. This study uses data on confirmed, death, and cured cases of COVID-19 from the China Data Institute (Hu et al., 2020).

Figure 6 shows some countries' COVID-19 epidemic indicators and comprehensive policy indices. First, some countries, such as Australia, France, and South Africa, experienced two peaks during the epidemic, while the US and Brazil never controlled the epidemic successfully even for a short time. On the one hand, the figure shows that the effects of epidemic prevention and control differ across countries. On the other hand, it shows the risk of a second outbreak on a global scale. Second, the newly added confirmed and death cases in all countries have relatively similar trends. When the number of newly added confirmed cases increases, that of the newly added death cases tends to increase, but the degree of this positive relationship is different in different countries and different periods. For example, in Australia, during the first peak of the outbreak, the number of newly added death cases significantly lagged behind that of newly confirmed cases, and the trend of the number of newly added death cases was relatively flat, but when the second peak came, the increasing trends of these two were relatively close. Further, there was almost no lag in the increase in the number of newly added death cases. The characteristics of the spread of the epidemic in the United States are the opposite of those in Australia. Third, the policy stringency index of Hale et al. (2020) and the index constructed in this study share a very close change process. However, owing to the difference in the construction process of the two indicators, the marginal difference is also obvious.



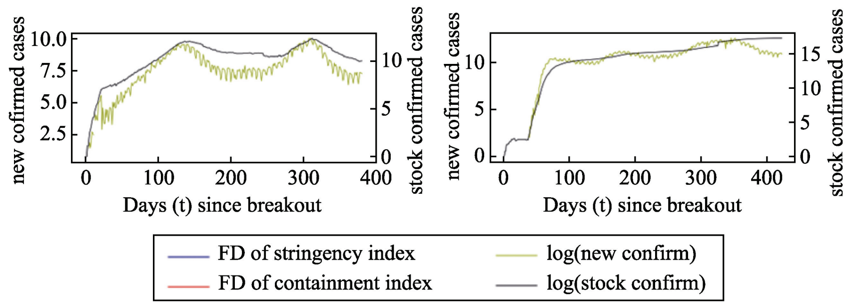



**Figure 6** Epidemic Indicators and Comprehensive Policy Indicators of Typical Countries

### 4.2 Classification and Analysis of Epidemic Prevention and Control Modes

To classify the epidemic prevention and control modes scientifically, this study analyzes the real-time response intensity of the policy indices to the epidemic based on the conclusions of the third part. The specification of the regression model is given by Formula (2). $policy_t$ is proxied by the above two policy indices (containment and economic indices). $infect\_rate_t$ and $death\_rate_t$ respectively represent the infection rate and death rate of stock confirmed cases. We do not use the level variable as the proxy variable of the status of the epidemic for several reasons. First, for many countries, the level variable has significant time trends, and this may result in incorrect estimation considering that the dependent variable is limited between 0 and 100. Second, the COVID-19 policy responds to marginal change of the epidemic data, and the huge absolute value of level variables may cause the marginal change to seem not significant, which may result in difficulties in distinguishing the most and least severe samples. Since the time trend is related to the development of COVID-19 and stages of epidemic prevention and control, and has no upper bound, the time trend is not included in the regressions.

$$policy_t = \beta_0 + \beta_1 infect\_rate_t + \beta_2 death\_rate_t + \varepsilon_t \qquad (2)$$

$\beta_1$ examines how the policy responds to the infectivity of the epidemic. To eliminate the scale effect and make the data comparable between countries, we construct the infection rate as the ratio between the newly confirmed and the stock confirmed cases. $\beta_2$ examines the response of the policy to the newly added death rate. Similarly, we construct the newly added death rate as the ratio between newly added death cases and stock confirmed cases. $\beta_0$ represents the level of policy control when both rates are zero (i.e., the epidemic ends completely). In fact, we can conclude that ( $\beta_1$ and $\beta_2$ capture the marginal policy response to COVID-19, and $\beta_0$ describes the overall intensity of policy.

When applying the model to the data, we consider the phased change of policy with the development of COVID-19 and allow the coefficients to vary with different stages of the epidemic. As the data volatility of the “In Control” stage is high, and this stage is less important compared with the other two stages, we exclude the sample of this stage in the regression.

The sample contains a total of 169 countries and regions, and each country or region has a total of 12 coefficients. Before performing cluster analysis on the coefficient vectors, we standardize all coefficients to reduce the influence of the large variance of some coefficients on the results. In this paper, the k-means clustering algorithm is used, and the number of clustering categories is set to be k=31 according to the Bayesian information criterion. The classification results are shown in Table 3 below.

