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Short Communication

COVID-19 incidence in border regions: spatiotemporal patterns and border control measures

Tobias Chilla^a, Tim Große^a, Stefan Hippe^a, Blake Byron Walker^{*,a}

Friedrich-Alexander University, Erlangen, Germany

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ABSTRACT

Objectives: Among the few studies examining patterns of COVID-19 spread in border regions, findings are highly varied and partially contradictory. This study presents empirical results on the spatial and temporal dynamics of incidence in 10 European border regions. We identify geographical differences in incidence between border regions and inland regions, and we provide a heuristic to characterise spillover effects.

Study design: Observational spatiotemporal analysis.

Methods: Using 14-day incidence rates (04/2020 to 25/2021) for border regions around Germany, we delineate three pandemic ‘waves’ by the dates with the lowest recorded rates between peak incidence. We mapped COVID-19 incidence data at the finest spatial scale available and compared border regions’ incidence rates and trends to their nationwide values. The observed spatial and temporal patterns are then compared to the time and duration of border controls in the study area.

Results: We observed both symmetry and asymmetry of incidence rates within border pairs, varying by country. Several asymmetrical border pairs feature temporal convergence, which is a plausible indicator for spillover dynamics. We thus derived a *border incidence typology* to characterise (1) symmetric border pairs, (2) asymmetric border pairs without spillover effects, and (3) asymmetric with spillover effects. In all groups, border control measures were enacted but appear to have been effective only in certain cases.

Conclusions: The heuristic of border pairs provides a useful typology for highlighting combinations of spillover effects and border controls. We conclude that border control measures may only be effective if the timing and the combination with other non-pharmaceutical measures is appropriate.

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Introduction

Efforts to stem the interregional spread of SARS-CoV-2 rely largely on carefully timed policies to reduce vector mobility.¹ Border management has therefore been a highly visible and often utilised form of non-pharmaceutical pandemic control following the SARS-CoV-2 outbreak, despite the rather controversial and legally complex nature of border policy.^{2–4}

Very few studies have examined patterns of COVID-19 spread and containment in and across border regions, with several notable exceptions. Alizon et al.⁵ and Klatt⁶ conducted regional analyses of COVID-19, providing some initial data, while Duvernet⁷ found that border control measures do not show a clear impact in the German context. Conversely, Hossain et al.⁸ postulate a positive effect in mainland China. Scarpone et al.⁹ identified clusters of high COVID-

19 incidence rates in several of Germany’s border regions and underscored the need for further research to directly examine the role of borders and border controls in SARS-CoV-2 containment.

This report responds directly to this need for closer investigation by providing initial results from our examination of border regions’ roles in the spatial and temporal dynamics of COVID-19, focussing on Germany and its nine bordering countries. The objectives of this study were to (i) identify geographical differences in incidence rates between border regions and inland regions in the study area, (ii) identify possible spill-over effects in border regions, and (iii) conduct a preliminary examination of the spatiotemporal association between border controls and COVID-19 incidence.

Methods

This analysis uses 14-day incidence rates (reported confirmed cases per 100,000 inhabitants) from week 04/2020 to week 25/2021 for border regions in and around Germany. Data were acquired from open data sources at the European Centre for Disease Prevention and Control and the Swiss Federal Office of Public Health. For several

* Corresponding author. Wetterkreuz 15, 91058 Erlangen, Germany. Tel.: +49 157 3419 1735.

E-mail address: blake.walker@fau.de (B.B. Walker).

^a These authors contributed equally to this article and share the first authorship.

regions, data were only available beginning in week 18/2020. We delineated three pandemic ‘waves’, differentiated by the dates with lowest recorded rates between peak incidence in Germany and the results were mapped and analysed. As early-pandemic data were only available for Belgium, Germany, and France, we focus particularly on waves 2 and 3, which feature complete data for all ten countries.

Our analysis uses COVID-19 incidence data at the finest spatial scale for which data were available (NUTS3 in DE, CZ; NUTS2 in PL, NL, CH, FR, DK, AT; NUTS1 in BE), and we compare their border regions’ incidence rates to their nationwide values (NUTS0). Administrative areas adjacent to a national border (including NUTS3 regions with min. 25% of their area within a 25 km buffer along the border, see [Supplement S1](#)) were selected and assigned a categorical variable for pandemic wave and country. The border regions’ incidence rates presented herein result from the non-weighted averages of their subunits.

(Land) Border control measures were defined as official suspensions of the Schengen agreement.¹⁰ The incidence rates and border control measures were analysed on the level of border pairs. The German-Czech border region was divided into two border pairs due to large differences in the spatiotemporal patterns between the CZ-Bavaria (BY) and CZ-Saxony (SN) regions. Bivariate linear models were run to examine the strength of correlation for incidence rates between border pairs.

