Summer School Holidays and the Growth Rate

in Sars-CoV-2 Infections Across German Districts

Thomas Plümper[1] and Eric Neumayer[2]

[1] Department of Socioeconomics, Vienna University of Economics and Business, Vienna, Austria, thomas.pluemper@wu.ac.at

[2] Department of Geography & Environment, London School of Economics and Political Science (LSE), London, UK , e.neumayer@lse.ac.uk

Abstract

How significant are school holidays for the Covid-19 crisis? In this ecological study, we analyse the association between summer school holidays and the weekly growth rate in SARS-CoV-2 infections in 401 German districts. In Germany school holidays are coordinated between states and spread out in order to reduce the number and length of traffic jams on motorways. We employ a district fixed effects Chow-type structural break model specification in which we test whether the holiday season as well as the period of two weeks after holidays end result in a statistically significantly higher infection growth rate than the period of two weeks before holidays start, our presumed counterfactual. We also allow the effect to vary week-by-week and by states. We find that between 30 and 50 percent of the growth rate in new infections in Germany can be attributed to the holiday season. A significant increase in the growth of new infections begins approximately four weeks after holidays begin – that is, shortly after the first wave of holiday-makers return. The effect becomes stronger the further holidays proceed and does not revert back to normal in the two weeks after the end of holidays. States in the West of Germany tend to experience stronger effects than those in the East. Part of this finding is explained by another result, namely that we find significant interaction effects of school holidays with per capita taxable income and the share of foreign residents in a district's population.

1. Introduction

When the first tourist charter flight from Germany since the closure of borders in Europe in March arrived in Mallorca on June 16, locals applauded the 189 passengers on board for their bravery. Fast forward three months and the applause for the return of tourism has been muted across Europe by the re-emergence of high and rising infection numbers in tourist destinations and the home countries of returning travellers (McKee 2020). In fact, many observers believe that international holiday travels present the root cause of the coronavirus pandemic's growing dynamic. Germany's Federal minister of health, Jens-Peter Spahn, recommended a simple remedy, namely to go on vacation within Germany.[1]

Just how significant are holiday-seasons and holiday-related travels for the Covid-crisis? According to the Robert Koch Institute (RKI) roughly 30-40 percent of all new infections can potentially be linked to a holiday trip abroad (RKI 2020).[2] What the RKI observes is that 30 to 40 percent of the known new infected people had been abroad shortly before they were tested positive for Sars-CoV-2. Of course, the RKI researchers cannot know for sure where the infection actually occurred but their presumption may seem plausible given the timing of events. This is particularly true for those positively tested individuals that had to undertake a test either at the airport itself or within 72 hours after arrival because they returned from an area deemed to be a high risk, i.e. virus hotspot, area. However, for the same reason one has to keep in mind that the share of infections related to foreign travel is likely to be biased upwards because returning travellers from high-risk areas were obliged

[1] https://www.tagesschau.de/inland/spahn-urlaub-coronavirus-101.html
[2] This was widely reported in the media, see for example https://www.zeit.de/wissen/gesundheit/2020-08/corona-tests-reiserueckkehrer-risikogebiete-pflicht

to be tested even if they showed no symptoms, while the people that had stayed in Germany were not usually not systematically tested unless they showed symptoms. In other words, the share of tested returning travellers was likely to be higher than the share of tested non-travellers, and this should bias the number of travel-related cases among all positive tests upwards.

While the debate in Germany focuses on holiday-makers returning from a vacation spent abroad, holidays can trigger higher infections even if travellers do not go abroad. Even if all holiday travellers had stayed in Germany, the spread of the virus would have been likely to accelerate because of the changed social behaviour during holidays (Ewing et al. 2017; Eames et al. 2011). Many holiday-makers have more and more intense social interactions, often to people that they do not know (Ewing et al. 2017). Mobility also reduces the health agencies' ability to successfully trace contacts of people that are infected with Sars-CoV-2 (Akian et al. 2020). These additional risks are hardly limited to international travels, it is a holiday hazard. In this paper, we thus broaden the perspective and focus on the extent to which school holidays have triggered an increase in the growth rate of weekly new infections, including but not limited to holiday-related travel abroad.

To the best of our knowledge, this paper is the first to estimate the association between summer school holidays and new Sars-CoV-2 infections. We employ an ecological analysis of variation in infection growth rates across German districts – there are no data at the individual level. Keeping the well-known limits of any ecological study in mind, Germany provides an excellent case study for the analysis of the association between school holidays and the growth in infections. We exploit a particular feature of the system of school holidays in Germany, namely that they are not uniform across the Federal Republic but vary in their start and therefore also their end date from state to state in a pre-determined way.[3] This idiosyncratic feature allows us to disentangle the effect that holiday-related travel has on new infections in German districts located in states that are or have been on holiday from the general upward trend in new infections in Germany. Our research design also allows us to capture any increase in infections caused by holiday-related travel within Germany, whereas the RKI's approach only looks at those who went abroad.