The clustering results show that five out of ten epidemic prevention and control modes cover most of the 169 countries and regions. The 2nd category, represented by China, contains 46 countries, which mainly include Latin American and Caribbean, Sub-Saharan African, and Asian countries. The fifth category, represented by Italy, contains 25 countries and regions, including most Southern European countries. The 7th category represented by South Korea and Japan, contains 54 countries and regions, including most countries in Sub-Saharan African countries, many East and North European countries, and some East Asian countries. The 8th category represented by the United States contains six countries and regions with typically poor prevention and control policies, and the 9th category represented by Germany contains eight countries and regions, including four European countries and three high-income central Asian countries. The above five modes are named “China (CHN) mode,” “South Europe (SE) mode,” “East & North Europe and Sub-Saharan Africa (ENE-SSA) mode,” “United States (US) mode,” and “Germany (DEU) mode,” and are the focus of subsequent analysis.

We further examine the differences among the above five modes from the perspective of the statistical characteristics and the mean value of the response coefficients of the policy indices.

**Table 3** Cluster Results for 169 Countries and Regions

| Prevention and control mode | Country/Region |
|---|---|
| 1 | Belarus, Burundi, Comoros, Dominica, Fiji, Laos, Liechtenstein, Nicaragua, Solomon Islands, Tanzania, Vanuatu, Yemen |
| 2 | Algeria, Argentina, Azerbaijan, Bahamas, Bangladesh, Barbados, Belize, Bhutan, Cape Verde, China, Croatia, Cuba, Ecuador, El Salvador, Eritrea, Eswatini, Ethiopia, France, Gabon, Georgia, Guatemala, Guyana, Honduras, Indonesia, Jamaica, Kazakhstan, Kosovo, Libya, Malta, Mauritius, Monaco, Mongolia, Morocco, Nepal, Paraguay, Peru, Philippines, Rwanda, San Marino, Saudi Arabia, Singapore, South Africa, Suriname, Trinidad and Tobago, Venezuela, Zimbabwe |
| 3 | Afghanistan, Albania, Central African Republic, Dominican Republic, Haiti, Iraq, Kenya, Lithuania, Mali, Oman, Sierra Leone, Sudan, Uganda |
| 4 | Bolivia, Syria |
| 5 | Australia, Austria, Brazil, Canada, Colombia, Cyprus, Egypt, Greece, India, Iran, Ireland, Italy, Lebanon, Malaysia, Mexico, Nigeria, Norway, Pakistan, Panama, Poland, Serbia, Slovenia, Spain, Switzerland, Turkey |
| 6 | Czech Republic, New Zealand |
| 7 | Andorra, Angola, Bahrain, Benin, Bosnia and Herzegovina, Botswana, Brunei, Bulgaria, Burkina Faso, Cambodia, Cameroon, Chad, Costa Rica, Denmark, Djibouti, Finland, Gambia, Ghana, Guinea, Hungary, Iceland, Japan, Jordan, Kyrgyz Republic, Latvia, Lesotho, Liberia, Luxembourg, Madagascar, Malawi, Mauritania, Moldova, Mozambique, Namibia, Niger, Papua New Guinea, Romania, Senegal, Seychelles, Somalia, South Korea, South Sudan, Sri Lanka, Taiwan (China), Tajikistan, Thailand, Togo, Tunisia, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Vietnam, Zambia |
| 8 | Belgium, Netherlands, Sweden, Timor-Leste, United Kingdom, United States |
| 9 | Chile, Estonia, Germany, Israel, Kuwait, Portugal, Qatar, Slovak Republic |
| 10 | Russia |

1) The statistical characteristics of the policy indices

The policy indices are based on the standardization results of the policy indicators provided by the OxCGRT. The standardized index is helpful for horizontal comparisons between countries, and differences in different modes were initially discovered. Table 4 shows the mean and median values of the different policy indices for the five modes.

**Table 4** Statistical Characteristics of Policy Indices under Different Modes

| | Mode | Stringency index | Government response index | Containment health index | Economic support index | Containment index | Economic index |
|---|---|---|---|---|---|---|---|
| Mean | CHN | 69.34 | 61.34 | 63.05 | 49.41 | 63.53 | 50.27 |
| | SE | 63.83 | 59.69 | 59.99 | 57.60 | 58.83 | 58.01 |
| | ENE-SSA | 52.74 | 48.95 | 49.87 | 42.50 | 50.18 | 42.91 |
| | US | 57.66 | 56.02 | 54.92 | 63.76 | 52.16 | 62.93 |
| | DEU | 64.20 | 61.21 | 61.38 | 59.96 | 59.55 | 60.25 |
| Median | CHN | 72.22 | 62.76 | 64.88 | 50.00 | 65.72 | 50.00 |
| | SE | 67.13 | 62.24 | 61.90 | 75.00 | 61.16 | 72.22 |
| | ENE-SSA | 52.78 | 49.84 | 50.00 | 50.00 | 50.89 | 50.00 |
| | US | 64.35 | 61.72 | 60.71 | 62.50 | 56.56 | 61.11 |
| | DEU | 66.20 | 63.54 | 64.88 | 62.50 | 65.25 | 61.11 |

