IN-PERSON SCHOOLING AND SARS-COV-2 TRANSMISSION ACROSS ITALIAN REGIONS[1] [2]

Daniela Ghio, Massimiliano Bratti, Nikolaos I. Stilianakis,
Simona Bignami-Van Assche, Yacine Boujija, John Sandberg,

1. Introduction

After worldwide school closures during the first wave of the corona virus disease (COVID-19) pandemic in spring 2020, the Fall school term has marked the return to in-person instruction for millions of children in Europe and North America. Nevertheless, this period has also coincided with the second pandemic wave in these regions, sparking a public debate about the role of in-person schooling for community transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

Although prolonged school closures have serious negative implications for children's health and educational development (Kuhfeld *et al.*, 2020; Hertz and Barrios, 2020; ECDC, 2020; Chanchlani *et al.*, 2020), the existing literature is not conclusive about the role in-person schooling for SARS-CoV-2 transmission plays.

Scholars (Goldstein and Lipsitch, 2020; Viner *et al.*, 2020) have focused on differences in susceptibility to infection along age groups concluding that children are less likely to become infected compared to adults. Using the cumulative incidence of SARS-CoV-2 infections, school re-opening effects have been assessed to identify the role of in-person schooling as pandemic amplifier (Alfano *et al.*, 2021, Riley *et al.*, 2020, Zamir *et al.*, 2020, Tosi and Campi, 2021). Specifically, Fenga and Galli (2021) have captured dynamics in the time series of the cumulative COVID-19 positive tested cases across Italian regions. However, only few scholars have assessed the effectiveness of school closing measures in reducing the spreading of SARS-CoV-2 and reproduction number of infected people (Brauner *et al.*, 2020; Li *et al.*, 2021).

Our contribution to the scientific literature is twofold. Firstly, we outline homogenous empirical evidence across Italian regions in the trends of SARS-CoV-2 weekly incidence among school-aged children vis-à-vis other age groups, from September 2020 to April 2021. Secondly, we deepen the statistical analysis for regions where associations between aggregated age group infections among children and

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[2] The authors are solely responsible for all aspects of this article including the research, the interpretation and the writing thereof. DG is the corresponding author.

parents are more marked. Results point to substantial regional variations in the role of school opening for second and third pandemic waves. In Lombardy, Emilia Romagna and Piedmont regions, we find that the decision to close schools has been associated with a medium-term significant decrease in infections of parents' age groups. Whereas further investigations are needed to definitely assert causality, our findings highlight the potential of school closing effects for limiting the spreading of SARS-CoV-2. These results support the argumentation that the decision to close or re-open schools should be guided by a comprehensive risk-assessment based both on the wellbeing of children and accounting for demographic and epidemiologic patterns of local communities (WHO, 2020). Therefore, the prioritization of in-person schooling should be planned and coherently implemented as part of a contextual setting to limit school related secondary infection transmissions.

2. The role of in-person schooling

Large-scale population-based studies on the determinants in the spreading of SARS-CoV-2 between school settings and surrounding communities, come primarily from the United States (US) (Honein *et al*., 2021). Notably, a national assessment found that increases in COVID-19 incidence and percentage of positive test results among adults were not preceded by increases in infections among the school-aged population 0-24 years old (US Department of Health and Human Services / Center for Disease Control, 2020). In other terms, the levels of COVID-19 transmission in school settings were not a contributing factor of community transmission, but rather reflected it, given that recommended mitigation strategies were widely adopted. Studies on the effects of school re-opening in Italy have underlined that the risk of infection among students is higher outside than inside the educational settings, where students are triggered to respect rules during in-person school hours (Buonsenso *et al.*, 2020). The relevance of social interactions occurring around school attendances (e.g. transportation services used for reaching schools) has also been reported in Catalonia (Spain), where, similarly to Lombardy, COVID-19 case-fatality achieved one of highest rates in Europa (Llupia *et al*., 2021). Gandini *et al.* (2021) argued that school opening was not the driver of the second COVID-19 wave in Italy. Notwithstanding, these conclusions are in contrast with observations from other zoonotic infections (namely H5N1 influenza virus) where a larger proportion of transmission clusters were identified among children (Zhu *et al.*, 2020). Using a stochastic model, Fenga and Galli (2021) found a statistically significant increase in the cumulative number of COVID-19 positive tested cases in all Italian regions due to the school re-opening. Similar conclusions were achieved by Casini and Roccetti (2021), demonstrating that in 15 out of 21 Italian regions, the Fall re-opening of schools was related to a 16-day

delay growth in the cumulative number of positive cases. Given regional differentials in the evolution of the pandemic and the public health measures implemented, more evidence is needed to properly assess the role of in-person schooling for SARS-CoV-2 transmission in Italy during the 2020-21 school year.

