

Appendices for: Good Fences:
The Importance of Setting Boundaries for Peaceful Coexistence

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APPENDIX A: METHODS

1. Identifying the propensity to violence using a wavelet filter

The potential for conflict is quantified in our model using a wavelet filter [A.1–A.3]. In essence, the filter evaluates the extent of the presence of a type in a circular area with a specified radius and subtracts from this the presence of the same type in a surrounding area. This results in cancellation if the same type is located in the surrounding area. Other types

are all treated with the opposite sign causing cancellation if there are mixed populations of the first type with the others. Thus, the largest values are obtained for an island of one type surrounded by other types. Large values are also obtained for a peninsula of one type into a sea of other types. To evaluate the likelihood of violence at a particular location, we apply the filter, centered at that location, for each of the types. The likelihood of violence in that region is the maximum over all types. Unlike the earlier method [A.4], we included all population types on each site of a grid rather than basing calculations on an agent model. Mathematically the expression for the filter applied at a location (x, y) , with the maximum taken over all types, is

$$c(x, y) = \max_s \sum_{x', y'} m(x - x', y - y') \left(p_s(x', y') - \sum_{s' \neq s} p_{s'}(x', y') \right), \quad (\text{A1})$$

which is a convolution of the fraction of the population of one type, $p_s(x, y)$ minus the fractional population of other types, with a wavelet,

$$m(x, y) = (1 - \rho(x, y)^2) e^{-\rho(x, y)^2}, \quad (\text{A2})$$

where the scaled distance from the center is given by

$$\rho(x, y) = \frac{\sqrt{x^2 + y^2}}{r_c}, \quad (\text{A3})$$

the Euclidean distance divided by the radius of the wavelet, r_c , which is half of the diameter, l_c , the model parameter identifying the size of groups that are likely to engage in conflict. The value of $c(x, y)$ serves as a measure of the likelihood of violence in the vicinity of the location (x, y) . When performing statistical tests on the prediction of violence, we specify a threshold that distinguishes regions of violence from regions of non-violence according to whether $c(x, y)$ exceeds the specified threshold.

2. Boundaries

We model both topographical and administrative boundaries within a country as preventing intergroup violence across them, similar to national boundaries in the earlier method [A.4]. A cliff separating a plateau from a plain is considered to be a barrier to movement between the upper and lower areas and thus serves as a boundary.

We generalize the previous method for incorporating boundaries to allow for partial boundaries and boundaries with gaps. Partial boundaries between areas within the country can arise due to mountains, lakes, or at convoluted political borders. For such boundaries, we consider the line of sight from a given location to identify the populations which impact on the propensity for violence at that location. Populations outside of the line of sight are not included as contributing to violence. Thus an effective map of populations as experienced at each site is constructed, determined by the specific orientation of any boundaries relative to that site. The areas which are blocked from sight are populated with a neutral population, the existing local proportions of the population. This better matches both the mixed and single type local populations than a single type. The local proportions were measured within a range of two characteristic lengths (wavelet diameters) of each site, considering only sites that are in a line of sight.

3. Empty sites

Some small areas are unpopulated. These and lake areas were treated as other sites, but the violence at these sites was set to zero. Only small differences arise if these unpopulated areas are treated differently.

There are two types of unpopulated areas, land and water. Unpopulated land areas are treated as other land areas for the purpose of the calculations. After the calculation we set the propensity to violence in those locations to zero. The results were not affected significantly (Fig. A.1). Water areas were treated similarly, with the exception that bodies of water that are large were considered to be topographical barriers, similar to mountains and cliffs. Specifically, we included the two largest lakes, Lemman and Neuchatel, both of which have a length above 10 km, which is comparable to the range of characteristic length scales used to detect a propensity to violence.

References:

- [A.1] I. Daubechies, Ten Lectures on Wavelets, (SIAM, Philadelphia, 1992).
- [A.2] A. Arneodo, E. Bacry, P.V. Graves, J.F. Muzy, Phys. Rev. Lett. 74, 3293 (1995).
- [A.3] P. Ch. Ivanov, M. G. Rosenblum, C-K. Peng, J. Mietus, S. Havlin, H.E. Stanley, A.L. Goldberger, Nature 383, 323 (1996)

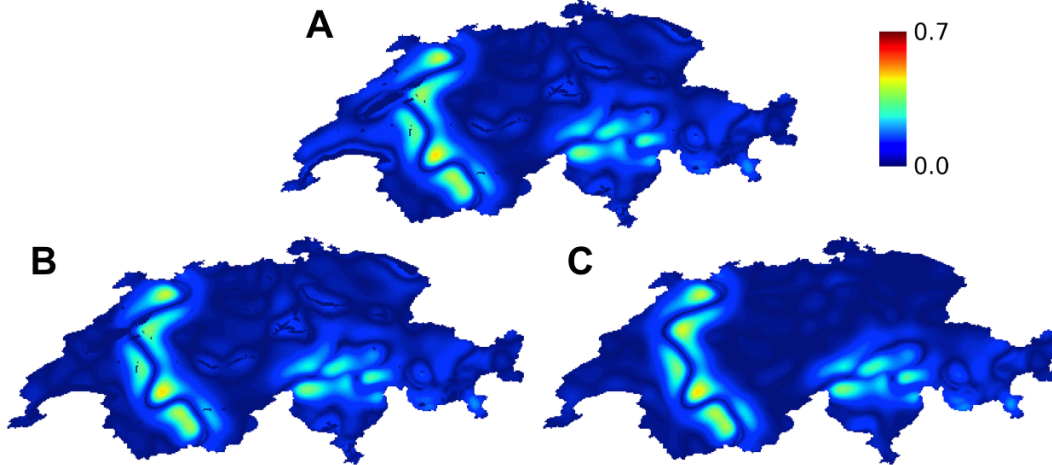


FIG. A.1: Level of predicted violence between linguistic groups in Switzerland using a characteristic length scale of 24 km. Each panel represents results for a different treatment of lakes and unpopulated land areas: **(A)** including lakes and unpopulated land areas as empty sites; **(B)** including as barriers the lakes of Lemman and Neuchatel; **(C)** interpolating a composition for all unpopulated sites from neighboring sites.

[A.4] M. Lim, R. Metzler, Y. Bar-Yam, Global pattern formation and ethnic/cultural violence. *Science* 317, 1540 (2007).