We test three hypotheses. First, the growth rate of infections systematically increases in districts with school holidays. Second, the growth rate of new infections increases over time as the school holidays proceed and does not revert back down to what it was before the start of holidays in the two weeks after holidays end. Third, the effect of summer school holidays and the two-week period after the end of holidays on the growth rate in infections is larger in districts that are richer and that have a larger share of foreigners amongst its resident population since richer people are more likely to go on holiday and more likely to go on holiday abroad and foreign citizens are likely to want to visit their home country during the holiday season.

Our estimates suggest that at least 30 percent of the new infections that occurred in Germany in all states during their summer school holidays can be attributed to summer school holidays on infections, but this effect goes to 50 percent towards the end of the holiday seasons and in the more affluent states and districts. We find substantively larger than average effects in the Western German states of Lower Saxony, Bavaria, and Baden-

[3] For more detail on how German states coordinate school holidays see www.eacea.ec.europa.eu/national-policies/eurydice/sites/eurydice/files/school_calendar_2018_19_final_report_0.pdf

Württemberg and substantively lower than average effects in the Eastern German states Saxony-Anhalt, Thüringen, Brandenburg and Mecklenburg-Vorpommern. The size of the effect is thus generally consistent with the RKI calculations.

Our findings contribute to various strands of the social science literature on Covid-19 and similar epidemics. First and most directly, our research is related to the growing number of studies interested in the social determinants of Sars-CoV-2 infections. Of course, as we explain in the next section, holidays do not directly cause a transmission of a virus, but they facilitate behaviours which are more conducive to transmissions than other behaviours and therefore make it easier for a virus to strive and spread (van Bevel et al. 2020, Jarvis et al. 2020). Second, our findings are consistent with studies that have simulated data to project a dampening effect of travel restrictions on the speed with which Sars-CoV-2 spreads (Chinazzi et al. 2020; Anzai et al. 2020; Devi 2020). We provide indirect evidence for the predictions based on these models using observed infection numbers. Third, our findings are broadly in line with analyses of infectious diseases other than Covid-19 (Yu et al. 2012; Nichol et al. 2010). Most closely related to our results, Poggensee et al. (2010) estimate that during the summer roughly 60 percent of infections with H1N1 influenza were related to travel. Like us, Poggensee and co-authors relate the effect of holidays to holiday-related travels. We find a somewhat smaller holiday effect, but this could be due to conceptual differences: while our data only count individuals tested positive for Sars-CoV-2 infections, Poggensee et al. (2010: 2) accept all individuals with “Influenza-like illness (…) defined as acute onset of respiratory symptoms, and fever, and cough, and headache or musculo-skeletal pain” as H1N1 cases.

2. Background: School Holidays and the Rise in Sars-CoV-2 Infections

The most straightforward argument against the hypothesis that holiday travels to foreign places increase infections back home is simple: if a holiday-maker travels to a destination that has fewer active cases per capita than her home area, the probability of an infection declines, all other things equal. Yet, not only did Germany have lower infection rates than many foreign holiday destinations. More importantly, all other things are not equal and, for at least three reasons, we would expect that holiday-related travels increase infections regardless of the relative difference in infection rates between Germany and other countries.

First, the process of travelling may in itself increase the risk of an infection. If the traveller journeys to an airport, train or bus station, waits around for boarding and then boards a plane, train or bus, a potentially crowded indoor space with imperfect ventilation, the probability of transmission through aerosols increases – small exhaled droplets that may contain the virus (Moravska and Cao 2020). The evidence on infections during flights and train rides is rather mixed. In unpublished work, Hu et al. (2020) report that the probability of an infection while sitting within 3 rows and 5 columns from an infected passenger is low on average (0.32 percent) but can be as high as 10.3 percent. Likewise, Schwartz et. al. (2020: E410) find no contagion on a (single) flight with infected passengers. They suggest that “studies of airplane transmission are commonly biased by contacts sharing exposure risks before boarding the air-craft.” However, the absence of evidence of an effect is not evidence of absence of such an effect. As Gonne and Hubert (2020) argue, travel restrictions are surprisingly easy to implement, but unsurprisingly difficult to access. Moreover, though very few infections have been demonstrably associated with trains and planes, there is at least some evidence that public transportation has contributed to the spread of the virus in early stages of the pandemic (Harris 2020; Fathi-Kazerooni et al. 2020). For example, Harris (2020) has compellingly argued that the underground public transportation system contributed to the spread of the virus in New York City during the early days of the pandemic. All in all, however, we would presume this first factor to be a relatively minor one relative to the other two.

