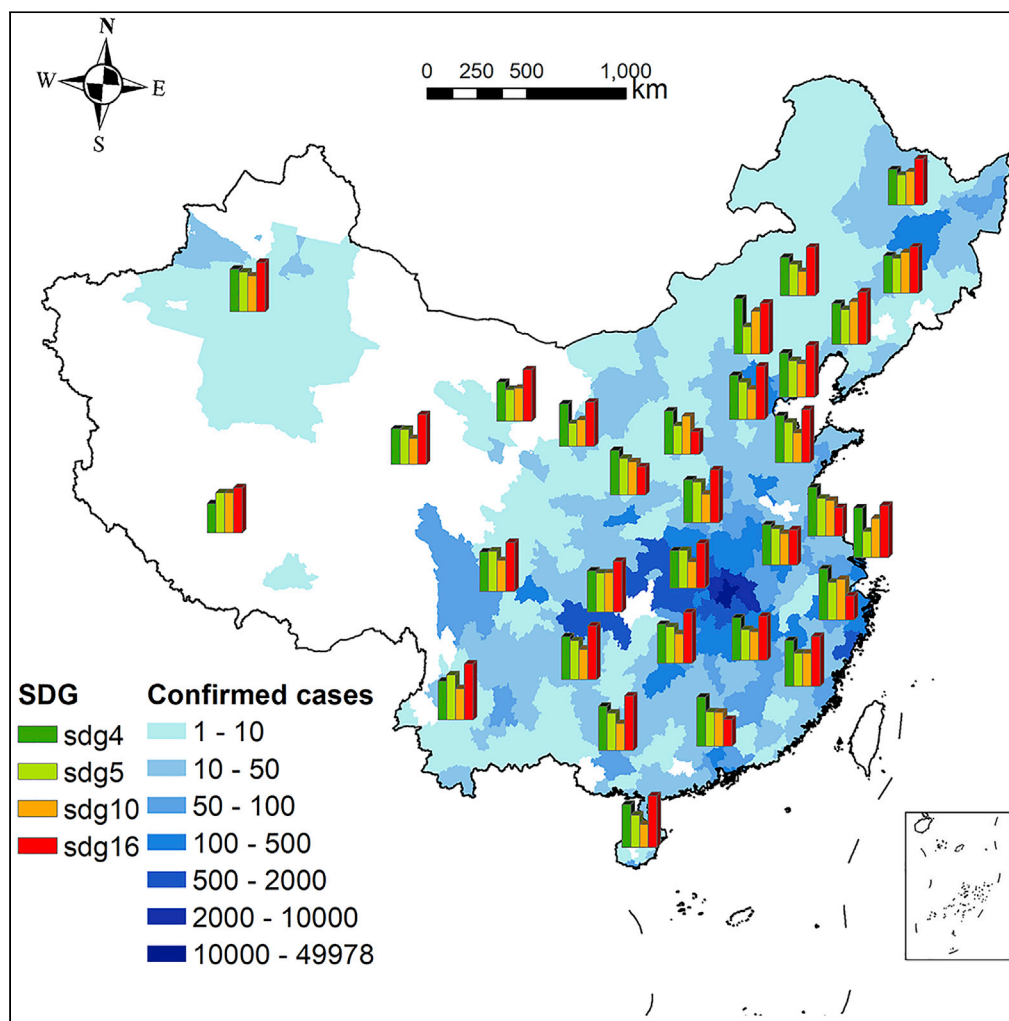**Article**

Sustainable social development promotes COVID-19 pandemic control

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Highlights

This study highlights the
importance of social SDGs
by linking them to
pandemic control

Social SDGs improve
pandemic prevention and
control in two pandemic
development stages

Cities with better
education/gender
equality performed better
in pandemic control

The impact of social SDGs
on pandemic control is
heterogeneous in
different regions

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Article

Sustainable social development promotes COVID-19 pandemic control

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SUMMARY

The rapid spread of COVID-19 had a negative impact on public health and economic recovery worldwide. There is a large and growing literature on pandemic prevention and control. However, these existing studies seldom focus on the role of sustainable social development in this process. By setting specifications of fixed-effect models based on the score data of sustainable development goals (SDG) and infection case data from 257 Chinese cities, we evaluate the positive effect of sustainable social development on pandemic control. Our results show that sustainable social development leads to a remarkable improvement in pandemic prevention and control, especially for SDG4 (Quality Education) and SDG5 (Gender Equality). Significant positive effects of sustainable social development still exist in the post-pandemic era. This study highlights the importance of promoting social SDGs by linking them with pandemic prevention and control and suggests region-specific policies based on the heterogeneous analysis results.

INTRODUCTION

COVID-19 is an emerging respiratory infectious disease, and its rapid spread has become a global public challenge. It is urgent for governments at different levels to take effective prevention measures to contain the spread of this pandemic. However, different countries take different measures by considering their realities, leading to different performances and social costs (Li et al., 2021). As such, factors affecting pandemic prevention and control have become hot topics that are currently receiving global attention. Scholars have conducted relevant studies evaluating the different effects of pandemic prevention and control in different countries (Mahajan and Kaushal, 2020; Persson et al., 2021; Hashim et al., 2021; Liu et al., 2020). These studies recognized the government's critical role in controlling the pandemic and proved that strict governmental governance could contain the spread of COVID-19 and reduce the total number of infections (Wang et al., 2021, 2021a).

Pandemic prevention and control are both medical and social problems. Recently, many studies have focused on investigating the relationships between pandemic prevention and control and specific social factors such as equality, education, culture, and lifestyle. For instance, education has been confirmed to have a positive effect on health and is closely related to infectious diseases (Ackerknecht, 1954; Hartog and Oosterbeek, 1998; Gerdtham and Johannesson, 1999; Meara et al., 2008). As educated people tend to obtain more health output (Mokdad et al., 2000) and get more information about their health problems (Pawlińska-Chmara and Wronka, 2007), they prefer to invest more in their health and their families (Guo et al., 2020), which are all conducive to pandemic prevention and control.