APPENDIX B: CENSUS DATA

The commune composition used in our calculations was based on the census of 2000 and 1990 published by the Swiss Statistical Office. Where municipalities have merged, an aggregate of their previous constituent municipalities was taken. Three official languages we considered are French, German and Italian, which comprise 91% of the total population. The fourth official language, Romansch, is 2%. The religions considered are Roman Catholic and Protestant accounting for 77% of the total with less than 8% belonging to other religious groups and the remainder not subscribing to a religion or not specifying one. The 1990 census data is only readily available on a cantonal level. As described in Section G, we estimated the commune composition using the 2000 value and the change in the parent canton between 1990 and 2000.

APPENDIX C: SUMMARY OF MODEL COMPARISONS WITH THE DATA

We briefly summarize the comparisons between model predictions and the observed data reported in the main section of the paper.

Our examination of linguistic and religious groups in Switzerland highlighted cases where violence is predicted without the presence of boundaries, but is mitigated by the consideration of topographical and political boundaries appropriate to linguistic and religious groups, respectively.

(1) Topographical boundaries reduced violence between linguistic groups. This occurred along (a) Alpine boundaries of the Swiss Alps between German-speaking and Italian-speaking populations, (b) Alpine boundaries between German-speaking and French-speaking populations, and (c) Jura range boundaries between German-speaking and French-speaking populations.

(2) Political boundaries reduced violence between religious groups. This is the case both for (a) canton boundaries and for (b) circle boundaries in the canton of Graubünden.

Our analysis also identified locations in which our model does not predict violence despite linguistic or religious heterogeneity and no explicit boundaries.

(3) The straightness of the boundary prevents violence between linguistic groups in Fribourg/Freiburg.

(4) Isolation of a Protestant population on an appendage from the Catholic majority prevents violence in Fribourg/Freiburg.

We also identified one area at the highest level of calculated residual propensity to violence and it corresponds to an area of unresolved historical conflict.

(5) The northeastern part of the canton of Bern is the location of both the highest prediction of propensity to violence, and a real-world history of intergroup tension. The unique condition of the conflict in this part of Switzerland and its correspondence to the prediction by the model provides additional confirmation of the model.

Considering the predicted and reported violence in the former Yugoslavia also demonstrated the importance of the boundaries which coincide with ethnic divisions.

(6) Political boundaries between Slovenia and Macedonia and the other countries of the former Yugoslavia prevent violence along their borders.

(7) The borders between the countries of Croatia, Bosnia, Serbia and Montenegro were

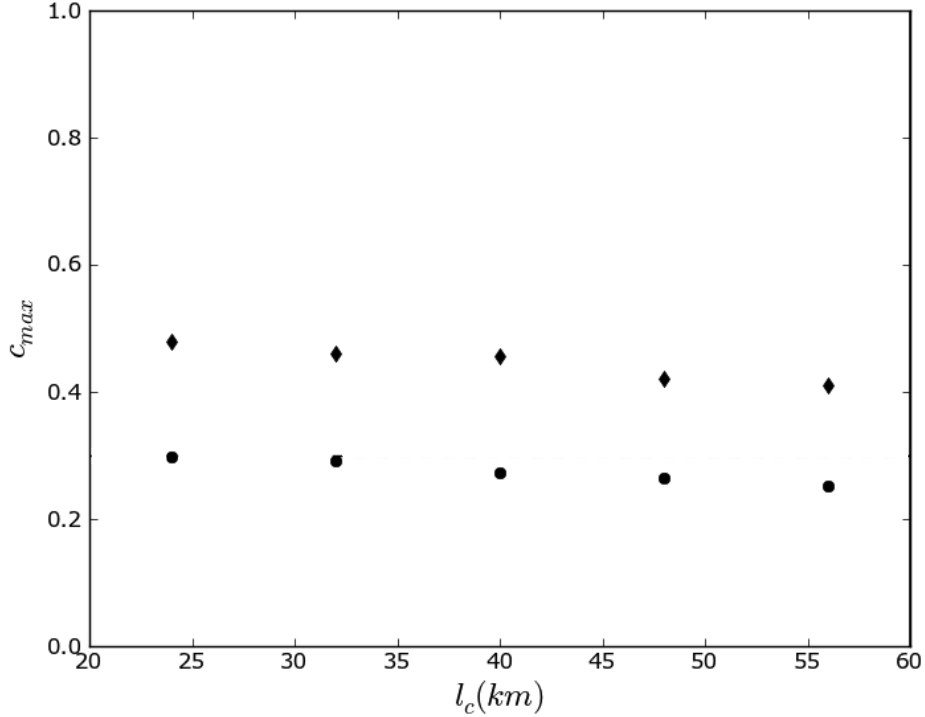


FIG. D.1: Maximum level of the propensity to violence between linguistic groups in Switzerland as calculated in the model as a function of the characteristic length scale. The calculation is performed with effect of topographical boundaries (●) and without effect of topographical boundaries (◆).

not aligned with the boundaries between ethnic groups and so were ineffective at reducing violence.

APPENDIX D: LANGUAGES

Here we describe in greater detail the results of the calculation of the propensity to violence between linguistic groups in Switzerland with and without the effect of topographical boundaries. In the main text we described the calculation of propensity for violence for a characteristic length scale of 24 km. Here we provide it for the length scales 24, 32, 40, 48 and 56 km. Figs. D.1–D.3 show that, at all values of the characteristic length scale, the propensity for violence is high for calculations without topographical boundaries and is dramatically reduced by their inclusion.

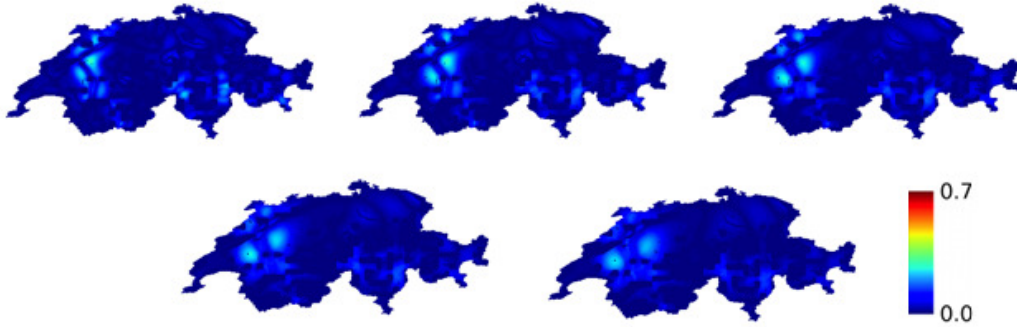


FIG. D.2: Level of propensity to violence between linguistic groups in Switzerland including the effect of topographical boundaries. Characteristic lengths increases from left to right, top to bottom with the values 24, 32, 40, 48, 56 km.