Second, people who go on vacation do not follow the same daily routines as they do at home. They are less likely to follow social distancing norms, partly because they follow holiday routines and partly because social control from family and friends declines. Migrant workers visiting their home countries often ignore rules of social distancing when visiting friends and family (Leung et al. 2020; Farias and Pilati 2020). It seems that long-established social courtesy norms are often stronger than relatively new and untrained social distancing rules, partly because of the misperception that family and friends do not pose a serious risk.[4] For migrant workers a summer holiday usually implies family visits, exchange of gifts, and parties. Likewise, tourists spend more time on leisure activities and visit bars and restaurants more often than they would at home. In an interview with the *Time* magazine, Martin McKee, professor of public health at the London School of Hygiene and Tropical Medicine, told journalist Madelaine Roach that the rise in new infections was “most likely” triggered by “tourists in crowded bars, restaurants, and nightclubs.”[5] There exists plenty of video and photo footage that shows tourists violating social distancing norms. What appears

4 The relevance of social capital for adherence to social distancing norms is now well established (Borgonovi et al. 2020; Bartscher et al. 2020; Papageorge et al. 2020; see also Pampel et al. 2010). What is missing, though, are analyses of how a change in the social environment influences social distancing behaviour.

5 Madeleine Roach, Time Magazine, August 27.

to be lacking, however, is systematic research on the behavioural-related differences of the same people at home and during their holidays as it could be that the same people shown on the footage also violate social distancing norms back home. In a computational model on H1N1 influenza, Shi et al. (2010) find that social gatherings and travels increase infections close to the peak of a pandemic, but have little effect when the number of active infections per capita is low. While this finding may be plausible for influenza where virtually all contagious people show symptoms, it does not need to hold for a virus that can be transmitted from asymptomatic infected people as is the case with Sars-CoV-2. We therefore find it plausible that holidays reduce the willingness and ability of people to adhere to social distancing norms.

Third, holiday travellers have more social interactions with people that they do not normally physically interact with and/or they do not know. Holiday travel inevitably implies interacting with more strangers or faintly acquainted individuals than back home. As a consequence, infected people will usually not be able to name their recent close contacts after they have been diagnosed with the virus. What makes matters worse is that tracing apps are incompatible across European countries. Hence, with holiday travel-related transmissions, contact tracing becomes prohibitively difficult: travellers are unlikely to identify many of their close contacts and technology will also be of little help since contact tracing apps do not work across European borders. Thus, even if the behaviour of holiday travellers were not to increase the spread of Sars-CoV-2 as such, the declining ability to stop the spread through contact tracing measures should eventually lead to an increase in infections.

In sum, holiday-related travels increase infections not necessarily because of the act of travelling itself though this might also contribute. Rather, travelling increases infections because tourism and family visits abroad have a profound effect on the number, intensity and nature of social interactions and significantly reduce the ability to trace social contacts. This logic implies that the odds of catching an infectious disease may increase even if travellers vacation in a region of their home country or another country with a lower infection rate. Likewise, though, the risk becomes larger the higher the rate of infection in the traveller's destination.

We use these theoretical considerations to test three hypotheses. First, school holidays have a positive effect on the infection growth rate in the home location of travellers. Second, given that there is a delay until holiday travellers return home, the later parts of any given holiday season should have a larger effect than its earlier parts. Empirical evidence suggests (Stiftung für Zukunfsfragen 2020; Gokovali et al. 2007) that the average lengths of holiday stay of German tourists is about 12-14 days. Therefore, one should expect that infections start to rise roughly 2 to 3 weeks after the beginning of the school holidays. In other words, the longer the holidays last, the stronger the increase in the infection growth rate. Reinforcing this logic, infections rise in practically all holiday travel destinations, both within and outside Germany, thus increasing the risk of catching the virus as the holiday season proceeds. Third, school holidays will have a stronger effect on the infection growth rate in districts that are richer on average and in which a larger share of the resident population are foreigners. Richer people are more likely to go on holiday, more likely to go on holiday abroad (where infection rates tend to be higher than in Germany) and foreign citizens are likely to return to their home country for family visits (possibly in addition to taking other holidays).

3. Data and Estimation

Our dependent variable is the weekly percentage growth rate in the number of infections in a German district. Infection data by district are sourced from the RKI website (www.rki.de). Our sample covers 401 districts with the temporal dimension drawn from the period starting with the weekly growth rate to Wednesday 10 June (week 23) and terminating with the weekly growth rate to Wednesday 23 September (week 38).[6] We deliberately define the week to end in a Wednesday rather than Sunday or Monday to avoid noise from occasional corrections made on Mondays or Tuesdays for underreporting over the weekend. For each district, we analyse the period ranging from two weeks prior to the beginning of holidays to two weeks after the end of the holidays. Our panel thus has N=401 districts and T=10 weeks equals 4010 observations. In Germany, the dates of the summer school holidays are chosen by each of the 16 states in close consultation with each other. The intention is to reduce the probability and length of traffic jams on Germany's crowded motorways during the summer months. In each state, schools close for roughly six weeks. In 2020, the summer school holiday season began on June 22 in Mecklenburg-Vorpommern and ended September 9 in Baden-Württemberg. Hence, Germany spreads the holiday season over almost 13 weeks.