The inequality problem is becoming more severe at the global level (Mongey et al., 2020; Palomino et al., 2020; Flor et al., 1999) owing to the disproportionate impact of the pandemic on vulnerable individuals (Crimmins et al., 1994; Cajner et al., 2020; Chetty et al., 2020; Shibata,2020). Several studies found that gender has a remarkable impact on health inequality. For instance, women have a longer physical disability in their old age than those men (Crimmins et al., 1994; Mathers et al., 2001). Also, women have always been in a disadvantaged position in social stratification, restricting their access to health resources (Ross and Bird, 1994; Rose and Hartmann, 2004). In addition, it is necessary to investigate the relationships between income inequality and diseases (Rodgers, 2002; Subramanian and Kawachi, 2004). Normally, income inequality affects local public healthcare investment owing to significantly different health services between the rich and the poor, leading to those poor citizens having fewer health expenditures (Krugman,

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1996; Deaton, 2003). When a pandemic occurs, poor communities will undoubtedly lack prevention and control capabilities. From the perspective of social psychology, the widening income gap increases the frustration and stress of low-income people, which may lead to their lower moods and unhealthy behaviors and thus worsen their health (Schor, 1998). Social inequalities interact in complex ways, greatly influencing the distribution of infectious diseases. Social inequalities are associated with higher rates of sexually transmitted diseases (STDs), lower life expectancy, stigma, and transmission of viruses, and so forth (Patterson-Lomba et al., 2014; Ackerson et al., 2012), thus creating the conditions for spreading infectious diseases, such as HIV, H1N1, and tuberculosis (Quinn & Kumar, 2014; Piot et al., 2007; Ponnambalam et al.,2011; Munayco et al., 2015). Those poorest children, who are often at the most significant risk of contracting preventable infectious diseases and are less likely to be vaccinated, are geographically clustered together. They have no access to vaccination and have to engage in herd immunity (Clouston et al., 2014). COVID-19 has further led to health care inequality. Those vulnerable groups had worse COVID-19 outcomes than others (Chang et al., 2021). Therefore, it is urgent to reduce social inequality so that infectious diseases can be prevented and controlled (Ellwanger et al., 2021; Alsan et al., 2011; Tausig et al., 2006). Recent studies have investigated the impacts of governmental policies in the post–COVID-19 era. For instance, Shao et al. (2022) assessed the environmental impact of COVID-19 and found that lockdowns and initial fiscal stimulus have marginal long-term effects on CO2 (Shao et al., 2022). Also, the economic and health impacts have been evaluated by using population-wide methods such as wearing masks and COVID-19 screening (Greenhalgh et al., 2020; Atkeson et al., 2020).

Essentially, pandemic prevention and control is one critical task for all the national governments in the short term. Nevertheless, all governments must promote overall sustainable development in the long term. These existing studies investigated the economic, health, and environmental impacts of pandemic prevention and control policies and uncovered the relationships between specific factors (such as education and inequality) and pandemic prevention and control effectiveness. However, there is still a lack of studies investigating the relationships between sustainable social development and pandemic prevention and control. Under such circumstances, this study examines various types of social development elements in different pandemic stages, so that valuable policy insight can be obtained.

Sustainable development is a crucial matter concerning the future of humans. Sustainable development goals (SDGs) were released by the United Nations to guide national and global efforts. SDG scores can be used as an indicator to measure the level of social development in one region (Griggs et al., 2013). Among all the 17 SDGs, sustainable social development plays a vital role in achieving these targets. In this study, we use the province-level SDG scores, which were calculated by Xu et al. (2020), and focus on the social dimension of sustainable development, including SDG4 (Quality Education), SDG5 (Gender Equality), SDG10 (Reduced Inequality), and SDG16 (Peace, Justice, and Strong Institutions). We expect to fill this research gap by systematically combining all the social factors reflected by SDG scores to evaluate the effect of sustainable social development on pandemic prevention and control.

China has rapidly prevented and controlled the COVID-19 pandemic during the last two years. Based on the real-time pandemic data on newly confirmed infection cases in 257 mainland Chinese cities and the provincial SDG score data in 2015, we set a fixed-effect model to examine sustainable social development's impact on pandemic prevention and control. We find that the improvement of sustainable social development can significantly reduce daily new confirmed cases. The first phase of pandemic prevention and control ended with full success. Since 10 March 2020, China has come into the post-COVID-19 era, although occasionally, several cases have occurred. This period is different from the most severe outbreak period, which was mainly caused by imported cases, related articles, and cold-chain food. We then assess the treatment effects of sustainable social development in the second stage to check whether those previous effects still exist.

Our city-level pandemic infection data cover 257 Chinese cities, while the 2015 SDG score data cover 31 Chinese provinces. We establish a fixed-effect model to control the time trend. Besides the distance to Wuhan city, the lagged new confirmed case number in log value, city-level characters such as economic indicators, geographic indicators, and traffic conditions are also added to avoid the potential risk of endogeneity. Our results suggest sustainable social development leads to a remarkable improvement in pandemic prevention and control. For instance, 1% increase in the SDG4 (Quality Education) score is associated with a 0.115% reduction in daily new confirmed infections on average. Also, a 1% increase in the SDG5 (Gender