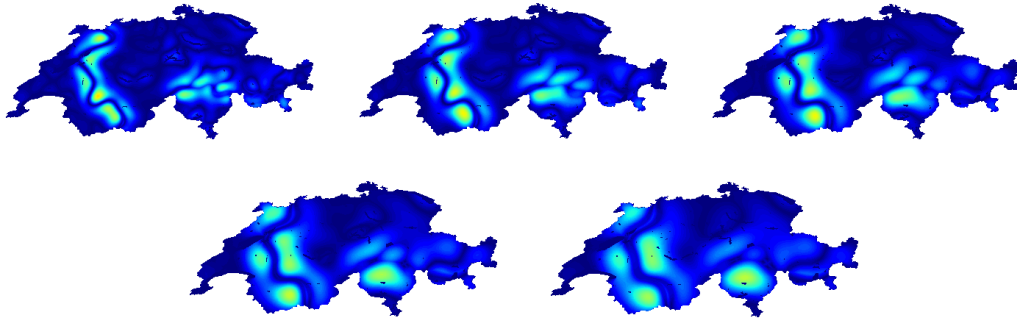


FIG. D.3: As in Fig. D.2 without the effect of topographical boundaries.

APPENDIX E: ELEVATION EDGES

Here we investigate the robustness of our analysis to variation of the calculation of topographical barriers extracted from the elevation data. We vary the gradient threshold that determines the presence of a boundary and compare the results for linguistic groups in Switzerland. We also include here a similar comparison of the calculation of the impact of topographical edges on the conflict between ethnic groups within the former Yugoslavia. Figure E.1 shows the variation of the maximum propensity to violence in Switzerland as the threshold gradient for geographical barriers varies. The propensity is robust to the variation across a range of angles. Still, as the gradient increases and barriers are removed the propensity to violence increases. The model results are consistent with the expectation that it is necessary to include geographical features as barriers in order to achieve agreement

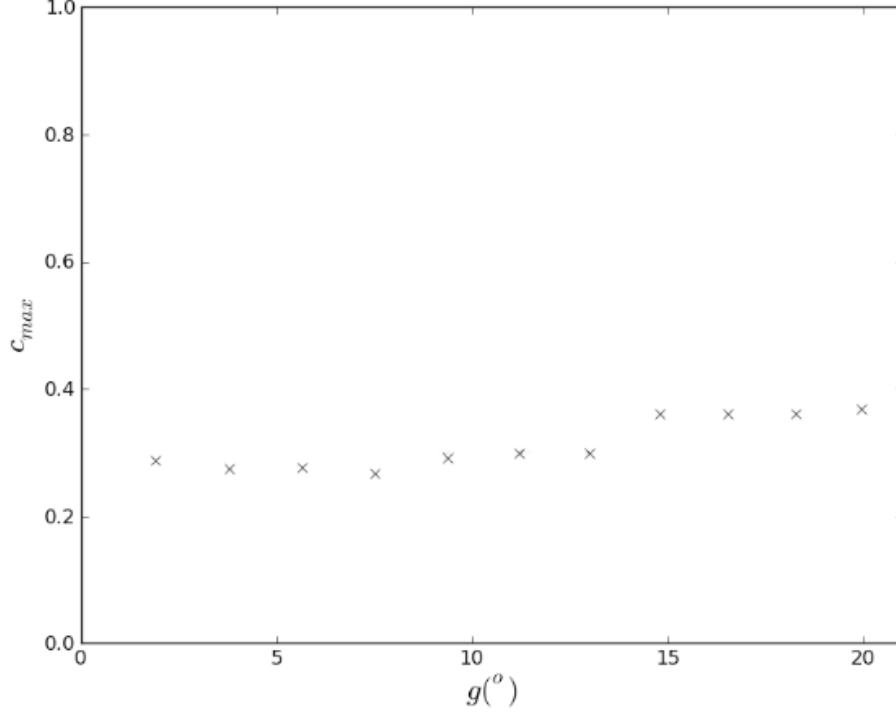


FIG. E.1: The maximum propensity to violence between linguistic groups in Switzerland as the threshold gradient for topographical barriers varies.

with the locations of actual reports of violence, and is consistent with the hypothesis that such barriers are effective in mitigating outbreaks of violence. Figure E.2 shows the maximum propensity to violence calculated for the former Yugoslavia as a function of changes in the gradient threshold, and the resulting correlation of predicted and reported violence. The results show that while some variation in the maximum value of the predicted violence propensity occurs, it remains above the threshold for expected violence. The correlation with observed violence is not very sensitive to the gradient of the edges in elevation. This indicates that areas of predicted violence continue to be proximate to the areas of reported violence. Topographical features are not sufficiently steep or aligned with the boundaries of population groups to inhibit violence.

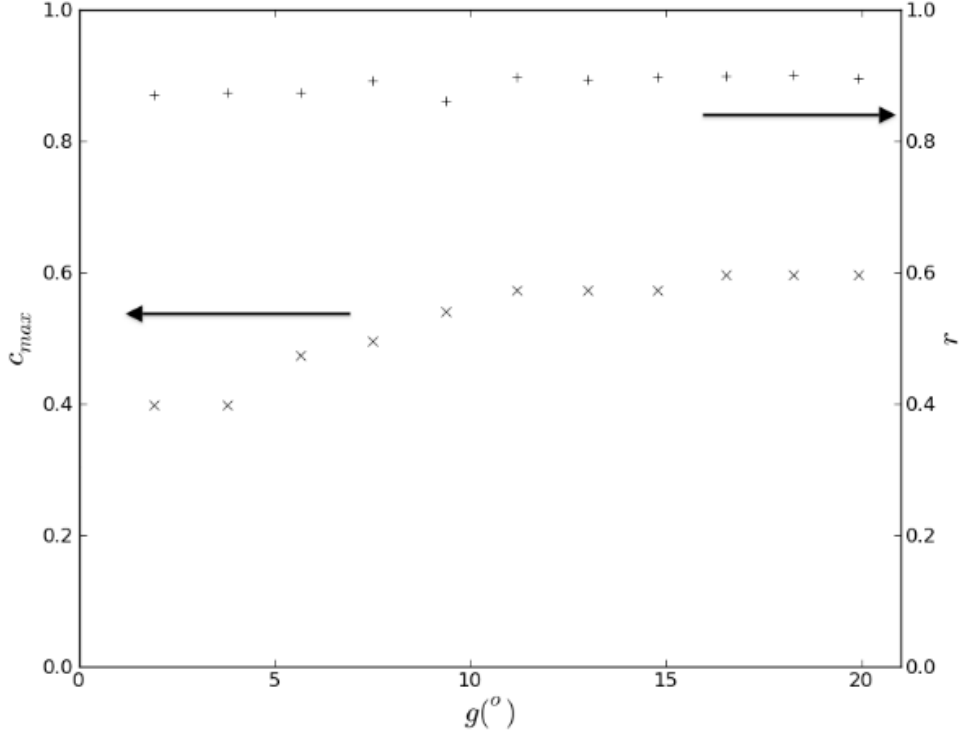


FIG. E.2: Maximum propensity to violence (\times , left axis) and correlation of predicted with reported violence ($+$, right axis) in the former Yugoslavia as the threshold gradient for topographical barriers g varies.

