School closure policy and infectious diseases

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Abstract

COVID-19 has drawn people's attention to public schools' influence on infection rates, but understanding its magnitude remains highly imperfect. To deepen our knowledge of factors affecting the transmission of infectious diseases with properties like COVID-19, I study influenza, pneumonia, and other respiratory infection to uncover intertemporal, within-family, and across-age cohort infection patterns. The key policy question is the extent to which changing school vacations, opening and closing dates affects infection transmission, which affects not only School-age children but also preschool, college, and adult populations. I combine patient information and diagnoses from the Merative® (formerly IBM) MarketScan® Commercial Database between July 1. 2010, and June 30, 2019, with MSA-level weekly school data previously collected by the author with coauthors documenting school opening and closing dates over the same pre-pandemic period (Chen et al., 2021). I use linear probability models that also include weather and other MSA-level control variables on a sample of 122,487,230 individuals and their weekly diagnostic data. I find that within-family infection rates of pneumonia, influenza, and other respiratory infection, especially high school students' infection rates, rise as the number of days schools are open. Infected primary and high school students are the main introducers of pneumonia, influenza, and other respiratory infections. School boards and local governance can use the methodology and results of this study to shape school closure policies that improve student welfare and limit the spread of infectious diseases.

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I Introduction

Recently, the public school closure policy reduced the peak infection rates of COVID-19 significantly (Keskinocak et al., 2020), which raises the question of whether the school closure policies effectively reduce the infection rates of other infectious diseases spreading via droplets. Public schools play a critical role in transmitting infection among students and between students and their families. School activities increase contact between students. Then, when students go home, they can transmit infectious diseases (influenza) to households (Longini et al., 1982). However, previous literature focused on the short-term effects of school closure policies on the local infection rate of COVID-19.

School districts decide school opening, closing, and vacation dates mainly based on state laws, social costs, and community consistency to ensure students' achievements (Drew, 2019). Nevertheless, they have not realized public schools' critical role in spreading airborne infectious diseases. School schedules vary by time and geography and change in the long run (Drew, 2019). The infection rates of some airborne infectious diseases that have appeared for decades, such as influenza, also vary by year and location. Understanding how altering school vacation periods and opening and closing dates impacts the spread of infections on a national scale can help policymakers and school boards maintain students' achievements while reducing infection rates.

This paper studies the transmission of three common airborne infectious diseases, pneumonia, influenza, and other respiratory infections, under regular school schedules with nine-year panel data, controlling seasonal and regional effects. With linear probability models, I mainly answer the following questions: (1) How do school schedules affect the infection rates of different aged people? (2) How are the three infectious diseases transmitted within families? (3) What factors (season, locations, or school closure policies) play a major role in spreading the three infectious diseases?

I collect patients' information and diagnoses from the Merative® (formerly IBM) MarketScan® Commercial Database between July 1. 2010, and June 30, 2019, with MSA-level weekly school data previously collected by the author with coauthors documenting school opening and closing dates over the same pre-pandemic period (Chen et al., 2021). I also web-scrape daily maximum and minimum temperatures, UV index, humidity, precipitation, and wind speed from each MSA- plus region's World Weather Online (WWO) website from July 1, 2010, to June 30, 2019.

With a sample of more than 120 million individuals, I explore the effect of public school schedules, the existence of infected family members, and weather conditions on the spread of pneumonia, influenza, and other respiratory infections, grouped by weeks over nine years (from July 1st, 2010 to June 30th, 2019). I use linear regression models that also include weather and MSA-level control variables. I find that pneumonia, influenza, and other respiratory infection rates significantly increased as more open school days. The result also states that having infected primary and high school students in the family significantly increases the probability of getting infected in homes. Schools and government policymakers can limit the spread of infectious diseases while keeping students' welfare based on the results of this study. The method and result of this study can also be leveraged to map the spread of COVID-19 better when it comes to the second stage.

II Literature review

To detect and control an emerging infectious disease, knowing how it transmits and limiting its transmission is urgent before the invention of vaccines (Cohen, M., 2000). A considerable amount of new literature shows that school closure policies efficiently limit the transmission of COVID-19. For example, Auger et al. (2020) investigated surveys from the United States and found that school closure directly decreased COVID-19 infection rates. Similarly, Keskinocak et al. (2020) found that school closure reduced the peak infection rates in Georgia. In addition, a rich study explores how school reopening influences COVID-19 incidence. Using data from Florida, Miron (2021) concluded that public school physical reopening increased COVID-19 incidence. However, other research has a diverse opinion about the role of students in COVID-19 transmission. For example, Harris et al. (2021) stated that school reopening did not increase the hospitalization rate due to COVID-19 by using data from the 2020 fall, which means that school closure may be unnecessary in the counties with lower hospitalization rates.

School closure is also an effective policy for reducing the transmission of other infectious diseases with the same spreading method: droplets. Previous literature showed that school closure reduced the infection rates of H1N1 and influenza (Isfeld-Kiely & Moghadas, 2014; Jackson et al., 2016). School closures in the US and Hong Kong reduce the number of H1N1 cases during the peak period (Wong et al., 2016). In addition, the effectiveness of school closure policies on infection rates depends on the severity and transmission speed of the infectious diseases and the duration and timing of school closure (Araz et al., 2012). School closure will significantly influence infection rates if infectious diseases have lower transmissivity (Mangtani, 2014; Jackson et al., 2014). If schools regularly open until the severity of a contagious disease reaches a certain level, it would be more challenging to control the transmission of the infection (Kahn, 2007). Hence, policymakers should play a role in choosing start dates and duration of school closure based on the severity and transmission speed of the infectious disease (Halder et al., 2010). Moreover, decisions on the starting time and duration of school closure should consider the weather and school population (Earn et al., 2012; Donaldson et al., 2020). Larger schools have higher influenza attack rates than smaller schools, so they need to pay more attention to the infection rates and decide the outbreak date and duration earlier (Donaldson et al., 2020)

Students are an essential source of influenza to other members of their families. Longini et al. (1982) showed that children are the primary sources of influenza in households. Sick children infect about 40 percent of household patients with flu (Vibous et al., 2004). Li and Leader (2007) also found that families with school-aged children have higher health spending than other families. Therefore, days schools remain open affect not only students but other people's infection rates. Two or more days' vacations would be long enough to reduce the peak infection rate of some mild infectious diseases, such as influenza (Cooley et al., 2016).

The above studies argue that students play vital roles in infection transmission. Therefore, it is crucial to explore the relationship between the days public schools remain open and infection rates of different diseases (Chao et al., 2010). However, previous studies have ambiguous results about the effect of school closure policies on infection rates of COVID-19 and only focus on severe emerging infectious diseases and influenza. To uncover intertemporal, within-family, and across-age cohort infection patterns, I study three common airborne infectious diseases with different severity and transmission speeds: pneumonia, influenza, and other respiratory infections.

III Data

School calendar data

This study takes advantage of a previous study that collected, analyzed, and cleaned the public schools' calendar information for Academic Years (AY) 2010-11 to AY2018-19 Chen et al. (2021). We focused on the largest school system in each MSA rather than finer geographic units because that is the finest unit observed in the MarketScan claims data. Web sources were used to identify fall and spring semester start and end dates, as well as any number of winter or spring vacation start and end dates. These were augmented with known federal and state holidays, varying timing across years and states. This was used to generate an MSA-level measure of days in school for each week from AY2011 through AY2019. In this previous study, we collected school opening and closing dates for more than 50% of all MSAs in our sample before the 2015-16 academic year and more than 80% of the sample of MSA data available after the 2016-17 academic year. In that study, we explored and tested the accuracy of various methods of imputing missing data on school openings and closings using data from previous and subsequent years and nearby districts.