Table 1. Regressions of new infection cases on the social SDGs in 2015

	Dependent variable: log value of new infection			
	(1)	(2)	(3)	(4)
	SDG4	SDG5	SDG10	SDG16
(1) Control lags of new infection				
log of SDG score in 2015	−0.0287	−0.0864[b]	0.0198	0.00603
	(−0.09045, 0.03294)	(−0.15579, −0.01715)	(−0.02276, 0.06233)	(−0.01005, 0.02208)
Observations	13,728	13,728	13,728	13,728
Number of id	278	278	278	278
(2) Control population and economy				
log of SDG score in 2015	−0.0820[a]	−0.0758[a]	−0.0124	0.00498
	(−0.13498, −0.02920)	(−0.13316, −0.01847)	(−0.04377, 0.01892)	(−0.01207, −0.02199)
Observations	13,696	13,696	13,696	13,696
Number of id	277	277	277	277
(3) Control transportation				
log of SDG score in 2015	−0.0878[a]	−0.0479[b]	−0.0132	−0.00172
	(−0.14374, −0.03205)	(−0.09164, −0.00436)	(−0.04481, 0.01847)	(−0.01585, 0.01238)
Observations	13,696	13,696	13,696	13,696
Number of id	277	277	277	277
(4) Control geographic features				
log of SDG score in 2015	−0.115[a]	−0.0411[c]	−0.0111	−0.00807
	(−0.18470, −0.04548)	(−0.08817, 0.00597)	(−0.05855, 0.03632)	(−0.02234, 0.00619)
Observations	12,909	12,909	12,909	12,909
Number of id	257	257	257	257

The time-fixed effect is controlled in all the regressions, and the standard errors are clustered at the city level. The 95% confidence interval is shown in the parentheses.

[a]Significant at the 1% level.
[b]Significant at the 5% level.
[c]Significant at the 10% level.

Equality) score is associated with a 0.0411% reduction. Although transmission channels are different during the second stage, both SDG4 and SDG10 (Reduced Inequalities) can result in a significant positive effect on pandemic prevention and control. These findings highlight the vital importance of promoting sustainable social development. Our results are robust to a battery of specification checks, such as a placebo test with a random assignment of SDG scores, an alternative measurement of the pandemic control situation, and the exclusion of several specific regions. To shed light on the heterogeneous effect on different Chinese regions, we further investigate regional disparities by considering their different natural conditions and development levels. We expect that the key findings of this study can provide valuable insights to those decision-makers so that they can prepare more appropriate policies by considering their realities.

RESULTS

Sustainable social development promotes pandemic prevention and control

By using the fixed-effect model, we apply SDG scores (SDG4, SDG5, SDG10, SDG16) in 2015 and daily new confirmed cases that occurred in the first stage to the regression model in the Equation (1) (see STAR Methods) and then estimate the effect of SDG achievement levels on pandemic prevention and control. The results are listed in Table 1. Panel (1) reveals that when lags of new infection and time-fixed effects are controlled, SDG5 (Gender Equality) is considerably negatively related to daily new confirmed cases at a 5% significance level. Panel (2) controls population and economic factors based on Panel (1). Panel (2) reveals that SDG4 (Quality Education) and SDG5 (Gender Equality) levels are considerably negatively related to daily new confirmed cases at a 1% significance level. Transportation factors are added in Panel
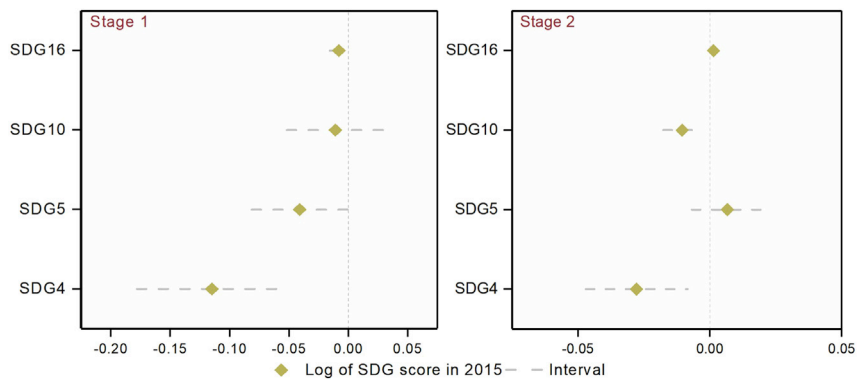
Figure 1. Effect of sustainable social development on pandemic control in the two stages
Notes: X axis is the impact of the SDG score on the number of daily new confirmed cases on average. The dots indicate point estimates and the horizontal dash lines indicate 95% confidence intervals. The left panel is for the first stage of the pandemic development and the right panel is for the second stage. Detailed coefficients can be found in Table S3 of the supplementary information.

(3). Panel (4) further controls geographic features based on Panel (3). These results show that quality education and gender equality significantly lead to better control of infections. Specifically, Panel (4) reveals that a 1% increase in the SDG4 score is associated with a 0.115% reduction in daily new confirmed infections on average and that a 1% increase in the SDG5 score is associated with a 0.0411% reduction in daily new confirmed cases on average. Although SDG10 (Reduced Inequality) and SDG16 (Peace, Justice, and Strong Institutions) levels have no significant impacts on new infections, their regression coefficients are negative.

Positive effects of social sustainable development still exist in the post-pandemic era

Based on the infection data in the second stage, we rerun the fixed-effect model after controlling all the traffic, economic and geographic characteristics (see Figure 1). Compared with the impact in stage 1 on the left, SDG4 and SDG10 levels are significantly negative in stage 2 on the right graph. As Panel (4) (see Table S3) suggests, a 1% increase in the SDG4 score is associated with a 0.0278% reduction in daily new confirmed infections on average, and that 1% increase in the SDG10 score is associated with a 0.0105% reduction in daily new confirmed cases on average, which means sustainable social development still leads to an improvement in pandemic prevention and control in the post-pandemic era although the positive effect on pandemic prevention and control is somewhat diminished. The positive effects of SDG5 are no longer significant, while SDG10 plays a more important role in the second stage.