APPENDIX F: RELIGION (2000 CENSUS)

Here we describe in greater detail the calculation of violence between religious groups in Switzerland. In the main text we described the calculation of propensity for violence for a characteristic length scale of 24 km. Here we provide the results for the length scales 24, 32, 40, 48 and 56 km.

Figure F.1 plots the maximum propensity to violence with canton and Graubünden circle boundaries, with canton boundaries only, and without political boundaries. The corresponding maps are shown in Figs. F.2–F.4. Autonomy within cantons and Graubünden circles has been established to prevent conflict. Consistent with the historical experience, the model results imply that without these boundaries violence would be expected, but with them it is not. The effect of canton boundaries is important across all length scales, that of the circles in Graubünden is important at the smaller length scales. This result specifically suggests

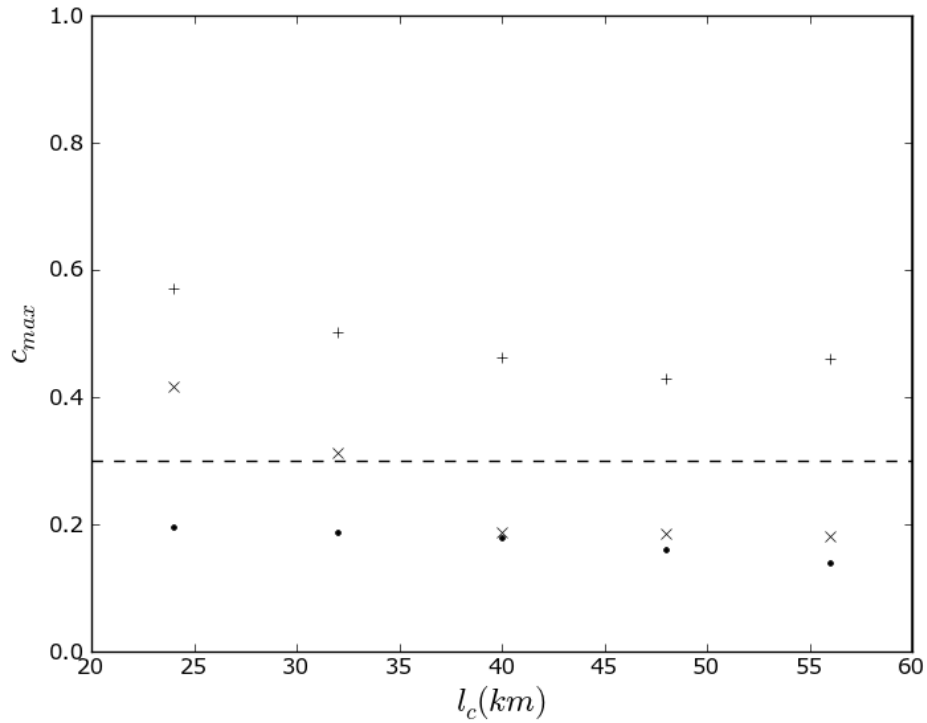


FIG. F.1: Maximum level of the propensity to violence between religious groups in Switzerland as a function of characteristic length scale according to the model. Calculations are shown including the effect of canton boundaries and Graubünden circle boundaries (\bullet), including the effect of canton boundaries only (\times), and without the effect of political boundaries ($+$). The dashed line represents the inferred threshold of propensity of violence in order for violence to occur.

that length scales of 24–32 km correspond to a geographical group size that is susceptible to violence.

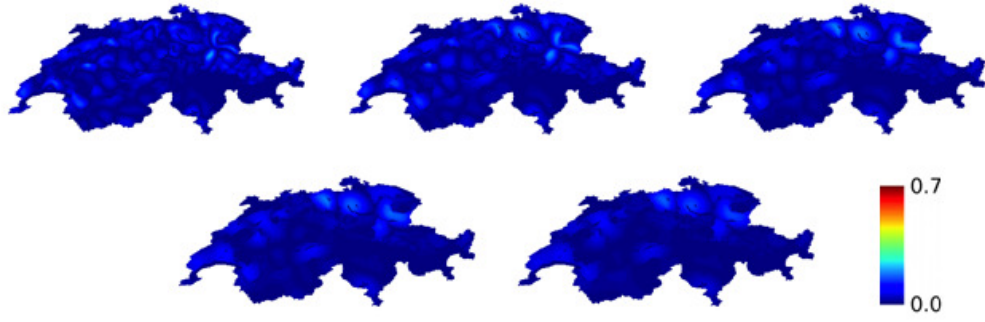


FIG. F.2: Level of predicted violence between religious groups in Switzerland with political boundaries, including both cantons and Graubünden circles (2000 census). Characteristic length increases from left to right, top to bottom for the values 24, 32, 40, 48, 56 km.

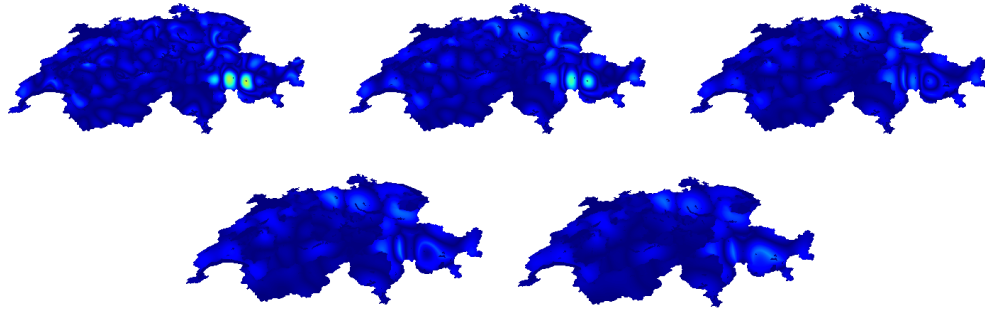


FIG. F.3: As in Fig. F.2 but including only the effect of canton boundaries.

