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Tatsushi Oka
Wei Wei
Dan Zhu

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A SPATIAL STOCHASTIC SIR MODEL FOR TRANSMISSION NETWORKS WITH APPLICATION TO COVID-19 EPIDEMIC IN CHINA

Tatsushi Oka, Wei Wei, and Dan Zhu*

Executive summary

We evaluate the effect of mobility restriction policies on the spread of COVID-19 across 33 provincial regions in China, using data on daily human mobility across regions. The results show that the spread of the disease in China was predominantly driven by community transmission within regions and the lockdown policy introduced by local governments curbed the spread of the pandemic. Further, we document that Hubei was only the epicenter of the early epidemic stage. Secondary epicenters had already become established by late January 2020. The transmission from these epicenters substantially declined following the introduction of human mobility restrictions across regions.

Key messages

- **Human mobility is one of the keys for the spread of COVID-19.**
- **Human mobility restrictions across and with regions lower the spread of COVID-19.**

Introduction

The ongoing pandemic of coronavirus disease (COVID-19) poses a threat to public health and has disrupted economic activities globally. Although there are limited policy tools available to stem the disease spread, restricting human mobility though lockdown or border closure policies was identified as an effective measure.Simply put, the virus itself cannot move anywhere without assistance. In many countries, mobility restriction led to the containment of the virus's spread. Given the importance of mobility restriction as an effective policy, it is critical to quantify its effects.

In this study, we consider a multivariate discrete-time Markov model to analyze the propagation of COVID-19 across 33 provincial regions of China. Thereby, we allow for heterogeneous disease transmission both within and across regions.1 Our model takes into account human mobility as a key driver of disease transmission across regions and identifies epicenters of disease propagation, as well as the effect of mobility restrictions on infection rates. We extract information on daily human mobility across regions from January 11 to March 15, 2020, from the Baidu-Qianxi database and apply the Bayesian framework to estimate the model. The sampling period in use for our analysis exhibits substantial exogenous variations in human mobility rates due to the high number of movements around Chinese New Year (January 25) and a sudden decline in movements after policy interventions were introduced. We evaluate the effect of mobility restrictions on the disease spread between regions by comparing outcomes under actual and counterfactual human mobility, which is extracted from the 2019 data.

Data, Methodology and Results

Data

We use the daily data on COVID-19 infection and individuals' mobility from January 11 to March 15, 2020. The daily data of the infection, death, and recovery cases for each region are obtained from the National Health Commission of China and its affiliates. The human mobility data is obtained from Baidu Migration. The data provides a daily outflux index for each of the 33 regions as well as the destinations of the outflux. For our counterfactual analysis, we use the mobility data set of 2019 from Baidu-Qianxi matched according to the Chinese New Year. The outflux indices before the Chinese New Year in both 2019 and 2020 are dominated by provinces such as Guangdong, Zhejiang, and Beijing. It is expected that most workers would be leaving these areas to return for their home provinces for the holiday. For Hubei, the outflux was moderate in both years. The outflux reduced to a negligible level at the time when the lockdown policy prevailed.

Methodology

In this study, we consider a multivariate discrete-time Markov model to analyze the propagation of COVID-19 across 33 provincial regions of China. Thereby, we allow for heterogeneous disease transmission both within and across regions. Our model takes into account human mobility as a key driver of disease transmission across regions and identifies epicenters of disease propagation, as well as the effect of mobility restrictions on infection rates. We consider a type of stochastic susceptible-infective-recovered (SIR) model. The most critical feature of our model is that it captures the impact of human movements on spatio-temporal disease transmission. The quantitative modeling of human movements has a long-standing history in fields like transportation, tourism, and urban planning. The use of the gravity model has been popular in these fields as well as in the field of economics. In the epidemiology literature, gravity-type models are also widely adopted in more recent studies. Alternatively, the radiation model is used to predict spatial disease transmission. Both the gravity and radiation models treat the transition probabilities of individuals from one place to another as a function of population sizes and geometric distances, both of which are almost invariant on a daily basis. By contrast, this study uses known information on daily human mobility to characterize disease transmission across regions and evaluate the dynamic impact of mobility restrictions.

Key message: Mobility restrictions are effective in curbing the spread of virus

Our empirical results document substantial heterogeneity in the rate of infection across regions. The results also demonstrate the effectiveness of the lockdown policy in curbing the spread of the pandemic. The transmission mechanism of the disease in China is found to be predominately community transmission within all regions. Further, our analysis based on the 2019 mobility data suggests that the external transmission would not have been suppressed if people had continued to be allowed to move freely across provincial borders as usual. Interestingly, our results show that Hubei is not the only epicenter of the early epidemic stage. Other epicenters, such as Beijing and Guangdong, had already become established by late January 2020. The pandemic radiated out to the subordinate regions of these cities with varying degrees of severity. Our approach sheds light on the evolution of the transmission network over time and provides useful insight into the formulation of lockdown policies amid the pandemic.

Policy recommendations

Our approach sheds light on the evolution of the transmission network over time and provides useful insight into the formulation of lockdown policies amid the pandemic.

**The authors are from Monash University.*

Centre for Development Economics and Sustainability
Monash Business School, Monash University
900 Dandenong Rd, Caulfield East VIC 3145
E: BusEco-CDES@monash.edu
W: Monash.edu/business/cdes
Twitter: CDES_Monash