Results

Many border pairs exhibit differences in their spatial and temporal development (see [Supplement S1](#)). These results exhibit both symmetry and asymmetry of incidence across border pairs. Several asymmetrical border pairs feature temporal convergence, which is a plausible indicator for spillover dynamics.

Based on the observed spatiotemporal patterns, we derived the following *border incidence typology*, summarising both a/symmetry and convergence/spill over. Four representative border pairs are shown in [Fig. 1](#), and all border pairs can be found in the appendix ([Supplement S2–7](#)).

- (1) **Symmetric border pairs** feature similar incidence rates and/or congruent trends on both sides of the border. In these instances, the border does not appear to inhibit infection dynamics. The border pair DK-DE in the first wave is a typical example featuring parallel temporal development ([Fig. 1](#)).
- (2) **Asymmetric border pairs without spillover effects** exhibit clear differences in their incidence rates and/or temporal trends. Over time, the values do not converge, i.e., spillover effects across the border appear unlikely. The BE-DE pair during the second wave shows clearly contrasting trends (a ten-fold difference, see [Fig. 1](#)). During this time, German border regions feature similar patterns as the German inland rates. As such, this asymmetry may indicate effective containment inhibiting any spillover effects.
- (3) Several border pairs are **asymmetric with spillover effects**, showing clear differences in the level of incidence while featuring temporal convergence. In these cases, a time lag between the peak incidence rates and an incomplete convergence are visible. The border pair CZ-BY during the second wave illustrates this pattern, with the incidence in Bavaria rising 8–9 weeks after the initial spike in the Czech Republic. During this time, the incidence rates in the German border region are notably higher than the national average, suggesting a spillover effect in this region.

While the CZ-BY case displays moderate evidence of spill over, the CZ-SN border pair during the second wave case features a much

stronger trend. The time lag is also approximately 8–9 weeks, but the convergence effect is much stronger ([Fig. 1](#)). The temporal dynamics in this region may provide an indication of a recurrent ‘yo-yo’ effect throughout the second and third waves. The incidence rates in Saxony appear to be decoupled from the German average values, which may provide further evidence of a spillover effect (in contrast to Duvernet,⁷ but similar to Hossain et al.⁸).

For the asymmetric border pairs with spillover effects, bivariate linear regressions indicated a high degree of correlation between incidence rates on either side of the border. For example, in the second wave, the CZ-SN pair exhibits a high degree of similarity with an R-square value of 0.82 ($P < 0.001$), while CZ-BY has an R-square of 0.666 ($P < 0.001$). Other border pairs featured a range between 0.451 and 0.262 ($P < 0.073$). These preliminary results provide evidence of a statistical dependence in all asymmetric border pairs with spillover effects. Asymmetrical border pairs without spillover effects do not feature correlation of rates.

All ten border pairs are therefore categorised by their a/symmetry and duration of border control measures. Among those with no border controls (or brief controls lasting less than 14 days), PL-DE, CZ-BY, and CZ-SN all exhibited asymmetry with spillover effects in the second wave. For the CZ-SN border pair, the difference between the second and third waves is strongly pronounced. In contrast, the border controls throughout the third wave are coincident with a weaker degree of symmetry. The remaining border pairs during waves 1 and 3 did not exhibit observable cross-border spillover effects.

Among borders that experienced border-crossing restrictions of 14 days or longer, symmetrical spatiotemporal development was observed in the first wave for DK-DE, PL-DE, and CZ-SN, and recurrent symmetry for DK-DE in the third wave. Also, during the third wave, CZ-SN and CZ-BY experienced border controls but still exhibited clear spillover effects. Border controls in other regions coincide with a lack of observable spill over, suggesting that the border-crossing restrictions may have been effective.

A notable outlier was observed for the Belgian-German border. During the peak incidence period of the second wave, no border controls were enacted. Nevertheless, a high degree of asymmetry suggests minimal or no spillover effects. In contrast, the third wave was accompanied by border controls, corresponding with increasingly asymmetrical development.

Discussion

Our preliminary results indicate that national borders may play a role in explaining the observed patterns of COVID-19 incidence, despite being within the Schengen Area. The outliers noted in our observations suggest that border controls were not universally effective for preventing spillover effects and that their effectiveness may be more closely related to the specific restrictions and means of enforcement, underscoring the need for detailed case studies to ascertain specifically the categories of measures that may be effective.

