The Impact of Conflict on Economic Activity: Night Lights and the Bosnian Civil War

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Abstract

The tendency of violent conflict to suppress economic activity is well documented in the civil war economic literature. However, differential consequences resulting from distinct characteristics of conflicts have not been rigorously studied. Utilizing new conflict data on the 1992-1995 Bosnian civil war from Becker, Devine, Dogo, and Margolin (2018) and DMSP-OLS night light data as a proxy for economic activity, this paper investigates the disparate economic impacts that different types of conflict have on Bosnia's municipalities.

This investigation first uses data from other Yugoslavian countries to impute pre-war night light values for conflict-affected Bosnian municipalities. Next, a spatial autoregressive model with fixed effects is used to evaluate the impact of different types of conflict on economic activity. This analysis finds that two of the five types of conflict have significant impacts on night lights and economic activity.

JEL Codes: F52, H56, O52

Keywords: civil war; Bosnia and Herzegovina; DMSP-OLS satellite night lights

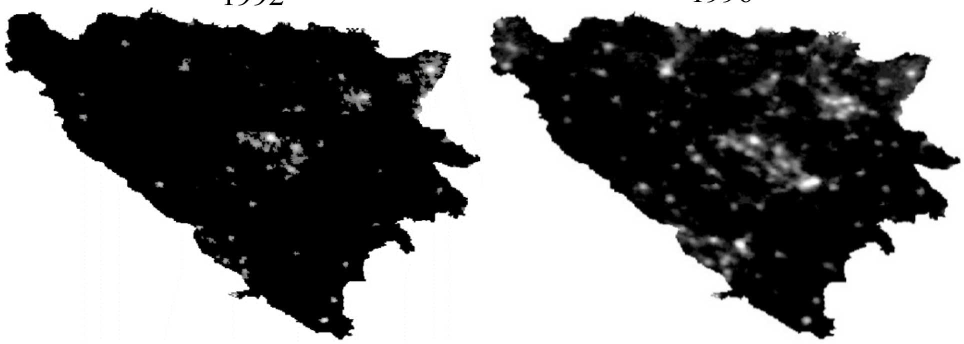
1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) established the archive of Defense Meteorological Program-Operational Linescan System (DMSP-OLS) nighttime light imagery in 1992; in the spring of the same year, the dissolution of the Socialist Federal Republic of Yugoslavia culminated in the outbreak of the Bosnian civil war. Minor conflicts had occurred in Slovenia and Croatia, which had previously declared independence from Yugoslavia; the war in Bosnia and Herzegovina[2] was the brutal climax of the Yugoslav Wars for Independence that fragmented former socialist state. This conflict was fought between the three dominant ethnoreligious groups of Bosnia: Muslim Bosniaks (supported by the Bosnian government), Christian Serbs (with backing from Serbia, which controlled the Yugoslav National Army), and Catholic Croats (with backing from Croatia). According to the 1991 census, an estimated 43.5% of Bosnia and Herzegovina's population of 4.3 million consisted of ethnic Bosniaks; 31.2% were Serb, and 17.4% were Croat. The remainder of the population, composed of "Others" and "Yugoslavs", totaled 7.9%.

The conflict between the ethnic groups lasted from early 1992 until the end of 1995. Data on Bosnia and Herzegovina's GDP are available from the World Bank beginning in 1994 and from the International Monetary Fund in 1995. This means that GDP for the first two years of the conflict is not captured. Furthermore, it is likely that the collection and production of the 1994 and 1995 economic data were affected by wartime violence. Nighttime light imagery suffers from certain limitations—such as issues related to changing satellite technology and temporal restrictions specific to the study of war in Bosnia—that must be addressed in analysis. However, it provides comprehensive, critical coverage of the war and was not affected by conflict. Therefore, the DMSP-OLS images offer a valuable alternative for evaluating the economic consequences of the Bosnian civil war.

[2] Bosnia and Herzegovina is referenced throughout this paper as both "Bosnia and Herzegovina" and "Bosnia".

Figure 1: DMSP-OLS Night Lights in Bosnia and Herzegovina



Images and data processing by NOAA's National Geophysical Data Center.
DMSP data collected by US Air Force Weather Agency.

Figure 1 shows the change in night lights between the first year of available night light data (1992) and the first year after the Bosnian civil war ended (1996). These images indicate that, despite the conflict that transpired between 1992 and 1995, increases in nighttime lights did occur. While overall luminosity in Bosnia increased over the war, variations in light changes between phases of the war are expected to result from differences in the characteristics of conflict that municipalities experienced.

This paper utilizes the conflict mapping developed by Becker, Devine, Dogo, and Margolin (2018), which identified five types of conflict that dominated the Bosnian civil war: siege, hybrid, civil war, dirty conventional, and conventional. DMSP-OLS nighttime light imagery is used as a proxy for economic activity due to the unavailability and unreliability of wartime GDP data. As DMSP-OLS nighttime images are unavailable before 1992, pre-war night lights for Bosnia's 109 municipalities[3] are imputed using data on light-generating industries in proximal, conflict-unaffected states. Using these imputed pre-war lights as a baseline for comparison against wartime night lights, a spatial autoregressive model with fixed effects is employed to isolate the impacts of the five types of conflict while accounting for spatial and temporal autocorrelation. The results of this investigation identify that hybrid and conventional conflicts have significant, negative effects on economic activity in a municipality. Finally, when the original night light imputation regressions are iterated through the five years following the

[3] This number comes from the 1991 boundaries.

end of the civil war, the estimates are shown to converge with the true values extracted from the postwar nighttime light images.

This research contributes to the economic civil war literature by identifying important variations in the consequences of war resulting from differences in characteristics of conflict. While night light research has been previously applied to economic investigations of violence and destructive events, the focus on the impacts of characteristics of conflict (rather than the general occurrence of war) enables a greater understanding of the variable effects of violence on economic activity. Furthermore, the imputation of pre-war night light levels introduces a novel means of expanding the temporal horizon of night light studies and allows for a comparative evaluation of post-war recovery.

