Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Student returnees from China's COVID-19 epicenter: Spatio-temporal movement and impact of tracing

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ABSTRACT

At the initial stage of COVID-19 outbreak, tracing returnees from Wuhan – the epicenter of the disease – is a major strategy in each province of China to contain its spread. However, scholars are yet to assess the impact of tracing on individuals. Drawing upon a large-scale survey with students from four major universities in Wuhan, we investigate individual experiences with tracing activities at government and community levels and the impacts on students' socio-psychological wellbeing. Findings indicate that tracing is likely to increase the risks of privacy infringement, verbal slur, and warning at residence; and students experience moderate-to-high levels of anxiety and fear. Improved public health measures are therefore necessary to balance the twin goals of containing disease and alleviating unintended consequences of tracing.

1. Introduction

The massive volume of population movements enabled by diversified modes of transportation and increased transit speed is a main facilitator of infectious disease transmission and spread, as demonstrated by the worldwide outbreak of the novel coronavirus (COVID-19) (Gatto et al., 2020; Jia et al., 2020; Kraemer et al., 2020). Wuhan, the capital of Hubei province and China's epicenter of COVID-19, is a strategic transportation hub that transits over 120 million travelers annually through its railway systems alone (Dai, 2015). The timing of COVID-19's onset – right before the holiday travel season of Spring Festival – further exacerbates the situation. Known as *Chunyun*, hundreds of millions of migrant workers and students make about 3 billion trips between major metropolitan areas and their hometowns at this time of the year (Chen et al., 2020). Wuhan alone is reported to transit 15 million people. Prior to the citywide lockdown on January 23, 2020, about 5 million people had left Wuhan, and a third of them traveled outside of Hubei. Given the sheer volume of movement and the geographic span at the time of *Chunyun*, it is critical for timely and stringent measures to contain the spread of COVID-19 across China.

Contact tracing is a major public health strategy to contain the spread of infectious disease (Ferretti et al., 2020; Maier and Brockmann, 2020). Through contact tracing, those who have been in close contacts with infected individuals are identified, reached out to, and instructed on precautionary measures such as self-quarantine (Ferretti et al., 2020). For example, countries such as Israel (Calvo et al., 2020) and South Korea (Parker et al., 2020) have used location data to enforce quarantine rules, alert their citizens before entering high-risk areas, and notify the contacts of infected individuals. In China, tracing of high-risk groups began in late January of 2020, when all provinces across the country issued the highest-level disease control response (Kraemer et al., 2020; Tian et al., 2020). However, there are few empirical assessments of the tracing process and their subsequent impacts on traced individuals, and such knowledge is crucial to generate evidence-based recommendations to prepare government, civil organizations, and other key stakeholders so they can effectively deal with unforeseen risks associated with measures to contain the pandemic.

During the initial stage of COVID-19 outbreak in China, tracing was implemented with four distinctive features compared to established international public health measures (Meng, 2020; Wang and Tan, 2020). First, rather than identifying contacts based on confirmed or highly probable patients, tracing in China indiscriminately targeted all travelers from Hubei (Wuhan in particular) and assumed them as high-risk individuals. Second, while contact tracing was mostly undertaken by public health personnel in other countries, it was implemented in China with massive mobilization of government officials and resources to inspect all travelers on the ground, and to strictly enforce quarantine rules on individuals deemed as high risk. Third, rather than a

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strictly top-down approach, civic organizations at the community level – such as neighborhood committees and village committees – also pivoted the efforts to control the spread. Neighborhood committees in urban contexts and village committees in rural contexts are a level of unofficial administration in China. According to the Chinese Constitution, these committees are "mass self-managing organizations at the grassroots level" (Derleth and Koldyk, 2004). The committee members are often selected by residents in the community and provide a series of public services authorized by government or decided by villagers/residents. In practice, they both assist subdistrict/township governments in carrying out day-to-day governance activities and respond to residents' needs and requests. It was estimated that China had over 100,000 various forms of community organizations in urban and over 550,000 in rural areas (Mei, 2020). Fourth, unlike patients being protected by privacy regulations in the Health Insurance Portability and Accountability Act (HIPPA), tracing in China often led to the exposure of personal information such as names, ID, occupation, and home addresses of infected and high-risk individuals alongside their travel and contact details. Given such indiscriminate, compulsory, and non-private nature of tracing in China, it is likely to generate negative impacts on traced individuals, and raises concerns about how to protect personal privacy and ensure wellbeing in the midst of a public health crisis (Gao et al., 2020). It is therefore imperative to improve public and scholarly understanding of the patterns and consequences of tracing so as to inform policymaking regarding future public health responses to infectious disease control and containment.

This research contributes a timely assessment of tracing activities and impacts on individuals returned from Wuhan. We focus on one particular group of epicenter-returnees – university students. Known as a major hub of higher education in China, Wuhan hosts 89 institutions of higher education and over one million college and graduate students. Each year, these students travel between Wuhan and their hometowns during the winter break (which overlaps with *Chunyun*). In early 2020, this massive migration occurred at the initial stage of COVID-19 outbreak, which not only had significant implications on disease spread, but also brought challenges to these students in terms of how to adapt to the evolving situation of COVID-19 and cope with the associated stress of being perceived as epicenter-returnees back in their hometowns.

Drawing upon an online survey with 8,231 college and graduate students from four main universities in Wuhan, this paper investigates their spatio-temporal movements from Wuhan, experiences with contact tracing in their hometowns, and associated socio-psychological consequences. Specifically, our movement-tracing-impact framework (Fig. 1) seeks to address the following three questions: 1) What is the spatio-temporal movement pattern of students leaving Wuhan at the beginning of the COVID-19 outbreak? 2) Whether and how are students traced in their hometown across China? 3) How are students affected by tracing socially and psychologically? To answer those questions, we first analyze the timeline and geographic destinations of student migration from the epicenter that propelled local governments and community organizations across the country to undertake strict measures to contain the spread of disease. Then, we examine the tracing patterns across provincial units in China to reveal the prominent features of local disease control activities. Next, we investigate impacts of tracing on students in terms of their social and psychological consequences. Finally, we discuss our research implications and provide policy recommendations on balancing the goals between maximizing health benefits and minimizing harm on traced individuals in future disease control efforts.