3. Data and Method

The age-specific incidence of confirmed SARS-CoV-2 infections were obtained from COVID-19 monitoring datasets, managed by the Italian Epidemiological Association (2021). As descriptive results, COVID-19 positive cases are presented using heatmap graphs to tracking regional trends in the weekly incidence of the disease by age-group, between September 13, 2020 and April 30, 2021, across Italian regions. We select three regions where the incidence among children (0-18) and adults (25-59) results more evident, Lombardy Emilia Romagna and Piedmont, for further statistical investigations. Since the mean age of mother at childbirth is around 32 years in the selected regions, 31.9 in Emilia Romagna, 32.1 in Piedmont and 32.2 in Lombardy, respectively (EUROSTAT, 2021), we formulate the following hypothesis of intergenerational links between children's and parents' behaviours:

Assuming 25-44 age group adults as theoretical parents of 0-13 age group children, and 45-59 age group adults as theoretical parents of 14-18 age group children, SARS-CoV-2 infections among parents are likely to be associated – albeit specificities of other contextual factors - with SARS-CoV-2 infections of children. Thus implies that the effectiveness of school closing, as a policy measure adopted to limit infections, should result in the decrease of the intergenerational transmission between children and parents.

We start investigating this hypothesis by estimating the following regression model by region:

$$\ln(parents_{t+2,c}) = \alpha + \beta \ln(children_{t,c}) + \gamma\, closed_{t,c} + \phi(\ln(children_{t,c}) \times closed_{t,c}) + \mu_c + \lambda_{j+1} + \epsilon_{t+1} \quad (1)$$

where:
t and c are time (week) and parents' cohort subscripts;
$\ln(parents_{t+2})$ and $\ln(children_t)$ are the number of positively tested infections between parents of cohort c and their children, respectively, accounting for the time lag in transmission;

$closed_{t,c}$ is an indicator for school closure at time t for children of parental cohort c and $\ln(children_{t,c}) \times closed_{t,c}$ an interaction term. Thus β captures the intergenerational correlation between parents' and children's infections at the baseline (i.e. when schools are open), while ϕ the change in this correlation when schools are closed. According to our hypothesis, we expect $\beta > 0$ and $\phi < 0$. λ_{j+1} is a time (week) fixed effect. Model (1) is estimated both pooling all parents' cohorts together, in which case we also include a cohort fixed effect (μ_c), and separately by cohort of parents (23-44, 45-59), in which case the cohort fixed effect is absorbed in the model intercept.
ϵ_{t+1} is an error term.

To investigate the dynamic of infections after/before school closures, we define a second model, which aims to capture impacts on *secondary* infections, based on demographic associations between age groups of children and related parents, accounting for the average delay of approximately 2 weeks (16 days according to Fenga and Galli, 2021) between the SARS-CoV-2 infections among children (*primary infections*) and the positive laboratory tested cases among parents (*secondary infections*). We apply the event-study approach, as a generalization of the difference-in-differences method (Clarke and Schythe, 2021), to include the time-varying controls of regional COVID-19 school policy and associated intergenerational (children to parents) infection transmissions. Our empirical strategy is motivated by the heterogeneity in weekly intensity of infections over time, when compared with a baseline reference period. Hence, changes do not homogeneously occur during the reference period, but could have rather different impacts along age-groups before and after the school closures. We carry out the cohort analyses using the log of cases by age group, due to the exponential nature of the COVID-19 pandemic evolution. The model reads as follows:

$$\ln(parents_{t+2,c,r}) = \alpha + \beta \ln(children_{t,c,r}) + \emptyset(\ln(children_{t,c,r}) \times closed_{t,c,r}) + \sum_{j=2}^{J} \beta_j \, Lag_{j,c,r} + \sum_{k=1}^{K} \gamma_k \, Lead_{k,c,r} + \mu_c + \lambda_{j+1} + \theta_r + \varepsilon_{t+1,r} \quad (2)$$

where:
θ_r is a region fixed effect;
$Lag_{j,c,r}$, and $Lead_{k,c,r}$, are binary variables indicating the number of periods before and after the school closing occurrence, which is considered as the event of interest in the reference time period. *Lag 1* serves as baseline and therefore is omitted from the model; therefore, leads and lags capture differences with respect to the baseline. We expect $Lag_{j,c,r}$, to capture the growing trend of transmissions which motivate school closures. Contrarily, $Lead_{k,c,r}$, is expected to be negative in case of effectiveness of

school closures, and increase (in absolute value, meaning a larger reduction of cases) over time;
J and K are the maximum number of lags and leads, respectively.