The second section of this text reviews literature pertaining to the connection between night lights and economic activity, the effect of destructive events on this connection, and the destruction that occurred specifically during the Bosnian civil war. The third section provides a theoretical framework for this investigation with a discussion of the conceptual relationship between war and economic activity. The fourth section describes the data used in the investigation and the processes employed to address the limitations of these data. The fifth section details the empirical strategy. The sixth presents the results of the primary investigation and the sensitivity tests used to verify them. The seventh section discusses the findings of the preceding section, remaining limitations, and future extensions of this research. The eighth and final section concludes.

2. Literature Review

Nighttime Light Imagery & Economic Activity

The relationship between night light data and economic activity has been investigated widely since the establishment of the NOAA archive. Under the reasonable assumption that lighting behaves as a normal good, night light data can serve as an invaluable proxy for economic activity (Donaldson and Storeygard, 2016). In an early study of the link between luminosity and economic activity, Elvidge *et al.* (1997) find strong, positive correlations between population, GDP, power consumption, and night lights in the 1994 composite images. DMSP-

OLS night lights are predictors of both cross-country income growth and GDP (Henderson, Storeygard, and Weil, 2012)[4] and subnational income growth (Bundervoet, Maiyo, and Sanghi, 2015)[5]. Hodler and Raschky (2014)[6] evaluate night lights at the subnational level across numerous countries and identify regional favoritism based on a region's status as the birthplace of a political leader. Henderson *et al.* (2018) use night lights as a proxy to study characteristics that determine the spatial distribution of economic activity, differentiating between agglomeration patterns and structural transformation for developed and developing nations. Zhou *et al*. (2015) use another variant[7] of night light data to investigate regional inequality resulting from economic growth in China. They identify positive correlations between population, GDP and night lights and conclude that these satellite imagery captures features of regional economic inequality. These works vary in their empirical approaches and are not solely focused on conflict; nonetheless, they establish the critical link between nighttime light imagery and economic activity that enables this investigation of the Bosnian civil war.

The relationship between GDP, population, and DMSP-OLS night light data in Bosnia is identified by Elvidge, Hsu, and Tilottama (2017), who trace the growth of lights in Eastern Europe through the transition from command to market economies. They find that Bosnia's night lights from 1992 to 2012[8] are strongly and positively correlated with both its GDP and its population. When both correlations are taken into consideration simultaneously, Bosnia has the strongest dual relationship of the Eastern European transition countries evaluated in their paper.

Satellite night lights can similarly be used to identify destruction from and recovery after natural disasters. Gillepsie *et al*. (2014) study the decrease in luminosity in Indonesia after the 2004 tsunami and investigate the extent to which per capita expenditures and night lights parallel one another in post-disaster recovery. They identify positive and significant relationships

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[4] Henderson *et al.* (2012) identify a highly significant elasticity of 0.3 between night lights and GDP; they note that while electricity consumption has a larger elasticity with respect to GDP, scarcity of such data disadvantages its use as a proxy for GDP.

[5] Bundervoet *et al.* (2015) replicate Henderson *et al*.'s (2012) analysis for GDP growth at the subnational level in Kenya and Rwanda and derive conclusions that align with the seminal 2012 work.

[6] Henderson *et al.* (2012) and Hodler & Raschky (2014) use the natural logarithm of sum of lights, which will also be used in this investigation.

[7] Zhou *et al*. (2015) use Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime light data, which they note to be better at identifying low-light emission and more strongly related to GDP than the more commonly used DMSP-OLS data. The VIIRS data cannot be used for this investigation, however, as collection began in 2011.

[8] 2013 is the last year of DSMP-OLS data available on the NOAA's archive.

between nighttime light brightness and per capita expenditures (as well as food and utilities expenditures). These findings regarding natural disasters reflect the reactivity of night lights to events that destroy infrastructure and suppress economic activity. Similar relationships are elucidated by studies of conflict that utilize night light data as a proxy for economic activity.

Night Lights & Conflict

While the relationship between conflict and night lights is not the focus of their paper, Henderson *et al.* (2012) include images of night lights to show the impact of the 1994 Rwandan Genocide with satellite data. They show "a temporary dimming from 1993 to 1994, with a return to 1993 levels by 1996", tracing the timeline of the conflict. Their findings regarding the relationship between income growth and night lights ultimately lead them to conclude that night light growth is a "useful" proxy for GDP growth. Bundervoet *et al.* (2015) also cite numerous instances in which changes in GDP are reflected in the behavior of night lights, including: sharp decreases in Zimbabwe that correspond to the 2008 inflation crisis; steady increases in Equatorial Guinea after the discovery of oil; and slight movement in Eritrea due to the 1998-2000 border conflict with Ethiopia, which had effects on GDP that were discernible despite being of lesser magnitude than the preceding examples. Their analysis identifies a "fairly strong" link between night lights and GDP in Sub-Saharan Africa that exists even in economic downturns of smaller sizes. Neither paper conducts a rigorous investigation of causal relationships between conflict and lights, but both present visual evidence of a connection in their discussion of DMSP-OLS data.

Rohner, Thoenig, and Zilibotti (2013) study the impact of ethnic conflict on trust in Uganda and extend their investigation to the economic consequences of ethnolinguistic fractionalization[9] in counties that experience conflict. Their regression of night lights on ethnic fractionalization indicates that the occurrence of violence does not have an economic effect in non-fractionalized (that is, ethnically homogeneous) counties. However, highly fractionalized

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[9] Ethnolinguistic fractionalization (ELF) represents the ethnic homogeneity of a population. This value accounts for the number and size of ethnic groups that compose a population. The fractionalization score of a municipality *m* is calculated with the following formula: $frac_m = 1 - \sum_{i=1}^{N} s_{im}^2$, where *i* represents the share of a given group in *m.* Thus, fractionalization takes a value between 0 and 1. The ethnic nature of the conflict in Bosnia and Herzegovina makes the fractionalization findings discussed in the Literature Review and Conceptual Framework relevant to patterns in night lights; however, ELF cannot be included in the main analysis due to the lack of time-variant population data between 1992-1995.

counties exhibited large and significant declines in luminosity due to violence, suggesting that ethnic violence inhibits economic cooperation to a greater degree than non-ethnic fighting. These results indicate that in the case of Bosnia and Herzegovina, where ethnic divisions formed the basis of the civil war, large effects of violence should be reflected in night light data.