2. Methods

Our data were collected through an online survey, which is arguably the most practical and appropriate method for data collection in the midst of a public health emergency. Participants were selected from four major national public universities in Wuhan, including Wuhan University, Huazhong Agricultural University, Central China Normal University, and Huazhong University of Science and Technology. Local students from Hubei province account for 20%–25% of undergraduate students in each of the four universities. The allocation of enrollment quota to other provinces is determined by two main factors: 1) the number of students participated in the college entrance exam in the province; and 2) the total population of the province. These four prestigious academic units have student populations with diverse geographic origins and socioeconomic backgrounds, which allow us to investigate tracing activities on Wuhan-returned students across China.

Between January 28 and 30, 2020, we distributed our survey via WeChat and email, and students participated in the survey on a voluntary basis. Our survey design was based on a similar survey that investigated the experiences of COVID-19 control measures of the general public (Yang et al., 2020). It includes questions on students' spatio-temporal movement at the inception of the outbreak, their experiences of being traced in hometowns (based on self-reported experiences of being contacted by local governments and community organizations), and their perspectives towards the impacts of tracing on personal wellbeing. All participants were anonymized to protect their identity. After removing invalid and incomplete answers, our sample included 8,250 responses, with students from all 31 provinces and municipalities of China. Since the study primarily focuses on local tracing of students returned from Wuhan, we excluded 19 students from the survey who were Wuhan residents (Table 1).

The majority of the students (78%) were pursuing college degrees across different disciplines, while the rest enrolled in master's or doctoral programs in the four universities. Students in their graduating

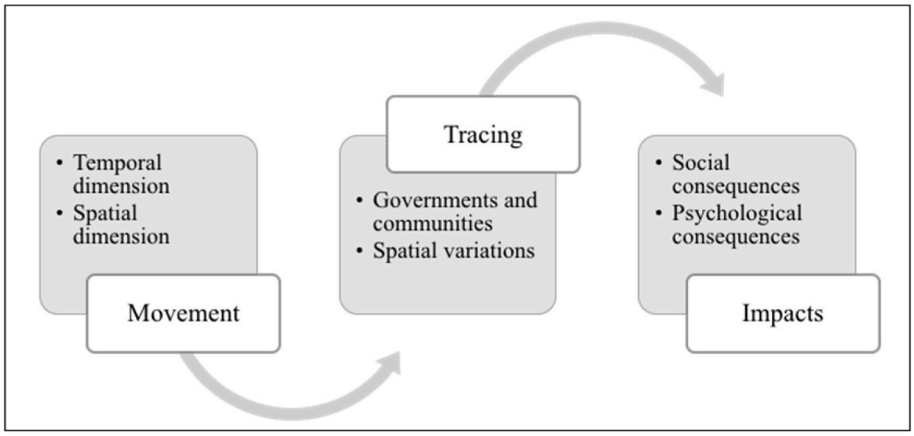

Fig. 1. Research framework.

Table 1
Sample characteristics (N = 8231).

Characteristics	Count	Percent
Sex		
Female	5039	61%
Male	3192	39%
Degree		
Undergraduate	6390	78%
Graduate	1841	22%
Degree status		
Graduating	1556	19%
Non-Graduating	6675	81%
Places of origin		
Hubei (excluding Wuhan)	1292	16%
Rest of China	6939	84%
Hukou status		
Urban	4661	57%
Rural	3570	43%

year account for 19% of our sample. In terms of places of origin, the sample consists of 1292 intra-provincial migrant students from Hubei, and 6939 inter-provincial migrant students from different parts of the country. Students with urban *hukou* status account for 57% of the sample. *Hukou*, or household registration, is an official documentation of a person's residency classification into agricultural (rural) or non-agricultural (urban) status. It also records a person's location of residence, i.e. places of belonging. Through *hukou*, government manages the physical mobility of Chinese citizens and determines if rural migrants can access *hukou*-based social services such as housing, education, health care in Chinese cities. Although the government has reformed *hukou* system over the past decades, it still functions as a mechanism of differentiation and results in social inequality (Chan, 2018).

Based on the survey data, we first investigated the pattern of students' movement over time and across provinces. For one, we analyzed students' movement against the major events along with the timeline of disease evolution in China, such as whistleblower warning, reporting unknown pneumonia to WHO, confirmed human-to-human transmission, and citywide lockdown in Wuhan. For another, we assessed the geographic destinations of these students and estimated the proportion of students being traced by local government and community organizations. We further compared tracing activities across provinces and between urban and rural areas.

We also investigated the social and psychological consequences of tracing. Specifically, we used the ordinary linear squares (OLS) regression to test the relationship between tracing and three types of social consequences - privacy infringement (i.e. personal information being disclosed to the public), verbal slur (i.e. allegation of returned students as potential carriers of COVID-19), and warning delivered to them at their residence at the provincial level. We adopted the nearest neighbor matching algorithm to evaluate the psychological consequences of tracing (Ho et al., 2007, 2011). During the survey, students were asked to report their level of fear and anxiety towards COVID-19, and their evaluation of the disease's future development; all were measured by an ordinal scale from 1 to 5 (a higher score indicates greater fear, anxiety, and pessimistic feeling). The matching method involved first pairing each observation in the treatment group (i.e. students who experienced tracing) to similar observations in the quasi-control group (i.e. students who did not experience tracing) based on individual characteristics and broader societal conditions. Our assumption was that the socio-psychological wellbeing scores of matched students in the quasi-control group is an estimate of the scores of students in the treatment group had they not been traced after controlling for individual characteristics and societal conditions. Eight variables were used for matching: personal characteristics include age, gender, graduate or undergraduate student status, graduating or non-graduating status, and *hukou* status; and broader societal conditions including total cases of COVID-19 in their home province by January 30 (when our survey was completed), the GDP per capita of their home province in 2019, and distance to Wuhan. Based on the matched samples, we then conducted OLS regressions to test the relationships between tracing and psychological indicator scores. Because anxiety and fear are highly correlated, we excluded the latter in our regression. All data analyses in this research was performed in the R statistical software (R Development Core Team, 2018).