The predicted fall school start dates, the first spring break start dates, and the spring school end dates are close to the actual dates with more than ninety percent R-square. The predicted fall semester end dates and spring semester start dates are relatively accurate because most schools choose to end the fall school right before Christmas and start spring school term a predicable number of days after New Year. Monthly and weekly school opening days calculations were based on actual and predicted school opening and closing dates. Because no schools start the fall semester before July 1 or end their spring semester later in June, we defined week one from July 1 through 7, regardless of the day of the week it falls on, numbered weeks consecutively through week 52, which ends just before July 1. To combine school data with the infections database, we recorded five-digit MSA codes (MSAs) with unique numbers for non-MSA rural areas in each state. Hence, our geographic areas, which we called MSA-plus, include both true MSAs and residual rural areas within each state that are not in an MSA, and together, these include populations of the total 50 states plus Washington DC.

Infection data

Infectious disease diagnoses and patient information are from the Merative® (formerly IBM) MarketScan® Commercial Database between July 1, 2010, and June 30, 2019. I select 122,487,230 enrollers with annual insurance from the MarketScan admission data file to track the same person's health records. Families with any covered person not eligible for the entire calendar year were also excluded. Five age groups were defined: (1) Preschool children are older than 0 but under five years old.[2] (2) Primary school children are ages 5 to 12. (3) High school students are 13 to 17 years old. Although primary and high school students are active in public schools and transmit contagious diseases from public schools to families, the severity and duration of getting infected should differ. (4) College students are from 18 to 24 years old. (5) Adults are defined as people between 24 to 64 years old.[3] I classify the number of individuals in each group enrolled and infected by MSA-plus, which is defined in the school calendar dataset.

Patients with pneumonia, influenza, and other respiratory infections are extracted from outpatient and inpatient service data. To identify the patients infected with pneumonia, influenza, and other respiratory infections from July 1, 2010, to June 30, 2019, I collected the diagnosis codes of both ICD-9-CM and ICD-10-CM from the Agency for Healthcare Research and Quality Clinical Classification System. Before October 2015, the diagnosis was documented by ICD_9_CM codes and then transited to ICD_10_CM. Diagnosis codes that mention pneumonia, influenza, and other respiratory infections are also selected. Although the diagnosis identification codes changed from ICD_9_CM to ICD_10_CM, pneumonia, influenza, and other respiratory illness infection rates before and after did not change significantly (Ellis et al., 2020). Within nine years, the total number of pneumonia, influenza, and other respiratory infections claims is 4,636,748, 5,086,332, and 118,625,477, respectively. Based on the dates of diagnoses, I grouped each patient's claims by year and week, defined as in the school calendar dataset. If a patient sees doctors for the same infectious disease more than twice within two weeks, only the first visit would be counted, which enables me to see the transmission path within schools and families.

Weather

Xu et al. (2020) argue that weather is crucial in transmitting COVID-19, which is the first paper that considers weather conditions when studying the spread of infectious diseases. Weather is expected to be vital in transmitting pneumonia, influenza, and other respiratory infections, as they spread similarly to COVID-19. I web-scraped daily maximum and minimum temperatures, UV index, humidity, precipitation, and wind speed from the World Weather Online (WWO) website from July 1, 2010, to

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[2] I exclude newborn infants because other factors can trigger some common symptoms of infectious diseases for infants. For example, pneumonia following birth is frequently due to amniotic fluid remaining in newborn lungs.

[3] Although elderly adults older than 65 are easily infected, they are primarily insured by Medicare, and are not included in the MarketScan commercially insured dataset.

June 30, 2019, of each MSA-plus region. Then, I calculated the weekly average temperature, the average difference between max and min temperature, the average UV index, humidity, precipitation, and average wind speed as control variables.

Data cleaning

Take pneumonia, influenza, and other respiratory infections in 2014 and 2017 as examples to explore the seasonal and regional effects on the infection rates. The infection rate equals the number of patients divided by the number of enrolled people grouped by age groups and regions in a month of 2014 and 2017. The 2014 data identified pneumonia patients by mapping diagnoses from ICD-9-CM, and the 2017 data set identified pneumonia with ICD-10-CM diagnosis codes.

Figure 1：Pneumonia infection rates by age group

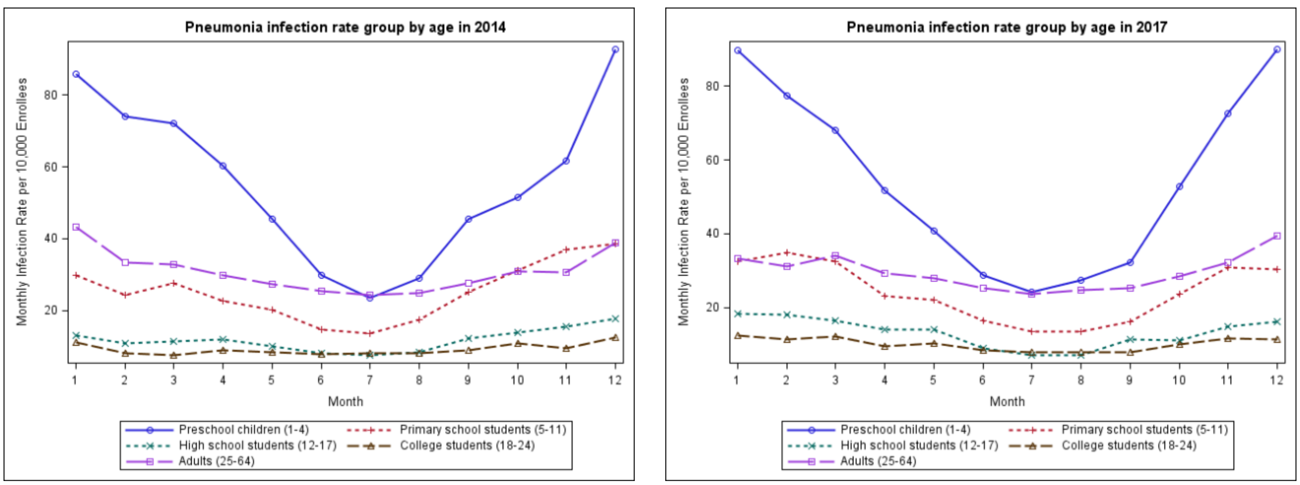

Figure 1 selects pneumonia infection rates per 10,000 enrollers in 2014 and 2017 as examples to show the across-age cohort infection patterns. Both graphs show that the infection rates of pneumonia are at a peak in December or January and at the lowest point in July for all age groups. Preschool children are most likely to be infected, and College students are the least likely to be infected with pneumonia. The infection rates of primary and high school students and adults seem to be related to public schools' schedules. It was low in June, July, and August but soared in September and October. Adults are more likely to be infected than students. Primary school students are more likely to be infected than high school and college students. The infection rates of pneumonia did not change a lot over the years.