Witmer and O'Loughlin (2011) study the relationship between night light data and wars in the Caucasus regions of Russia and Georgia, which experienced heavy bombardment and refugee movement during the Second Chechen War (1999-2009). They too find that night lights are highly correlated with population and GDP (in addition to electricity-related variables); their analysis finds decreases in light levels in war-impacted regions where mass emigration and significant destruction of light-generating infrastructure occur. They also find that population shocks, such as a mass influx of refugees, yield at least temporary increases in luminosity levels in the cities that receive these refugees. They ultimately conclude that they are successful in identifying the occurrence of violent events, which, in the context of the Caucasus wars, included light-shock events (such as long-lasting fires) as well as light-drop events (large emigration), with night light data.

The Witmer and O'Loughlin (2011) finding that refugee movements are associated with night lights parallels the more general findings that population is correlated with the DMSP-OLS data. Both emigration (movement of refugees) and internal migration (movement of internally displaced persons) should generate wartime changes in night lights in Bosnia's municipalities. The United Nations Refugee Agency (UNHCR) estimated in 1999 that 1.2 million Bosnians fled the during the war, and another 1.3 million were displaced within the country. They note that the war impacted nearly 60% of the pre-war population. Kondylis (2009) reports that 1.1 million refugees resettled in Bosnia after the war (Bosniaks primarily in the Federation of Bosnia and Herzegovina and Serbs in Republika Srpska). The World Bank's World Development Indicators reports 13,440 battle-related deaths between 1992 and 1995; casualty data from Becker *et al.* (2018) sum to a wartime total of 286,822 deaths over the course of the war. Population loss from deaths during the war amounted to some 6.6% of the total pre-war population.

Becker *et al.* (2018) investigate the specific details of the war in terms of resources, temporal divisions, and types of fighting. Using the U.S. Central Intelligence Agency's military history of the war, they distinguish between three periods of the war and identify five types of conflict. Weidmann and Ward (2010) use the Armed Conflict Location and Events Dataset (ACLED) to perform spatial and temporal analyses of the war. This dataset includes all reported confrontations between warring parties with the time and place of occurrence, such that the analyzed conflict variable takes on a value of "1" if one or more confrontations occurred in a municipality in a certain month; it is valued at "0" if the municipality did not experience conflict in that month. This classification does not account for the characteristics or severity of the conflict.

Weidmann and Ward (2010) report that conflict activity erupted in two waves, one at the beginning and one at the end of the war, finding that many of the reported events were concentrated in the cities of Sarajevo and Mostar. Their results indicate that municipalities with larger populations and greater ethnic heterogeneity have a greater likelihood of experiencing conflict; proximity to borders and hilliness also have a positive but lesser effect. Experiencing one- and two-month conflict lags as well as conflict in neighboring municipalities also increases probability of conflict occurrence within a given municipality. Becker *et al.* (2018) find similar spatial and temporal dependence in their model of the war; because theirs is the primary conflict dataset used in this investigation, these spatial and temporal dependencies as well as the details of the data will be described in Section 4.

3. Conceptual Framework

Civil war impacts economic activity through the destruction of both human and physical capital. In addition to bombardment, fires, and loss of human life, further suppression of economic activity occurs in war-torn regions due to the disruption of trade networks, elimination of foreign investment, and dissolution of trust. Paul Collier's (1999) seminal investigation finds that the annual growth rate of per capita GDP is decreased by 2.2% during a civil war. He lists five effects of civil conflict that damage an economy: destruction of resources (losses in the labor force and infrastructure), added social disorder (loss of safety and trust networks), diversion of public expenditure from productive activities to destructive ones (lost property rights, increased transaction costs, and diminished rule of law), dissaving (which is equated to destruction of the nation's capital stock), and investment flight (both physical and financial capital are removed from the nation in conflict). Thus, as the marginal returns on assets within Bosnia decrease relative to foreign assets, which occurs through increased capital destruction, lost property rights, and lowered factor productivity, investment is shifted out of the country, suppressing economic activity.

The outflow of investment and decreases in GDP due to ethnic conflict are studied by Abadie and Gardeazabal (2003), who investigate the economic costs of terrorism in Basque Country, Spain, and investment flight through the creation of a synthetic region[10]. They find that the gap in GDP between the counterfactual and the actual Basque regions is almost perfectly explained by terrorist activity, and that stock performance (this time comparing between actual Basque and non-Basque stocks) behaved similarly. The European Bank of Reconstruction and Development's 2008 Transition Report shows zero net inflows of foreign direct investment recorded in Bosnia's balance of payments from 1995-1997. When the capital city (Sarajevo) is besieged for four years and ethnic cleansing is perpetrated in nearby municipalities, it is impossible for economic relationships to remain undisturbed.

Kothari *et al.* (2020) find that countries in Sub-Saharan Africa that experience conflict have annual growth rates 2.5% lower (on average) than those that do not experience conflict, and that the size of this gap is magnified with increases in the duration of conflict. They also observe that increasing conflict intensity significantly lowers both real investment growth, exports, and productivity growth, citing safety, disruption of trade routes, labor losses, destruction of human and physical capital, and investment uncertainty as drivers of these decreases in growth. Furthermore, Kothari *et al.* investigate the relationship between conflict-related deaths and economic activity using night light data. They find that conflicts with a greater than median share of deaths are associated with night light growth 17-percentage-points lower than under-median-share conflicts; they link this decrease in lights to a 6.5% lower growth rate of real GDP. The results of their study support the expectation that conflict types will exhibit differential impacts on Bosnian municipalities depending on characteristics and intensity.

Similar disruptions of economic activity in Bosnia are expected from conflict deaths, labor outflow from internally displaced persons and refugees, and destruction of capital.

[10] This technique is not applied to this investigation of Bosnia due to temporal restrictions. Difficulties in this strategy would also arise in defining and isolating "treatments" of conflict incidence, which would be necessary for synthetic control comparisons.