The average weekly growth rate of infections in the sample across all German districts is 2.70 percent with a standard deviation of 3.48 percent. For an average district, the incidence rate would double roughly every 26 weeks. In Germany as a whole, the number of new infections had been stable at around 500 per day until the end of July. In August, the number of daily infections begun to rise reaching approximately 1,500 new daily infections

[6] Due to lack of disaggregated data on income and the share of foreigners amongst residents, the twelve districts of Berlin are aggregated to one single city state district.

at the end of August and about 2,000 daily new infections at the end of September.

The upward trajectory in infections in Germany coincides with the summer school holiday seasons. It is unlikely, however, that the return of rising infection numbers has been determined by school holidays alone. To isolate the predicted effects from other influences, we include a lagged dependent variable in the model that accounts for the common trend in the data (Engle and Kozicki 1993; Vahin and Engle 1993; Plümper et al. 2005; Ding and Li 2019).[7] This is a conservative research strategy since part of this trend was most likely caused by returning holiday-makers. However, it is impossible to provide a precise estimate of the influence of holidays on the trend because holiday travel was allowed in all states and all districts at all times, not just during school holidays. In fact, it is a limitation of our research design that we can only capture holiday-related travel triggered by school holidays. Families with children of school-age in particular are dependent on school holidays for their holiday travel and the same holds for the employees of firms that close down for company holidays over the summer. Thus, the majority of holiday travels will take place during school holidays but certainly not all of it, which potentially biases downwards our estimate of the effect of holiday-related travel on Sars-CoV-2 infection.

We include district fixed effects (Allison 2009) to absorb any variation across districts that is time-invariant such as demographic, geographic and socio-economic factors that render some districts more generally exposed to the pandemic than others. Since potential control variables come from annual data, they are time-invariant for the panel structure we have. These time-invariant variables are perfectly collinear with the district unit effects and we

[7] Results are similar if we use an alternative approach for taking out the common trend, such as an autoregressive model.

therefore cannot simultaneously include control variables and estimate a district fixed effects model. We cluster standard errors on districts. If we additionally apply two-way clustering of standard errors also by states results are hardly affected (results not reported).

In table 1 we report results on a dummy variable that is set to 1 if a district is located in a state in which schools are on summer holidays in that week as well as a dummy variable for the two-week period after the holidays. This model can be interpreted as a Chow-type model (Chow 1962; Dufour 1982) in which the dummy variables estimates whether there is a structural break between the period before holidays and the holiday period as well as the period before holidays and the period of two weeks after the holidays. We find that summer school holiday weeks are on average predicted to increase the infection growth rate by 0.72 percentage points relative to the period before holidays, consistent with our first hypothesis. This equates to 27.3 percent of the weekly growth rate in Germany during the entire holiday season.

We also find that the growth rate in infections in the two-week period after the holiday season ends is statistically significantly higher than either the pre-holiday period but also the holiday period ($p<0.01$). This is caused by late returners from holidays, the incubation time which is estimated to be 2 weeks for some cases, time it takes from infection to being counted as infected by the RKI and by the further spread of travel-related infections in Germany by those returnees who infect others either unwittingly (in the case of asymptomatic individuals) or before their self-isolation. This suggests that we should see holiday effects from roughly week 3 of the holidays to at least 2 weeks after the holiday ends, but of course it is highly likely that holidays have a persistent and lingering effect on infection rates that last much longer than the holidays. Moreover, our findings suggest that, as expected, the holiday effect is not constant over the period of holidays so that the effect reported in model 1, which pools all holiday weeks together, masks that the effect is likely to vary across the holiday period and increase over time as holidays proceed. To test our second hypothesis, model 2 therefore allows the effect of holidays and the 2-week period thereafter to differ week-by-week. As expected, we find that the effect increases in later weeks of the school holidays.

Table 1. School Holiday Effects, Pooled and Time-varying

	m1	m2
Infection growth rate (t-1)	0.256**	0.227**
	(0.0211)	(0.0263)
summer school holidays dummy	0.724**	
	(0.157)	
2 weeks after summer school holidays dummy	1.957**	
	(0.201)	
1st week of summer school holidays		0.0669
		(0.208)
2nd week of summer school holidays		-0.0356
		(0.169)
3rd week of summer school holidays		0.284
		(0.183)
4th week of summer school holidays		1.027**
		(0.208)
5th week of summer school holidays		1.257**
		(0.217)
6th week of summer school holidays		1.905**
		(0.239)
1st week after summer school holidays		2.138**
		(0.253)
2nd week after summer school holidays		1.945**
		(0.242)
Observations	4,010	4,010
R-squared	0.139	0.171
Number of districts	401	401

Note: standard errors clustered on districts in parentheses. ** p<0.01, * p<0.05

The effect is essentially zero in the first two week not least because of the lag caused the incubation period. The effect turns positive in week three and becomes statistically significant from week four onwards and then increases to 1.91 percentage points in week 6. The coefficients of the first and the second week after school holidays finish show that the increases in infection growth brought about by the school holidays do not disappear but essentially remain constant.