As Table S8 presents, in the post-pandemic era, outbreaks are mainly caused by imported cases, related articles, and cold-chain food. They mainly occurred in four province-leveled municipalities, provincial capitals, and regional central cities with international airports such as Xi'an and Tianjin. Therefore, we focus on 34 municipalities and provincial capitals in the second stage to investigate the specific effects of four social SDGs indicators on pandemic prevention and control. Table 2 lists these results, showing different effects in municipalities, provincial capitals, and other cities in the second stage. For municipalities and provincial capitals, columns (1) and (3) reveal that SDG4 (Quality Education) and SDG10 (Reduced Inequality) levels are negatively related to daily new confirmed cases at a 5% significance level. For other cities, column (6) reveals that SDG5 (Gender Equality) levels are negatively related to daily new confirmed cases. These results provide valuable information on the differences between both stages. The economic development in these provincial capitals is relatively faster. Also, income gaps between the rich and the poor are becoming larger in these cities. Income inequality affects public healthcare investment, which will undoubtedly reduce local prevention and control capabilities (Krugman, 1996; Deaton, 2003). Besides, if one region significantly suffers from the pandemic in the first stage, it will receive public health assistance from its superior government and other regions. But in the post-pandemic era, each region's education level and medical investment reserves play a more important role. Therefore, the role of SDG10 begins to become prominent in the second stage.

Previous studies confirmed that economic impact hits women harder than men when the pandemic becomes normalized, as women tend to work in sectors that are more vulnerable to the pandemic

Table 2. Regressions of new infections on the social SDGs in 2015 in the second stage among different cities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	SDG4	SDG5	SDG10	SDG16	SDG4	SDG5	SDG10	SDG16
	municipalities and provincial capital cities				other cities			
log of SDG score in 2015	−0.236[a]	−0.00517	−0.0991[a]	0.00308	−0.00493	−0.00294[a]	0.000799	0.000544
	(0.113)	(0.0960)	(0.0481)	(0.0128)	(0.00480)	(0.00148)	(0.00160)	(0.000752)
Lags of new infection	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Population and economy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transportation features	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic features	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of id	28	28	28	28	235	235	235	235
Observations	19,096	19,096	19,096	19,096	160,270	160,270	160,270	160,270
R-squared	0.624	0.623	0.623	0.623	0.558	0.558	0.558	0.558

The time-fixed effect is controlled in all regressions, and the standard errors in the parentheses are clustered at the city level.
[a]Significant at the 5% level.

(Flor et al., 2022). As a result, it is crucial to promote SDG5 in cities with more serious gender inequality so that a more positive effect can be obtained on long-term pandemic prevention and control.

Heterogeneous effect among different regions

China has a vast territory. Different cities are facing different challenges owing to their different locations, climate, economic development levels, and openness. In order to uncover the heterogeneity of sustainable social development on pandemic prevention and control, we classify these cities and re-estimate the baseline.

First, we classify these investigated Chinese cities as southern and northern cities by using Qinling-Huaihe Line as the boundary. Figure 2 illustrates such classifications. We found that the impact of social SDGs on pandemic prevention and control is heterogeneous between northern and southern cities. Compared with southern cities, SDG4 and SDG5 scores significantly influence pandemic prevention and control in northern cities. Both Figures S3 and S4 show that most Northern provinces have relatively lower SDG4 and SDG5 scores, indicating that their marginal effects on pandemic prevention and control are more significant. These results confirm that different levels of sustainable social development have different policy implications in different Chinese regions and emphasize the importance of promoting sustainable social development in most northern provinces.

Second, warmer temperatures decrease the infectivity of the virus (O'Reilly et al., 2020). We define cities with temperatures below 8°C during the day or −2°C at night in February as cold cities. (According to the China Meteorological Administration, the lowest average daily temperature in February in China is -2 degrees Celsius, while the highest average daily temperature is 8 degrees Celsius. http://www.tianqi.com/qiwen/china-2/) As illustrated in Figure 2, SDG5 scores have a more significant impact on pandemic control in cold cities than in warm cities.

Third, cities with relatively higher per capita GDP can take more efficient measures to control the pandemic. Their citizens are more educated and aware of the consequences of the pandemic. Figure 2 also shows that SDG four scores have a significant impact on pandemic prevention and control. Other indicators have no significant impact on new infections, but their regression coefficients are negative. Except for SDG 10, all the other scores have no significantly different impacts between low-income cities and high-income cities. Such results indicate that even if one region does not have a solid economic foundation, local government can still prevent and control the pandemic by actively promoting educational services, gender equality, and sustainable social development. This means that local governments should take necessary measures, such as improving the quality of fundamental education, developing higher education, and so forth. Normally, cities with more advanced economic development normally have larger income gaps. For such cities, it is
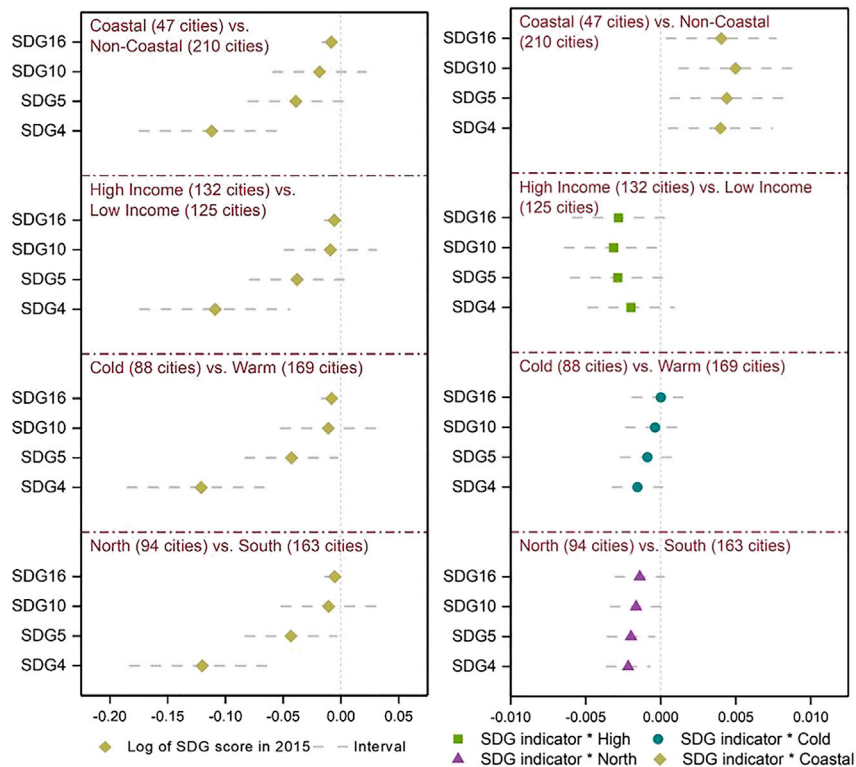
Figure 2. Effect of sustainable social development on pandemic control in different regions