While some borders exhibited strong cross-border spillover effects, others appear to have been effective at controlling the spread of SARS-CoV-2. However, the ability to infer the effect of border controls may be inhibited by missing incidence data for certain regions in the early phases of the pandemic, as well as different spatial resolutions, i.e., that some regions report incidence by NUTS2 while others report at the NUTS3 scale. Border control measures are one of many non-pharmaceutical measures, such as lock-ins, compulsory masks, and social distancing; the observed cross-border differences may reflect policy differences in this regard. However, the complexity of the observed patterns underscores the need for detailed examination of specific border control measures and consideration of how multiple non-pharmaceutical measures can be utilised.

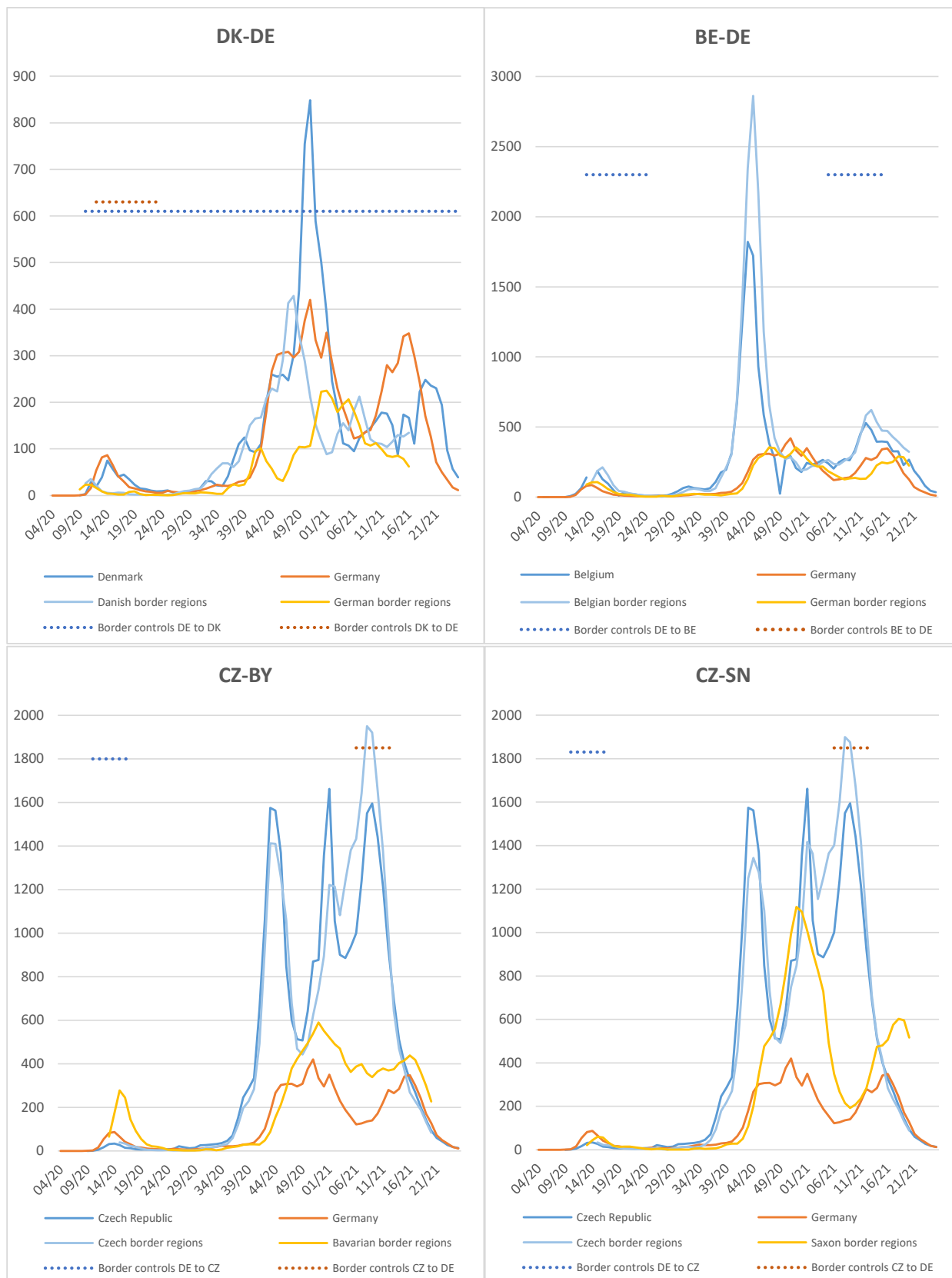


Fig. 1. Timeline of incidence rates and border controls for four selected border pairs. Axes labels: Y = Confirmed cases per 100,000 inhabitants, X = Week.

Author statements

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Ethical approval

This analysis only uses anonymised, open data at the aggregate level and is therefore low-risk and not subject to ethics approvals at the host institution.

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Competing interests

The authors declare that they have no conflict of interest in the submission and publication of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.puhe.2021.11.006>.

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