From the perspective of the medical prevention and control index, taking the containment index as an example, the mean of the CHN mode is 63.53 and ranks first among the five modes. The DEU mode ranks second but is lower than the CHN mode by nearly four points. The SE mode is close to the DEU mode, as they are close in geography and share a similar culture and economic status. The mean values of the US and ENE-SSA modes are quite close, ranking 4th and fifth respectively, and are lower than the CHN mode by 10 more points. The rank of the median values for the five modes remains the same as the mean value. Therefore, evidently, the CHN mode has the greatest prevention and control strength. The modes of DEU and SE are lower than, but relatively close to, the CHN mode. This shows that most countries in these three modes attach great importance to the prevention and control of the epidemic and act very actively. The prevention and control strength of the US and ENE-SSA modes are relatively low, which may not benefit epidemic control.

The containment health and stringency indices are two other indicators used to evaluate medical prevention and control. Although the composition and weight of these two are different, the ranking results are very close to those of the containment index among the different modes, indicating the robustness of our index.

Regarding economic support, the US mode has the highest average level of the economic index 62.93, which surpasses the second-place DEU mode by 2.68 units. The level of the SE mode is close to that of the DEU mode and ranks third. The ENE-SSA mode had the lowest average level of 42.91. For the median level, the SE mode reaches 72.22, and is the highest. The median values of the US and DEU modes, and the CHN and ENE-SSA modes are the same, and the former is ranked 11.11 higher. The relative results between the economic support and the economic indices are generally the same, which shows the robustness of our index again.

Regarding the government response index, the average levels of the CHN and DEU modes are very close, both slightly higher than 61. The average level of the SE mode ranks in the middle place and is higher than that of the US mode by 3.67. The ENE-SSA mode ranks last.

The above analysis of the characteristics of policy indices reflects the difference in epidemic response strategies among different modes. Both the DEU and SE modes have relatively high levels of prevention and control of the epidemic and economic stimulus. In the ENE-SSA mode, both aspects are relatively low. The CHN mode uses a strategy that emphasizes prevention and control, but takes less account of the economy. The US mode is the opposite of the CHN mode, and its prevention and control strength are relatively low, but its economic stimulus policy index is very high. These strategies have a major impact on the effectiveness of epidemic prevention and control. Exploring the epidemic prevention and control modes and their effects will have great significance for future epidemic prevention and control.

2) Means of response coefficients of policy indices

Tables 5 and 6 show the means of the normalized regression coefficients of the two policy indices (containment index, economic index) under the “Up” and “Down” stages for countries and regions under the above five modes.

**Table 5** Regression Coefficients of Containment Index

| Mode | Stage | Infect_rate | Death_rate | Cons | Stage | Infect_rate | Death_rate | Cons |
|---|---|---|---|---|---|---|---|---|
| CHN | Up | 0.43 | –779.45 | 11.14 | Down | –18.60 | –1210.81 | 14.42 |
| SE | Up | –71.66 | –199.45 | 10.47 | Down | 23.41 | 1746.34 | 8.04 |
| ENE-SSA | Up | 12.12 | –218.54 | –3.96 | Down | 25.95 | 109.67 | –1.45 |
| US | Up | –83.68 | –294.33 | 7.96 | Down | 20.10 | –350.78 | –53.99 |
| DEU | Up | –23.29 | 4415.28 | 4.05 | Down | –10.68 | 1711.35 | 12.43 |

As far as prevention and control policies are concerned, in the "Up" stage of the epidemic, the policy strengthening of CHN and ENE-SSA mode is mainly aimed at the infection rate and the mean response is positive. Regarding the DEU mode, countries focus more on the death rate of COVID-19. However, for the SE and US modes, the mean responses to the epidemic infection and death rates are all negative. As the constant represents the policy level or intensity without an epidemic, the CHN and SE modes are significantly higher than the other modes. Given that the death rate is not very high, the policy response for the CHN mode has a high probability of outperforming other modes.

In the "Down" stage of the epidemic, the prevention and control characteristics of four modes (except DEU) have undergone major changes. The response intensity of the CHN mode declines, whereas for the other modes, they enhance the response intensity on average. Regarding the SE and US modes, they make an average positive response to the infection and death rates; regarding the ENE-SSA mode, the average response to death rate also changes to positive. However, these changes reflect that after the initial epidemic, countries around the world have generally strengthened the control of the source of the epidemic, and as the epidemic is gradually controlled, more attention is paid to life safety. Regarding the constant, the CHN and DEU modes are very close and significantly higher than those of other countries, which indicates that the policy is changed to be more intensive in these two modes.

It is important to note this is an average statistic for a group, and does not mean that each country in the mode follows the mean response. For example, it is clear that, the response coefficients ($\beta_1, \beta_2$) of China in the "Up" and "Down" stages are respectively (27.662,–1869.313) and (27.733,–365.300). Moreover, the response of the infection rate is high in the total sample, but the response remains stable in two stages.