3. Patterns of spatio-temporal movement

The outbreak of COVID-19 occurred simultaneously with the massive population movement under *Chunyun* in China, when hundreds of millions of migrant workers and university students traveled back to their hometowns for the lunar New Year. For our student sample, the movement started before a whistleblower warning about a SARS-like pneumonia on Dec 30, 2019 (Fig. 2). The peak of movement occurred around January 10, 2020, which was consistent with the official start date of winter break for those four universities (ranging between January 9 and 13) and was 10 days before the official confirmation of human-to-human transmission of COVID-19. By January 23, when the Wuhan government announced citywide lockdown, over 99% of students of non-Wuhan origin in our sample had already left the city. The end of student migration coincided with the beginning of soaring COVID-19 case across China, and the WHO eventually announced COVID-19 as a global health emergency on January 30.

As COVID-19 became a national and global crisis, students' knowledge of the disease also grew over time. In general, students in our sample reported being aware of COVID-19 relatively early, but it took them a while to become vigilant about the severity of the disease (Fig. 3). Over 32% had heard about the emergence of SARS-like disease before December 30, the day when the local government in Wuhan made an official announcement of unknown pneumonia cases. Another 37% learned of the disease from the government announcement on Dec 30. Yet, 57% of the students did not take the disease seriously until January 19, one day before the official confirmation of human-to-human transmission by a leading infectious disease expert in China. This time lag between the disease's onset and official recognition of its high transmissibility likely resulted in students' failure to take precautions until serious outbreaks were reported in Wuhan and beyond, which led to hasty control measures adopted by central and local governments across China to contain the spread.

On the spatial dimension, the Wuhan-returned students covered all provincial-level administrative units in China. Among the 8231 non-Wuhan students, 5% had already left the city for their hometowns that cover all provinces except Hainan by December 30 (Fig. 4A). As of January 15, 81% had left Wuhan for their hometowns in all provinces of China (Fig. 4B). Another 19% of students left Wuhan after January 15 but before the lockdown on January 23 (Fig. 4C). In general, provinces that are closer to Hubei host a larger number of Wuhan-returned students. The top five home provinces are Hubei, Henan, Shandong, Hunan, and Hebei, which account for 43% of all students in our sample.

By the time provinces across China began to respond to the disease in late January, the majority of returned students had already passed the incubation period of 14 days. Yet, as the following section shows, a large proportion were still identified as high infection risk individuals by their hometown government agencies and community organizations.

4. Government and community tracing

As COVID-19 spread rapidly across China under *Chunyun*, Guangdong and Zhejiang, where large numbers of infected cases were first reported outside of Hubei, announced the highest-level of emergency response on January 23. As of January 29, all provinces in China issued similar emergency response measures.

While scholarly and media studies heavily focused on the central government's handling of COVID-19, local intervention also played a

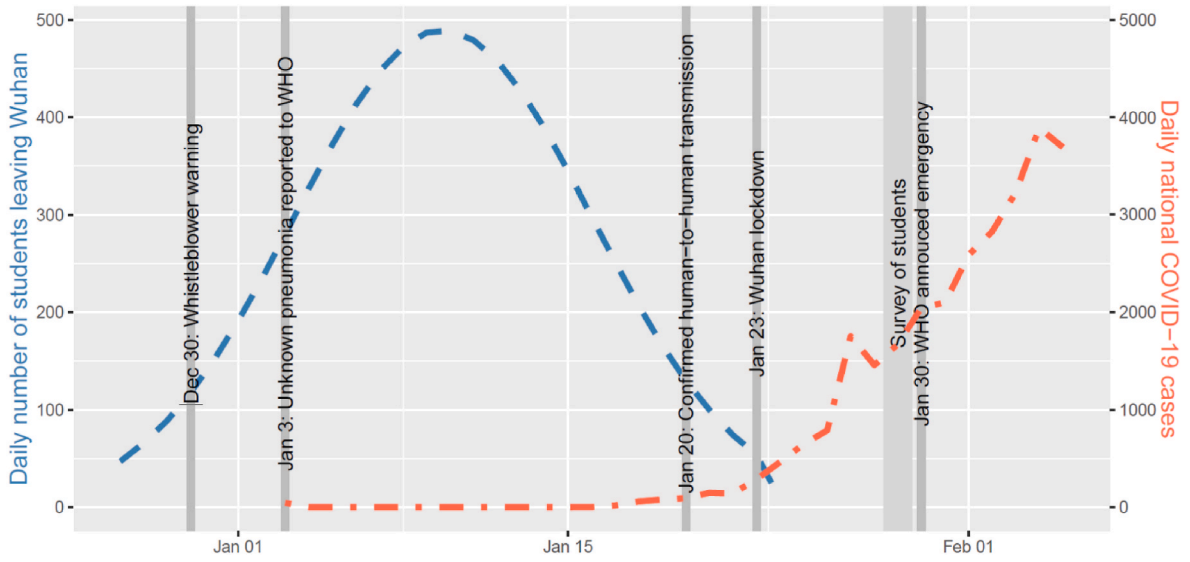

Fig. 2. Temporal movements of students and daily new cases of COVID-19 in China.