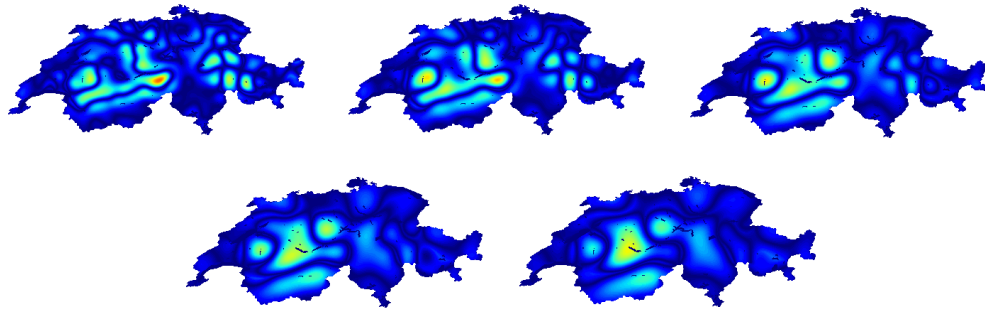


FIG. F.4: As in Fig. F.2 but without the effects of political boundaries.

APPENDIX G: RELIGION (1990 CENSUS)

In the main paper we reported the propensity for violence between religious groups for the 2000 census for the characteristic length of 24 km. During the 1990s there was a significant reduction in religious affiliation. We therefore considered also the 1990 census. The results are very similar to those of the 2000 census with maximum propensity without boundaries of 0.59 (compared to 0.57) reduced to 0.23 when including the political boundaries (compared to 0.20).

In 2000 Roman Catholicism and Protestantism accounted for 87% of the population, 10% more than in 1990, and with only 9.5% identifying themselves as atheist or not specifying religious affiliation. The census for religions in Switzerland in 1990 is readily available only at a canton level resolution rather than the municipality level used in our calculations. We used the reduction of religious affiliation in the entire canton to estimate religious composition for each municipality in 1990. Explicitly:

$$p = p' \times \frac{1.0 - \beta a'}{1.0 - a'}, \quad (\text{G1})$$

where p and p' are the value of the municipal Catholic or Protestant proportion of the population estimated for 1990 and given for 2000, a' is the unaffiliated municipality population proportion in 2000, and

$$\beta = \frac{A}{A'} \quad (\text{G2})$$

is the ratio of unaffiliated canton population proportions, A and A' , in 1990 and 2000. Fig. G.1 is a map of the resulting religious affiliation. Figs. G.2–G.5 show the calculations of the propensity for violence for the 1990 census corresponding to the results for the 2000 census results shown in Fig. F.1–F.4.

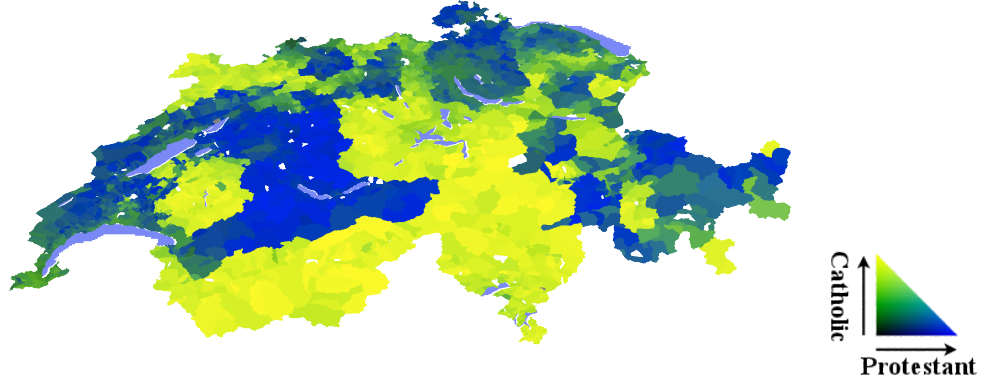


FIG. G.1: Proportion of religious groups according to interpolated 1990 census. Communes are colored according to proportion of Protestant (blue) and Catholic (yellow) as shown by color triangle.

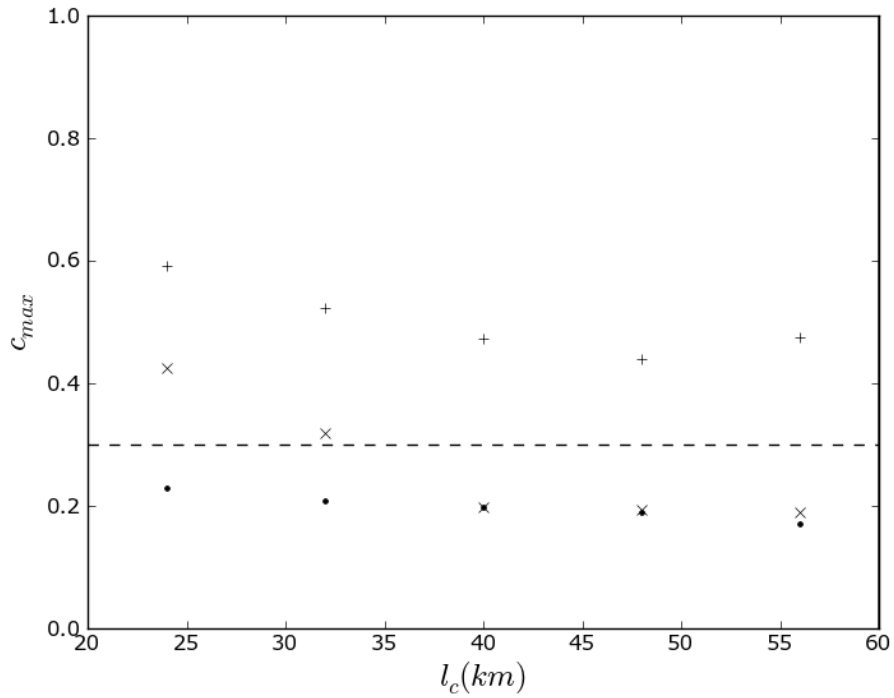


FIG. G.2: As in Fig. F.1 for the 1990 census.