Generally, the regression coefficients of the containment index show that the CHN mode attaches more importance to the prevention and control of the infection rate during the "Up" and "Down" stages of the epidemic and that its prevention and control is relatively strong. After the epidemic situation is eased, its marginal policy response declines slightly, while the policy level or intensity increases. The ENE-SSA mode is close to the CHN mode in the marginal response to the epidemic. However, its overall intensity is not as strong as that of the CHN mode. Both the CHN and ENE-SSA modes focus on early stage prevention and control, and focus on cutting off transmission paths and reducing the infection rate during the development period of the epidemic. During the development period of the epidemic, the DEU mode mainly responds to the newly added death rate. This is a manifestation of a slow response that requires greater policy strength in future. The prevention and control strategy of the DEU mode during the recession period is similar to that of the CHN mode. The overall prevention and control of the epidemic under the US and ENE-SSA modes is relatively negative. This is consistent with the argument that some politicians from the United States and other countries have put COVID-19 and the common flu on par since the outbreak of the COVID-19 epidemic.

**Table 6** Regression Coefficients of Economic Index

| Mode | Stage | Infect_rate | Death_rate | Cons | Stage | Infect_rate | Death_rate | Cons |
|---|---|---|---|---|---|---|---|---|
| CHN | Up | 19.33 | –44.18 | 5.96 | Down | 16.21 | –334.21 | 7.64 |
| SE | Up | –81.71 | –352.31 | 20.13 | Down | 2.24 | –42.49 | 18.50 |
| ENE-SSA | Up | 15.87 | –500.33 | –4.05 | Down | –0.98 | 267.77 | –2.59 |
| US | Up | –139.26 | 820.35 | 18.27 | Down | 7.23 | 442.11 | –45.40 |
| DEU | Up | –20.20 | 4477.87 | 11.46 | Down | –93.91 | –810.99 | 23.54 |

As far as economic policies are concerned, in the “Up” stage of the epidemic, the CHN mode and ENE-SSA mode all have a positive response to the increase in infection rate, while the DEU and US modes are the opposite. The response of the SE mode is negative to both infection and the new death rate. For the overall stable level, the SE and US modes are significantly higher than the other modes.

In the “Down” stage of the epidemic, the strategies of CHN mode remain the same compared with those in the “Up” stage. The US mode responds positively to infection and new death rate, and its stable level declines to a large negative number, which is opposite to the DEU mode. The average response of the SE mode to the infection rate increases to be positive. The ENE-SSA mode changes to focus more on the new death rate.

Generally, the regression coefficients of the economic index show that all modes have responded to the spread of the epidemic with enhanced economic support policies with different focus. The CHN mode focuses more on the infection rate, and the policy intensity is moderate. The ENE-SSA mode is similar to the CHN mode in the “Up” stage but changes to focus more on new death rates in the "Down" stage. The policy level of SE mode is high, but the average marginal responses are negative in the "Up" stage and change to slightly positive to the new infection rate in the "Down" stage. The US and DEU modes focus more on the new death rate in the "Up" stage, but transform to totally different types: they respond positively and negatively to the two kinds of rates, respectively.

## 5 Analysis of Prevention and Control Effects of Different Modes

### 5.1 Model Setting

In the previous text, through a series of regressions, the epidemic prevention and control of the 169 sample countries and regions were divided into 10 modes, of which there were five main modes. However, what is the difference in the prevention and control effect of each mode? This is the second question that this study needs to answer. According to the analysis of the SEIR model in the third part, the dynamic changes in the spread of infectious diseases can be regarded as the pathological characteristics of COVID-19. The living habits, cultural characteristics, social structure, capital, and related technologies of the residents of a country remain constant. The epidemic prevention and control policy intervenes in the two links of infection contact and active treatment to reduce the number of infected people and the number of people in the latent period, and to increase the probability of treating the infected to control the trend of the epidemic.

This model assumes that the identification and treatment of patients are insufficient. If the infected people can be identified immediately and quickly isolated and treated, they will rarely infect susceptible people, and the infectious disease will be quickly controlled, reducing the possibility of large-scale infection to almost zero. This was also corroborated in Scenario 5 of the previous text. Therefore, this study designs regression equation (3) to capture the impact of COVID-19 prevention and control policy on the number of newly added confirmed cases.

$$infect_t = \alpha_0 + \alpha_1 \sum_\eta infect_{t-\eta} + \alpha_2 stock\_infect_{t-H-1} + \alpha_3 inter_1 + \alpha_4 inter_2 + \varepsilon_t \quad (3)$$

Among them, $\eta$ is the latent period. According to *Chinese Clinical Guidance for COVID-19 Pneumonia Diagnosis and Treatment* (the 8th edition) published by the National Health Commission, the latent period of COVID-19 is generally 1–14 days, mostly 3–7 days, so $\eta$ in is set to be 3 to 7. $\sum_{\eta} infect_{t-\eta}$ is the number of newly added confirmed cases in the latent period. $stock\_infect_{t-H-1}$ is the number of stock confirmed cases one day before the latent period set by the model, while $H$ is the maximum potential value of the latent period, which is 7. $inter_1$ is the product of the policy index (containment index) selected in this section and $\sum_{\eta} infect_{t-\eta}$ after decentralization. $inter_2$ is the product of the selected policy index (containment index) selected in this section and $stock\_infect_{t-H-1}$ after decentralization.

