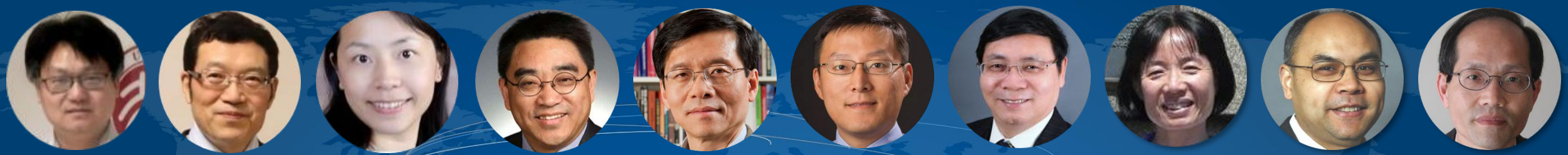

新冠疫情数据分析系列公益讲座(10) COVID-19 Data Analysis Webinars

“中美日防疫模式与疫情影响分析”论坛

人口流动、疫情空间蔓延及封城政策评估

报告：沈体雁，张超 北京大学
点评：刘国恩，北京大学国家发展研究院

议题 Topics

- 研究背景Background
- 以往研究及问题Previous Study & Problems
- 数据及特征事实Data & Stylized Facts
- 研究方法Methodology
- 计量模型设定及变量说明Econometric Model & Variables
- 计量结果分析Model Analysis & Results
- 总结与讨论Summary & Discussion

研究背景Background

- **传染病是当前人类健康最重要的威胁之一。**最近20年来，重大传染病事件在世界范围内频频出现，2003年始于中国广东顺德SARS疫情在短时间内就迅速扩散至东南亚，最终导致全球确诊感染8069例，死亡774例。2009年H1N1流感病毒始发于墨西哥，随后迅速蔓延至美国，致使美国约6080万例感染，12469例死亡。2014年爆发于西非的Ebola病毒共计造成19031人感染，死亡7373人。这也引发了学者们对传染病疫情的动态演化特征和演化机制等问题的关注，旨在探究传染疫情时空动态演化的定量模型开始大量出现。

- 当前新型冠状病毒（2019-nCoV）肺炎疫情传播迅猛，在不到两个月时间里蔓延至全国所有省份，并传播到20多个国家和地区。

研究背景Background

针对新型冠状病毒（2019-nCoV）疫情发展，国内外相关学者分别从以下方面展开探讨：

- 新型冠状病毒宿主来源（Dong et al.，2020；Zhu et al.，2020；Zhou et al.，2020）
- 新冠肺炎临床特征及潜伏期（Letko and Munster，2020；Benvenuto et al.，2020；Chen et al.，2020；Ceraolo and Giorgi，2020）
- 病毒传播模式（Riou and Althaus，2020；Linton et al.，2020；Li et al.，2020）
- 疫情传播动力学建模及预测（Chen et al.，2020；Zhang and Wang，2020；Ming，Huang and Zhang，2020；Cao et al.，2020；Jung et al.，2020）
- 新冠肺炎疫情的经济社会影响评估（Munster et al.，2020；Nishiura et al.，2020；Liu et al.，2020；Tang et al.，2020；Du et al.，2020；Kupferschmidt and Cohen，2020）
- 新冠肺炎治疗方案（Liu and Wang，2020；Ramaiah and Arumugaswami，2020；Ju et al.，2020；Richardson et al.，2020；Liu et al.，2020）
- 疫情防治举措有效性（Gostic et al.，2020）

以往研究及问题Previous Study & Problems

基于人口流动视角的疫情传播研究主要从两方面展开：

- **其一是人口流动影响传染病动态演化的仿真模拟和预测研究。**Thieme（1977）；Dirk Brockmann（2009）；Balcan等（2010）；Belik等（2011）。
- **其二是人口流动影响传染病空间蔓延的实证研究。**Gonzlez（2008）；Balcan（2009）；Wesolowski（2012）；Ciddio等（2017）；Kraemer等（2017）

以往研究及问题Previous Study & Problems

Corrected 8 May 2020. See full text.