Andersson *et al*. (1995) estimate that agricultural production immediately after the war could have been increased by 11% without the placement of landmines. They report that, on average, each mine blast killed 0.54 people and wounded 1.42. Kondylis (2009) reports that displaced persons in the war were 16-19% more likely to be out of work than those who did not leave during the conflict; two of the three[11] explanations she gives, the loss of network access and employment disruption, are outlined by Collier (1999) as conflict suppressants of economic activity. The World Bank's World Development Indicators statistics indicate that relative to 1991 levels, the total labor force in Bosnia had decreased by 12.7% by 1995.

In a wider study of developmental outcomes after conflict, Gates *et al.* (2012) find that violence of median severity (taken as battle-related deaths) increases undernourishment by 3.3% and infant mortality by 10%; it decreases life expectancy of a citizen of a conflict-impacted country by nearly a year and GDP per capita by 15%. At a lower level of significance, battle-related deaths decrease access to water. In nations neighboring the conflict center, secondary schooling decreases. Their simulations to compare growth trajectories of conflict and non-conflict countries indicate that in the first five years of violence, the conflict country grows 5% slower than the non-conflict country.

The results produced by Gates *et al*. suggest that the impacts of war in Bosnia on economic activity will be reflected through numerous outlets. As proposed by Collier (1999) and numerous subsequent works, the degradation of human capital through undernourishment and decreased life expectancy translates to a lower marginal product of this input, which translates to decreased economic activity. Furthermore, the existence of spatial relationships is supported by Gates *et al.*'s findings; while only the dimension of education is found significant in this portion of the evaluation, it indicates that there is a spillover effect in contiguous nations. This spillover is likely to be magnified by the greater proximity and interconnectedness of the Bosnian municipalities.

The ethnic nature of conflicts also has implications for the economic consequences of war. Costalli *et al.* (2017) study ethnic fractionalization across twenty countries by creating non-conflict counterfactuals and find a 17.5% gap between counterfactual and actual GDP. Ethnic

[11] The third explanation that she gives is the informality of the labor market, which is not represented as a direct product of conflict.

fractionalization significantly decreases per capita GDP between the observed and synthetic countries—an increase in ethnic fractionalization of one standard deviation decreases per capita GDP by 8%. Furthermore, they find negative and statistically significant coefficients on the interactions between ethnic fractionalization and battle deaths. In the case of Bosnia, Costalli and Moro (2012) differentiate between ethnic fractionalization and polarization. They find that these heterogeneity variables are predictive of severity of violence only in the early years of the war. Rohner *et al.* (2013) find that the occurrence of conflict diminishes interethnic trust while strengthening intra-ethnic identification in addition to the previously discussed impact of fractionalization and violence on night light growth. Their results indicate that high fractionalization and violence reduce interethnic cooperation; this in turn inhibits economic activity.

Ethnicity and interethnic dynamics in conflict have been found to influence the economic consequences of conflict; shifting aggression and alliance between the warring parties in Bosnia (particularly in the relationship between the Croat and Bosniak factions) did impact the course of the war. The cessation of Bosniak-Croat hostilities in the end of 1993 (Becker *et al*., 2018) and subsequent regaining of territory previously taken by Serb forces (UCDP) is expected to manifest in the night lights analysis conducted in this study. Weidmann (2011) studies the extent to which micro- and macro-level ethnic tensions explain outbreaks of violence in the Bosnian civil war, finding that micro-level tensions (personal, town- and neighbor-specific aggression) largely drove the occurrence of violence in the beginning of the war, while macro-level tensions (impersonal, group- or non-specific aggression) drove violence in later phases. This is congruent with the Costalli and Moro (2012) results, where municipality-specific ethnic heterogeneity is found to be important in the early years of the war but is insignificant at the end.

In another, broader review of the economic impacts of civil war, Collier *et al.* (2003) note that there is a double loss that occurs in the diversion of public spending to war spending: first, resources are lost from the community as funding is removed to engage in warfare; then, the damage inflicted by this warfare further diminishes the community's economic activity. The backing of the ethnic groups by various governments (Bosnian Croats by Croatia, Bosnian Serbs by Serbia and the Yugoslav National Army, and Bosniaks by the Bosnian government) surely involved the diversion of public expenditure towards destructive activities (for example, the covert purchasing and transporting of weaponry, which had been outlawed by the UN arms embargo of September 1991 (Stockholm International Peace Research Institute, 2012)) that would have diminished economic activity.

As GDP and other related measures are unavailable over the civil war period, night light data can serve proxy for economic activity, as its collection is not interrupted by conflict and spans the years of the war. Studies of nighttime light imagery have repeatedly corroborated the strength of the relationship between economic activity and night lights in conflict and non-conflict circumstances. The impacts of conflict have been identified in both satellite night light data as well as traditional income and GDP accounts. The findings of the literature reviewed above regarding night lights and conflict in combination with the underlying theories of the conflict-economic activity relationship are thus applied in the context of Bosnian civil war to identify the economic effects of specific types of conflict.

4. Discussion of Data

Night Light Data & Satellite Calibration

Night light data are taken from the NOAA's DMSP-OLS Nighttime Light Series archive, which are available on the NOAA's website. The images under study are yearly composites and have been cleared of cloud interference. Ephemeral events (such as fires) and general background noise are filtered out by the NOAA prior to download, such that the yearly composites contain persistent lighting from human settlements in addition to gas flares (NOAA). While gas flares would pose a problem for analysis by inflating a region's luminosity, they do not create an issue in Bosnia, which does not have gas extraction that produces such flares. The images are 30 arc second grids, which scales to almost 1 kilometer, and span from -180° to 180° longitude and -65° to 75° latitude (NOAA). Data are available on the NOAA archive between 1992 and 2013.