In model 3, reported in table 2, we revert back to the simple Chow-type structural break model with two dummy variables but allow the structural breaks to vary state-by-state. We exclude the two states of Hamburg and Berlin since both are counted as consisting of only one district in our data, which would result in unreliable estimates. Table 2, in which we sort states by the point estimate of the holiday period dummy variable, shows large variation in the holiday effect on infection growth rates across districts in different German states. Overall, we find that richer states are more likely to show relatively large effects, and we find that the increase in infections associated with the holiday season is larger in the Western German states than in the Eastern German states. Looking state by state, we find a statistically significant effect of either the holiday period or the two-week period after the end of holidays or of both in 12 of the 16 states.

Only Thüringen, Saxony-Anhalt and Brandenburg, all located in the East, and North Rhine-Westphalia show no statistically significant effects. The three Eastern German states have low and slowly but linearly rising growth rates in Infection numbers and therefore no significant holiday effect.

Table 2. School Holiday Effects, Varying by State

m3	during school holidays	after school holidays
Infection growth rate (t-1)	0.246**	
	(0.0224)	
Lower Saxony	2.033**	0.200**
	(0.326)	(0.0334)
Baden-Württemberg	1.178**	1.536**
	(0.221)	(0.253)
Bavaria	1.118**	1.213**
	(0.144)	(0.143)
Schleswig-Holstein	1.116**	0.168**
	(0.226)	(0.0340)
Bremen	0.938**	0.339*
	(0.244)	(0.160)
Hesse	0.845**	0.571**
	(0.313)	(0.0890)
Saxony	0.799**	0.209**
	(0.214)	(0.0658)
Saxony-Anhalt	0.703	0.0300
	(0.476)	(0.0319)
Thüringen	0.593	0.0591
	(0.332)	(0.0327)
Rhineland-Palatinate	0.329	0.255**
	(0.336)	(0.0434)
Saarland	0.171	0.0828*
	(0.398)	(0.0389)
Mecklenburg-Vorpommern	-0.290	0.381*
	(0.674)	(0.160)
North Rhine-Westphalia	-0.352	0.137
	(0.951)	(0.100)
Brandenburg	-1.123	0.0241
	(0.644)	(0.224)
Observations	4,010	
R-squared	401	
Number of districts	0.163	

Note: standard errors clustered on districts in parentheses. ** p<0.01, * p<0.05

In contrast, North Rhine-Westphalia had high infection rates and growth rates above 4 percent already before the holidays begun due to super-spreader events in a slaughterhouse of the Tönnies company in the districts of Gütersloh and Warendorf with no further acceleration during the holiday period. These events have reduced the estimate of holiday-related growth in infections for this state because the strong decline of infections in these two districts after containment measures were put in place locally compensates for the holiday-related increase in the growth rate of infections in all other districts of North Rhine-Westphalia. In fact, if we drop the two districts of Gütersloh and Warendorf from the estimations then both coefficients of the holiday and post-holiday periods become significantly positive for this state.

Figure 1a and 1b show cumulative infection numbers and the growth rate in infections for the states of Bavaria, the richest German state bar the two city states of Bremen and Hamburg, and Saxony-Anhalt, the state with the lowest average per capita income. As Model 3 has shown, the holiday season was associated with a significant increase in infections in Bavaria, while we did not find a significant increase in infections relative to the trend in Saxony-Anhalt. Figures 1a and 1b support these findings from our regression analysis. The vertical lines depict the first and the last day of school holidays, the blue line represents the cumulative number of known infections (left scale) and the bars display the weekly growth rate of these infections calculated for each day with respect to the past seven days. Even without econometric controls for the trend in the data, one can see a structural break in Bavaria's infection dynamics and the absence of such a structural break in Saxony-Anhalt's infection rates.

Bavaria's growth rate in infections is slowly increasing from about 0.4 percent on day 167 to about 1 percent on the day its summer holidays started. Two weeks later, when holiday-makers began to return, the growth rate still stood at 1.06 percent (day 226), but quickly rose to 3.87 percent on day 237. We find so such effect for Summer-Anhalt. This state had a short outbreak of infections in mid-June, with the infection growth rate then falling to below 1 percent and then starting to climb almost linearly over the summer, with no obvious structural break triggered by the beginning of the school holidays.