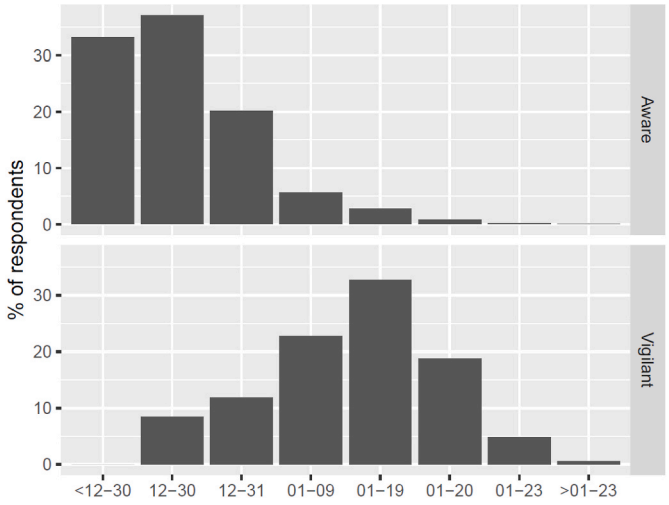

Fig. 3. Timeline of students becoming aware of and vigilant about COVID-19. The six major dates in the timeline include: 1) 12–30: whistle-blower warning; 2) 12–31: end of year 2019; 3) 1–9: start of winter break in 2020 for the four major universities in Wuhan; 4) 1–19: the day before official confirmation of human-to-human transmission; 5) 1–20: the day when human-to-human transmission was officially confirmed; 6) 1–23: the start of Wuhan lockdown.

crucial role in controlling the spread. The local mechanisms, such as locking down residential communities, enforcing quarantine and daily temperature checks, contact tracing, and providing personal/household services, were primarily executed by various governance bodies. For one, together with provincial and municipal bureaus of National Health Commission, officials at multiple levels of administration and from various segments of the government system were mobilized to participate in activities to contain the disease. For example, the provincial high court mobilized over one thousand of its employees to work in neighborhoods for disease control. In a district of Beijing, a daily estimate of 2500–3000 officials worked in communities from the end of January (Mei, 2020).

For another, traditional community organizations of neighborhood/village committees as well as property management companies and homeowners' associations were also active in conducting tracing and delivering household services. The recently developed grid governance system also played crucial roles in disease control. Under this system, urban and rural areas are partitioned into a number of grid cells, each including a few residential buildings with 300–500 households (He et al., 2020; Ren, 2020). Grid managers are assigned to handle a wide range of social affairs within the grid, and can serve as the intermediary between community organizations and subdistrict/township governments. Originally established for identifying and preventing potential social issues, the grid system has mobilized the grassroots resources and manpower for timely information collection, preventive measures enforcement, and service delivery in the midst of COVID-19 (Cai, 2018).

In the early stages of local response to COVID-19, a major strategy to contain the spread was to trace and inspect any personnel traveling from Hubei, and Wuhan in particular, and to place them in self-quarantine at home. As observed by journalist Peter Hessler (2020a) in Chengdu, Sichuan:

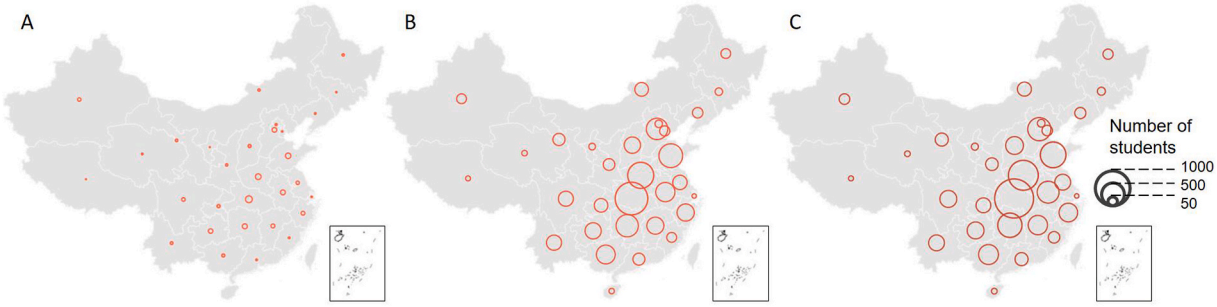

Fig. 4. Cumulative number of students who left Wuhan for their hometowns by Dec 30, 2019 (A), Jan 15, 2020 (B), and Jan 23, 2020 (C).

> [T]he government tracked such links so intensively that locals became terrified by the sight of a car with Hubei plates. Many Chengdu hotels turned away guests from Wuhan. […] [T]he Party team organized periodic door-to-door surveys, which was how they learned of the resident's Hubei trip. Thus far, people had come to my apartment three times, and they always asked about Hubei and Wuhan. Their policy was to call the community's Health Service Center if anybody had visited those places.

Similarly, although over 85% of the students in our sample had spent at least 14 days in their hometown before the start of nation-wide responses to COVID-19, a large proportion of them were still identified as high-risk groups. Overall, 47% of the students reported being traced by local governments in their hometowns, and 59% by community organizations. Among students from Hubei (excluding Wuhan), 11% were contacted by local governments, and 39% by community organizations. Among those of non-Hubei origin, the rates were 54% and 63% respectively. One possible explanation for the greater tracing activities in non-Hubei provinces is that during the early outbreak of COVID-19, the Hubei government was overwhelmed by other disease control and treatment tasks, while other provinces' priority was on monitoring travelers from Hubei.

Our study not only highlights the prevalence of tracing, but also reveals the geographic unevenness of tracing activities. In fact, while containing the spread was of paramount importance to the central government, local administrations still retained autonomy in specific intervention measures based on the severity of local COVID-19 outbreak. Our survey reveals a high proportion of students who reported tracing by local governments in Heilongjiang (86%), Ningxia (85%), Hainan (85%), and Xinjiang (83%) (Fig. 5A), even though these provinces had a relatively small number of infected cases by the end of January and were not major home origins of migrants in Wuhan. In contrast, students from Zhejiang (90%), Fujian (86%), Jiangsu (82%), Anhui (75%), Jiangxi (75%) reported a high rate of community tracing. These provinces not only had relatively larger numbers of infections and more returnees from Wuhan, but also had developed diverse modalities of governance at the neighborhood level that could potentially translate to more efficient community tracing (Li, 2017). Students from Ningxia (80%), Xinjiang (73%) and Zhejiang (72%) experienced high rates of tracing by both local government and community organizations (Fig. 5C).