The night light data are given on a luminosity scale ranging from zero to 63. A pixel receives a score of zero if it is completely dark; it receives a score of 63 if it has full light saturation. Thus, urban areas with high development levels with greater light infrastructure will have luminosity numbers approaching 63, while less-developed, more rural areas with less light infrastructure will have lower luminosity numbers. In the conflict analysis, a municipality's luminosity will be given as the natural logarithm of sum of the luminosity of its constituent pixels. In the first year of observation, the lowest municipality SOL[12] was zero (that is, no light infrastructure or so little that it was not detected by the satellite), and the highest was 4,947. The log of the former will be taken as zero[13]; the log of the latter is 8.51. Using ln(SOL) as opposed to SOL allows for interpretation as the percentage change in district luminosity resulting from conflict experience. Even more importantly, this allows the distribution of luminosity to approximate a Gaussian distribution with a slight leftward skew.

The SOL scale may be affected by differences in the satellites used to capture the images. Over the twenty-two years of data production, the NOAA has used six different satellites to collect night light imagery. Between 1992 and 1994, the satellite F10 captured the images used to generate the yearly composites; it was then replaced by F12, which captured images between 1994 and 1999. The year of overlap (1994) between the two satellites provides an opportunity to calibrate between F10 and F12 to mitigate the effects of differences that might result from satellite characteristics. The F10 values from 1992 and 1993 will be converted to the F12 basis, and the 1994 and 1995 F12 values will remain as they are. The inclusion of a quadratic term in the calibration regression adds explanatory power and is a better visual fit for the 1994 data; the linear and quadratic regressions and corresponding scatterplots are included in Tables A.3.2 and A.3.3 and Figures A.3.1 and A.3.2 in the appendix. The calibration regression takes the form:

$$F12_{m,t} = 36.285 - 0.0001(F10_{m,t})^2 + 1.370(F10_{m,t})$$

where each dependent-independent variable pair is indexed by municipality m and year t. Thus, the regression is run over 109 observations. If a municipality had a 0 SOL in all four years of observation or in 1992-1994, the estimated F12 value was replaced with 0 SOL.

The night light data for the Bosnian municipalities are extracted from the NOAA images using ArcGIS and a 1991 municipal boundaries shapefile from the data scientist Andreas Berger[14]. This shapefile initially contained 107 municipalities (the four central Sarajevo districts were combined into two) and was adjusted to fit the original 109 municipalities of 1991.

[12] The municipality's sum of lights is referenced as SOL, while the natural logarithm is ln(SOL). SOL is also referred to as luminosity.
[13] This simply replaces estimates that are undefined when the logarithm is applied to SOL.
[14] Andreas Berger, Predictive Heuristics. Bosnia 1991 Municipalities. Jan. 18, 2011.

Imputation of Pre-War SOL

The primary focus of this investigation will be night lights between 1992-1995, the years over which the Bosnian civil war occurred. One significant limitation of the night light data is that the first year of collection is 1992. Although all the war years are captured in the night light images, there are no available pre-war images for comparison. As conflict begins in early 1992, and the lights are a yearly composite, the earliest year of data captures a large portion of the first phase of conflict. The use of 1992 as a baseline year is therefore problematic in the models that will be used in this investigation, as they rely on comparisons to pre-war luminosity to estimate the effects of conflict. To account for this issue, pre-war luminosity levels will be calculated for the Bosnian municipalities using imputation regressions.

The pre-war SOL levels are estimated using data from municipalities in other Yugoslavian republics that did not experience conflict. Data must be relatively free of the influence of social unrest and must be consistent in period of measurement across nations. Violence in Croatia and Slovenia excludes them from use; Macedonia's incomplete census and housing data from 1991 pose serious problems, as significant changes in these statistics likely occurred between 1991 and 1994, when a second, complete census was taken of the population. Serbia and Montenegro, however, remain as viable candidates for estimating pre-war luminosity in Bosnia's municipalities. Data from the last Yugoslavian census in 1991 as well as the 1991 Yugoslavian Statistical Yearbook with a topographical complement are used generate the pre-war SOL estimates for Bosnia's municipalities. Due to limitations imposed by data availability, four primary variables will be used to predict a municipality's ln(SOL): population size, average elevation, size of the industry and mining sector by number of workers, and number of dwellings.

In the literature discussed previously, population size is found to be strongly and positively related to luminosity. Therefore, the natural log of the municipalities' population according to the 1991 census and its square is taken as the first predictors of lights. In addition to population, the number of industry and mining workers, a light-generating sector, isused as a measure of local economic activity. These data come from the 1991 Yugoslavian Statistical Yearbook for municipalities in all three countries. An elevation control is added to account for variations in average topography across the districts. The World Bank's topographical map of global elevation above sea level is used to calculate the average elevation of a district.

Urban development emits greater light than rural areas with little or no light-generating infrastructure. While a total of urban development infrastructure or total consumption of electricity would be ideal for this prediction, neither statistic is accessible or available on the countries' statistical websites. Their censuses do, however, include variants of the total number of dwellings in an area. Bosnia's housing in 1991 is subdivided into total, private and social for each municipality; Serbia's census provides the total number of permanent dwellings. Montenegro includes dwellings built each decade since the 1920s, including a "pre-1918" category that represents a total of the buildings built prior to 1918; thus, a sum can be taken across these additional dwellings before 1991 to estimate the total number of dwellings in a municipality in 1991. The total number of dwellings is the last of the four predictors of ln(SOL) that will be used to impute Bosnia's pre-war sums of lights.

Overall, Serbia and Montenegro provide a total of 179 control units for the imputation after new boundaries are adjusted to fit those of the 1991 census and Statistical Yearbook. The ln(SOL) estimates for both countries will be calculated using the same standardization regression technique as was applied to Bosnia. The associated equations and coefficients are in Tables A.3.2 and A.3.3 of the appendix.