Figure 2: Influenza infection rate by age group

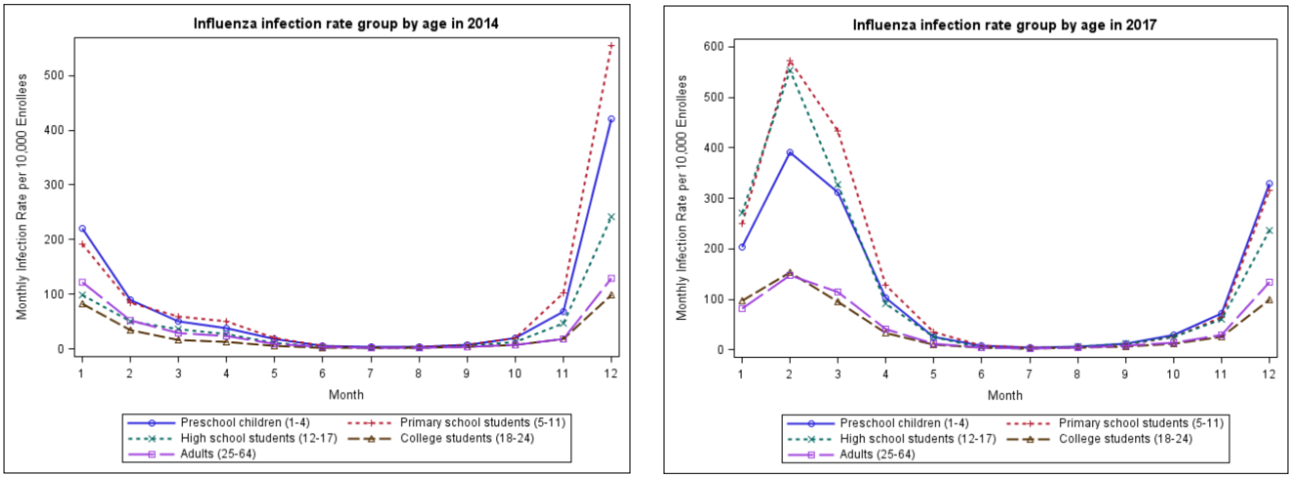

Figure 2 represents how influenza infection rates vary across age groups and time. In 2014, the influenza infection rates peaked in December and decreased to zero in June, July, and August. However, in 2017, the influenza infection rates peaked in February. In most months, influenza is much higher for all age groups than pneumonia infection rates. The influenza infection rates of students increased significantly in October and November. They dropped considerably in February, indicating that the influenza infection rates of students may correlate more to the weather than the school schedules. Hence, within the regression models, school schedules may significantly affect pneumonia more than influenza infection.

Figure 3: Other respiratory infections infection rate by age group

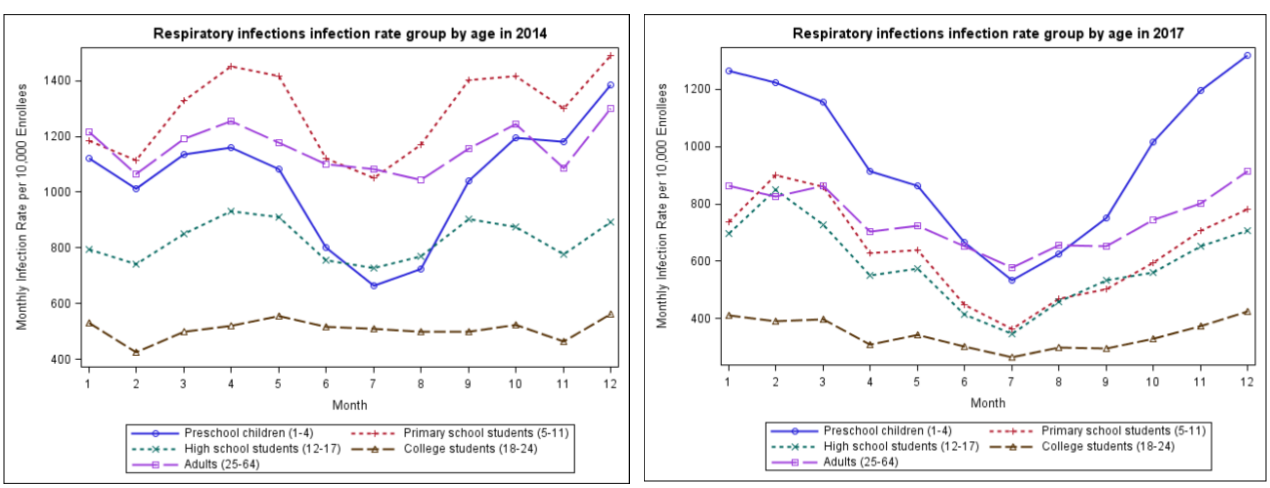

Figure 3 shows monthly respiratory infection rates grouped by age. In 2014 and 2017, the respiratory infection rates peaked in December and hit bottom in July, which suggests that school schedules play a role in respiratory infection. Unlike the pattern of infection in 2017, respiratory infection rates reached the second highest level in April and October. Primary school children and adults were more likely to have respiratory infections in 2014 than in 2017. Respiratory infection rates are much higher for all age groups than pneumonia and influenza.

Figure 4: Pneumonia infection rate by census region

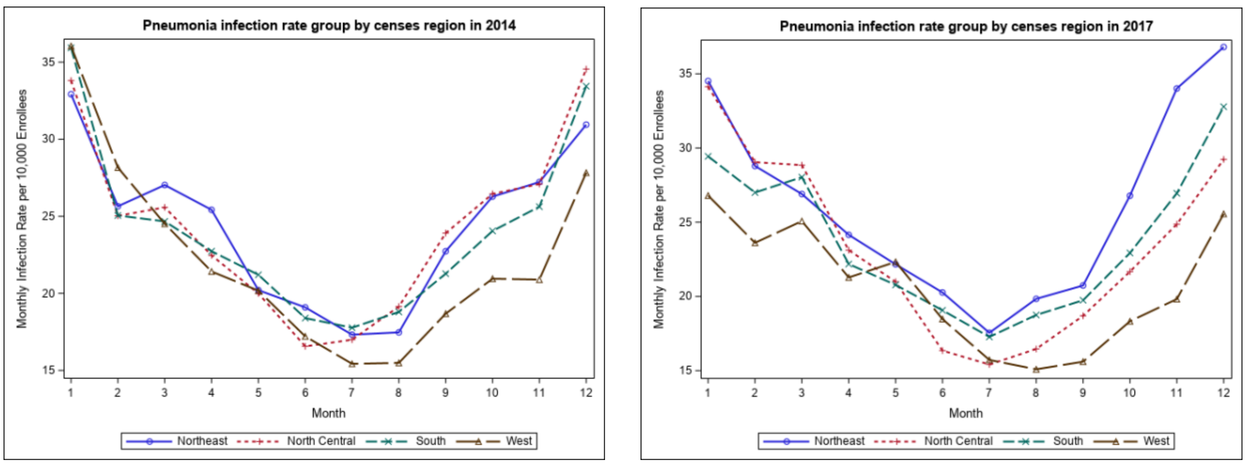

Figure 4 illustrates how the pneumonia infection rates vary by the census region. All regions have similar patterns in both 2014 and 2017: the infection rates started at the highest point. However, they dropped significantly, reached the lowest point in July, and rose significantly back to a similar level as in January. Compared to other regions, the infection rates in the West were the highest among all groups at the beginning of the year but dropped to the lowest by July. In 2017, the infection rates in the west remained the lowest compared to the other three areas. However, the pneumonia infection rates in the Northeast increased rapidly in September and October 2014 and stayed almost higher than in the other three regions in 2017. School schedules could explain these phenomena because schools in the West start their fall semester early and end later in the Northeast.