In addition to provincial variations, significant differences also exist between students from urban and rural areas. For urban students, the tracing rate by local government was 46%, lower than those from the rural area at 49% ($p = 0.02$). However, in terms of tracing by community organizations, students living in rural areas reported a rate of 71%, which was 21% higher than urban-based students at 50% ($p < 0.01$). Further analysis of provincial variations of the urban-rural differences in local government tracing reveals that Tibet (100%), Heilongjiang (87%), Ningxia (84%), Xinjiang (83%) were the top reported provinces for urban-based students (Fig. 6A); whereas Hainan (91%), Qinghai (88%), Ningxia (86%), Inner Mongolia (84%), and Heilongjiang (83%) were top for rural based-students (Fig. 6B). As for community tracing, the top areas for urban-based students included Ningxia (94%), Zhejiang (89%), Fujian (83%), Xinjiang (81%), and Tianjin (78%) (Fig. 6C); and the top ones for rural-based students were Qinghai (100%), Gansu (98%), Xinjiang (97%), Ningxia (95%), and Tibet (93%) (Fig. 6D) (see Fig. 7).

Several reasons can explain these urban-rural differences. First, given the comparatively poorer access to health care services in rural areas, local governments and community organizations may be more concerned with rural outbreaks. Second, village committees in rural areas typically have higher social mobilization capacity comparing to residential committees in urban areas due to relatively deeper social ties and greater authority over community resources (X. Fei, 1992). Second, the relatively intimate social relations in China's rural society indicates that news can spread quickly in village communities (Knight and Gunatilaka, 2010), which could have facilitated the identification of Wuhan-returnees more rapidly compared to urban areas.

As discussed earlier, the majority of students in our sample had returned home and passed the incubation period of 14 days before local governments and communities started to trace Wuhan-returnees. As a result, most students in our sample believed that their chance of being infected was low, with a mean score of 2.21 and median of 2 (on a 1–5 scale where 5 indicates the highest likelihood of infection). Nonetheless, being identified by home governments as high-risk populations brought various impacts on their lives.

5. Impacts of tracing

When students were traced by local governments and/or community organizations, their identities as Wuhan-returnees were likely to be disclosed in their neighborhoods and hometowns. For confirmed COVID-19 patients, it is common practice to collective personal information such as name, occupation, and address. Such information is published on local media and disseminated through WeChat (i.e. the Chinese version of WhatsApp) discussion groups or official accounts. In extreme cases, apartment doors of high-risk individuals were sealed to prevent them from leaving their residence (Hessler, 2020b). Our survey with students reveals a number of social and psychological consequences of government and community tracing activities.

5.1. Social consequences

Our survey explored whether being identified as Wuhan-returnees led to negative experiences for students, in terms of privacy infringement, verbal slurs, and warnings at residence. Overall, 36.4% students experienced privacy infringement, which included the leakage of personal information such as name, ID, and home address. Another 20.4% suffered from verbal slurs or other types of harassment in their communities. Moreover, 6.5% of students experienced hostile warnings at

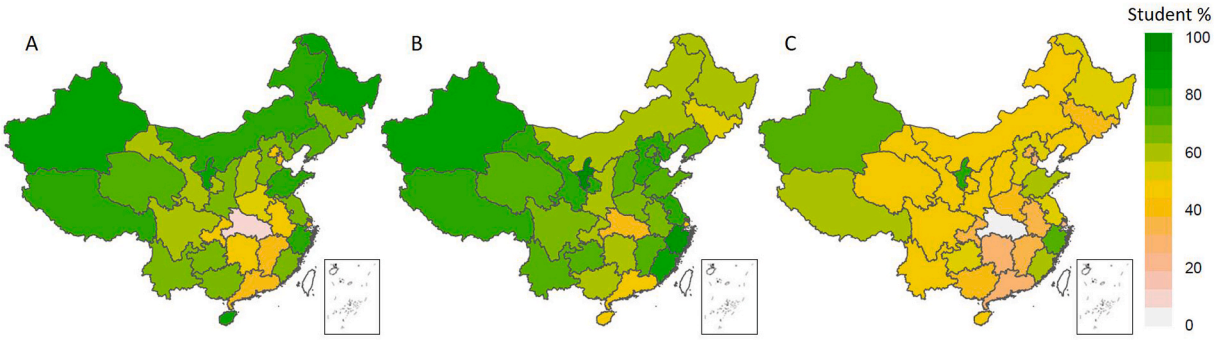

Fig. 5. Proportion of students traced by local government (A), community organizations (B), and both (C) across provincial units in China.