RESEARCH

CORONAVIRUS

An investigation of transmission control measures during the first 50 days of the COVID-19 epidemic in China

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Responding to an outbreak of a novel coronavirus [agent of coronavirus disease 2019 (COVID-19)] in December 2019, China banned travel to and from Wuhan city on 23 January 2020 and implemented a national emergency response. We investigated the spread and control of COVID-19 using a data set that included case reports, human movement, and public health interventions. The Wuhan shutdown was associated with the delayed arrival of COVID-19 in other cities by 2.91 days. Cities that implemented control measures preemptively reported fewer cases on average (13.0) in the first week of their outbreaks compared with cities that started control later (20.6). Suspending intracity public transport, closing entertainment venues, and banning public gatherings were associated with reductions in case incidence. The national emergency response appears to have delayed the growth and limited the size of the COVID-19 epidemic in China, averting hundreds of thousands of cases by 19 February (day 50).

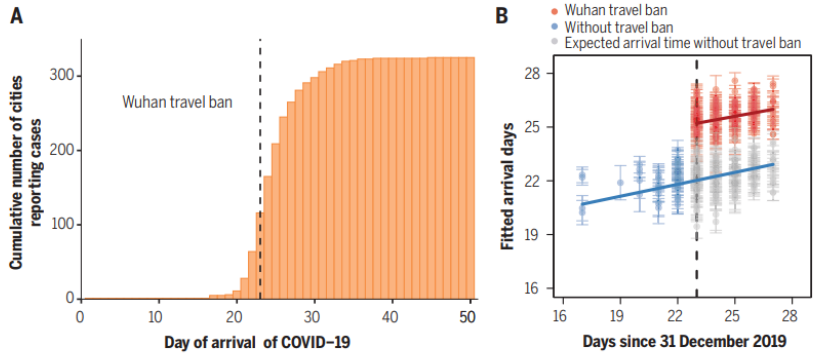


Fig. 3. Spatial dispersal of COVID-19 in China. (**A**) Cumulative number of cities reporting cases by 19 February 2020. Arrival days are defined as the time interval (days) from the date of the first case in the first infected city (Wuhan) to the date of the first case in each newly infected city (a total of 324 cities), to characterize the intercity transmission rate of COVID-19. The dashed line indicates the date of the Wuhan travel ban (shutdown). (**B**) Before (blue) and after (red) the intervention by 30 January 2020, 1 week after the Wuhan travel ban (shutdown). The blue line and points show the fitted regression of arrival times up to the shutdown on day 23 (23 January, vertical dashed line). Gray points show the expected arrival times after day 23, without the shutdown. The red line and points show the fitted regression of delayed arrival times after the shutdown on day 23. Each observation (point) represents one city. Error bars give ±2 standard deviations.

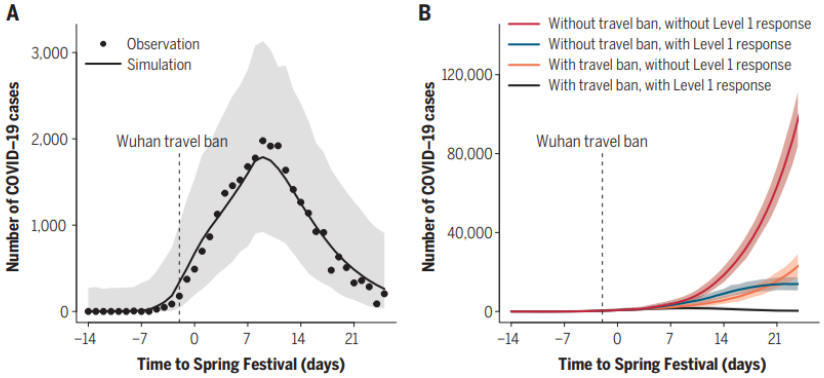


Fig. 4. The role of interventions in controlling the COVID-19 outbreak across China. (**A**) Epidemic model (line) fitted to daily reports of confirmed cases (points) summed across 31 provinces. Hubei excludes Wuhan city. (**B**) Expected epidemic trajectories without the Wuhan travel ban (shutdown), and with (blue) or without (red) interventions carried out as part of the Level 1 national emergency response, with the Wuhan travel ban and with (black) or without (orange) the intervention. Vertical dashed lines in (A) and (B) mark the date of the Wuhan travel ban and the start of the emergency response on 23 January. Shaded regions in (A) and (B) mark the 95% prediction envelopes.