This model is estimated pooling all regions together and results are presented for all parents' cohorts. Statistically significant and negative lead-coefficients would indicate that school closures mitigate the transmission among parents, measured as weekly case incidence of SARS-CoV-2 infections among parents.
Regression results' graphical representations are obtained by applying the Stata routine `eventdd` (Clarke and Schythe, 2020).

4. Results

Since March 2020, national authorities opted for a school closure policy as one of the key interventions to control COVID-19 pandemic, but as of September 2020, the majority of governments decided to re-open schools. UNESCO (2021) reports that in Italy, from September 13, 2020 to March 30, 2021, all schools remained closed at national-wide level for 13 weeks, and partially closed for 21 weeks (where partially refers to school closures restricted to some regions or some educational grades). Comparing Italy with other European countries, a similar school policy was adopted in Germany, where schools were fully closed for 14 weeks and partially closed for 13 weeks. By contrast in Spain, where COVID-19 epidemic evolution presents strong similarities with Italy, full school closures were limited to 10 weeks. Nevertheless, in Italy school opening follows a regional scheduling. For instance, in Lombardy Emilia Romagna and Piedmont, schools started on September 14, 2020, whereas Campania and Calabria postponed the opening day to September 24.

We detect increases in infections among 14-18 age-groups (primary infections) preceded that of adults age 45-54 (potentially as secondary infections) in Emilia-Romagna, Lazio, Lombardy, Marche, Piedmont, and Tuscany, representing more than half of national infections (Bignami Van-Assche *et al.*, 2021). Lombardy, Piedmont and Tuscany were the first to be declared red zones as of November 6, 2020 (DPCM, 2020) and, following mandatory high school closing, COVID-19 weekly incidence among 14-18 years old dropped before older age groups. A similar effect was observed in Emilia-Romagna, Piedmont and Tuscany after high schools opening in late January 2021. Results are confirmed by official figures indicating that, nationally, the rise in incidence among high school students age 14-18 has preceded that of adults age 45+ after school opening in Fall 2020 and January 2021 (ISS, 2021).

Descriptive results give evidence that the role of school openings across Italian regions on both the second and third COVID-19 waves should not be minimized.

Table 1 summarizes main measures adopted by regional authorities to limit school-related infection transmissions in Lombardy, Emilia Romagna and Piedmont.

Table 1 – *School-related measures adopted to contrast SARS-CoV-2 transmission.*

Measures adopted by National and Regional Authorities	**Lombardy**	**Emilia Romagna**	**Piedmont**
All school levels go back in person	14-Sep-20	14-Sep-20	14-Sep-20
Secondary and high schools move 50% -75% online			Oct 24-26, 2020
High-schools and university move online	6-Nov-20	6-Nov-20	2-Nov-20
Orange zone		14-Nov-20	
Red zone			19-Nov-02
Yellow zone		6-Dec-20	
National-wide red zone, all schools closed	24 Dec-6 Jan 6-21	24 Dec- 7-Jan-21	24 Dec-8 Jan-21
Elementary schools go back in person	7-Jan-21	7-Jan-21	7-Jan-21
Orange zone		8-Jan-21	17-Jan-21
Red zone, high-schools and university stay online	16-Jan-21		
High schools go back in person 50-75%		18-Jan-21	
Orange zone, middle schools go back in person	25-Jan-21		
High schools go back in person 75%	1-Feb-21		1-Feb-21
High schools and university move online		1-Feb-21	
Yellow zone	21-Feb-21		1-Feb-21
Orange zone		Feb 21st	
Dark orange zone, all school levels move online	Mar 5-14, 2021	3-Mar-21	Mar 5-14, 2021
National red zone, all school levels close	Mar15-Apr 6, 2021	Mar15-Apr 6, 2021	Mar15-Apr 6, 2021
Red zone extension for 14 days			2-Apr-21
High schools stay on line 50%		12-Apr-21	

Sources: http: www.regione.lombardia.it , www.regione.emilia-romagan.it, www.regione.piemonte.it .

We check the statistical significance of changes in infections among children and parents when school restrictions occurred.