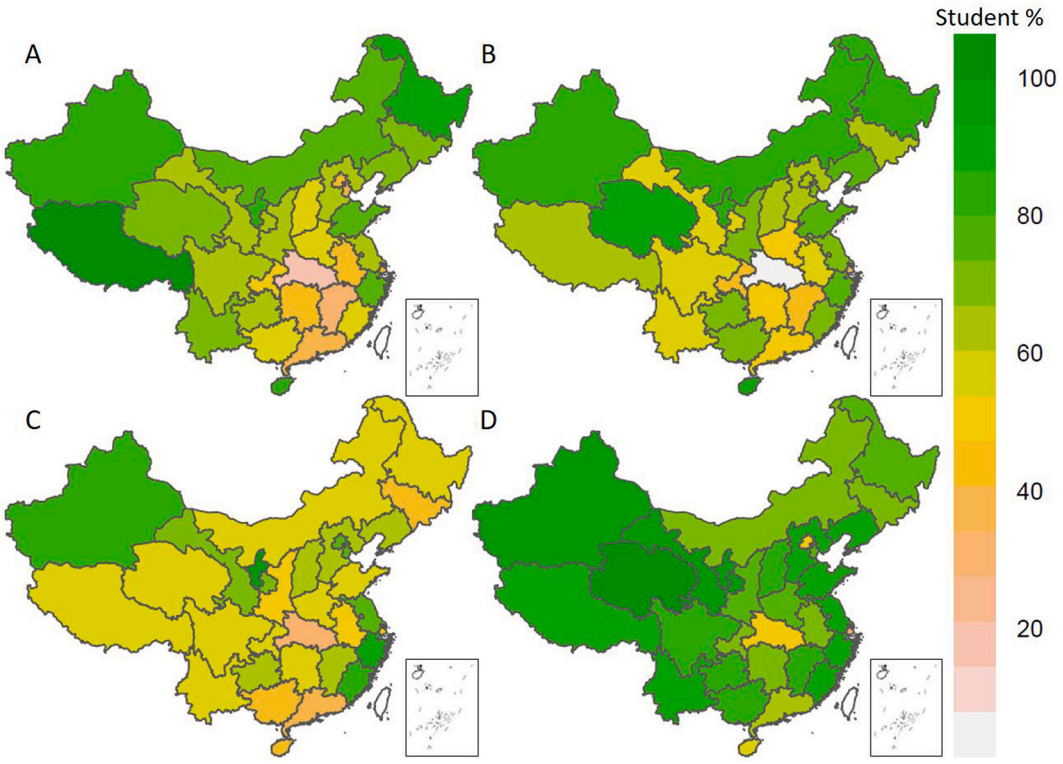

Fig. 6. Proportion of students traced by local government in urban (A) and rural (B) areas, and by community organizations in urban (C) and rural (D) areas.

Fig. 7. The proportion of Wuhan-returned students that experienced privacy infringement (A), verbal slur (B), and warning at residence (C).

their residence, such as hanging banners to notify students about the risks they brought to the community.

Geographically, students from southern provinces reported a lower rate of negative experiences of all three types than those from northern provinces. Specifically, those from Guangdong reported the least suffering, with only 12%, 8%, and 1% for each type of experiences, respectively. In contrast, students from Inner Mongolia (70%), Shandong (56%), and Heilongjiang (48%) reported a high rate of privacy infringement; those from Liaoning (28%), Ningxia (25%), and Shandong (21%) experienced a high rate of verbal slur; while those from Xinjiang (13%) and Henan (9%) suffered from a high rate of warning at residence compared to other provinces. Overall, students in rural areas were more prone to various negative consequences than those based in cities.

We further assessed how the three types of social consequences are related to government and community tracing. The results show that compared to untraced students, traced individuals reported a significantly higher rate of unfriendly treatment in their hometowns ($p < 0.01$) (Fig. 8). Both government and community tracing approximately doubled the occurrence of privacy infringement and slur for traced students. Among them, it is important to note that community tracing nearly quadrupled the ratio of warnings at residence, while local

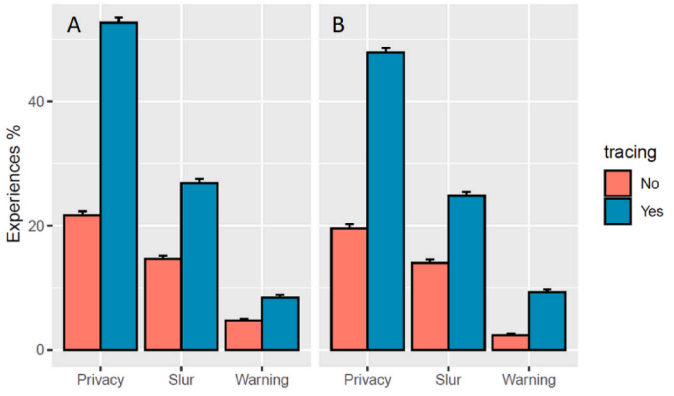

Fig. 8. Government (A) and community (B) tracing on students' experiences of privacy infringement, verbal slur, and warning at residence.

government tracing doubled this consequence.

We applied OLS to test the relationships between tracing activities and the three social consequences in students' hometowns at the provincial level. The results suggest that the positive relationships are significant at the 0.1 level for privacy infringement by government and community tracing; at the 0.05 level for slur by government tracing; and at the 0.01 level for warning at residence by community tracing (Fig. 9). Specifically, while tracing is likely to result in a higher chance of privacy infringement, the effect is marginal for both government and community tracing: for 1% increase in tracing rate, there is 0.3% increase in disclosing personal information. In terms of verbal slurs, only government tracing led to significantly higher negative experiences, with a 1% increase in tracing resulting in a 0.16% higher slur reporting. Regarding warning at residence, while government tracing demonstrated no significant relationship, community tracing clearly increased the likelihood of this consequence, with 1% of higher local tracing leading to 0.2% higher occurrence of warning at residence.

5.2. Psychological consequences

In addition to the above three types of social consequences, we also investigated the psychological impacts of government and community tracing. Specifically, we focused on students' levels of anxiety, fear, and perceptions towards the future development of COVID-19 as a result of tracing. Overall, on a scale from 1 to 5 that represents greater concern, most students reported a moderately high level of anxiety (mean = 3.53, median = 4) and fear (mean = 3.34, median = 3), and the two were highly correlated (correlation index = 0.85). In terms of their perception of how COVID-19 would evolve in the future, most students were pessimistic about its broader impact on the society, with mean at 3.81 and median at 4.

Results from OLS model estimation based on the matched sample suggest that tracing by government and community generates different impacts on students (Tables 2&3). Specifically, we find that both government and community tracing significantly increased students' pessimistic feeling towards the future prospects of COVID-19. However, their effects on anxiety were different. In contrast to community tracing that led to significantly higher anxious feeling by students, the effect of government's tracing activities was insignificant.