Figure 2: Actual vs. Imputed 1992 ln(SOL)

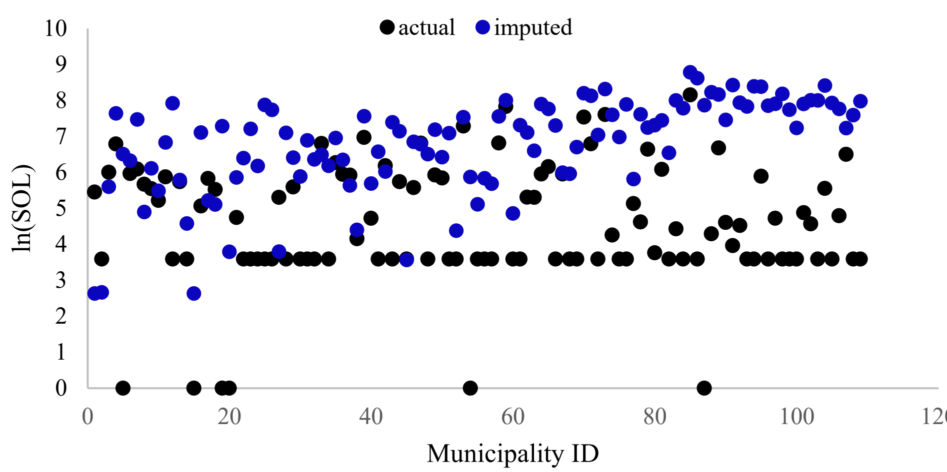


Figure 2 shows the differences between imputed and actual night light sums in the 109 municipalities; on average, the imputed light sums are 53% larger than the actual light sums[15]. An initial review of the ln(SOL) values for the Serbian and Montenegrin control units in 1992 reveals a much higher rate of zero-SOL municipalities in Bosnia than in either of the control nations. In the 1992 composites, Serbia and Montenegro have a total of 4 zero-SOL municipalities (2% of the municipalities), while Bosnia has a disproportionate 49 municipalities that emit no light (45% of municipalities). Furthermore, where the general literature on satellite night light data and Elvidge *et al.*'s (2017) findings on Bosnia consistently identify strong, positive correlations between population and luminosity, only a weak relationship exists between the conflict-affected 1992 municipality sums and their population sizes. In 1992, ln(pop) and ln(SOL) for Bosnia have a correlation of only 0.145. The number of zero-sum municipalities and the weakness of the population-lights correlation in 1992 reiterate the importance of imputing baseline levels to establish pre-war luminosity for Bosnia's 109 municipalities.

After calibrating the night lights for the Serbian and Montenegrin municipalities with their F12-F10 standardization regression, a series of regressions were conducted using various forms of the four night light determinants. As the independent variables have a large range (84,823 for dwellings; 244,396 for population; 1,488 for elevation; 40,813 for industry & mining workers), the natural log of each is taken to restrict outlier influence. Table 1.1 contains the correlation matrix and Table 1.2 the descriptive statistics for the variables used to predict ln(SOL):

Table 1.1: ln(SOL) Predictors Correlations for Serbia and Montenegro

	ln(SOL)	ln(pop)	$[\ln(pop)]^2$	ln(ele)	ln(dwe)	ln(ind)
ln(SOL)	1.000					
ln(pop)	0.717	1.000				
$[\ln(pop)]^2$	0.700	0.999	1.000			
ln(ele)	-0.510	-0.281	-0.275	1.000		
ln(dwe)	0.639	0.776	0.776	-0.252	1.000	
ln(ind)	0.621	0.809	0.807	-0.107	0.757	1.000

[15] This number is likely smaller than the actual average difference. Several municipalities with an actual SOL value of zero in 1992 are assigned a 100% value in the comparison calculation.

The strength of the correlations is consistent with the relationships outlined literature. Population variables exhibit stronger relationships with ln(SOL) than the other three determinants. The dwellings correlation, which does not account for all light-generating infrastructure in a municipality, is reasonable; a similar conclusion applies to the industry and mining workers variable.

Table 1.2 contains descriptive statistics on the ln(SOL) predictors for comparison between the Bosnian and control municipalities. Overall, the statistics in the table indicate that the control units are viable comparators for the Bosnian municipalities. There are slight differences in the mean and median quantities of ln(ele) and ln(dwe); however, the municipalities are, on average, comparable.

Table 1.2: ln(SOL) Descriptive Statistics Comparisons

	Bosnia				Serbia & Montenegro			
	ln(pop)	ln(ele)	ln(dwe)	ln(ind)	ln(pop)	ln(ele)	ln(dwe)	ln(ind)
minimum	8.336	4.415	6.859	4.060	8.213	4.286	4.060	4.836
median	*10.311*	*6.549*	*8.901*	*7.952*	*10.267*	*5.752*	*9.113*	*7.853*
maximum	12.184	7.149	10.828	10.204	12.422	7.353	11.349	10.618
mean	*10.311*	*6.275*	*8.893*	*7.951*	*10.398*	*5.641*	*9.210*	*7.907*
standard deviation	0.783	0.703	0.789	0.914	0.828	0.944	0.983	1.218
variance	0.614	0.494	0.623	0.836	0.686	0.890	0.967	1.484

The R^2 value of the regression of ln(SOL) on the predictor variables is 0.703. The full results of these regressions are reported in Table A.4.1 of the appendix. The final structure of the 1992 imputation regression is:

$$\ln(SOL)_m = -50.321 - 0.449\ln(pop)_m{}^2 + 10.167\ln(pop)_m - 0.531\ln(ele)_m + 0.215\ln(dwe)_m + 0.216\ln(ind)_m$$

Thus, Bosnia's pre-war ln(SOL) values are imputed according to this equation using each municipality's 1991 population, number of dwellings, number of industry and mining workers, and average elevation.

Descriptive statistics on the pre-war (indicated by Period 0) and wartime ln(SOL) as well as changes in ln(SOL) between periods are presented in Table 2:

Table 2: Wartime ln(SOL) & Change in ln(SOL) Descriptive Statistics

	ln(SOL)				Change in ln(SOL)		
	Period 0	Period 1	Period 2	Period 3	Period 0-1	Period 1-2	Period 2-3
minimum	2.631	0.000	0.000	0.000	-7.867	-1.507	-2.578
median	*7.110*	*5.204*	*5.606*	*6.110*	*-1.775*	*0.318*	*0.373*
maximum	8.783	8.151	8.212	8.585	2.892	1.379	4.804
mean	*6.783*	*5.024*	*5.326*	*5.881*	*-1.758*	*0.302*	*0.556*
standard deviation	1.335	1.615	1.705	1.503	1.762	0.519	1.153
variance	1.781	2.607	2.909	2.260	3.103	0.269	1.329

Table 2 shows that average ln(SOL) in each period of the war is lower than the imputed pre-war average. However, after large initial losses, the average and median ln(SOL) in the municipalities increase as the war progresses. The average and median change in ln(SOL) is negative in the first period (that is, municipalities on average experience losses) and positive for the second and third periods (municipalities on average experience growth). The negative minimum values in the change in ln(SOL) indicate that in all phases of the war, there are municipalities that suffer decreases in luminosity.