Table 2 shows regression coefficients by region, and cohort of parents (Model 1, Section 3). Results clearly show a statistically significant positive correlation between adults' and children's incidence of SARS-CoV-2, which is higher for the older cohort of parents in all regions but Piedmont, in which the correlation in the two cohorts is very similar.

Table 2 – *Regression coefficients by region.*

	Lombardy			Emilia Romagna			Piedmont		
Ln-parents		Age			Age			Age	
		25-44	44-59		25-44	44-59		25-44	44-59
School-closure	1.495**	-0.253	0.080	1.904***	-0.715	-0.003	1.816***	1.000	0.433
	(0.578)	(1.320)	(0.648)	(0.548)	(1.500)	(0.950)	(0.650)	(1.169)	(0.731)
Ln-child	0.698***			0.561***			0.803***		
	(0.076)			(0.065)			(0.090)		
Ln-child 0-13		0.779***			0.613***			0.933***	
		(0.120)			(0.094)			(0.117)	
Ln-child 14-18			0.924***			0.896***			0.954***
			(0.066)			(0.066)			(0.086)
Interaction between School-closure and Ln-child	-0.214**	0.036	-0.039	-0.251***	0.104	-0.023	-0.263**	-0.170	-0.071
	(0.104)	(0.204)	(0.119)	(0.088)	(0.212)	(0.164)	(0.118)	(0.185)	(0.137)
Constant	1.183**	0.539	0.607	1.849***	1.432**	0.609*	0.630	-0.282	0.331
	(0.452)	(0.750)	(0.385)	(0.407)	(0.612)	(0.356)	(0.518)	(0.683)	(0.475)
Observations	62	31	31	62	31	31	62	31	31
R-squared	0.642	0.697	0.924	0.678	0.717	0.878	0.678	0.766	0.880

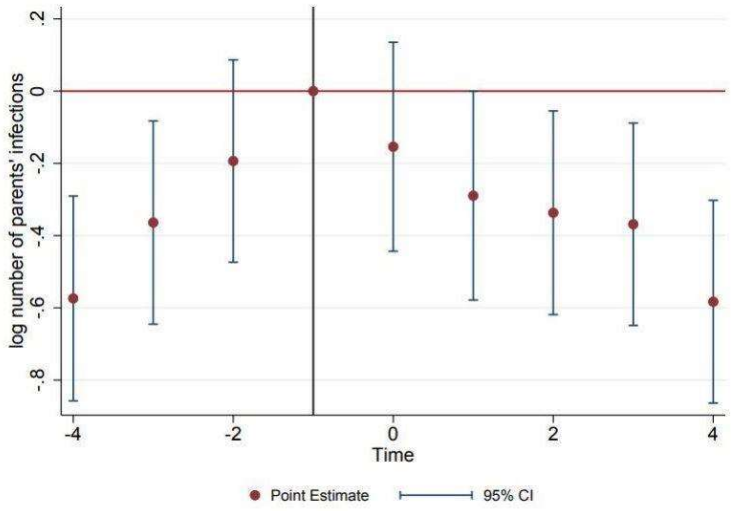
Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Given the log-log specification, our model shows a 0.9 elasticity of adults' cases with respect to children's cases (i.e. a 1% increase in the latter increases the former by 0.9%). Interestingly, this intergenerational correlation is reduced after school closing by about 0.21-0.26 log points depending on the region (higher for Piedmont and Emilia Romagna, lower for Lombardy), albeit the estimate is statistically significant only in the models pooling all cohorts of parents together. In order to better look at the dynamic of infections around school closure, we carried out an event-study analysis (Model 2, Section 3).

The time pattern of the school closure coefficients is plotted in Figure 1, where the coefficients of leads and lags are on the x-axis, starting from 4 weeks before the school closures (after the re-opening on September 2020) occurred for the first time in November 2020. The coefficients of leads are negative and increase in their absolute magnitude, meaning that the event *school closure* (taking place at week -1) is associated with a decreasing number of SARS-CoV-2 positive tested cases among parents. After 3 weeks, the decrease stabilizes. Expectedly, the coefficients of the lags, i.e. the incidence of cases before the school closure, is getting larger approaching the event-time *school closure*, which represents the peak of cases.

Figure 1 – *Event cohort study; plot of lead and lags for all cohort of parents.*



We also estimated Model (2) keeping in the sample only the older cohort of parents (45-59), who exhibited the higher intergenerational transmission (Table 2). In Lombardy, Emilia Romagna and Piedmont, the weekly incidence decrease of SARS-CoV-2 infections in the 45-59 age group is statistically associated with school closures, and the related changes in SARS-CoV-2 infections among 14-18 age groups, from September 2020 to April 2021.