Table 2
Estimation of relationships between anxiety/pessimism and government tracing (n = 7010).

Variable	Anxiety		Pessimism	
	Estimate	Std. Error	Estimate	Std. Error
Intercept	3.525***	0.015	3.787***	0.013
Local gov	−0.004	0.021	0.060***	0.019

Significance code: ***: p < 0.01.

Table 3
Estimation of relationships between anxiety/pessimism and community tracing (n = 5064).

Variable	Anxiety		Pessimism	
	Estimate	Std. Error	Estimate	Std. Error
Intercept	3.494***	0.018	3.787***	0.016
Community	0.090***	0.025	0.052**	0.022

Significance code: ***: p < 0.01; **: p < 0.05.

6. Discussion

Although the Chinese government's delayed response to the onset of COVID-19 was much criticized, the country has later managed to contain the spread of disease by taking a series of control measures. Emerging studies have identified distinctive elements of the Chinese approach to the public health crisis, including the strong and determined central party-state leadership, the bureaucratic mobilization of nationwide resources, the rigid social control over populations, the collectivist culture in Chinese society that is marked by people's willingness to sacrifice personal interests for societal benefits, and the experiences from combating previous crises such as SARS (He et al., 2020; Mei, 2020; Ren, 2020; Tian et al., 2020).

Among various efforts to contain disease spread, the role of local initiatives and actions is becoming increasingly recognized (Cheng et al., 2020; Zhang et al., 2020). Attributing disease control outcomes solely to central leadership can be misleading as it overlooks the massive mobilization efforts by local governments and community organizations at the frontline of disease control and containment. In the midst of COVID-19, local interventions were administered and executed by an extensive network of institutions and authorities, including

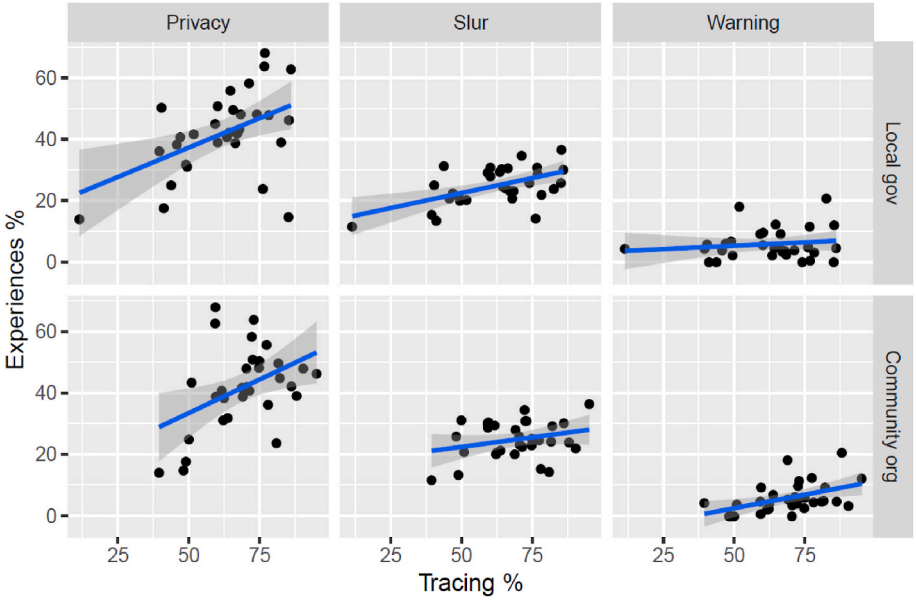

Fig. 9. Relationship between percent of returning students that were traced by two types of agencies and three types of social consequences.

governments at municipal, township, district and street levels, traditional community organizations such as homeowners' associations and property management companies, as well as the newly developed grid governance system. The grassroot-level interventions not only allowed for timely information collection and implementation of prevention measures, but also effectively promoted education of and knowledge dissemination to residents to adopt proper self-protective measures across China.

Despite these achievements, local strategies for disease control at the early stage of COVID-19 outbreak were not free from issues. After provinces across China announced emergency responses to COVID-19 at the end of January 2020, massive resources were mobilized to screen local populations and identify individuals who came from the epicenter. Among them, students who returned home from Wuhan for winter break were targeted and tagged as high-risk individuals, and their lives were affected as a result. It is under this background that our research, based on a survey of over 8000 Wuhan-returned students, provides timely and crucial evidence on their spatio-temporal movement patterns, experiences of tracing, and socio-psychological wellbeing.

In terms of students' movement patterns, we find that provinces closer to Hubei hosted a larger proportion of Wuhan-returned students. This echoes a gravity model prediction that there is a higher travel volume from Wuhan to geographically proximate provinces (Jia et al., 2020). In our sample, students' movement peaked on January 10, which is at the early stage of massive population movement from Wuhan according to the literature (Pan et al., 2020). Therefore, when students traveled to their hometowns, the general public across China was largely unaware of the emergent pandemic and was yet to take preventive measures.

Our analysis of the temporal migration patterns suggests that most students had passed the incubation period and should have been considered low risk when their hometown officials initiated disease response measures. Yet, students in our survey still reported a high rate of tracing by local government and community organizations. Analysis of tracing measures reflects not only the pronounced urban-rural divide but also the inter-provincial variation in local governance activities. The economic reform since the late 1970s has resulted in entrenched spatial variation and unevenness in economic development, social infrastructure, governance style, and cultural openness/awareness across provinces (Wei, 2001). This variation not only exists between rising urban areas and declining rural regions, but also among regions. In the latter case, decades of reform have opened up China's coastal regions to foreign investment, western culture, and modern ways of living (Fei, 2017). These provinces have also become pivotal places to experiment with diverse governance styles. In contrast, the "rust-belt" provinces in the northeast and frontier provinces in the northwest have lagged in social and economic developments (Denyer, 2015; Goodman, 2004). These differences are reflected by how provinces handle public health emergencies such as COVID-19.