Figure 5: Influenza infection rate by census region

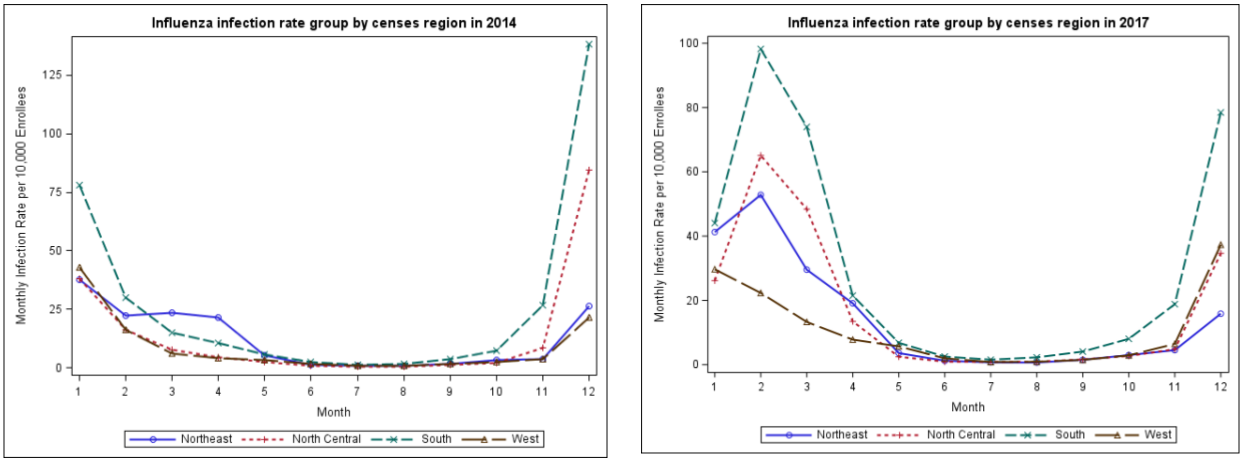

Figure 5 shows the changes in the influenza infection rates across months grouped by census region in 2014 and 2017. All regions show similar patterns in 2014 and 2017. Consistent with Figure 2, the influenza infection rates peaked in December 2014 and February 2017. In most months, the influenza infection rates in the south were higher than in other regions. Conversely, the influenza infection rates in the West were the lowest in both 2014 and 2017. Compared to the pneumonia infection rates in Figure 4, although the peak of the flu infection rates is much higher, the flu infection rates were close to 0 from May to October. The lower flu infection rates can be explained by the spread of influenza relying more on regional and seasonal factors than school schedules.

Figure 6: Other respiratory infections infection rate by census region

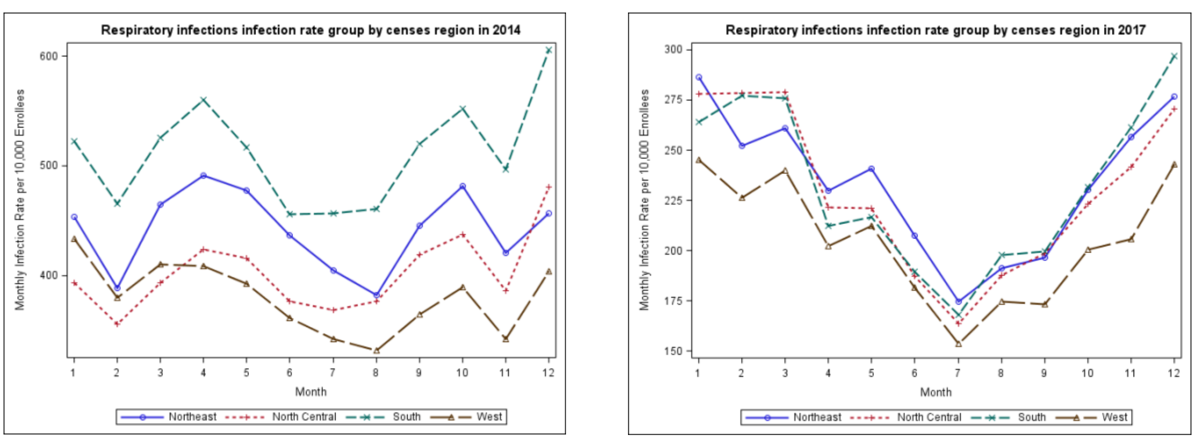

Figure 6 shows the monthly respiratory infection rates grouped by census region in 2014 and 2017. All regions had similar patterns in 2014 and 2017. Consistent with Figure 3, respiratory-related infection rates peaked in April, October, and December 2014, as well as in January and December 2017, and achieved the lowest points in August 2014 and July 2017. In both years, infection rates of respiratory illnesses were highest in the South and lowest in the West, compared to the North and the Central. In addition, the infection rates in 2014 were much higher than those in 2017. Even the lowest infection rates in 2014 are higher than the peaks in 2017. Compared with pneumonia and influenza, respiratory infections have higher infection rates ---- about four times the influenza infection rates and 19 times the pneumonia infection rates.

In conclusion, preschool and primary school students are the most likely to be infected with pneumonia, influenza, and other respiratory infections. Infection rates of all three infectious diseases vary both seasonally, by year, and by census region. The prima facie evidence shows that pneumonia and other respiratory infection rates depend more on school schedules, yet influenza infection rates depend more on seasonal effects.

IV Method

I used the linear probability model to find the probability of contracting pneumonia, influenza, and other respiratory infections. I expect this model to answer the following four questions: What is the additional probability of getting infected when one more day of school remains open? Who are the primary introducers of infection to the families? How does weather help transmit pneumonia, influenza, and other respiratory infections? What roles do locations and gender play in the transmission of infectious diseases?

The model and variables are as follows:

$$I_{i,r,t}^{a,d} = \beta_0 + \beta_1 O_{r,t} + \beta_2 N_{-i,r,t} + \beta_3 F_{-i,r,t}^{a,d} + \beta_4 F_{-i,r,t-1}^{a,d} + \beta_5 W_{r,t} + \beta_6 W_{r,t-1} + \beta_7 X_{i,r,t} + \alpha_t + \delta_r + \varepsilon_{i,r,t}$$

I used i to index individuals, d to index infectious diseases (pneumonia, influenza, and other respiratory illness), r to index MSA-plus, a to index age groups (preschool children, primary school students, high school students, young adults, and adults, and t to index the weekly time variable. The variable I is a dummy variable that equals 1 when the person is initially infected in a week. Note that I equals 0 when the person is not infected or was infected in the previous week. The variable O is the weekly open school days. Remember that week one is seven consecutive days starting on July 1st. The variable N is the number of family members. The variable F represents the number of infected family members. The variable W is a weather vector, including weekly average temperature, the average difference between max and min temperature, average humidity, average UV index, average wind speed, and average precipitation. The variable X represents a vector of demographic characteristics, including gender and whether the individual lives in a rural area. α_t controls time fixed effect. δ_r controls MSA-plus fixed effect.

Xu et al. (2020) mentioned that even the UV index 21 days before would influence the probability of infection. I include both the current and previous week's weather as captured in six dimensions in the models. In addition, the infection period of most infectious diseases is about three to seven days, which indicates that the number of infected family members in each age cohort in the current and previous week should be considered in the model.

V Results

Pneumonia

Table 1 shows the effect of days schools remain open on the pneumonia infection rate. The more days schools remain open, the higher the probability of preschool, high school students, and adults getting infected significantly. I do not find enough evidence showing that days schools remain open to increase the probability of a primary school student contracting pneumonia. In addition, living in rural areas lowers the pneumonia infection rate of preschool and primary and high school students. Interestingly, I find heterogeneous effects across gender. Gender differences could arise because females are biologically more or less resistant to these diseases or because different genders tend to participate in different activities, such as group activities. Female preschool children and primary and high school students are less likely to be infected with pneumonia, but female adults are more likely to be infected.