These results are consistent with Fenga and Galli (20210 that highlight the association between the re-opening of schools and the peak of the epidemic curve; yet, a careful assessment of causality would require further investigations.

5. Conclusion

Empirical analyses have revealed that schools can operate safely as the pandemic unfolds by adopting appropriate public health measures to maintain low levels of COVID-19 community transmission and recommended mitigation strategies in schools. As embedded in the World Health Organization's recommendations, two main conditions need to be satisfied: community transmission of COVID-19 should be maintained at low levels; recommended mitigation strategies in schools should be in place (WHO, 2020). These measures include: cohorting and keeping students and staff in small groups or bubbles that do not mix; the universal use of masks; limiting

physical presence in classrooms in order to reduce crowding; and ensuring adequate and appropriate ventilation.

Our findings complement the available evidence regarding transmissions associated with in-person schooling in two important ways. First, we compare age-specific incidence of SARS-CoV-2 infections across Italian regions from September 2020 to April 2021, tracking how trends in parents' (*secondary*) infections has been 2-week preceded by children's (*primary*) infections. Second, using an event cohort study, we find that the school closure is associated with the decrease of *secondary* infections which remains statistically significant until 4 weeks from the event occurrence. These results highlight the importance of minimizing community transmission to ensure a safe environment for in-person learning, especially when the prevalence of new variants might rise COVID-19 incidence in school-age children sharply.

Our study has a number of limitations that should be borne in mind. First, being a comparative case study, it is inherently limited by heterogeneity in the regional application of mitigation measures and testing, that might be biased from higher fractions of asymptomatic infections especially among the youngest population age-groups (Fisman et al., 2021). Second, the study presents limitations due to the lack of data availability, since we could not evaluate trends in COVID-19 incidence by individual demographic and epidemiologic profiles, but only by stratified age-group. Notably, high school is attended by children up to 19 years of age, while the available aggregation, excluding age 19, does not align perfectly with school levels. Yet, because effects about these groups are underestimated, this constraint presumably does not amend but strengthens validity of our conclusions.

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SUMMARY

In-person schooling and SARS-CoV-2 transmission across Italian regions

BACKGROUND. The role of in-person schooling for community transmission of SARS-CoV-2 has immediate policy relevance for deciding how to operate schools safely as the pandemic unfolds, new variants of SARS-CoV-2 are circulating, and immunization coverage remains limited among children.

OBJECTIVES. We compare trends in SARS-CoV-2 weekly incidence among school-aged children vis-à-vis other age groups, during Fall 2020 and Spring 2021, by analysing empirical evidence across all Italian regions. Looking at regions where intergenerational effects are more evident, Lombardy, Emilia Romagna and Piedmont regions, we detect impacts of secondary infections based on intergenerational dynamics between children and parents.

METHODS. COVID-19 case data are analysed using a standard descriptive methodology to capture dynamics in weekly incidence of the disease among children, adolescents and young adults between September 2020 and April, 2021. Statistical analyses are then extended adopting an event cohort method to quantify the impacts of school closures on COVID-19 positive laboratory tested cases among parents, *secondary infections*, accounting for changes in SARS-CoV-2 infections among children, *primary infections*, over time.

RESULTS. Increases in weekly incidence among school-aged children 14-18 have preceded increases in other age groups in several Italian regions during the second and third waves. In Lombardy, Emilia Romagna and Piedmont regions, we find that the decision to close schools has been associated with a medium-term significant decrease in infections of parents' age groups. Whereas further investigations are needed to definitely assert causality, our findings highlight the potential of school closing effects as last resort to limit the resurgence of SARS-COv-2 viral transmission.

Daniela GHIO, European Commission, Joint Research Centre (JRC), Daniela.Ghio@ec.europa.eu

Massimiliano BRATTI, Università degli Studi di Milano, massimiliano.bratti@unimi.it

Nikolaos I. STILIANAKIS, European Commission, Joint Research Centre (JRC) and University of Erlangen-Nuremberg, Nikolaos.Stilianakis@ec.europa.eu

Simona BIGNAMI-VAN ASSCHE, Université de Montréal, simona.bignami@umontreal.ca

Yacine BOUJIJA, Université de Montréal, yacine.boujija@umontreal.ca

John SANDBERG, George Washington University, jsandber@gwu.edu