The parameter $\alpha_1$ (denoted as the latent period effect) can evaluate the impact of infected people in the latent period on the number of new infections. If the prevention and control policy, especially the contact tracing policy, is very strict, $\alpha_1$ should be very small. In fact, with the implementation of policies and the accumulation of experience, $\alpha_1$ will have a downward trend. However, if the government does not focus on the isolation of infected people and the tracking of close contacts, $\alpha_1$ will be relatively large, and there will be a tendency for $\alpha_1$ to increase. The parameter $\alpha_2$ (denoted as the isolation therapy effect) is a measure of the impact of the stock infected on the newly infected. $\alpha_2$ mainly depends on the prevention, control, and patient admission policies. The stronger the prevention and control policy is, and the better the admission and treatment policy is, the smaller $\alpha_2$ will be. To analyze the impact of the epidemic prevention and control on these two epidemiological parameters, two interaction terms were added to the regression equation.

The formulation and implementation of epidemic prevention and control policy are related to many factors and change with the development of the epidemic. Therefore, these parameters also change over time. To identify the characteristics of these time-varying policy effect parameters, this study adopts a rolling regression strategy. The length of each window is fixed at 15 days, and the interval between two adjacent time starting points is 3 days. Given that the latent period is generally no more than two weeks, the sample period should include, as much as possible, the length of time the policy takes effect, as well as for the statistical significance of regressions; therefore, the window length is set at 15 days.

The figure below shows the results of the rolling regression. According to the clustering results of the epidemic prevention and control modes, for each of the five main prevention and control modes, a typical country is selected as a representative to show the effects of epidemic prevention and control (Italy, South Korea, China, Germany, and the United States are selected). The starting point of time in the figure below is the time when countries have epidemic and prevention and control policies simultaneously, which is basically the same or close to the occurrence of the COVID-19 epidemic. In the rolling regression, the rolling unit of the sample is 3 days, so every 10 units in the figure below represent one month.

### 5.2 Result Analysis

Generally, under all the modes, the changes and effects of the epidemic prevention and control policies are significantly positively correlated. However, the differences in the infectiousness of the virus, the prevention and control modes, and their effects are also very obvious.

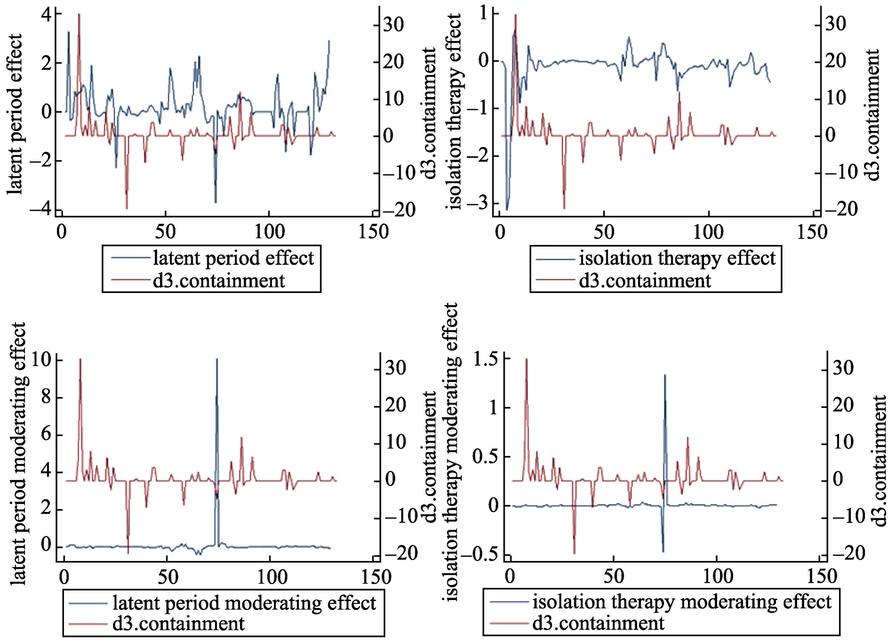
In general, the prevention and control performance of the US mode ranks at the bottom of the five modes. It can be summarized as a slow response and weak strength. First, after the outbreak of the epidemic, the United States failed to pay enough attention and did not upgrade its prevention and control to a higher level, hence missing a valuable opportunity to contain the epidemic early. In the early stages of the outbreak, the latent period effect in the United States was significantly greater than zero for a long period of time (close to two months). In other countries during the same period, the effect was significantly lower, and the duration with the latent period effect greater than zero was significantly shorter. Additionally, the isolation therapy effect in the United States has also been oscillating in the early stage, and once exceeded four. Second, considering the entire development process of the epidemic, it can be concluded that the United States has had a weak response to the epidemic not only in the early stages, but also from beginning to end. Especially in the later period of the US epidemic, when there were multiple outbreaks and the increase in the number of infections and deaths far exceeded the previous period, the strength of US policies has never reached the level of the initial period. In addition, compared with other example countries, the infectiousness of people in the latent period and the infected is very high. Every time the United States reduces policy strength, there is an increase in the latent period effect (greater than zero). In recent epidemic prevention and control, the latent period effect in the United States has risen to an unprecedented level of nearly 40. This level is likely to result in rapid infection of the entire population in the infectious disease model, and the epidemic will be more difficult to control. These reflect the poor performance of the United States in terms of case tracking and patient admission.