Table 2 states that having infected family members in the previous or the same week increases the probability of getting infected. Infected primary school and high school family members in the last week significantly increased the likelihood of getting infected for individuals in all age groups getting infected, especially preschool children. Having infected family members, regardless of age, in the same week has a more significant effect on the transmission of pneumonia than in the previous week.

Compared to individuals in other age groups, preschool children are the most likely to be infected, and college students are the least likely to be infected within families. Among all infected family members, primary and high school students are the leading introducers of pneumonia to a family.

Table 3 shows that the spread of pneumonia highly correlates with the previous and current week's temperature difference, UV index, and humidity. Higher temperature difference, UV index, and humidity decrease the likelihood of getting infected with pneumonia significantly, especially in the current week.

Influenza

Table 4 shows how days schools remain open related to the influenza infection rate. As I hypothesized from Figure 2, seasonal effect, instead of days school remains open, has a more significant effect on influenza infection rate. Only the probability of high school students being infected with influenza increases significantly as more days schools remain open. Living in rural or urban areas plays a minor role in influenza transmission. Female preschool children, primary school, and high school students are less likely to be infected with influenza, while female college students and adults are more likely to be infected.

Table 5 shows that having infected family members in the previous or the same week significantly increases the probability of getting infected with influenza. Individuals with family members infected with influenza in the same week are twice as likely to be infected than those with infected family members in the previous week. Living with infected family members increases the chance of a preschool child getting infected with influenza the most ---- 12 times more than a college student. Infected primary and high school students are the significant sources of influenza transmission to their families. Nevertheless, an adult's likelihood of getting infected with influenza significantly increases if he/she lives with other infected adults in the same week.

Table 6 proves that the transmission of influenza is significantly correlated with previous and current weeks' weather conditions. Higher average temperature and average temperature differences increase the likelihood of influenza infection. Conversely, the higher the average UV index, average precipitation, and average humidity, the lower the chance of getting infected with influenza. Higher average wind speed in the previous week also significantly decreases the chances of influenza infection. The previous week's weather conditions have a more substantial impact on the spread of influenza than the current week's weather conditions.

Other respiratory infections

Table 7 shows the impact of days schools remain open on the probability of infection with other respiratory infections. More days schools remain open contributes to a higher likelihood of infection with other respiratory infections in primary and high school students, preschool children, college students, and adults. Living in rural areas significantly decreases the chance of preschool children, as well as primary and high school students, getting infected with other respiratory infections but increases adults' likelihood of other respiratory infections. Moreover, females under 18 are less likely to be infected with other respiratory infections, yet females older than 18 are more likely to be infected.

Table 8 states the transmission path of other respiratory infections within families. Having infected family members in previous and current weeks significantly increases the probability of contracting other respiratory infections. More specifically, in the same week, infected preschool children and primary school students are the leading introducers of other respiratory infections in children under 17. Infected primary and high school students are the primary resources for spreading other respiratory infections to high school students, college students, and adults. Having infected primary and high school students in the previous week is the primary reason for spreading other respiratory infections within families.

Table 9 provides evidence that the previous and current week's weather significantly influenced the spread of other respiratory infections. The probability of contracting other respiratory infections increases as average temperature and average temperature difference increase and declines as average UV index, wind speed, and precipitation increase. The current week's weather conditions have a more considerable impact on the transmission of other respiratory infections than the previous week's weather conditions.

VI Discussion

School schedules play a crucial role in the spread of pneumonia and other respiratory infections but have a weak position in the transmission of influenza compared to the seasonal effect. Figure 7 compares the impact of school opening days on the infection rate of pneumonia, influenza, and other respiratory infections of different age cohorts. School schedules have the most significant effect on other respiratory infections, which is about four times the effect on the pneumonia infection rate. Days schools remain open significantly increase the likelihood of a high school student getting infected with all three infectious diseases transmitted by droplets, indicating that high school students are bridges of transmission of droplets infectious diseases from schools to families. School boards or government policymakers should pay more attention to high school schedules to reduce the infection rates of diseases spreading by droplets and focus on primary school schedules to decrease other respiratory infections.

Figure 7: Coefficient of school opening days (1000 times)

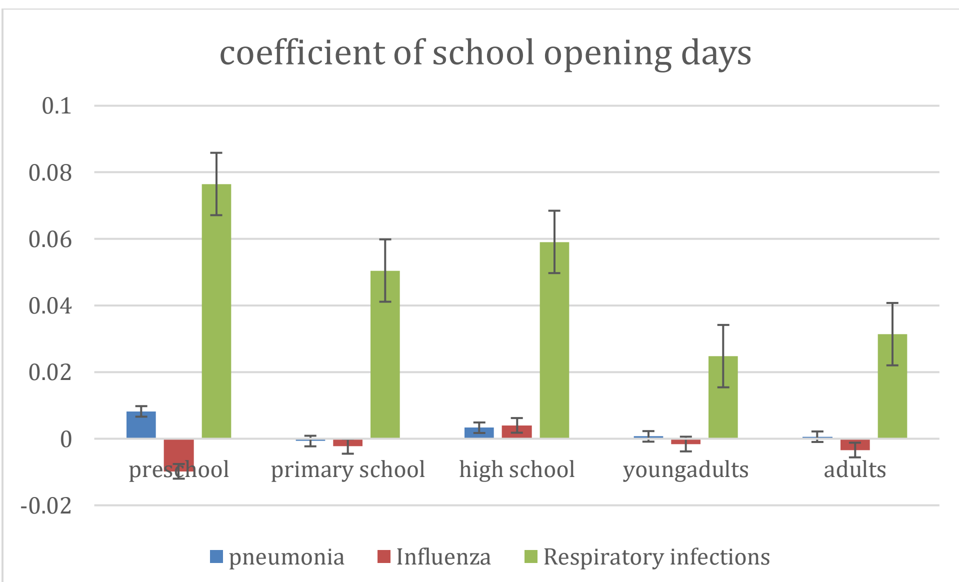

Figure 8: Transmission of pneumonia, influenza, and other respiratory infections within families