以往研究及问题Previous Study & Problems

“封城”、“开城”的时空开关问题：从疫情时空动态演化视角评价、模拟地方政府的封城、开城、人口流动政策

- **政策评估：**如何从疫情蔓延和疫情增长角度评估中国“封城”、“开城”政策?
- **情景模拟：**“封城政策”实施的城市组合选择？时序选择？不同城市疫情“刹车时间”？

数据及特征事实Data & Stylized Facts

- **数据来源：**
- 新冠肺炎累计确诊人数、肺炎累计康复人数和肺炎累计死亡人数数据均来源于国家和各地区卫健委每日公布的数据。两地区人口流动数据采用百度提供的每日城市间迁移流量规模指数数据。
- **新冠肺炎疫情变动趋势及空间蔓延特征：**从空间上看，疫情以武汉市为中心呈现圈层向外蔓延的趋

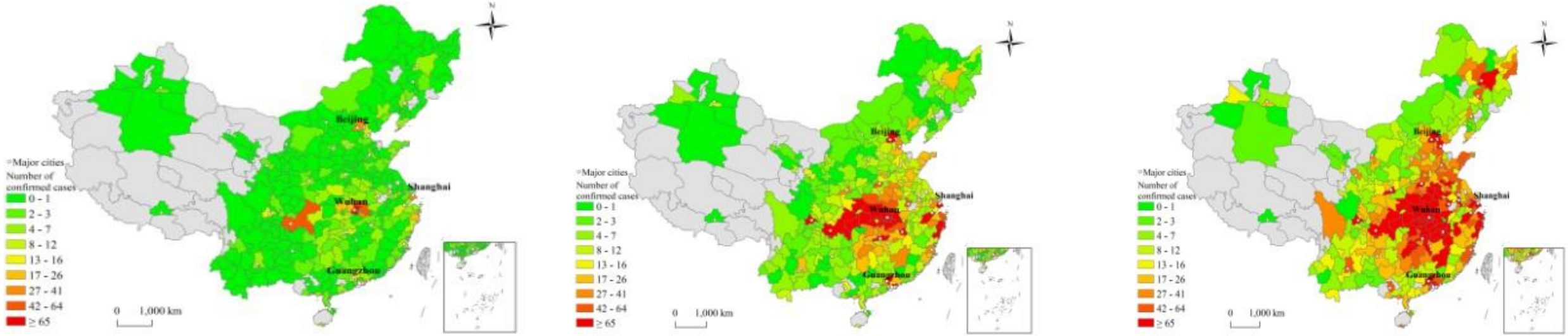
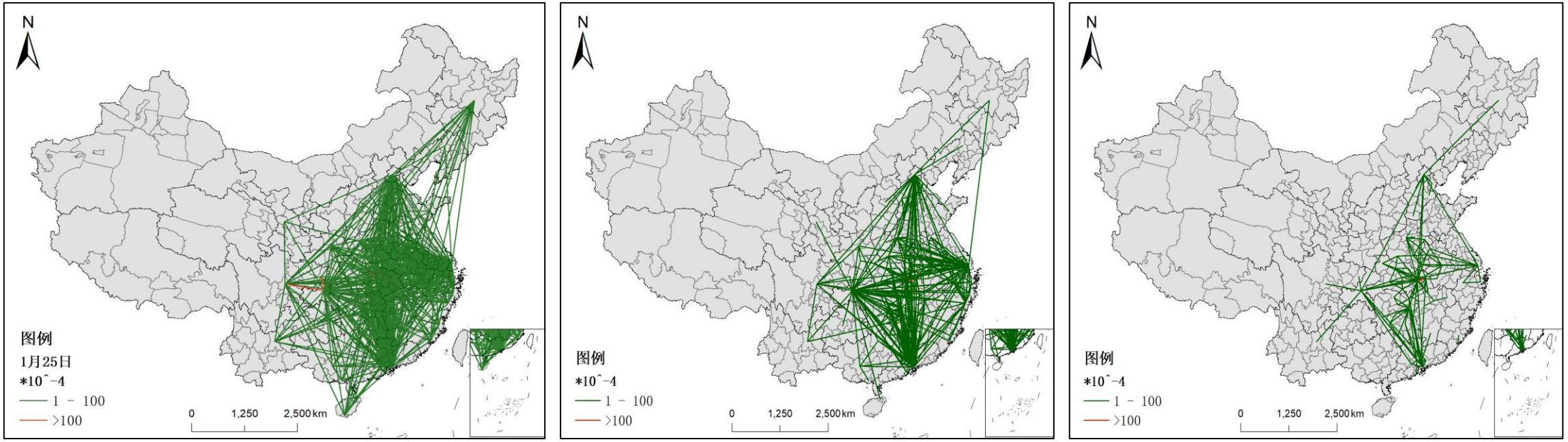