The dots indicate point estimates and the horizontal dash lines indicate 95% confidence intervals. In the left panel, X axis is the impact of the SDG score on the number of daily new confirmed cases on average. In the right panel, X axis is the difference in the impact of SDG score on the number of daily new confirmed cases in different city groups. In particular, the top panel shows the difference in the impact between coastal cities and non-coastal cities. The second panel shows the difference in the impact between cities with higher incomes and cities with lower incomes. The third panel shows the difference in the impact between cold cities and warm cities. The bottom panel shows the difference in the impact between northern cities and southern cities. Detailed coefficients can be found in Table S7 in the supplementary information.

critical to reducing the inequality reflected by the SDG10 score by promoting the equalization of basic public services and minimizing the income gaps.

Fourth, coastal cities are more open than inland cities and can attract more travelers and temporary workers. Figure 2 shows that the positive effects of SDG4, SDG5, SDG10, and SDG16 scores on pandemic prevention and control are more significant in inland cities than in coastal cities. Such results reflect that although coastal cities have relatively high economic and social development levels, it is more difficult to prevent and control the pandemic in such cities as they are facing more floating populations. Therefore, the marginal impact of improving the level of sustainable social development on pandemic prevention and control is less in such cities than in inland cities. This means that such cities should pay more attention to pandemic prevention and control by taking more effective measures.

DISCUSSION

Based on data obtained from 257 Chinese cities during this COVID-19 pandemic and provincial SDG score data, this study discusses the impact of sustainable social development on the prevention and control of COVID-19 spread, which is of great significance to the protection of public health when pandemic prevention and control is becoming the norm. Our research results suggest that regardless of the stage of pandemic development, efforts to improve social sustainability could always generate positive effects on the prevention and control of COVID-19, although specific indicators might be different.

We evaluated the impacts of sustainable social development on COVID-19 infections in Chinese cities and identified the key characteristics of cities in which the positive effect of sustainable social development on pandemic prevention and control is effective.

First, we found that cities that provided better education performed better in preventing and controlling COVID-19. The results show that a 1% increase in the SDG4 score is associated with a 0.115% reduction in daily new confirmed cases on average. The role of quality education in the prevention and control of COVID-19 can be explained by three factors: people with quality education can better collect and screen information about COVID-19 and therefore would take scientific measures and avoid rumors; they are more aware of the risks of infection and would prefer to follow the COVID-19 prevention protocols; they also bring externalities to their family members by better protecting their children and those elderly from potential infection risks.

Second, we found that cities with better gender equality performed better in controlling new infections. In our sample, a 1% increase in the SDG5 score is associated with a 0.0411% reduction in daily new confirmed infections on average at a 10% significance level. Four factors can explain these effects: First, gender equality could avoid cluster infection among more vulnerable social groups to a certain extent; Second, women usually play an essential role in family life, such as raising and educating the next generation, a relatively equal society between males and females can guarantee equal access to medical resources, thus avoiding negative influence of women's physical diseases on their offspring; Third, such a society tends to invest more in public health services. Forth, a relatively gender-equal environment helps ease people's anxiety and frustration, which improves the immune system (Ader et al., 1995; Reiche et al., 1994).

Third, we found that in the case of COVID-19, sustainable social development was especially crucial in regions where the virus could easily survive and spread. The impact of sustainable social development on preventing and controlling infections is significantly more effective in colder cities and inland Chinese cities. In terms of economic development, for cities with different levels of economic development, there is no significant difference in the positive effects of sustainable social development on pandemic prevention and control. These results indicate that it is never too late for governments to improve sustainable social development to contain pandemic outbreaks regardless of economic development levels.

Practically, our findings provide valuable insights to those public health decision-makers. First, from the global situation of COVID-19, we are aware that the battle against COVID-19 is not only a medical issue but also a social issue. Those developed countries with more medical resources and strong economic power have performed poorly in preventing and controlling infections of COVID-19. Our study shows that this situation was partly owing to social division in these countries. For countries where the pandemic outbreak is poorly controlled, we suggest that their governments should take appropriate actions to solve social problems related to pandemic prevention and control. Second, COVID-19 is a big challenge to the sustainable social development agenda. Although governments are working hard to prevent and control the pandemic's spread and recover their economy, they should also pay more attention to improving sustainable social development, especially increasing quality education investment and reducing gender and income inequality. Third, in the new post-pandemic era, we should be more conscious of the reality that development is never a one-dimensional concept but a balance between economic development, social governance, and environmental protection. Currently, most countries are making efforts to promote sustainable development. According to our findings, these measures can improve their capabilities to fight COVID-19.