Moreover, our research shows that tracing activities are far from being risk neutral (Fahey and Hino, 2020). Our research reveals social consequences and psychological impacts of tracing. On the one hand, students across China experienced various levels of privacy infringement, verbal slurs, and warnings at their residences. On the other hand, students also expressed moderate to high levels of fear, anxiety, and pessimistic views of the future development of COVID-19. While existing studies have shown that direct exposure to a public health emergency can reinforce public mental health problems (Ji et al., 2017; Mak et al., 2009; Ran et al., 2020; Xie et al., 2020), our research identifies additional risks associated with local intervention measures.

Therefore, despite the justification to protect the health of the broader population, tracing is likely to generate negative consequences if left unregulated in the effort to mitigate public health risks. In China, both local governments and community organizations have been mobilized to trace individuals with likely exposure to COVID-19. Although containing disease spread is a widely recognized achievement, there is emerging concern regarding how to balance maximizing health benefits and minimizing harm. Among various control measures, it is crucial to choose the one that least compromises individual wellbeing. Recent studies have shown that it is feasible to conduct contact tracing without collecting and storing extensive amounts of personal information (Abeler et al., 2020). It is therefore possible to adjust tracing measures to incorporate more ethical standards and practices in such procedures (Ferretti et al., 2020).

Since 2020, various technical and legal approaches were adopted in China to improve its public health emergency reports system. For example, instead of traditional forms of tracing, IT technologies were widely utilized for tracing purposes. Residents are required to check in with government-approved apps when entering public places like hospitals, shopping malls and buses. Check-in data can be used to identify close contacts when a confirmed case reports the places s/he has visited, which has significantly increased tracing accuracy. Moreover, *Suggestions on Punishment of Illegal and Criminal Offenses Against Prevention and Control of COVID-19* was jointly issued by Supreme People's Court, Supreme People's Procuratorate, Ministry of Public Security, and Ministry of Justice. It stipulates the obligations of residents during disease containment activities and provides a legal basis to regulate uncooperative individual behaviors, such as violating quarantine requirements and information hiding (Yao, 2021).

In addition to improving measures of contact tracing, the Office of the Central Cyberspace Affairs Commission issued a notification on the protection of personal information during data-driven disease control in February 2020. The notification identifies the legal entities that can collect and disseminate tracing information, which includes medical institutions, disease control agencies, township/subdistrict governments, and residential/village committees. Unauthorized community organizations, however, are not allowed to collect personal information. The notification also identifies two criteria for information collection: informed consensus and minimum information disclosure. Particular in the latter case, it requires data collectors to anonymize affected individuals and limit the information shared to the public (Jiang, 2020; Yan and Wu, 2020).

We acknowledge a few limitations of our research that need to be addressed in future research. First, our survey was conducted in a short time frame and with a particular focus on student population. Future research should survey a wider population and obtain a more representative sample of returnees from Wuhan or other heavily-impacted areas in China. Second, in our analysis, we used self-reporting to determine whether a student was being traced. Future research design should incorporate additional questions to cross-validate the experience of tracing by different agencies. Third, we identified three social consequences and three psychological impacts of tracing. It is imperative for future research to include more diverse social, economic, and psychological indicators to better assess the wellbeing of traced individuals. Fourth, our research offers only an initial investigation of the spatial patterns of movements and tracing impacts. Given the rapidly changing policies and practices in China regarding COVID-19, future research needs to continue monitoring new improvement and emerging challenges in tracing activities. It is also crucial to monitor the long-term impacts of tracing with multiple rounds of surveys based on longitudinal data on the mental health and wellbeing of returnees, which will certainly evolve alongside the development and containment of COVID-19 in China and globally.

7. Conclusion

Tracing returnees from Wuhan was a primary strategy in containing the initial outbreak of COVID-19 in China. Rather than focusing on confirmed patients, any individuals who returned from Wuhan could be subject to local government and community tracing. However, scholars are yet to assess the tracing process and their subsequent impacts on the traced individuals. The unique Chinese approach of tracing,

characterized by indiscriminate identification of all travelers from high-risk areas, a combination of government and community tracing, and public exposure of the identities of high-risk population, necessitates timely scholarly assessments. This paper addresses the knowledge gap by investigating the wellbeing of returned university students in the midst of COVID-19 in terms of how they were traced in their hometowns and what consequences these tracing activities incur to their daily lives and wellbeing.

Drawing upon an online survey with over 8000 students from four major universities in Wuhan, our research provides quantitative assessments on the spatio-temporal movement of students and tracing efforts by local government and community organizations, and highlights the socio-psychological impacts of tracing. We find that tracing activities vary across provinces and between urban and rural areas. While tracing contributes to disease control, it is also likely to generate unintended consequences such as increasing the risks of privacy infringement, verbal slurs, and warnings at residence, and leads to anxious and pessimistic feelings for traced individuals.

Our findings emphasize the need for government agencies and local communities to work together to be more strategic in infectious disease containment policy implementation, and enhance health infrastructure in less developed regions to alleviate negative effects on these groups. Despite improvement in tracing measures and privacy regulations, there is room for additional enhancement in public health emergency response system to balance the twin goals of maximizing disease containment and minimizing the negative impacts on individuals. For example, policy makers can consider incorporating the HIPPA regulations during disease control implementation, and provide training to data collectors at government and community levels to promote ethical practices, privacy awareness, and sensitivity to confidentiality issues.

Credit author statement

Ding Fei: Conceptualization, Writing – original draft, Methodology, Writing – review & editing. Chuan Liao: Writing – original draft, Data curation, Methodology, Writing – review & editing. Huan Yang: Conceptualization, Writing – original draft, Data curation, Writing – review & editing.

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