图2 不同时间节点新冠肺炎累计确认人数空间分布（1月25日、1月31日和2月11日）

数据及特征事实Data & Stylized Facts

- **疫情期间的人口流动特征及其与新冠肺炎疫情的相关性分析**



（a）1月25日　　（b）1月31日　　（c）2月11日

图4 不同时间节点按新冠肺炎疫情加权的地区间人口流动规模指数

研究方法Methodology

- **考虑地区间人口流动影响的SIR传染病模型**

$$S_i + I_i \xrightarrow{\alpha} 2I_i$$

$$I_i \xrightarrow{\beta} R_i$$

$$S_i \xrightarrow{w_{ij}} S_j$$

$$I_n \xrightarrow{w_{ij}} I_m$$

包含空间人口流动的SIR模型所得出的代表性地区不同类型人群变动将为：

$$\partial_t S_i = -\alpha \frac{S_i I_i}{N_i} + \sum_{j \neq i} [w_{ij} S_j - w_{ji} S_i]$$

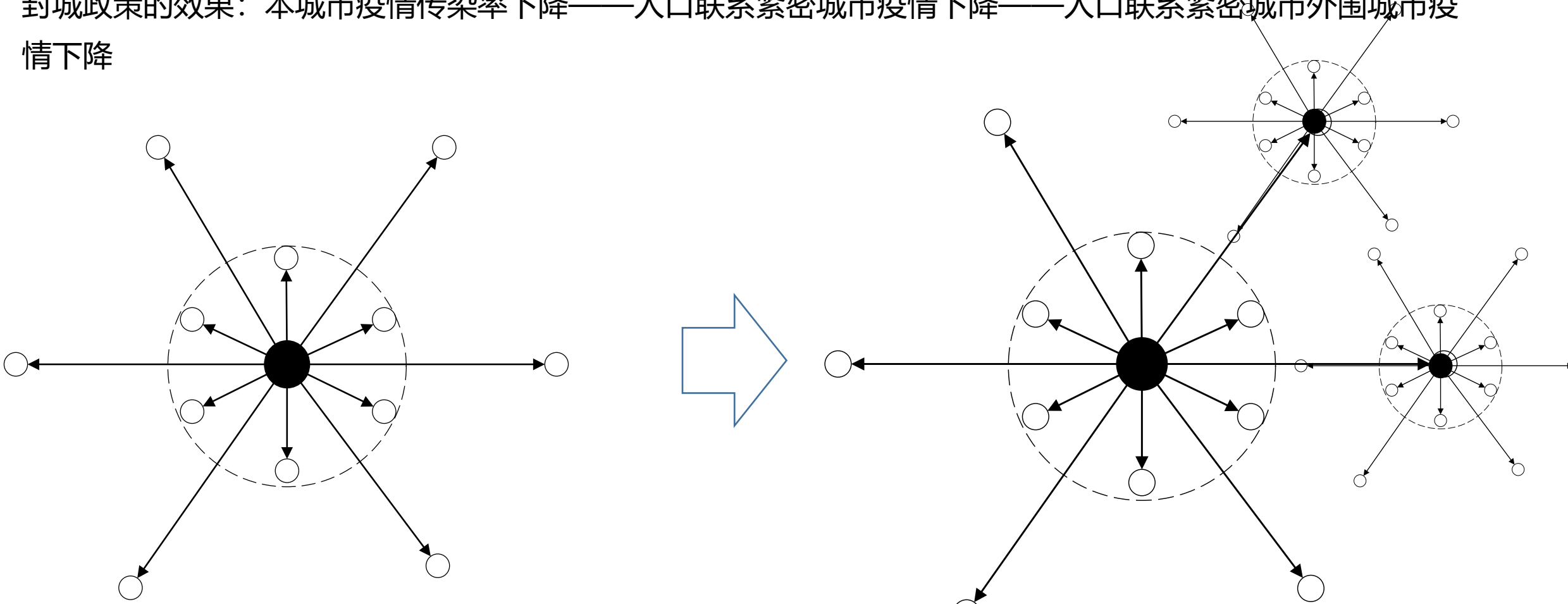
$$\partial_t I_i = \alpha \frac{S_i I_i}{N_i} - \beta I_i + \sum_{j \neq i} [w_{ij} I_j - w_{ji} I_i]$$

即某一地区当期疫情规模将与其上一期疫情规模、上一期周边地区疫情规模、上一期周边地区到本地的流量等均有关系。在此，感染者潜伏期应作为时期划分的重要参考。

研究方法Methodology

疫情空间扩散经历了“封城前的以武汉为疫情传播中心的扩散阶段”——“封城之后与武汉人口联系紧密城市的疫情爆发”——“新疫情城市为中心向外围城市扩散”