In addition, our results indicate that there are still several barriers to sustainable social development, making it difficult to prevent and control the pandemic. According to the World Economic Outlook released by International Monetary Fund (IMF) on October 10, 2020 https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/ (IMF, 2020), this pandemic increased inequality owing to disproportionate impacts on economically vulnerable individuals and influenced public education because of school closures. Our findings indicate that such barriers to sustainable social development may hinder the pandemic's prevention and control. We suggest taking necessary measures to address such inequality and make sure that fair education can be provided to the whole society.

Finally, the refined management of pandemic prevention and control may not be reflected in these SDG scores. Our results provide solid evidence that social SDGs are of great importance during pandemic

prevention and control, which means that existing SDG indicators can uncover key factors that affect pandemic prevention and control. However, these indicators don't include all the influential factors. These ignored factors may be mixed with observable factors in SDG indicators to jointly affect pandemic prevention and control.

This study evaluates the positive effect of sustainable social development on pandemic prevention and control by using one fixed-effect model based on the matched data of SDGs and infection data in 257 Chinese cities. Our results show that sustainable social development is directly associated with pandemic prevention and control. Sustainable social development leads to a remarkable improvement in pandemic prevention and control, especially for SDG4 (Quality Education) and SDG5 (Gender Equality). The significant positive effects of sustainable social development still exist in the post-pandemic era. Through heterogeneity analysis, this study identified that the positive effect of sustainable social development on pandemic prevention and control in northern cities, cold cities, and inland cities is significant. This study also discusses the impact of sustainable social development on the prevention and control of COVID-19 spread, which is of great significance to the protection of public health when pandemic prevention and control is becoming the norm.

Limitations of study

Several limitations exist in this study. First, our data were obtained from mainland Chinese cities and therefore cannot reflect other cultures. Thus, it would be better to initiate similar studies in other countries so that different findings can be obtained for comparison studies. Second, compared with the most severe outbreak period, current pandemic prevention and control measures have experienced significant changes. Thus, future studies should investigate the roles of social factors in the second stage of pandemic spread. In addition, although this study uses comprehensive indicators to measure sustainable social development, we did not uncover which component of the SDG score is key to helping prevent and control the infections of COVID-19. Therefore, it is critical to have more studies to discuss the effectiveness of detailed dimensions of sustainable social development so that valuable insights can be obtained for governments to prepare more appropriate medical policies to address these issues.

METHODS

All methods are detailed in the supplemental file.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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  - Data and code availability
- METHOD DETAILS
  - Data
  - Empirical strategies
  - Positive effects of social SDGs still exist in the post-pandemic era
  - Robustness check of effect in different regions
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  - Heterogeneous effects in different regions

SUPPLEMENTAL INFORMATION

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AUTHOR CONTRIBUTIONS

Conceptualization, YT and YZ; methodology, YT and WN; software, YT; visualization, WN; validation, YT and SF and WW; formal analysis, YZ; investigation, YT and WW; resources, SF; data curation, YT and SF; WN and YZ; writing—original draft preparation, YT; WN and YZ; writing—review and editing, SF, WW, and YG; supervision, WW and YG; project administration, SF; funding acquisition, WW, YG and SF. All authors have read and agreed to the published version of the article.

DECLARATION OF INTERESTS

All authors declare no competing interests.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Province-level data on the SDGs in China	Xu et al.(2020)	https://doi.org/10.1038/s41586-019-1846-3
City-level infection data	Dingxiangyuan	https://ncov.dxy.cn/ncovh5/view/pneumonia
	Wind	https://www.wind.com.cn/NewSite/edb.html
City-level economic, traffic and geographic data	China City Statistical Yearbook	https://data.cnki.net/trade/Yearbook/Single/N2016030128?zcode=Z027
City-level geographic data	This study. Baum-Snow et al. (2018)	https://doi.org/10.1016/j.jue.2018.05.001
Software and algorithms		
STATA 14	This study	https://www.stata.com/stata 14/ (RRID:SCR_012763)
ArcGIS for Desktop Basic	This study	(RRID:SCR_011081)
Python 3.8.8	This study	https://www.python.org/downloads/release/python-388/

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources and data should be directed to and will be fulfilled by the Lead Contact, Wendong Wei (wendongwei@sjtu.edu.cn).

Materials availability

This study did not use or generate any reagents.

Data and code availability

- In this paper, the infection case data come from the real-time pandemic data released by Dingxiangyuan at https://ncov.dxy.cn/ncovh5/view/pneumonia and Wind at https://www.wind.com.cn/NewSite/edb.html. The province-level data on the SDGs in China are based on the assessment of Xu et al. (2020). The province-level data cover 31 provinces and two census years, 2000 and 2015. The city-level data, including economic, traffic, and geographic characteristics, are collected and calculated based on the data from China City Statistical Yearbooks and Baum-Snow et al. (2018).

- The preliminary data and regression code are available on request from the lead contact. Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

- Additional supplemental items are available from Mendeley Data at https://doi.org/10.17632/cmzvs82j5j.1

METHOD DETAILS

Data

City-level infection data

COVID-19 is an emerging respiratory infectious disease that was first detected in early December 2019. After the pandemic outbreak, the Chinese government isolated the source of infection, cut off the route of transmission, and quickly launched overall pandemic prevention and control measures. On 22 January, 2020, the outflow of people from Hubei Province, where the pandemic was relatively severe, was strictly controlled. Subsequently, a first-level response mechanism for major public health emergencies was launched in all the provinces. With the gradual implementation of various pandemic prevention and control

measures, China has achieved remarkable pandemic prevention and control results, and the positive trend has been further consolidated. On May 2, 2020, the emergency response level of public health emergencies in Hubei Province was adjusted from level 1 down to level 2, and relevant prevention and control measures were adjusted accordingly. At this point, all the provinces had lifted the level 1 emergency response. Since then, the transmission of the local pandemic has been basically blocked in China, intermittent small-scale epidemics and outbreaks became regular occurrences, and the pressure from overseas pandemics remained for a long time, forming a new normal between social operation and epidemic prevention and control. China moved into "the post-pandemic era". However, COVID-19 has not been effectively controlled on a global scale. Globally, as of 12:00 p.m. CET, 24 January 2022, there have been 372,468,204 confirmed cases of COVID-19, including 5,656,290 deaths, as reported by the WHO. From the real-time report of WHO: https://covid19.who.int/. To date, this coronavirus is still spreading, leading to a long-term public health crisis with far-reaching implications.