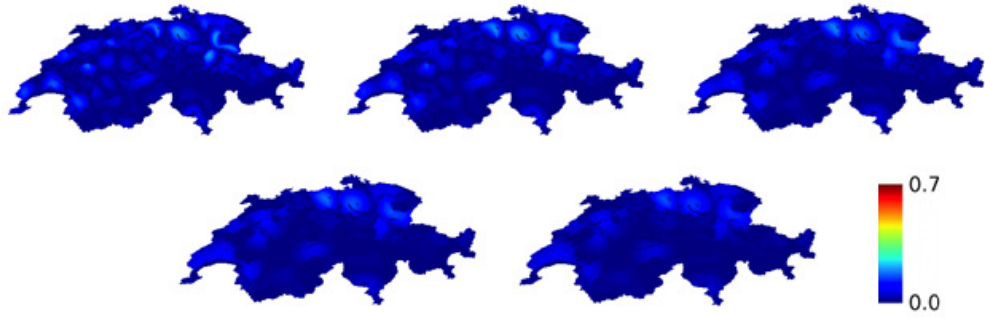


FIG. G.3: As in Fig. F.2 for the 1990 census.

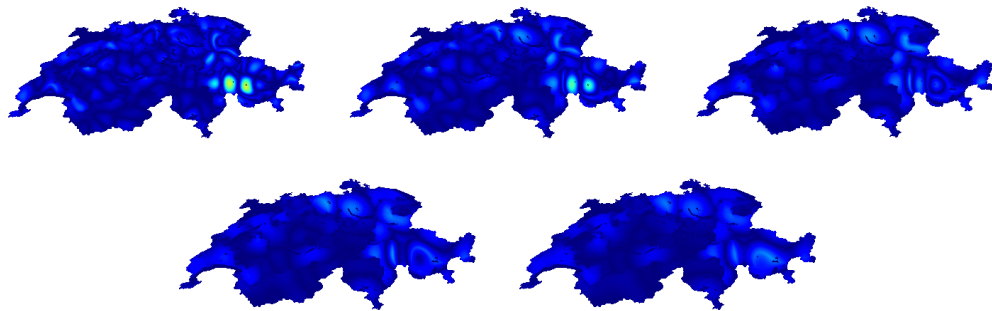


FIG. G.4: As in Fig. F.3 for the 1990 census.

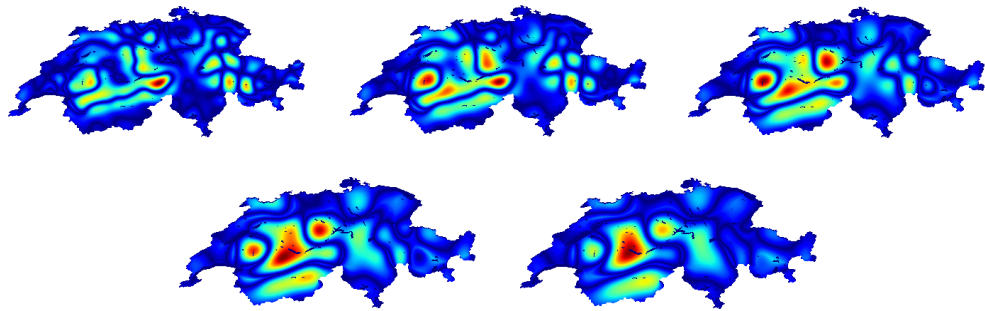


FIG. G.5: As in Fig. F.4 for the 1990 census.

APPENDIX H: BERN/JURA VIOLENCE

Unique in Switzerland in recent decades, the violence in the area of Bern/Jura based on linguistic conflict included targeted arson and bombings and a violent encounter between demonstrators. We performed an analysis of the correlation of reported violence with the location of highest propensity calculated by the theory, which is reduced by local geography compared to what would be expected without it. The resulting correlation is greater than 0.95. We note that the difficulty in relieving the conflict in the northern area of Bern is consistent with an expectation that political boundaries are used for inter-religious rather than inter-lingual conflict, for which purpose they may not be as well adapted.

Specific events, listed by location:

Glovelier - March 24, 1961, arson against a military arsenal. [H:1]; July 16, 1972, explosion of a military arsenal. [H:2] (<http://www.bijube.ch/page-7207.html>)

Les Auges - October 21, 1962, arson against a military barracks. [H:3] (<http://www.bijube.ch/page-6210.html>)

Bourrignon - March 26, 1963, arson against a military barracks. [H:3] (<http://www.bijube.ch/page-6303.html>)

Genevez - April 28, 1963, arson against a farm. [H:3] (<http://www.bijube.ch/page-6304.html>)

Montfaucon - July 18, 1963, arson against a farm. [H:3] (<http://www.bijube.ch/page-6307.html>)

Mont-Soleil - October 5, 1963, a house bombing against a leader of an anti-separatist group. [H:3,4] (<http://www.bijube.ch/page-6310.html>)

Malleray - December 23, 1963, a bombing of a property of an anti-separatist group leader. [H:3]; October 20, 1987, arson against a shooting range. [H:5] (<http://www.bijube.ch/page-6312.html>, <http://www.bijube.ch/page-8509.html>)

Studen - February 27, 1964, bombing of a railway line. [H:3,S8:6] (<http://www.bijube.ch/page-6402.html>)

Delemont - March 12, 1964, bombing of a branch of the Cantonal Bank of Berne. [H:3]; March 4, 1966, government administration building attacked. [H:1] (<http://www.bijube.ch/page-6403.html>)

Saignelégier - November 20, 1965, arson against a hotel. [H:1]; On October 1, 1987,

explosion of a munitions depot. [H:7] (<http://www.bijube.ch/page-6511.html>, <http://www.bijube.ch/page-8710.html>)

Mont-Crosin - May 29, 1966, arson against a hotel. [H:1] (<http://www.bijube.ch/page-6605.html>)

Cortébert - March 16, 1980, violent fighting between separatists and anti-separatists with stones, firecrackers, and flare guns. Demonstrators on both sides were injured. [H:8] (<http://www.bijube.ch/page-8003.html>)

Moutier - September 4, 1985 bombing of the district court. [H:9] (<http://www.bijube.ch/page-8509.html>)

Reussilles - September 11 and 23, 1993, arson against a munitions depot. [H:7,H:5]

Perrefitte - October 21, 1987, bombing of a shooting range. [H:5] (<http://www.bijube.ch/page-8710.html>)

Büren - April 5, 1989, arson against a historic wooden bridge. [H:10] (<http://www.bijube.ch/page-8509.html>)

Montbautier - May 24, 1992, arson against a German-language school, previously vandalized. [H:11]

Courtelary - January 7, 1993, bombing of a house of an anti-separatist. [H:12,S8:13] (<http://www.bijube.ch/page-9301.html>)

Berne - January 7, 1993, premature explosion of a bomb in a car killing one person. [H:13] (<http://www.bijube.ch/page-9301.html>)

References:

[H:1] “Les incendiaires ont avoué,” Journal de Genève, July 6, 1966.