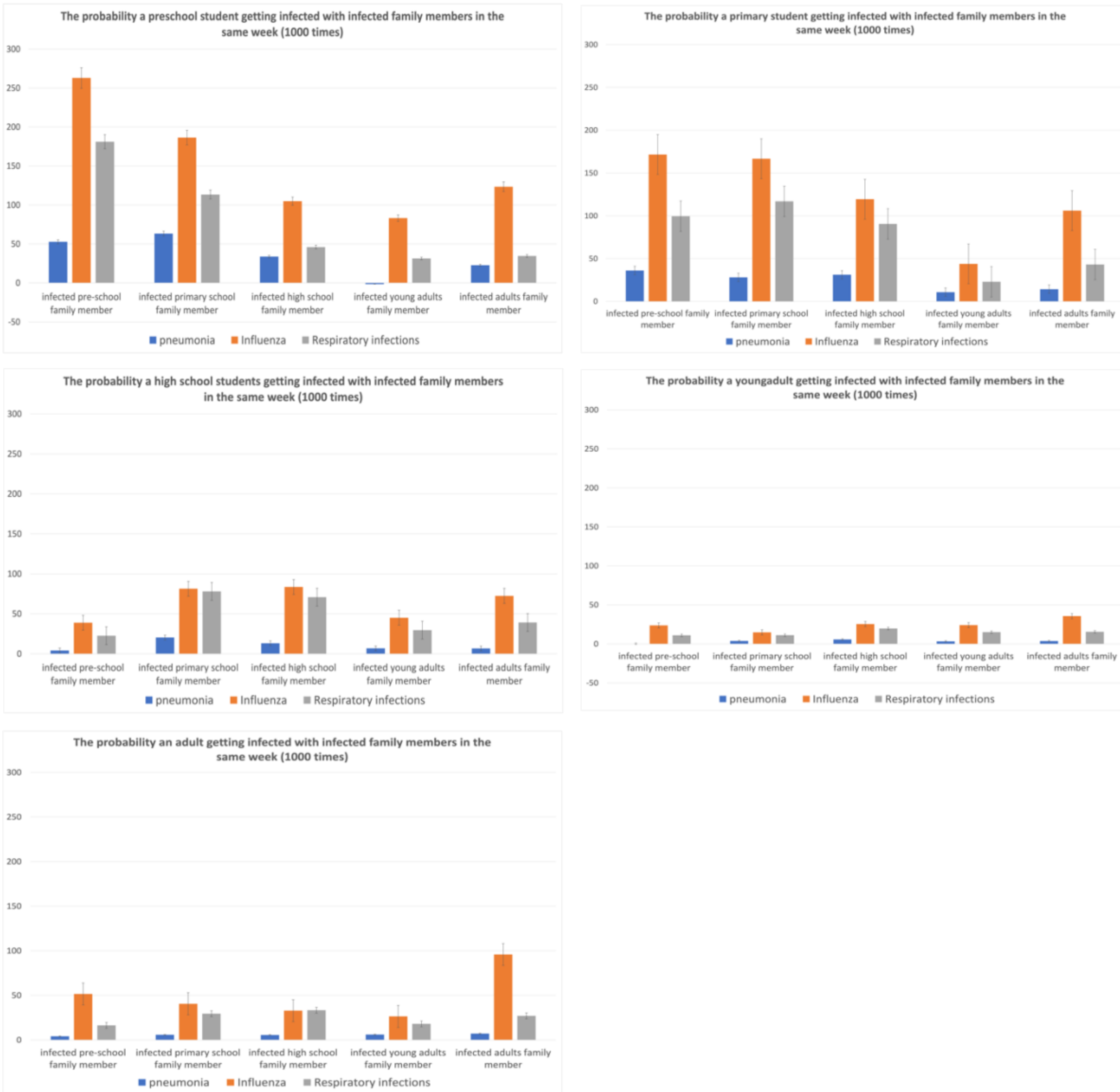

Figure 8 compares the coefficients of infected family members in the linear probability models. For all age groups, individuals are most likely to be infected with influenza if they have infected family members in the same week. They have the slightest chance of being infected with pneumonia, even if there are infected family members. Young adults are not likely to be infected by family members or to introduce infectious diseases to families because they usually move out for college.

From Tables 1 through 9, I conclude that girls under 18 are less likely to be infected with pneumonia, influenza, and other respiratory infections. In contrast, women older than 18 are more likely to be infected. I also find that living in rural areas decreases preschool children and primary and high school students' probability of being infected with pneumonia and other respiratory infections. In the meantime, living in rural areas significantly increases adults' likelihood of contracting pneumonia and other respiratory infections.

Cluster Sampling

I applied cluster sampling to check the robustness of the linear probability model. Using a simple random selection method to cluster a sample with 6 million individuals from each age cohort, I ensure that there are, on average, 20 individuals in each cohort-week-MSA category.

The effects of school schedules become weaker on the probability of being infected with pneumonia for all aged individuals while staying almost the same on the likelihood of getting infected with influenza and other respiratory infections. The coefficients of all infected family members in the current and previous weeks become larger in the models analyzing pneumonia infection probabilities yet stay at the same level in the influenza and other respiratory infection probabilities models. The effects of weather-related factors are weaker in models with pneumonia infection rates but remain the same in the regressions with influenza and other respiratory infections infection rates. These results are predictable because I find that the pneumonia infection rates are the smallest among the three infection rates in Figures 1 through 6. Hence, the linear probability models have enough power to show the significant effects of school schedules on pneumonia and other respiratory infections, the effects of infected family members in the current and previous weeks on pneumonia, influenza, and other respiratory infections, and the effects of weather on the three infection rates.

VII Conclusion

School closure policies could be effective before the invention of vaccines to limit the spread of emerging infectious diseases, yet the magnitude remains unclear. Previous literature states that school closure policies significantly reduce the peak of COVID-19 and decrease influenza infection rates. Although public schools are critical in spreading infectious diseases, school schedules are decided mainly to maximize students' achievement. Because school schedules and infection rates vary by time and geography, studying long-term and nationwide school schedules' effects on the spread of common infectious diseases helps policymakers reduce infection rates while maintaining students' welfare.

To study the three common infectious diseases spread via droplets: pneumonia, influenza, and other respiratory infections, I collected diagnosis information from the Merative® (formerly IBM) MarketScan® Commercial Database between July 1. 2010, and June 30, 2019. I obtained MSA-level weekly school data previously collected by the author, with coauthors documenting school opening and closing dates over the same pre-pandemic period (Chen et al., 2021). I use linear probability models to analyze the effect of school schedules, weather conditions, and existing infected family members on the probability of getting infected with pneumonia, influenza, and other respiratory infections with a massive sample of 122,487,230 individuals. My results state that within-family infection rates, especially high school students' infection rates of pneumonia, influenza, and other respiratory infections, rise significantly as the number of days schools are open. Infected primary school students and high school students are the main sources. Compared to the effect of school schedules, weather conditions affect the influenza infection rates more. School boards or government policymakers should pay more attention to high school schedules to reduce the infection rates of diseases spreading by droplets and focus on primary school schedules to decrease other respiratory infections. To control the spread of influenza, they should pay attention to temperature differences, UV index, precipitation, and humidity.

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Note that all the coefficients are 1000 times the actual value.

Appendix

Table 1: Effect of school opening days on pneumonia infection probability grouped by age

	The probability a preschool child getting infected with pneumonia	**The probability a primary school student getting infected with pneumonia**	**The probability a high school student getting infected with pneumonia**	**The probability of a college student getting infected with pneumonia**	**The probability an adult getting infected with pneumonia**
School opening days	0.0082*** (0.0020)	-0.0007 （0.0010）	0.0033*** (0.0007)	0.0007 (0.0005)	0.0006* (0.0003)
Rural area	-0.5370*** (0.0927)	-0.4044*** （0.0482）	-0.2509*** (0.0307)	-0.0114 (0.0248)	0.0074 (0.0152)
Gender	-0.0671*** (0.0040)	-0.0213*** （0.0020）	-0.0208*** (0.0013)	0.0086*** (0.0011)	0.0458*** (0.0006)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 2: Probability of infection with pneumonia if family members were infected