封城政策的效果：本城市疫情传染率下降——人口联系紧密城市疫情下降——人口联系紧密城市外围城市疫情下降



计量模型设定及变量说明Model & Variables

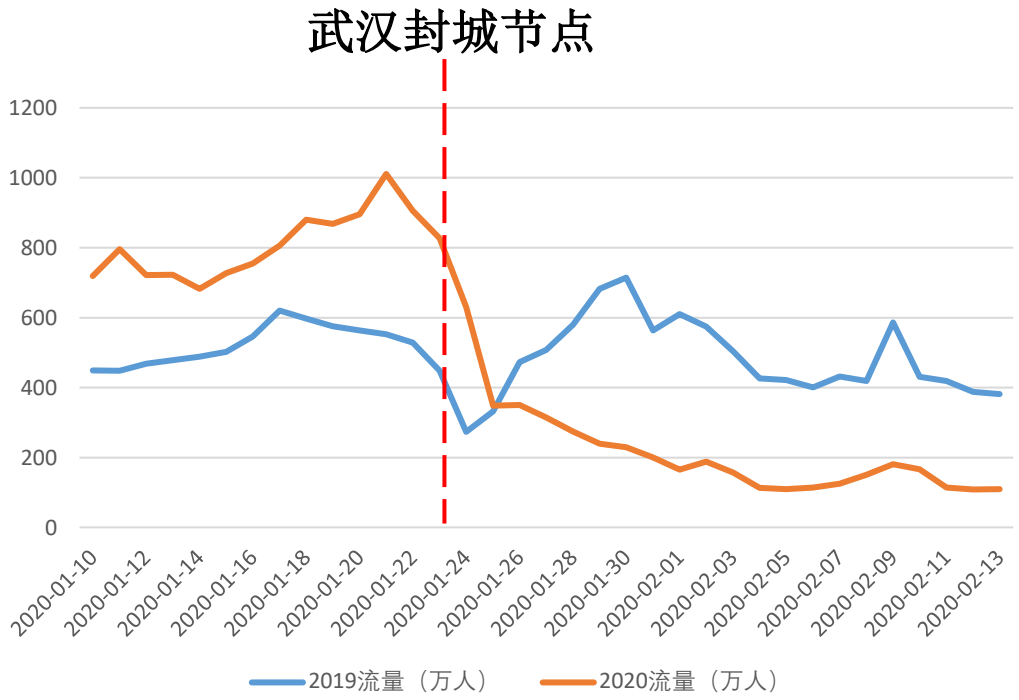
- 根据上文纳入潜伏期传播时滞并考虑人口流动影响的SIR模型，同时参考已有实证研究设计，本文设定的基本计量模型如下：

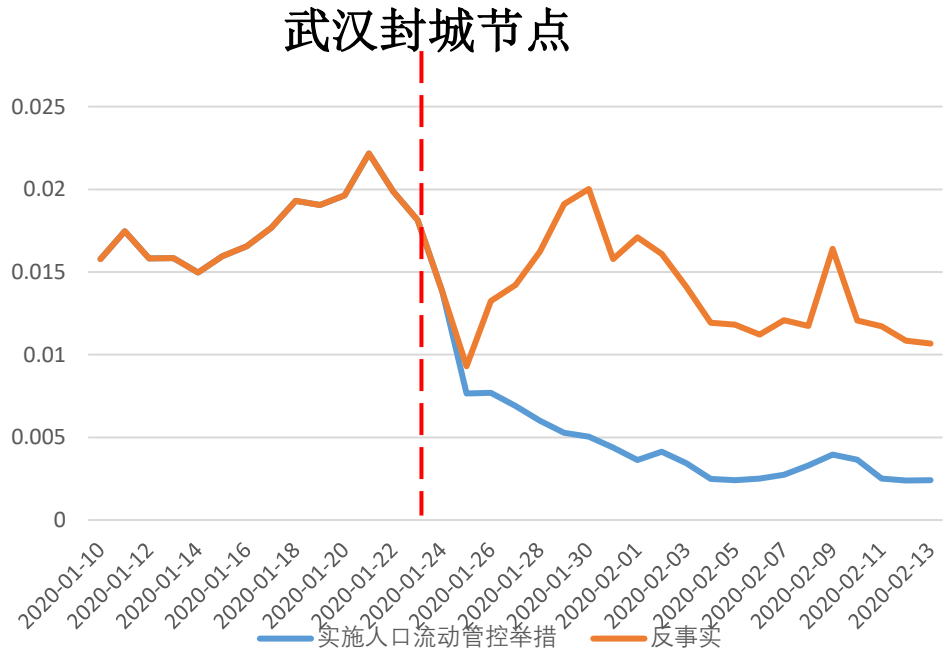
$$INFPOP_{it} = \beta_0 + \beta_1 INFPOP_{it-\tau} + \beta_2 INFLOW_{it-\tau} + \beta_3 DENSITY_{it-\tau} + \beta_4 TRAVEL_{it-\tau} + \mu_i + \lambda_t + \varepsilon_{it}$$