[H:2] “Le FLJ fait sauter un dépôt de munitions de l’armée,” Journal de Genève, July 17, 1972.

[H:3] “De l’incendie à l’explosion en passant par les menaces,” Gazette de Lausanne, October 13, 1965.

[H:4] “Plastic contre la villa d’un dirigeant UPJ,” Gazette de Lausanne, October 7, 1963.

[H:5] “La série des attentats s’allonge,” Journal de Genève, October 22, 1987.

[H:6] “Le Sabotage du FLJ serait confirmé,” Gazette de Lausanne, March 4, 1964.

[H:7] “Dépôt de munitions détruit à Saignelégier,” Journal de Genève, October 2, 1987.

[H:8] “Cortébert: violents incidents entre séparatists et pro-bernois,” Gazette de Lausanne, March 17, 1980.

[H:9] “Enormes dégâts à Moutier,” Gazette de Lausanne, September 4, 1985.

[H:10] “Le pont historique de Büren incendié,” Gazette de Lausanne, April 6, 1989.

[H:11] “Les flammes ravagent une école du Jura bernois,” Le Nouveau Quotidien, May 26, 1992.

[H:12] “Deux explosions, dont une mortelle dans le canton de Berne,” Gazette de Lausanne, January 8, 1993.

[H:13] “Retour tragique des poseurs de bombes jurassiens,” Le Nouveau Quotidien, January 8, 1993.

APPENDIX I: YUGOSLAVIA

Figures showing the correlation of predicted and reported violence for the former Yugoslavia without administrative or topographical boundaries (Fig. I.1) with administrative boundaries (Fig. I.2) and with topographical boundaries (Fig. I.3).

We also provide a similar analysis of the former Yugoslavia including Macedonia and Slovenia, without (Fig. I.4) and with (Fig. I.5) political boundaries. Without political boundaries the agreement of predicted and reported violence is dramatically reduced.

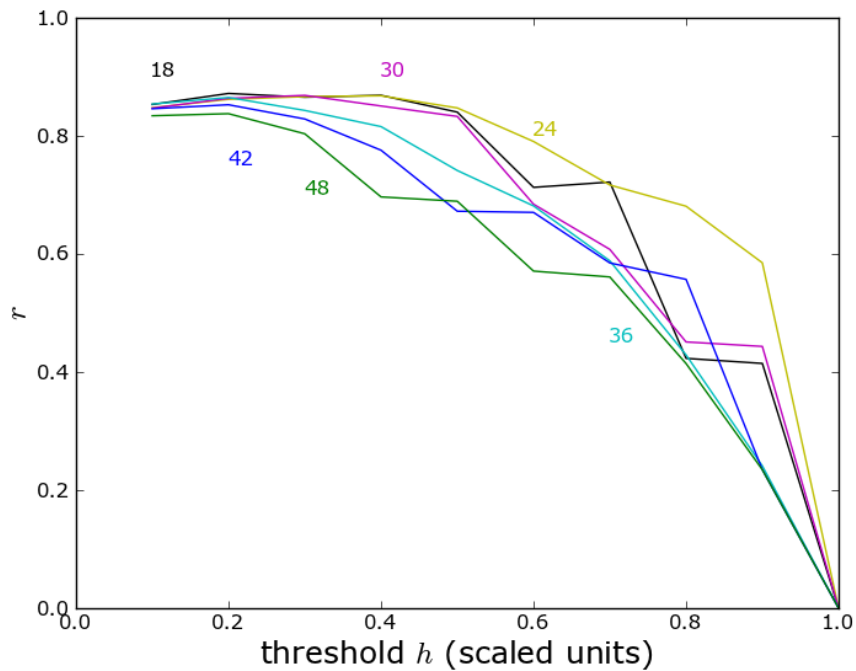


FIG. I.1: Correlation of proximity maps of predicted and reported violence in Yugoslavia without topographical or political boundaries, as a function of threshold for violence divided by the maximum propensity for violence. Each curve is labelled by the characteristic length (km). (Compare with Figure S4.3 in Ref. [14].)

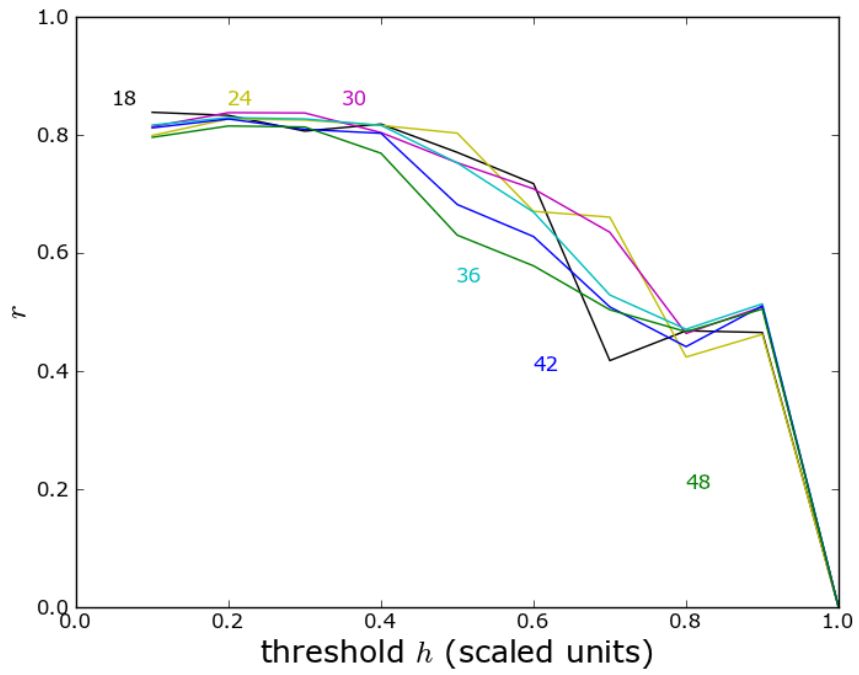


FIG. I.2: As in Fig. I.1 but including the effects of administrative boundaries.