	The probability a preschool child getting infected with pneumonia	**The probability a primary school student getting infected with pneumonia**	**The probability a high school student getting infected with pneumonia**	**The probability of a college student getting infected with pneumonia**	**The probability an adult getting infected with pneumonia**
Preschool family members get infected in the same week	52.7561*** (0.1907)	36.1287*** (0.0933)	4.2088*** (0.1268)	0.2695 (0.1448)	4.0596*** (0.0443)
Primary school family members get infected in the same week	63.2748*** (0.1720)	28.1181*** (0.0868)	20.3922*** (0.0748)	3.8387*** (0.1049)	5.7830*** (0.0413)
High school family members get infected in the same week	33.8141*** (0.5434)	31.1532*** (0.1439)	13.2401*** 0.0946	5.6815*** (0.0889)	5.5905*** (0.0632)
College family members get	-1.5259 (1.0017)	10.8346*** (0.3316)	6.7774*** (0.1291)	3.3159*** (0.0927)	6.0114*** (0.0811)

infected in the same week					
Adults family members get infected in the same week	22.7366*** (0.1522)	14.2986*** (0.0703)	6.6792*** (0.0479)	3.6792*** (0.0375)	7.1199*** (0.0358)
Preschool family members get infected in the previous week	4.9560*** (1.4562)	-0.7348 (0.8987)	-0.4790 (1.1570)	-0.2760 (1.2744)	-0.4491 (0.4186)
Primary school family members get infected in the previous week	41.0389*** (0.1729)	9.3117*** (0.0869)	12.2572*** (0.0749)	2.4227*** (0.1049)	3.5344*** (0.0413)
High school family members get infected in the previous week	21.3380*** (0.5438)	18.6424*** (0.1444)	4.8158*** (0.0946)	4.1877*** (0.0889)	3.4751*** (0.0632)
Collage family members get infected in the previous week	1.7937 (1.0028)	7.4271*** (0.3319)	3.8260*** (0.1300)	0.7173*** (0.0927)	3.1072*** (0.0812)
Adults family members get infected in the previous week	14.3167*** (0.1524)	8.3736*** (0.0704)	4.0003*** (0.0480)	2.0785*** (0.0375)	2.6001*** (0.0358)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 3: Effect of weather on the probability of infection with pneumonia

	The probability a preschool child getting infected with pneumonia	**The probability a primary school student getting infected with pneumonia**	**The probability a high school student getting infected with pneumonia**	**The probability of a college student getting infected with pneumonia**	**The probability an adult getting infected with pneumonia**
Average temperature	0.0039** (0.0014)	0.0010 (0.0007)	0.0006 (0.0005)	0.0008* (0.0004)	0.0017*** (0.0002)
Average temperature difference (max-min)	-0.0080*** (0.0018)	-0.0056*** (0.0009)	-0.0020** (0.0006)	-0.0017** (0.0005)	-0.0021*** (0.0003)
Average UV index	-0.0359*** (0.0073)	-0.0123** (0.0037)	-0.0074** (0.0024)	-0.0051** (0.0019)	-0.0124*** (0.0011)
Average wind speed	0.0012	0.0022***	-0.0002	0.0001	-0.0003

	(0.0009)	(0.0005)	(0.0003)	(0.0002)	(0.0001)
Average precipitation	0.0008 (0.0007)	-0.0020*** (0.0003)	0.0002 (0.0002)	-0.0001 (0.0002)	-0.0001 (0.0001)
Average humidity	-0.0036*** (0.0004)	-0.0013*** (0.0002)	-0.0007*** (0.0001)	-0.0003** (0.0001)	-0.0004*** (0.0001)
Average temperature (lag 1)	-0.0040** (0.0014)	0.0010 (0.0007)	0.0005 (0.0005)	-0.0003 (0.0004)	-0.0007** (0.0002)
Average temperature difference (max-min) (lag 1)	-0.0082*** (0.0018)	-0.0036*** (0.0009)	-0.0022*** (0.0006)	0.0000 (0.0005)	-0.0001 (0.0003)
Average UV index (lag 1)	-0.0051 (0.0073)	-0.0145*** (0.0037)	-0.0084** (0.0024)	-0.0013 (0.0019)	-0.0097*** (0.0011)
Average wind speed (lag 1)	-0.0021* (0.0009)	0.0007 (0.0005)	-0.0001 (0.0003)	0.00004 (0.0002)	-0.0001 (0.0001)
Average precipitation (lag 1)	0.0014* (0.0006)	-0.0012** (0.0003)	-0.0002 (0.0002)	0.00002 (0.0002)	0.0001 (0.0001)
Average humidity (lag 1)	-0.0021*** (0.0004)	-0.0004* (0.0002)	-0.0006*** (0.0001)	-0.0001 (0.0001)	-0.0003*** (0.0001)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 4: Effect of school opening days on influenza infection probability grouped by age

	The probability a preschool child getting infected with influenza	**The probability a primary school student getting infected with influenza**	**The probability a high school student getting infected with influenza**	**The probability of a college student getting infected with influenza**	**The probability an adult getting infected with influenza**
School opening days	-0.0098*** (0.0020)	-0.0023 （0.0013）	0.0040*** (0.0001)	-0.0016* (0.0007)	-0.0034*** (0.0003)
Rural area	0.1954* (0.0914)	0.0542 (0.0624)	0.0507 (0.0450)	0.0386 (0.0347)	0.0299* (0.0131)
Gender	-0.0508*** (0.0039)	-0.0283*** （0.0027）	-0.0214*** (0.0020)	0.0759*** (0.0015)	0.0552*** (0.0005)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 5: Probability of infection with influenza if family members were infected

	The probability a preschool child getting infected with influenza	The probability a primary school student getting infected with influenza	The probability a high school student getting infected with influenza	The probability of a college student getting infected with influenza	The probability an adult getting infected with influenza
Preschool family members get infected in the same week	262.8949*** (0.1298)	171.6801*** (0.1002)	38.8574*** (0.1333)	23.6825*** (0.1536)	51.5745*** (0.0407)
Primary school family members get infected in the same week	186.4769*** (0.0817)	166.7234*** (0.0650)	81.3771*** (0.0624)	14.8594*** (0.0772)	40.5625*** (0.0297)
High school family members get infected in the same week	104.8725*** (0.2328)	119.4061*** (0.0901)	83.5454*** (0.0711)	25.4978*** (0.0606)	32.8663*** (0.0401)
College family members get infected in the same week	83.1284*** (0.4639)	43.8710*** (0.2487)	45.1335*** (0.1023)	24.0983*** (0.0699)	26.3818*** (0.0543)
Adults family members get infected in the same week	123.4603*** (0.0690)	106.0645*** (0.0510)	72.4023*** (0.0435)	35.6124*** (0.0344)	95.8765*** (0.0280)
Preschool family members get infected in the previous week	-9.8678*** (0.9490)	-6.5456*** (0.7392)	-7.9423 (0.9430)	-3.5693** (0.9879)	-3.1172*** (0.2504)
Primary school family members get infected in the previous week	77.3585*** (0.0820)	58.4132*** (0.0650)	37.8153*** (0.0624)	7.8077*** (0.0771)	18.7253*** (0.0296)
High school family members get infected in the previous week	46.3398*** (0.2331)	54.7170*** (0.0904)	36.6697*** (0.0712)	14.5022*** (0.0607)	14.9828*** (0.0402)
Collage family members get infected in the previous week	44.1083*** (0.4654)	25.0157*** (0.2494)	26.2270*** (0.1023)	13.3695*** (0.0670)	12.3699*** (0.0545)
Adults family members get infected in the previous week	53.0102*** (0.0690)	45.2568*** (0.0510)	34.1832*** (0.0436)	19.2366*** (0.0344)	40.1985*** (0.0280)

N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 6: Effect of weather on the probability of infection with influenza