The SE and DEU modes are also Western epidemic prevention modes, and have similarities in that their policy response in the early stages of the epidemic was relatively slow. However, in the case of Italy and Germany, their policies are generally stronger than those of the United States, and they have made more frequent policy adjustments based on the real-time situation of the epidemic in the middle and later stages of the development of the epidemic. In terms of the control of the infectivity of people in the latent period and confirmed infected, Italy's performance is generally better. The latent period effect and the isolation therapy effect are generally controlled below 4 and 1, respectively, but there was a short-term increase and dive in the isolation therapy effect. Simultaneously, Italy's moderating effects are zero except for the above-mentioned abnormal fluctuations, which reflects the main characteristics of Italy's epidemic prevention mode are "control" and "stability." When the epidemic is controllable, its policy can control the infectivity of the virus, so that the infected person has almost no impact on the susceptible population. In Germany, the control of infectivity of people in the latent period often fluctuated in the early stage, and the performance was poor. The peak value of Germany's latent effect was once close to 8, resulting in a relatively high infectivity of people in the latent period. However, the latent period effect in Germany was controlled in the middle and later stages, and the epidemic prevention and control were successful. In terms of policy moderating effects, Germany's prevention and control policies can significantly reduce the latent period effect and the isolation therapy effect in a short period of time in the mid-term, but they rebound in the later period.

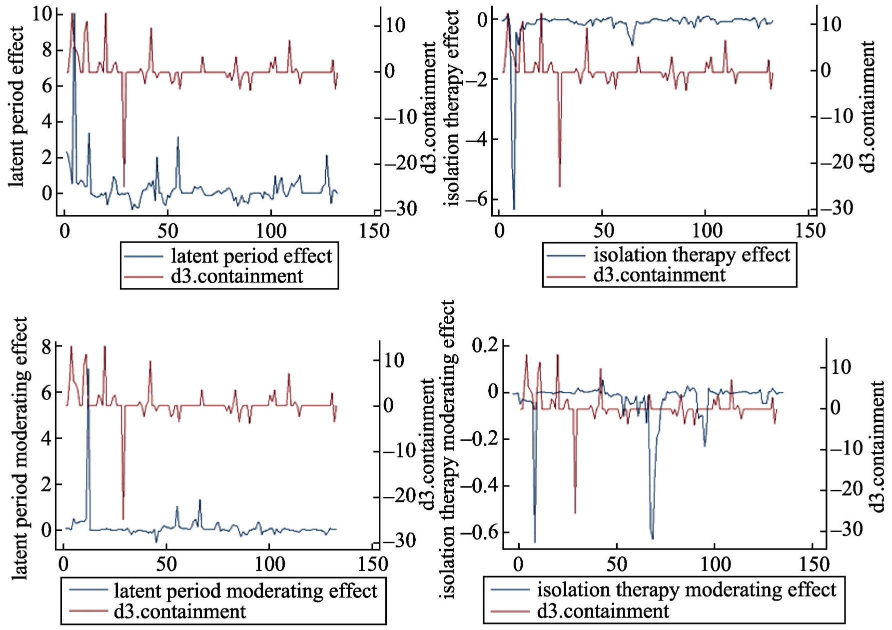
The ENE-SSA and CHN modes present different characteristics from the three Western modes mentioned above. We take South Korea and China as examples. First, they responded quickly to the epidemic, raising the strength of prevention and control policies to a higher level. In the early stage of the epidemic in China, owing to the large population density and the large-scale population movement that coincides with the Spring Festival, the virus was more contagious, but China's prevention and control policies were also significantly stronger (nearly twice of that of South Korea). The unfavorable situation in the early stage of the epidemic had been quickly reversed through measures such as closing the exits from Wuhan, requiring residents to stay at home, and quickly building centralized medical facilities. In the middle and late stages of the development of the epidemic, infectivity in South Korea and China was well controlled. From the perspective of the latent period moderating effect, this effect in China is zero and below, which highlights the effect of the strict case tracking and isolation treatment of the CHN mode for prevention and control, which are very rare in all prevention and control modes. From the perspective of the isolation therapy moderating effect, South Korea performs better than China. However, considering the limitations of the data structure of China, the result should be that China's performance is better. The case data in this study do not distinguish between local and imported cases. Fluctuations in the infectivity of the virus in China in the middle and later stages of the epidemic are largely caused by imported cases. As China has implemented a strict entry epidemic prevention policy since March 2020, the impact of imported cases on China's local epidemic is almost negligible, so China's prevention and control performance in the middle and late stages of the epidemic is much better than that presented in this article.