Our city-level infection data were obtained from Dingxiangyuan and Wind, which comprehensively aggregates authoritative data released by the National Health Commission of China, the Chinese Center for Disease Control and Prevention, and medical and health institutions in most provinces and cities across the country. These data cover the daily statistics of newly confirmed cases dead and cured cases in mainland China during the period from the outbreak of COVID-19 on 24 January, 2020 to 24 January, 2022. We thus calculate daily new case data. As the COVID-19 data in Wind contains newly confirmed cases, dead cases, and cured cases each day, we use such data as the data verification instrument. Figure S1 shows the accumulative case number of pandemic infections in the outbreak stage across the country from 24 January, 2020 to 10 March, 2020, and the number in the second stage from 10 March, 2020 to 24 January, 2022, respectively.

Figure S2 shows the numbers of daily new pandemic infection cases across the country in the first and second stages, respectively. As the left graph depicted, China has experienced rapid widespread and emergency prevention and control in the first stage. On 10 March, 2020, the number of newly confirmed cases nationwide had dropped to less than 20, and the daily new cured case increased rapidly. Since then, China has come into the Post-Covid-19 era, in which most confirmed cases came from intermittent small-scale outbreaks or were imported. In the second stage, there are few daily new cases.

Sustainable social development data

Sustainable development is a crucial matter concerning the future of humans. At the 2012 United Nations Rio+20 Conference, a set of sustainable development goals (SDGs) were created. In 2015, 193 United Nations Member States formally adopted a document at the Sustainable Development Summit, covering 17 SDGs and 169 other targets aiming to advance three ambitious global goals in the next 15 years, namely, eradicating extreme poverty, fighting inequality and injustice, protecting the environment, and curbing climate change. Statistics of SDGs for the year 2015 are listed in Table S1. Among all the 17 SDG indicators, we concentrate on SDG4 (Quality Education), SDG5 (Gender Equality), SDG10 (Reduced Inequality), and SDG16 (Peace, Justice, and Strong Institutions) because these four indicators can best reflect the level of sustainable social development in one region.

Table S2 lists the statistics of province-leveled SDG4, SDG5, SDG10, and SDG16 scores for the year 2015. From the standard error values of the four SDGs, we can observe that SDG16 has the largest variation among different provinces in China. The spread of the pandemic is also affected by city characteristics, including population, economy, transportation, and geographic factors. We controlled these variables in our model. Panel (2) of Table S2 summarizes these control variables.

Figure S3 illustrates the distribution of four SDG scores in different provinces in 2015. The distribution of SDG4 scores shows a decreasing trend from southeast to northwest geographically, and coastal provinces have significantly higher scores than inland provinces. In contrast, western provinces have relatively higher SDG5 scores, while southeast and northeast provinces have relatively lower SDG5 scores. The SDG10 scores are generally higher in western and eastern provinces than in central provinces. The SDG16 scores in northern and southwest provinces are generally higher than those in southern provinces. Figure S4 illustrated the SDG score distribution in 2000. Compared with Figure S3, it illustrates the changes in the scores of four social SDGs in different provinces from 2000 to 2015. The SDG4 and SDG10 scores in the northern provinces increased significantly. The SDG4, SDG5, SDG10, and SDG16 scores in northeast provinces have

increased, among which the SDG10 scores have increased greatly. The SDG4, SDG5, SDG10, and SDG16 scores in central provinces increased slightly. The SDG4 and SDG10 scores in southwest provinces have increased significantly. The SDG4, SDG10, and SDG16 scores in northwest provinces have increased to a certain extent. Overall, 4 SDGs in all the provinces had improved from 2000 to 2015, although with different change ranges.

Empirical strategies

To investigate the impacts of the SDGs on pandemic prevention and control, we use the specification of fixed-effect models based on the SDG data and daily new confirmed infections in 257 cities across the country. The latest level of social development in 2015 may affect the prevention and control of COVID-19, so the first empirical model used in this study is expressed in Equation (1):

$$Infection_{cpt} = \alpha + \beta \ln SDG^i_{p,2015} + \gamma X_{cpt} + \mu_t + \epsilon_{cpt} \qquad \text{(Equation 1)}$$

$Infection_{cpt}$ is the log value of daily new confirmed infections in city c of province p at time t. $\ln SDG^i_{p,2015}$ is the log value of SDG i's score of province p in 2015. X_{cpt} includes lagged infection increase in log value, population in log value, GDP in log value, the fraction of agricultural industry, the fraction of service industry, number of railway stations in log value, number of airports in log value, dummy of having international airports. As the spread of COVID-19 is different in cities with different distances to Wuhan, we control the railway distance to Wuhan for each city. we control the distance between Wuhan and each investigated city in our regression analysis since different cities face different pandemic-spread situations and have different distances to Wuhan. We measured such distance by using the length of the railways between Wuhan and each investigated city and using the geographical straight-line length between Wuhan and each investigated city. The regression results from these two approaches are the same, confirming that our results are robust. The population directly affects the spread of the pandemic. Economic activities, especially the service industry, tend to attract more floating people and make interpersonal contact more frequent. Therefore, GDP and the proportion of the service industry reflect the level of population concentration in each city. Unlike those with a high proportion of service industry, cities with a higher proportion of agricultural industry tend to have lower population concentrations. Adding city-level economic indicators to this econometric equation can eliminate the influence that SDG achievement has on the level of pandemic prevention and control by affecting economic development. Therefore, this study can focus on the contribution of social-related SDGs to pandemic prevention and control. In addition, by referring to Baum-Snow et al. (2018), this study adds relevant geographic indicators, including land areas, ruggedness, and distances to the coastline. Land areas and ruggedness are directly related to economic activity and population concentration. Coastal cities normally have more economic activities. Time-fixed effects control for the changes in the pandemic in different periods that are not affected by regions. For example, the COVID-19 pandemic has experienced stages of spread, outbreak, stability, and decline at the national level. Therefore, the regression analysis in this study effectively solves the endogeneity concerns of the results.