These descriptive statistics indicate that on average, there is increasing luminosity in the country through the years of conflict. Kothari *et al.* (2012) find a similar trend in Sub Saharan Africa—economic effects of conflict are largest in the first year and decline in subsequent years. This average increase seems counterintuitive; however, when considered alongside the variance (specifically the pre-war through the second period), the motivation of this research is reaffirmed: municipalities differ in the behavior of their sums of lights throughout the war, indicating the existence of differences in conflict consequences that demands investigation.

Conflict Data

The conflict data that will be used in this research come from the Becker *et al.* (2018) analysis of the Bosnian civil war. They codify and analyze the CIA's military history of the Yugoslav Wars. Via Principal Component Analysis, Becker *et al.* identify three distinct periods of fighting and five types of conflict; each period is defined by three of the five types of conflict.

The three-period structure is the reduction of twelve quarters outlined in the CIA history of the war. These periods do not neatly map onto the years: the first period begins in the spring of 1992 and concludes at the end of Spring 1993; the second period stretches from the summer of

1993 to the end of the 1993-94 winter; the final period picks up in the spring of 1994 and ends in the fall of 1995. Adjustments must be made so that the difference between time periods and years can be reconciled to the greatest extent possible. For example, in considering the third period, the use of only 1995 SOL ignores a critical nine months of conflict that occur in 1994; the same issue applies to the two previous periods. To resolve this problem, this analysis weighs the light levels for the municipalities according to the proportion of months they represent in each time period.

The first period of the war begins in the spring of 1992 and ends in the spring of 1993, which means that fourteen months are characterized by the first period types of conflict (which will subsequently be described in detail). Nine of these months (April through December) occur in 1992; five more (January through May) occur in 1993. The second period includes seven months (June through December) of 1993 and two months (January and February) in 1994. The final period spans ten months (March through December) of 1994 and eleven months (January through November) in 1995. To generate weighted sums of lights for each period, the year light level is multiplied by the fraction of months it covers in a period:

Period 1: $SOL = \frac{9}{14}(sum\_1992) + \frac{5}{14}(sum\_1993)$

Period 2: $SOL = \frac{7}{9}(sum\_1993) + \frac{2}{9}(sum\_1994)$

Period 3: $SOL = \frac{10}{21}(sum\_1994) + \frac{11}{21}(sum\_1995)$

During the initial phase of the war, the warring groups unite and establish preliminary control of territory. Over the second segment, the groups sought to capture important assets and strengthen their hold over their existing territory. In the final stage, they sought to weaken opponents and acquire more territory (which in the peace settlement would largely be divided along the extant frontlines of the conflict) as the fighting drew to a close (Becker *et al.,* 2018; Costalli and Moro, 2012). This progress of the goals in the war proves to be especially relevant in the later sections of this investigation.

The Becker *et al*. data reduce the CIA war history from quarters to three periods; they also identify nine types of conflict events present in the record. These conflict events are taken as "1" = occurred or "0" = did not occur and can occur multiple times in one municipality for a given period. For example, the municipality of Novo Sarajevo has seven siege components in Period 3.

The nine original fighting components over which principal component reduction occurs include: captured (transition of control between ethnic groups in the same period), recaptured (two transitions of control between ethnic groups in the same period), trenches ("dugouts or prepared formation of a front line"), war crimes ("organized rape, targeting or killing of civilians (including ethnic cleansing), or organized killing of prisoners of war"), sieges (encircled municipality, town, or troops), pockets (loosely encircled municipality), infighting (conflict between two groups based in the same municipality), threatened (shelling and bombardment without the ability for a ground assault), and contested (traditional conflict between two groups) (Becker *et al*., 2018).

The five reduced types of conflict include siege, hybrid, dirty conventional, civil war, and conventional. Siege conflict is defined by the presence of sieges and trenches throughout the war, with recaptured components in the middle of the war and war crimes towards the end. This type of conflict occurs in all three periods of the war. Hybrid conflict occurs in the first and third periods of war. In the first, they are defined by captured, recaptured, and threatened components; in the third, they are defined by pockets, war crimes, and threatened components. Civil war occurs only in the second period and includes pockets, threatened, contested, and infighting. Conventional type conflicts, which appear only in the third period, consist of captured, recaptured, and contested components. Dirty conventional conflicts occur in the first and second periods of the war. In the first period, dirty conventional is defined by war crimes, threatened, and infighting; in the third period, it is defined by captured, war crimes, and contested. Table 3 provides a visual representation of the five categories and their fighting components by period of the war.

Table 3: Five Types of Conflict by Period and Components

Period	Siege	Hybrid	Dirty Conventional	Civil war	Conventional
1	trenches sieges	captured recaptured pockets	war crimes threatened infighting		
2	trenches sieges recaptured		captured war crimes contested	pockets threatened contested infighting	
3	trenches sieges war crimes	pockets threatened war crimes			captured recaptured contested

Furthermore, Becker *et al.* have compiled a record of resource (utilities) presence in the municipalities, which comes originally from the CIA war data. These utilities include power plants, armories, ore mines, elevation, and highway systems. Additional variables resulting from conflict in this data set include wartime casualties and placement of landmines[16].