In summary, the CHN mode is in sharp contrast with the US mode. The CHN mode is better than the US mode in terms of speed and strength of response and policy effects and has become a paragon among the five modes. The ENE-SSA mode is relatively close to the CHN mode and has good prevention and control effects. The SE and DEU modes failed to respond in time in the early stages, resulting in a major outbreak of the epidemic. However, their policy modes and effects in the middle and later stages are similar to those in the CHN mode, and good prevention and control effects were achieved. Therefore, in view of the impact of the COVID-19 epidemic, the optimal prevention and control mode requires policies to respond effectively and quickly at all stages, and the CHN mode is undoubtedly an example of this prevention and control standard.

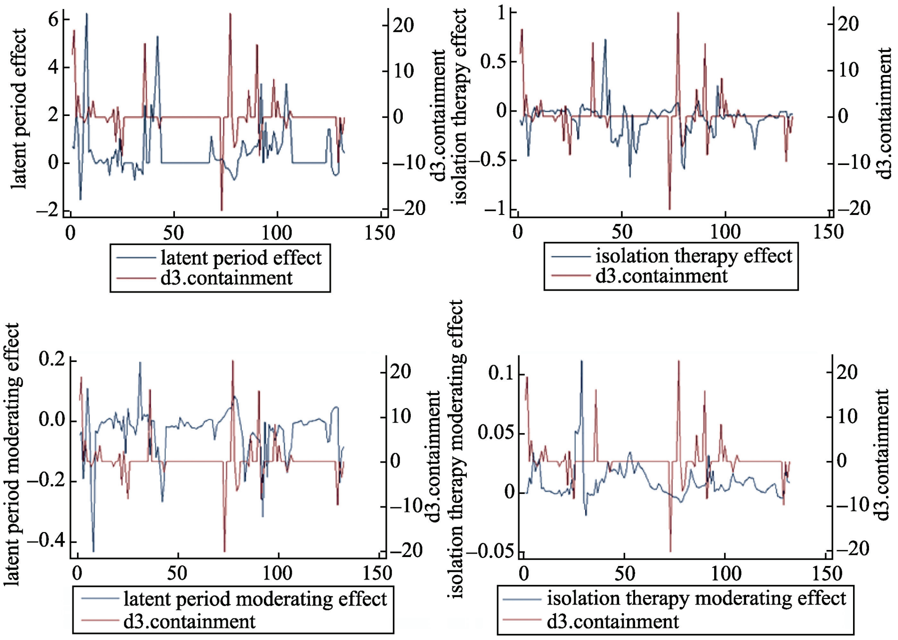
ITALY



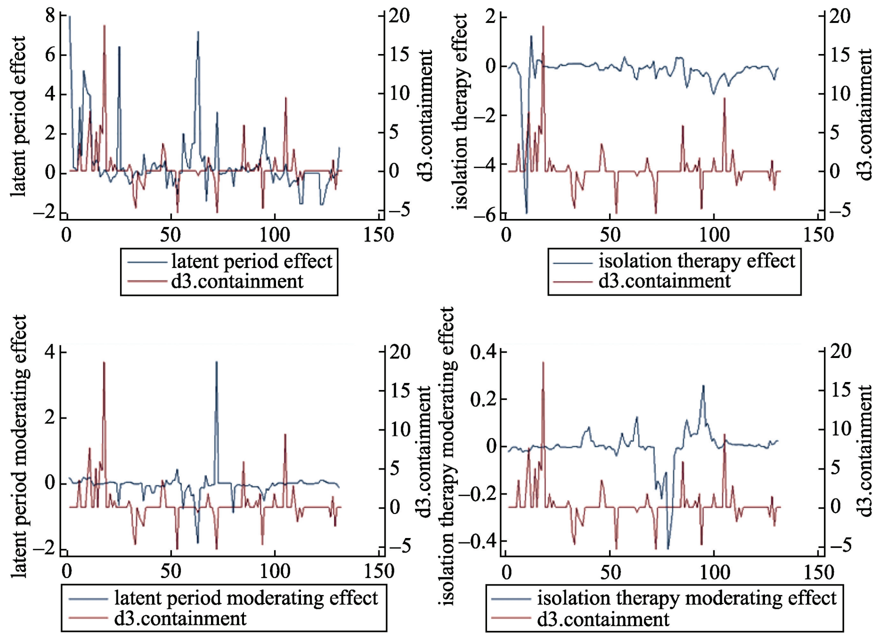

SOUTH KOREA



CHINA




GERMANY



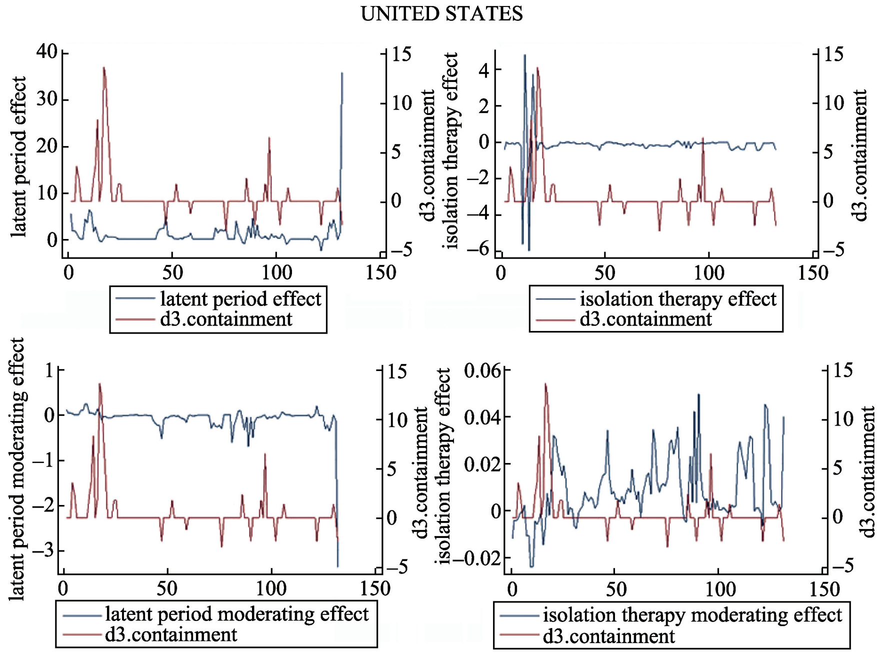



**Figure 7** Effects of Epidemic Prevention and Control in Representative Countries

## 6 Discussion and Conclusion

Based on the simulation, we evaluated the effects of two major policies: contact restriction and active treatment. Further, through regression and cluster analysis, we successfully classified and analyzed the characteristics of epidemic prevention and control modes in most countries around the world. Finally, differences in the prevention and control effects of typical countries in each mode are comprehensively investigated in this study. The result shows the following.

First, contact restriction and active treatment are both important prevention and control measures, and both play important roles in the prevention and control of the epidemic. Nevertheless, the policy effect of contact restrictions in the early stages of the outbreak is more significant. If the two policies are combined, the speed and scale of the development of the epidemic can be optimally controlled.