核心解释变量“疫情加权流量吸附指数”表示其他所以地区流入本地区的加权人口流入量，在此权重以各地疫情比重确定。

计量结果分析Model Analysis & Results

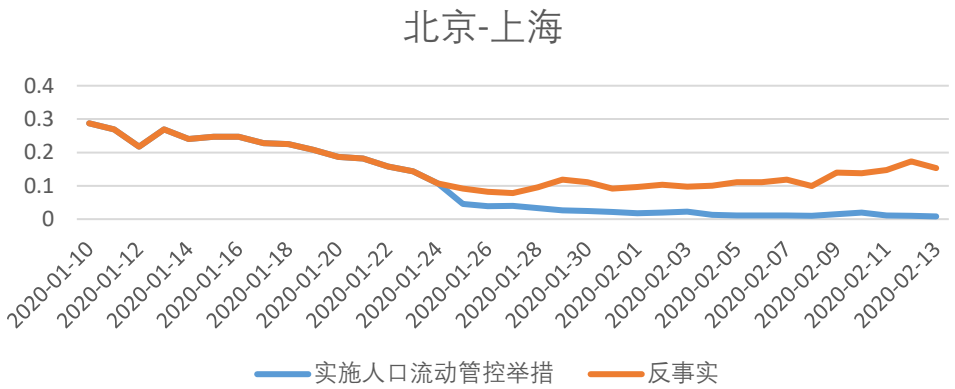
- **各地人口流量限制措施对中国城市间人口流动的影响：**至2020年2月11日，各地人口流量限制措施使得样本城市间人口流量总和减少72.59%。