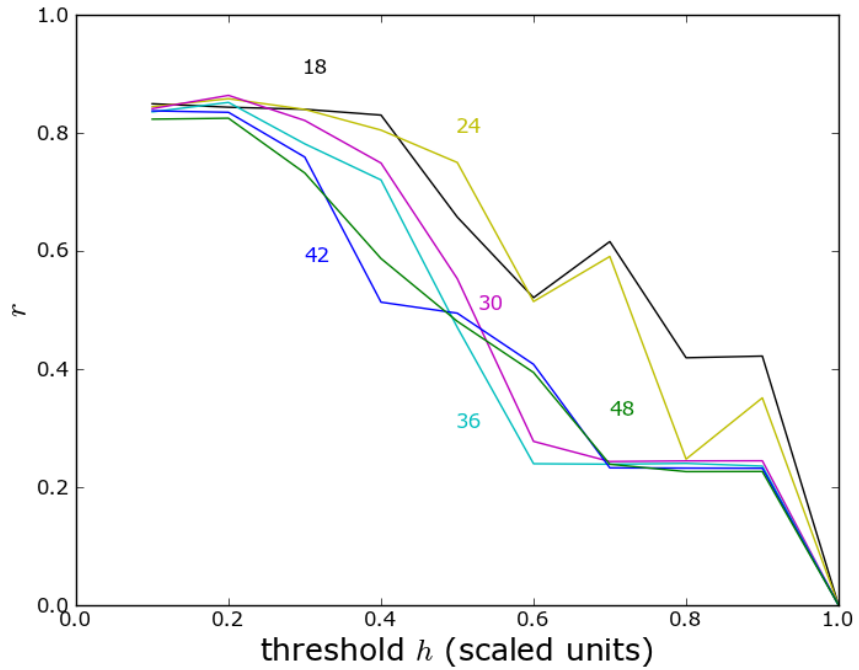


FIG. I.3: As in Fig. I.1 but including topographical boundaries.

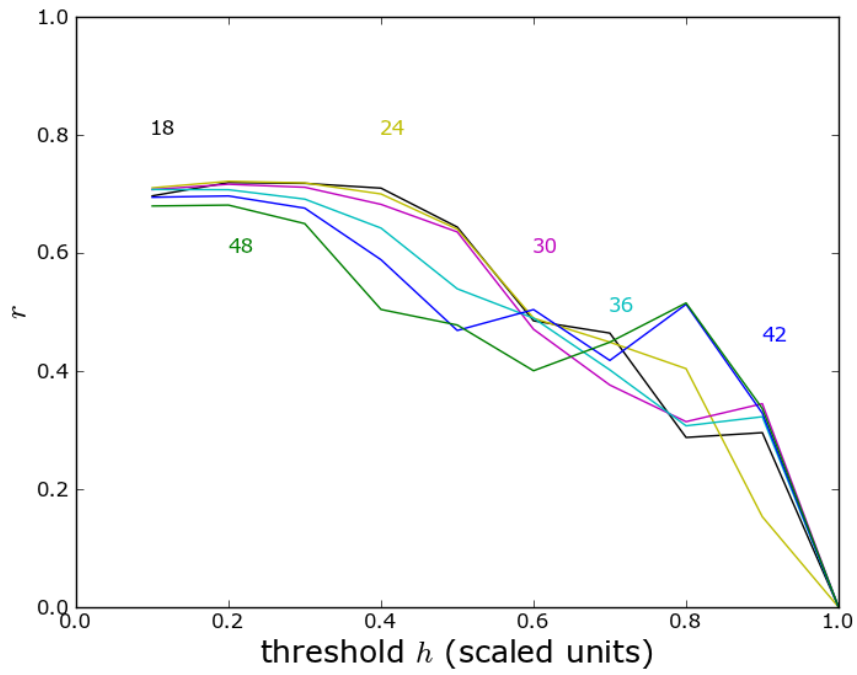


FIG. I.4: As in Fig. I.1, but including Slovenia and Macedonia.

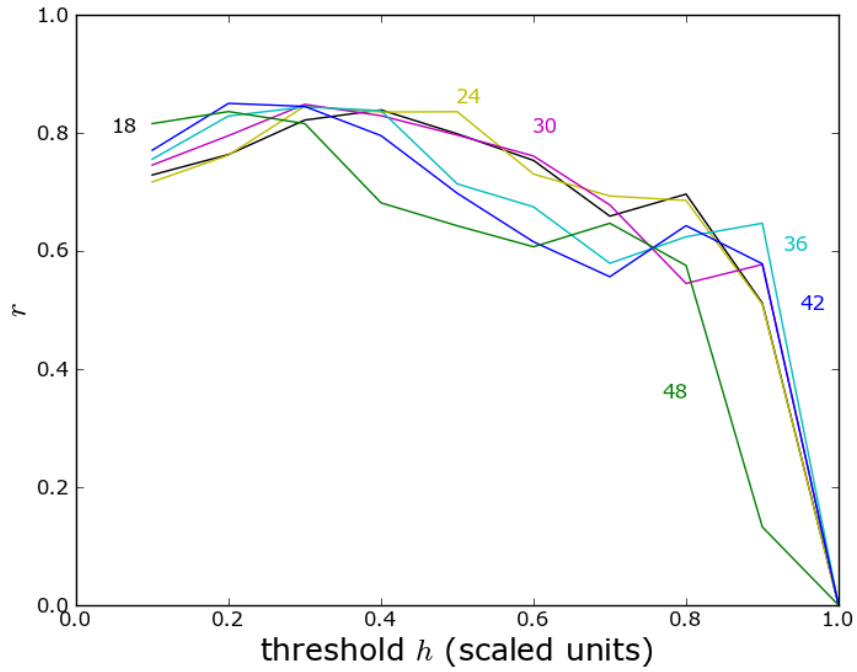


FIG. I.5: As in Fig. I.4 but including the effect of political boundaries.

APPENDIX J: EXPANDED BIBLIOGRAPHY ON ETHNIC CONFLICT

In recent years there have been increasing efforts to understand the causes and enabling conditions for civil war and ethnic conflict. The attached bibliography [J:1–118] expands on citations included in the main text and in supplementary materials of Ref. [14]. These efforts include examinations of geography and other structures within countries [J:18–50] as well as the effects of transnational geography [J:51–67]. Extensive analysis explores the role of political structures, particularly federalism, in enabling or preventing civil and ethnic conflict [J:68–89]. Research has begun to include quantitative studies and modeling to understand human behavior and conflict [J:90–94]. A body of research examines Switzerland regarding the presence or absence of tensions and possible causes [J:95–118].

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[J:4] K. Eck, L. Hultman, One-sided violence against civilians in war: Insights from new fatality data. *J. Peace Res.* 44, 2, 233–246 (2007).

[J:5] J. Esteban, D. Ray, Polarization, fractionalization and conflict. *J. Peace Res.* 45, 2, 163–182 (2008).

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- [J:14] N. Sambanis, What is civil war? Conceptual and empirical complexities of an operational definition. *J. Conflict Res.* 48, 6, 814–858 (2004).
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