Second, under different epidemic prevention and control modes, the differences in epidemic prevention and control policies are also obvious. Both the DEU and ENE-SSA modes have a higher level of epidemic control and economic stimulus than the other modes. The CHN mode has a relatively strong prevention and control policy. However, its economic stimulus policy is not strong. It is a strategy that emphasizes prevention and control, and the economic stimulus comes second place. The US and ENE-SSA modes have relatively low levels of prevention and control, but the level of economic stimulus is similar to those of the DEU and ENE-SSA modes, which emphasizes the economic stimulus more than epidemic prevention and control.

Third, the spread of the epidemic is closely related to the implementation of policies, and the effects of different modes are relatively different. The CHN mode is better than the US mode in terms of speed and the intensity of the response and policy effects and has become a model among the five types of modes. The ENE-SSA mode is relatively close to the CHN mode and yields better prevention and control effects. The SE and DEU modes failed to respond in time in the early stage, resulting in a major outbreak of the epidemic then. However, their policy and effect in the middle and late stages are similar to the CHN mode, and yielded better prevention and control effects. The US mode needs to be reinforced in terms of the enthusiasm and intensity of prevention and control.

Currently, the prevention and control of COVID-19 are still ongoing worldwide. Doing so will be a long-term process. Before vaccination has reached the level of group epidemic prevention, the epidemic prevention and control policy cannot be relaxed. Theoretically, the threat of infectious diseases cannot end automatically without vaccination. Although many countries in the world, including China, have controlled the epidemic, this is only temporary, and huge social resources are required to manage the next outbreak of the epidemic. To manage the epidemic completely, it is fundamentally necessary for countries around the world to invest in scientific research related to the COVID-19 vaccine more, and actively conduct vaccine-related research cooperation to make vaccination cover all kinds of susceptible people as much as possible on a global scale.

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