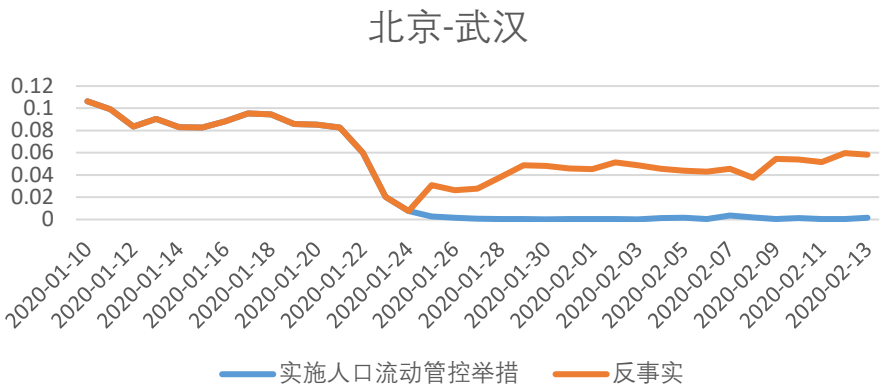


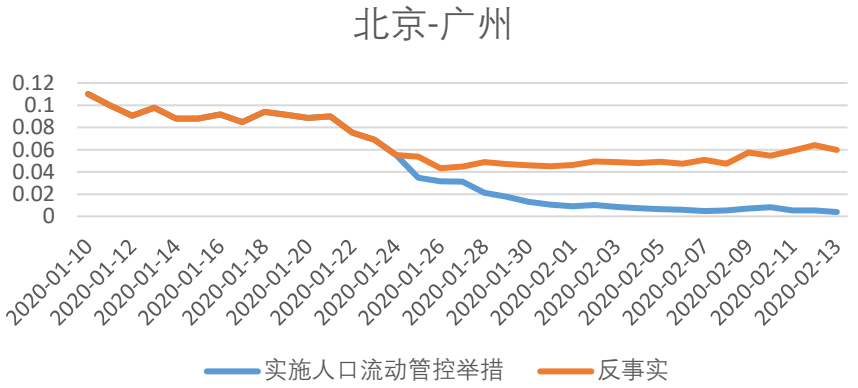


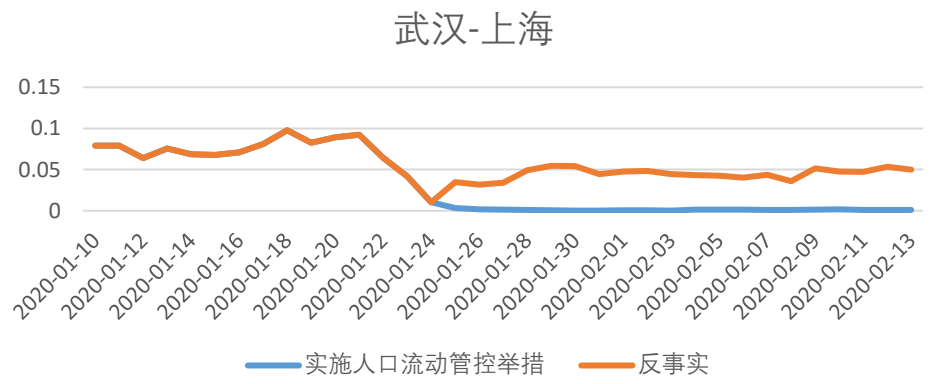
计量结果分析Model Analysis & Results

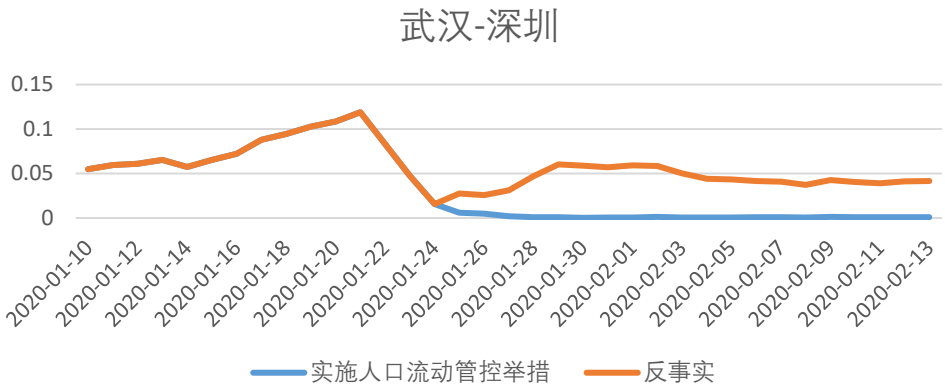
各地人口流量限制措施对中国典型城市间人口流动的影响：





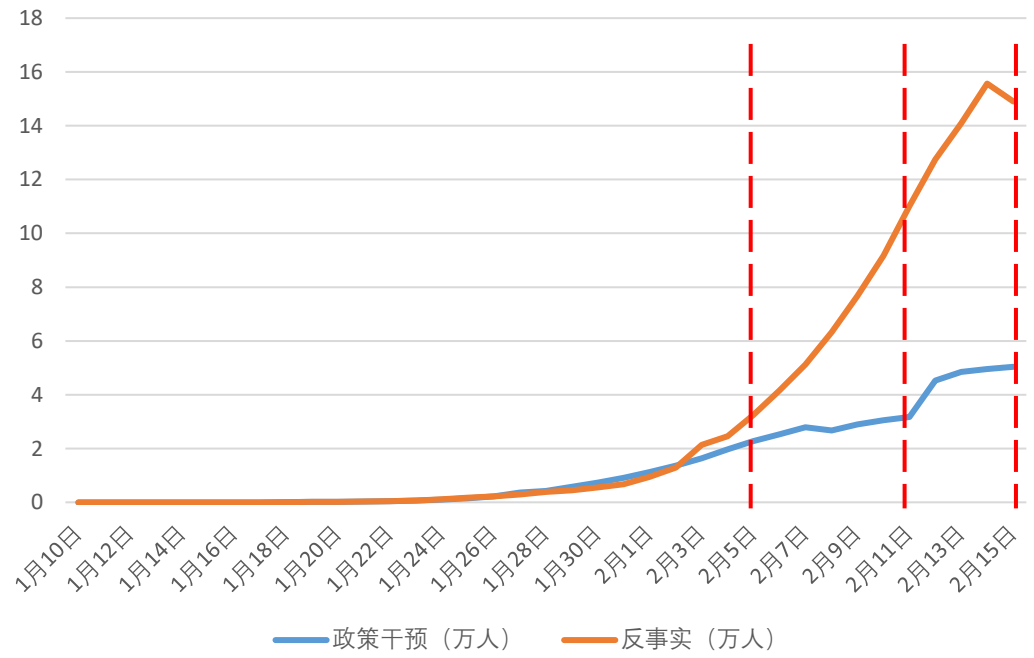






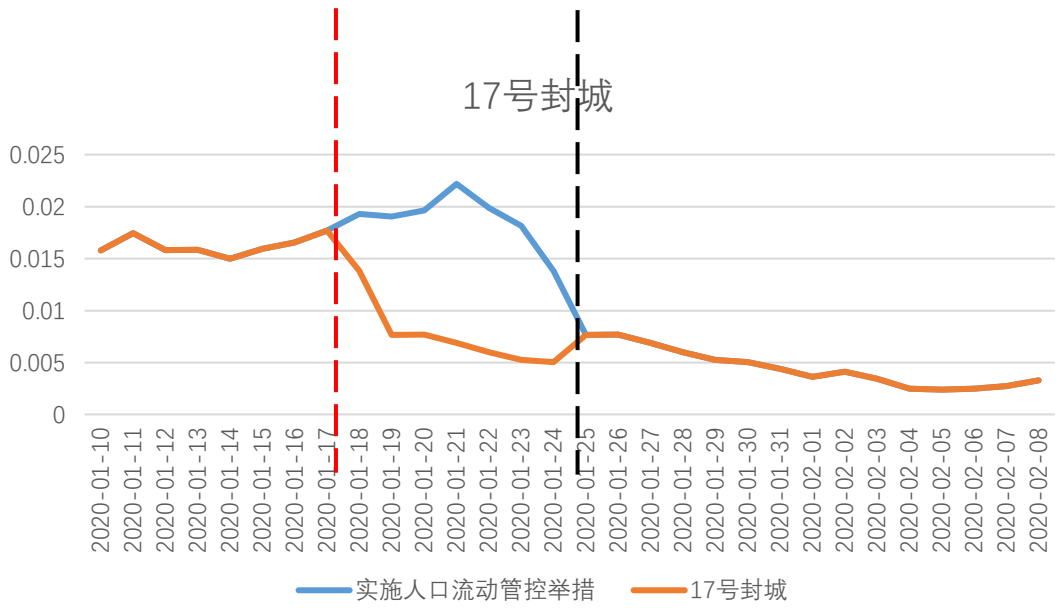