Positive effects of social SDGs still exist in the post-pandemic era

Based on the infection data in the second stage, we rerun the fixed-effect model after controlling all the traffic, economic and geographic characteristics (see Table S3). As Panel (4) suggests, sustainable social development still leads to an improvement in pandemic prevention and control in the post-pandemic era, even though the positive effect on pandemic prevention and control is somewhat diminished compared with the coefficient in stage 1. To provide more specific insights into the differences between both stages, we divide all the sample cities into two categories: municipalities, provincial capital cities, and other cities. Then we rerun the fixed-effect model after controlling all the traffic, economic and geographic characteristics, and time-fixed effects. The results are listed in Table 2.

Robustness check of effect in different regions

We further conduct a robustness check in different regions and listed the results in Table S4. A first concern about the robustness of the baseline estimation is that the four province-leveled municipalities (Beijing, Shanghai, Tianjin, and Chongqing) in the baseline sample have a high administrative level and far exceed the average prefecture-level cities in terms of economic development and population. The high level of urbanization, dense population, and mass migration movements make the transmission of the pandemic in municipalities different from that in other prefecture-level cities. Therefore, it is necessary to verify the regression results of samples excluding such province-leveled municipalities. In Robustness check (2),

we analyze the effect without these four province-leveled municipalities. A second concern is that since cities in Hubei Province are close to Wuhan, where the infections were concentrated, the spread of the pandemic in Hubei Province may be different from that in other provinces. Therefore, in Robustness check (2), we exclude cities in Hubei Province. The two results are also depicted in Figure S5.

Robustness check of placebo test

Since we used panel data regression analysis in this study, the coefficients and significance of the baseline regression results may be affected by time series or random statistical factors. In order to exclude the effect of accidents, we added a placebo test (see Figure S6). According to the logic of the placebo test, when the randomly ordered SDG scores are used for baseline regression, the coefficients of the core explanatory variables should no longer be significant, thus proving the robustness of the conclusions. Therefore, we randomly assigned the data of the SDG scores at the provincial level in random order, keeping other variables unchanged, and then used the same method to test the randomly ordered samples. We performed a total of 100 tests to obtain the estimated coefficients and t-values for the 100 regressions, with the distributions plotted in Figure S6. Since the estimated results do not have statistical significance and economic significance, the placebo test shows that our benchmark model is validated and the baseline regression results are reliable, not generated by accidental statistical factors, which means the social SDGs have a significant impact on suppressing the spread of the pandemic.

Robustness check of changing the independent variable measure

Besides newly confirmed cases data, the newly death cases are another indicator that reveals the pandemic prevention and control level. Compared with a newly confirmed case, there is a possibility that a death case may be more directly affected by regional medical resources and the level of prevention and control. We use the log value of daily new death cases as the primary dependent variable to test whether there is a different relationship between the scores of social SDGs and pandemic prevention and control. Table S5 lists the related results.

Robustness check of IV estimation

Although we tend to avoid the reverse causality problem by using SDG scores in 2015 to proxy the sustainable social development level, the endogeneity problem may still be an issue if there are unobservable variables simultaneously influencing Covid-19 infections and SDG scores in 2015. Therefore, in addition to the basic identification strategy, we also used the literacy rate in the 1982 census as the instrumental variable for the SDG score in 2015 so that the omitted variable problem can be solved. Using the literacy rate of the historical period can ensure the exogeneity of the instrumental variable. Historical literacy rates have a long-lasting influence on population quality, as well as the current social development level. The results are listed in Table S6.

Heterogeneous effects in different regions

In order to uncover the heterogeneity of sustainable social development on pandemic prevention and control, we classify all the investigated Chinese cities into different groups and generate relevant dummy variables. We then introduce interaction terms of the group dummy variable and the SDG indicators into the model and re-estimate the baseline (see Table S7). The coefficient of the interaction reveals the differences between different city groups.

To test the heterogeneity between northern cities and southern cities, we generate a dummy variable to represent northern cities by setting up the boundary along the Qinling-Huaihe Line. Then, we interact this dummy with the log value of the SDG scores in 2015 and introduce this interaction term into the model.

To test the heterogeneity between cold cities and warm cities, we generate a dummy indicating cold cities whose temperatures are below 8 degrees Celsius during the day or -2 degrees Celsius at night in February, interact this dummy with the log value of the SDG scores in 2015, and introduce the interaction term into the model (1).

To test the heterogeneity among cities with different levels of per capita GDP, we generate a dummy variable to highlight cities with a per capita GDP above the national median level, interact this dummy with the log value of SDG scores in 2015, and introduce this interaction term into the empirical model (1).

To test the heterogeneity among the cities in the coastal and inland areas, we generate a dummy for coastal cities, interact this dummy with the log value of SDG scores in 2015 from 2000 to 2015 separately, and introduce this interaction term into the two empirical models. The coefficient of the SDG indicator represents the marginal effect of those inland cities, and the coefficient of the interaction term represents the difference in the marginal effect of the coastal cities.