Figure 1a: School Holidays and Infections in Bayern

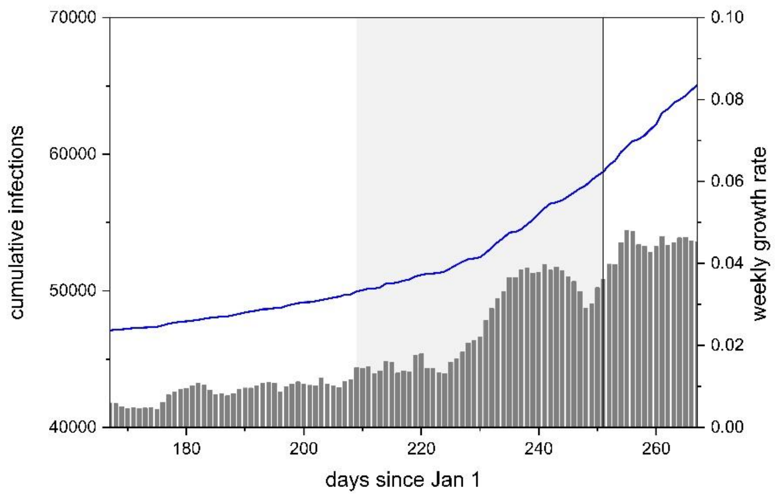
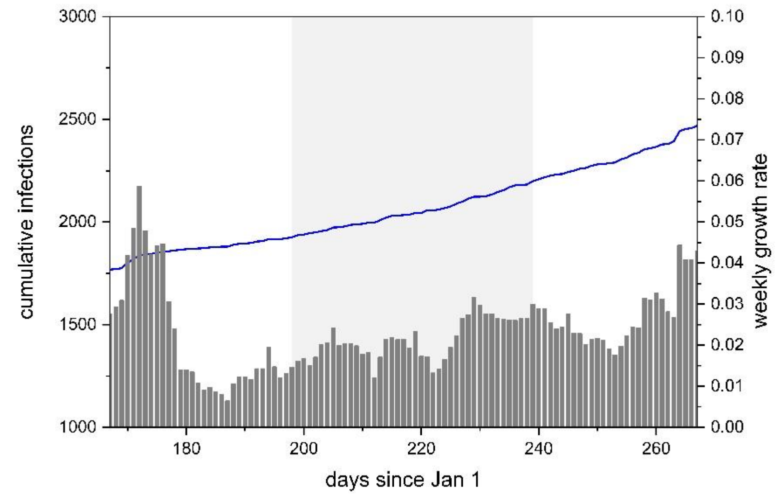


Figure 1b: School Holidays and Infections in Saxony-Anhalt



Saxony-Anhalt and Bavaria differ in many respects. Bavaria is richer, more industrial, more urbanized, and it also hosts a larger share of foreign residents. In table 3, we allow the effect of summer school holidays and the two-week period after holidays to be conditioned by one or both of two variables, namely by average taxable income in a district as well as by the share of foreigners amongst a district's residents. We have selected these variables because they are likely to determine the number of holiday-related travels. Richer people are more likely to go on vacation and go on vacation abroad and foreign residents will be keen to visit their home country. The data for these two variables are sourced from the regional database of the German statistical office.[8] These variables are time-invariant for our sample, therefore we cannot estimate coefficients for these variables as such in a model with district fixed effects. However, we can estimate the conditioning effect of these variables on the time-varying holiday variables.

Table 3. The Conditioning Effect of Average Taxable Income and of the Share of Foreign Residents

	m4	m5	m6
infection growth rate (t-1)	0.255**	0.251**	0.251***
	(0.0211)	(0.0215)	(0.0215)
Summer school holidays dummy	-0.669	0.391	-0.627
	(0.572)	(0.206)	(0.563)
post-holidays dummy	0.0333	0.836**	0.322
	(0.771)	(0.279)	(0.747)
holidays dummy * taxable income p.c.	0.0770*		0.0664**
	(0.0328)		(0.0317)
post-holidays dummy * taxable income p.c.	0.107*		0.0335
	(0.0429)		(0.0406)
holidays dummy * share foreign residents		3.031	1.393
		(1.780)	(1.636)
post-holidays dummy * share foreign residents		10.23**	9.405***
		(2.411)	(2.314)
Observations	4,010	4,010	4,010
R-squared	0.141	0.144	0.144
Number of districts	401	401	401

Note: standard errors clustered on districts in parentheses. ** p<0.01, * p<0.05

Model 4, reported in table 3, shows a positive and statistically significant interaction effect between average taxable income and the dummy variables for school holidays and for the two-week post-school holiday period. Model 5, also reported in table 3, shows positive interaction effects between the share of foreigners amongst a district's residents and the school holidays and the post-holiday period dummies. However, only the interaction effect

8 www.destatis.de

with the post-holiday period is statistically significant at the 5 percent level. The two conditioning variables are correlated at r = 0.44 with each other. In model 6 we include interaction effects with both taxable income per capita and the share of foreigners amongst a district's residents. The conditioning effects are rather similar in model 6 as they were in models 4 and 5, except the one between the post-holiday dummy variable and taxable income per capita is no longer statistically significant.

4. Conclusion

Many believe that holiday-related travels, particularly to foreign places, have been at the root of rising infection numbers in Germany. We have analysed the association between summer school holidays and the weekly growth rate of Sars-CoV-2 infections in German districts. Our findings lend support to the widely shared belief: We find a statistically significant and substantively important increase in the growth rate of infections due to the holiday season and the two-week period thereafter. Disaggregating the effect week-by-week, we find that the effect increases over the holiday period, becoming statistically significant from week 4 onwards and not reverting back to the growth rate from before the holiday period in the two weeks after holidays end.