	The probability a preschool child getting infected with influenza	**The probability a primary school student getting infected with influenza**	**The probability a high school student getting infected with influenza**	**The probability of a college student getting infected with influenza**	**The probability an adult getting infected with influenza**
Average temperature	0.0402** (0.0014)	0.0422*** (0.0009)	0.0289*** (0.0007)	0.0118*** (0.0005)	0.0118*** (0.0002)
Average temperature difference (max-min)	0.0236*** (0.0018)	-0.0154*** (0.0012)	0.0029** (0.0009)	0.0030*** (0.0007)	-0.0021*** (0.0002)
Average UV index	-0.2437*** (0.0072)	-0.2253*** (0.0048)	-0.1354** (0.0035)	-0.0701*** (0.0027)	-0.0699*** (0.0010)
Average wind speed	-0.0019* (0.0009)	0.0008 (0.0006)	0.0003 (0.0005)	0.0000 (0.0003)	-0.0005*** (0.0001)
Average precipitation	-0.0066*** (0.0006)	-0.0063*** (0.0004)	-0.0045*** (0.0003)	-0.0012*** (0.0002)	-0.0008*** (0.0001)
Average humidity	-0.0014*** (0.0004)	-0.0011*** (0.0002)	-0.0005** (0.0002)	-0.0004** (0.0001)	-0.0006*** (0.00005)
Average temperature (lag 1)	0.0348*** (0.0014)	0.0296*** (0.0009)	0.0193*** (0.0007)	0.0084*** (0.0005)	-0.0071*** (0.0002)
Average temperature difference (max-min) (lag 1)	0.0412*** (0.0018)	0.0273*** (0.0012)	0.0153*** (0.0009)	0.0111*** (0.0007)	0.0089*** (0.0002)
Average UV index (lag 1)	-0.3857*** (0.0072)	-0.3467*** (0.0048)	-0.2113*** (0.0036)	-0.1021*** (0.0027)	-0.0933*** (0.0010)
Average wind speed (lag 1)	-0.0083*** (0.0009)	-0.0068*** (0.0006)	-0.0041*** (0.0005)	-0.0015*** (0.0003)	-0.0015*** (0.0001)
Average precipitation (lag 1)	-0.0045*** (0.0006)	-0.0033*** (0.0004)	-0.0026*** (0.0003)	-0.0007** (0.0002)	-0.0003*** (0.0001)
Average humidity (lag 1)	-0.0098*** (0.0003)	-0.0109*** (0.0002)	-0.0063*** (0.0002)	-0.0026*** (0.0001)	-0.0028*** (0.00005)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 7: Effect of school opening days on other respiratory infection probability grouped by age

	The probability a preschool child getting infected with respiratory infections	**The probability a primary school student getting infected with respiratory infections**	**The probability a high school student getting infected with respiratory infections**	**The probability of a college student getting infected with respiratory infections**	**The probability an adult getting infected with respiratory infections**
School opening days	0.0754*** (0.0065)	0.0505*** （0.0039）	0.0591*** (0.0034)	0.0248*** (0.0028)	0.0314*** (0.0014)
Rural area	-1.9622*** (0.3013)	-0.5556** (0.1890)	-1.2865*** (0.1591)	-0.0497 (0.1338)	0.2604** (0.0703)
Gender	-1.8079*** (0.0128)	-1.4962*** （0.0080）	-0.2342*** (0.0069)	1.4072*** (0.0058)	2.2575*** (0.0028)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 8: Probability of infection with respiratory infections if family members were infected

	The probability a preschool child getting infected with respiratory infections	**The probability a primary school student getting infected with respiratory infections**	**The probability a high school student getting infected with respiratory infections**	**The probability of a college student getting infected with respiratory infections**	**The probability an adult getting infected with respiratory infections**
Preschool family members get infected in the same week	181.0775*** (0.1313)	99.5251*** (0.0972)	22.6338*** (0.1481)	11.0953*** (0.1866)	16.3170*** (0.0611)
Primary school family members get infected in the same week	113.3712*** (0.0942)	116.9068*** (0.0635)	77.9997*** (0.0685)	11.1632*** (0.1002)	29.4541*** (0.0479)
High school family members get infected in the same week	46.0144*** (0.2518)	90.6054*** (0.0841)	70.7428*** (0.0700)	19.7669*** (0.0714)	33.3552*** (0.0573)
College family members get infected in the same week	31.3689*** (0.4459)	22.9311*** (0.2076)	29.5828*** (0.0884)	15.0908*** (0.0696)	18.0280*** (0.0682)
Adults family members get	34.5646*** (0.0606)	43.1578*** (0.0374)	39.1397*** (0.0318)	15.5264*** (0.0261)	27.0653*** (0.0273)

infected in the same week					
Preschool family members get infected in the previous week	-1.2697 (1.4220)	-0.1770 (1.1258)	-6.2219** (1.8156)	-0.8744 (2.1137)	0.3457 (0.6193)
Primary school family members get infected in the previous week	52.6437*** (0.0943)	41.2016*** (0.0635)	37.4845*** (0.0684)	7.6411*** (0.1001)	13.7275*** (0.0479)
High school family members get infected in the previous week	23.2048*** (0.2519)	42.1659*** (0.0843)	30.4706*** (0.0700)	13.4054*** (0.0714)	14.9053*** (0.0573)
Collage family members get infected in the previous week	20.7846*** (0.4462)	15.6077*** (0.2078)	19.6584*** (0.0887)	10.1996*** (0.696)	11.3439*** (0.0683)
Adults family members get infected in the previous week	22.7981*** (0.0605)	24.1978*** (0.0374)	23.1363*** (0.0318)	11.4333*** (0.0261)	16.3239*** (0.0273)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y

Table 9: Effect of weather on the probability of infection with respiratory infections

	The probability a preschool child getting infected with respiratory infections	**The probability a primary school student getting infected with respiratory infections**	**The probability a high school student getting infected with respiratory infections**	**The probability of a college student getting infected with respiratory infections**	**The probability an adult getting infected with respiratory infections**
Average temperature	0.0533** (0.0045)	0.0400*** (0.0028)	0.0373*** (0.0024)	0.0240*** (0.0020)	0.0434*** (0.0010)
Average temperature difference (max-min)	-0.0716*** (0.0058)	0.0313*** (0.0036)	0.0219*** (0.0031)	0.0164*** (0.0026)	0.0150*** (0.0013)
Average UV index	-0.2450*** (0.0237)	-0.1522*** (0.0146)	-0.1320*** (0.0125)	-0.0835*** (0.0104)	-0.1951*** (0.0053)
Average wind speed	-0.0166*** (0.0030)	-0.0025 (0.0019)	-0.0096*** (0.0016)	-0.0066*** (0.0013)	-0.0113*** (0.0007)
Average precipitation	-0.0139*** (0.0021)	-0.0207*** (0.0013)	-0.0117*** (0.0011)	-0.0028** (0.0009)	-0.0086*** (0.0005)

Average humidity	-0.0015 (0.0012)	0.0021** (0.0007)	-0.0014* (0.0006)	-0.0001 (0.0005)	-0.0026*** (0.0003)
Average temperature (lag 1)	-0.0360** (0.0045)	0.0437*** (0.0028)	0.0310*** (0.0024)	0.0181*** (0.0020)	0.0033** (0.0010)
Average temperature difference (max-min) (lag 1)	-0.0378*** (0.0238)	0.0239*** (0.0036)	0.0180*** (0.0030)	0.0139*** (0.0026)	0.0199*** (0.0013)
Average UV index (lag 1)	-0.3478*** (0.0238)	-0.2351*** (0.0147)	-0.1497*** (0.0126)	-0.1104*** (0.0105)	-0.1304*** (0.0053)
Average wind speed (lag 1)	-0.0213*** (0.0031)	-0.0054** (0.0019)	-0.0044** (0.0016)	-0.0052*** (0.0013)	-0.0095*** (0.0007)
Average precipitation (lag 1)	-0.0097*** (0.0021)	-0.0107*** (0.0013)	-0.0038** (0.0011)	0.0024** (0.0009)	0.0026*** (0.0005)
Average humidity (lag 1)	-0.0009 (0.0011)	-0.0001 (0.0007)	0.0010 (0.0006)	-0.0003 (0.0005)	-0.0012*** (0.0003)
N	228,400,000	360,270,000	402,460,000	534,390,000	2,624,000,000
MSA_plus fixed effect	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y