计量结果分析Model Analysis & Results

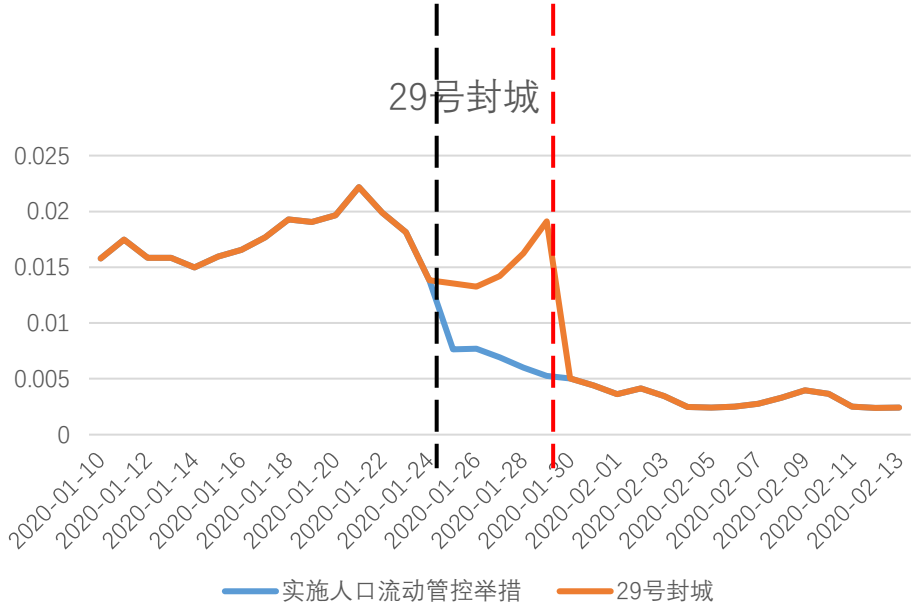
- **各地人口流量限制措施对中国疫情减缓的贡献：**至2020年2月5日，各地人口流量限制措施使得样本城市疫情感染规模减少 0.98万人。



计量结果分析Model Analysis & Results

- **武汉提前6天封城（1月17日封城）与推迟6天封城（1月29日封城）对中国城市间人口流动的影响。**





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