While infection numbers would probably have gone up in the counterfactual case of no summer holidays because large parts of the population have become tired of anti-coronavirus policies and social distancing, this article has provided evidence that about 30 percent of new infections were associated with school holidays. For example, model 1 predicts that the average summer school holiday week increases the growth rate in infections by 0.72 percentage points relative to the period before holidays. This equates to 27.3 percent of the average growth rate in Germany during the entirely holiday season. Yet, this is an average across time and across space. As Model 2 suggests, in week 6 of the holidays the growth rate in infections is predicted to be 1.91 percentage points higher than it was during the two weeks before holidays begun. This translates to approximately 50 percent of the average growth rate in infections.

Our findings also go beyond simply confirming the widely held belief that holidays increased infections. We have explored how the effect differs across German states and have shown that the average effect also holds for most of the German states, if to varying degrees. There are statistically significant structural breaks in the growth rate of infections in at least 10 of the 14 German states[9] with more than one district in our dataset. The stronger effects take place in the Western German states. In fact, those without a statistically significant structural break are all located in Eastern Germany with the exception of North Rhine-Westphalia which is however an outlier due to a very large local outbreak before the holiday season though spreading of course beyond the two districts immediately affected. Two main reasons for this heterogeneity across German states are that the states with a stronger effect consist of districts that tend to be both richer and have a larger share of foreign residents amongst their population, both of which spurs holiday-related travel. Corroborating this, we have shown that the higher is per capita income and the higher the share of foreigners in a district, the larger the increases in the growth rate of infections. This would result in higher than average effects for Hamburg, Baden-Württemberg, Bavaria and Hesse, all of which are dominated by districts with above average income and an above average resident share of foreigners, and lower than average effects for each single state in

[9] If we account for the superspreading event in two slaughterhouses in Westphalia in 11 out of 14 districts.

East Germany with the exception of Berlin, which are all relatively poor (by German standards) and have a low share of foreigners amongst their residents.

These holiday effects are not just substantial, they were also predictable. Of course, it would not have been realistic for either the German federal government or state governments to implement let alone enforce prohibitions on holiday-related travel. However, neither Germany as a whole nor the states systematically kept reminding travellers of the importance of maintaining social distancing and keeping track of close contacts. Doing so may have been futile anyway but they did not prepare to deal with the predictable rapid increase in infections either. What they could and arguably should have done was to significantly drive up testing facilities to compensate for the increase in infections and the reduced contract tracing capabilities. Eventually, Germany did drive up testing capacities, but this came too late to prevent a significant increase in the growth rate of infections. We contend that this in a second wave of infections starting earlier with higher growth rates in infections than would have otherwise happened.

References

Akian, M., Ganassali, L., Gaubert, S., & Massoulié, L. (2020). Probabilistic and mean-field model of COVID-19 epidemics with user mobility and contact tracing. arXiv preprint arXiv:2009.05304.

Allison, P. D. (2009). *Fixed effects regression models*. SAGE, Thousand Oaks.

Anzai, A., Kobayashi, T., Linton, N. M., Kinoshita, R., Hayashi, K., Suzuki, A., ... & Nishiura, H. (2020). Assessing the impact of reduced travel on exportation dynamics of novel coronavirus infection (COVID-19). *Journal of clinical medicine*, 9(2), 601.

Bartscher, A. K., Seitz, S., Slotwinski, M., Siegloch, S., & Wehrhöfer, N. (2020). Social capital and the spread of Covid-19: Insights from European countries. CESIfo working paper 8346.

Borgonovi, F., & Andrieu, E. (2020). Bowling together by bowling alone: Social capital and Covid-19. *Covid Economics*, 17, 73-96.

Chinazzi, M., Davis, J. T., Ajelli, M., Gioannini, C., Litvinova, M., Merler, S., ... & Viboud, C. (2020). The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science*, 368(6489), 395-400.

Chow, G. C. (1960). Tests of equality between sets of coefficients in two linear regressions. *Econometrica*, 591-605.

Devi, S. (2020). Travel restrictions hampering COVID-19 response. *The Lancet*, 395(10233), 1331-1332.

Ding, P., & Li, F. (2019). A bracketing relationship between difference-in-differences and lagged-dependent-variable adjustment. *Political Analysis*, 27(4), 605-615.

Dufour, J. M. (1982). Generalized Chow tests for structural change: A coordinate-free approach. *International Economic Review*, 565-575.

Eames, K. T., Tilston, N. L., & Edmunds, W. J. (2011). The impact of school holidays on the social mixing patterns of school children. *Epidemics*, 3(2), 103-108.

Engle, R. F., & Kozicki, S. (1993). Testing for common features. *Journal of Business & Economic Statistics*, 11(4), 369-380.

Ewing, A., Lee, E. C., Viboud, C., & Bansal, S. (2017). Contact, travel, and transmission: The impact of winter holidays on influenza dynamics in the United States. *The Journal of infectious diseases*, 215(5), 732-739.

Farias, J. E. M., & Pilati, R. (2020). Violating social distancing amid COVID-19 pandemic: Psychological factors to improve compliance. Psyarxiv

Fathi-Kazerooni, S., Rojas-Cessa, R., Dong, Z., & Umpaichitra, V. (2020). Time Series Analysis and Correlation of Subway Turnstile Usage and COVID-19 Prevalence in New York City. arXiv preprint arXiv:2008.08156.

Gokovali, U., Bahar, O., & Kozak, M. (2007). Determinants of length of stay: A practical use of survival analysis. *Tourism management*, 28(3), 736-746.

Gonne, N and O Hubert (2020). Spatial distancing: air traffic, COVID-19 propagation, and the cost efficiency of air travel restrictions. *Covid Economics* 24: 111-125.

Harris, J. E. (2020). The subways seeded the massive coronavirus epidemic in New York City. NBER Working Paper, (w27021).

Hu, M., Lin, H., Wang, J., Xu, C., Tatem, A. J., Meng, B., ... & Xie, H. (2020). The risk of COVID-19 transmission in train passengers: an epidemiological and modelling study. *Clinical Infectious Diseases*.

Jarvis, C. I., Van Zandvoort, K., Gimma, A., Prem, K., Klepac, P., Rubin, G. J., & Edmunds, W. J. (2020). Quantifying the impact of physical distance measures on the transmission of COVID-19 in the UK. *BMC medicine*, 18, 1-10.

Leung, C. C., Lam, T. H., & Cheng, K. K. (2020). Let us not forget the mask in our attempts to stall the spread of COVID-19. The International Journal of Tuberculosis and Lung Disease, 24(4), 364-366.

McKee, M. (2020): A European Roadmap out of the Covid-19 Pandemic. *BMJ* 369: 1-2.

Morawska, L., & Cao, J. (2020). Airborne transmission of SARS-CoV-2: The world should face the reality. *Environment International*, 105730.

Nichol, K. L., Tummers, K., Hoyer-Leitzel, A., Marsh, J., Moynihan, M., & McKelvey, S. (2010). Modeling seasonal influenza outbreak in a closed college campus: impact of preseason vaccination, in-season vaccination and holidays/breaks. *PloS one*, 5(3), e9548.

Pampel, F C, P M Krueger, and J T Denney (2010), "Socioeconomic disparities in health behaviors", *Annual Review of Sociology* 36: 349–70.

Papageorge, N. W., Zahn, M. V., Belot, M., van den Broek-Altenburg, E., Choi, S., Jamison, J. C., & Tripodi, E. (2020). Socio-Demographic Factors Associated with Self-Protecting Behavior during the COVID-19 Pandemic (No. 13333). Institute of Labor Economics (IZA).

Plümper T., Neumayer, E. & Shaikh, M. (2020). Lockdown Policies and the Dynamics of the First Wave of the Sars-CoV-2 Pandemic in Europe. Unp. Manuscript London School of Economics.

Plümper, T., & Neumayer, E. (2020). The pandemic predominantly hits poor neighbourhoods, or does it? SARS-CoV-2 infections and Covid-19 fatalities in German local districts. *European Journal of Public Health*.

Plümper, T., Troeger, V. E., & Manow, P. (2005). Panel data analysis in comparative politics: Linking method to theory. *European Journal of Political Research*, 44(2), 327-354.

RKI (2020). Täglicher Lagebericht. 18.08.2020.

Rose G., (1981): Strategy of prevention: lessons from cardiovascular disease, *Br Med J* 282: 1847-51.

Schwartz, K. L., Murti, M., Finkelstein, M., Leis, J. A., Fitzgerald-Husek, A., Bourns, L., ... & Yaffe, B. (2020). Lack of COVID-19 transmission on an international flight. *CMAJ*, 192(15), E410-E410.

Stiftung für Zukunftsfragen (2020): Tourismusanalyse 2020, www.tourismusanalyse.de.

United Nations World Travel Organization (2020): Covid-19 Related Travel Restrictions: A Global Review for Tourism. UNWTO April 28 2020.

Vahid, F., & Engle, R. F. (1993). Common trends and common cycles. *Journal of Applied Econometrics*, 341-360.

Van Bavel, J. J., Baicker, K., Boggio, P. S., Capraro, V., Cichocka, A., Cikara, M., ... & Drury, J. (2020). Using social and behavioural science to support COVID-19 pandemic response. *Nature Human Behaviour*, 1-12.

Yu, H., Cauchemez, S., Donnelly, C. A., Zhou, L., Feng, L., Xiang, N., ... & Peng, Z. (2012). Transmission dynamics, border entry screening, and school holidays during the 2009 influenza A (H1N1) pandemic, China. *Emerging infectious diseases*, 18(5), 758.