Becker *et al.* identify significant types of conflicts as those with eigenvalues greater than 1. This analysis follows their heuristic: a conflict type "occurs" in a municipality if its principal component value is greater than one. For example, the municipality of Novo Sarajevo receives a siege indicator of 1 in each period of the war, as the principal component of the siege is 6.891 in the first period, 7.409 in the second, and 6.204 in the third (Sarajevo experienced a siege throughout the war; incidentally, the twenty-five-year anniversary of the lifting of the Siege of Sarajevo will occur this year). The municipality of Kreševo, per contrast, receives siege indicators of 0 in each period, as it has a principal component of -0.109 in Period 1, -0.611 in Period 2, and -0.231 in Period 3.

[16] Casualties, mines, and utilities data pose a problem like that encountered with ELF—they do not vary over the three phases of conflict. Casualties are taken as a post-war aggregate and represent a municipality's total death count over the four years of the war. Mine data are a post-war count of mines placed in a municipality and cannot account for damage inflicted by explosions during the war. While Becker *et al*. use these variables in the Principal Component Analysis that generates the conflict types studied in this investigation, these time invariant characteristics are inevitably swept out of this analysis as fixed effects.

5. Empirical Strategy

To evaluate the variable impacts of the conflict types and characteristics on economic activity, this investigation employs a spatial autoregressive model with municipality fixed effects (SAR-FE). This model can be used to incorporate spatial and temporal lags, which Weidmann and Ward (2010) found to be significant predictors of conflict occurrence. Spatial autocorrelation that is displayed by night light data (Donaldson and Storeygard, 2016) can also be controlled in this model. Spatial weights are taken based on inverse distance from a municipality, such that the effects of both contiguous and proximal municipalities are considered while accounting for the marginal effects of distance. The spatial lag is specified over the dependent variable (ln(SOL)), the conflict type independent variables (siege, hybrid, dirty conventional, civil war, and conventional), and the error terms of the regression.

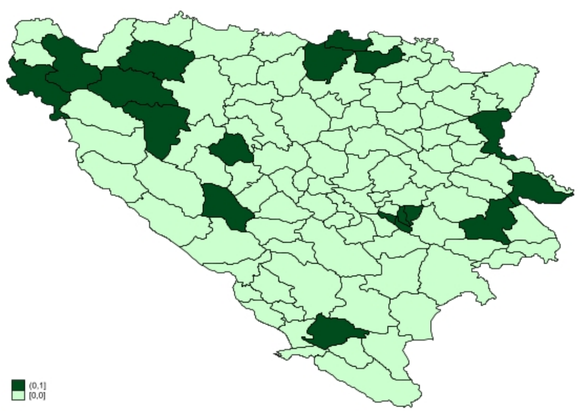


Figure 3.1: Period 1 Hybrid Conflict

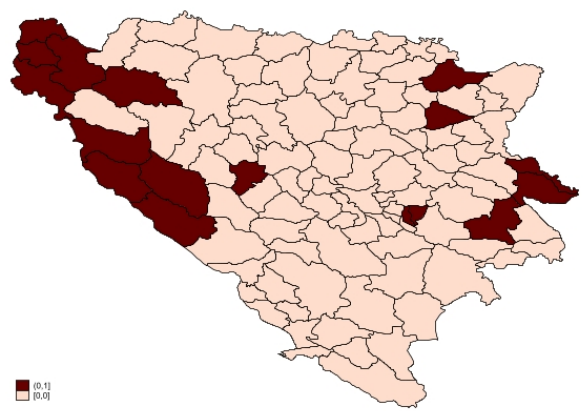


Figure 3.2: Period 3 Conventional Conflict

Figures 3.1 and 3.2 are maps of incidence of select types of conflict. A visual survey of these images supports the findings of Weidmann and Ward (2010): there appears to be a spatial factor that underlies conflict type incidence. Both types exhibit heavy clustering patterns; similar behavior is evident in the maps presented in Table A.7 of the appendix, which presents maps of all conflict types by period. Thus, controlling for spatial autocorrelation is essential to this analysis.

The demographic and utilities variables cannot be included in the more intensive SAR-FE model, as their time invariance in the data characterizes them as fixed features of the municipalities. While this is a limitation of the empirical strategy employed in this analysis, it is not debilitating flaw. As shown in Table 4, the demographic and utilities variables exhibit only weak correlations with the conflict variables. Similarly, the conflict variables do not exhibit strong intercorrelations.

Table 4: Conflict, Demographic, Utilities Variables Correlations

	siege	hybrid	dirty conv.	civil war	conv.
siege	1.000				
hybrid	0.106	1.000			
dirty conv.	0.213	0.265	1.000		
civil war	0.112	-0.053	0.159	1.000	
conv.	0.059	0.189	-0.049	-0.041	1.000
ln(death)	0.179	0.211	0.085	0.090	0.091
ln(pop)	0.184	0.131	0.053	0.013	0.075
frac	0.076	0.091	0.089	0.081	-0.073
share_bos	0.074	0.116	0.093	0.096	0.104
share_serb	-0.053	-0.036	-0.080	-0.139	-0.009
roads	0.143	0.044	-0.031	0.098	-0.021
ln(ele)	0.125	0.013	0.063	0.100	0.035

Table 5: Baseline Panel Regression

Conflict Variables		*Demographic Variables*		*Utilities Variables*	
siege	*-0.717***	lnpop	*0.708***	power	0.025
	(0.346)		*(0.224)*		(0.245)
hybrid	*-0.991****	frac	*-1.623***	armory	0.285
	(0.278)		*(0.804)*		(0.314)
dirty conv.	-0.466	share_bos	*-7.289***	extr	0.238
	(0.296)		*(3.342)*		(0.226)
civil war	*-0.786***	share_serb	*-6.337**	roads	*0.517***
	(0.334)		*(3.415)*		*(0.220)*
conv.	-0.453	share_croat	-5.296	junc	-0.363
	(0.339)		(3.306)		(0.302)
lndeath	0.165			mines	-0.004
	(0.166)				(0.032)
				lnele	*-0.323**
					(0.167)
constant	6.271				
	(4.702)				
Obs.					428
Wald χ^2					143.04*** (0.000)
R^2					0.359

Note: The share of the population that identified as "Other" (which includes the "Yugoslavian" category) is omitted from this regression. ***p < 0.01, **p < 0.05, *p < 0.10.

The table above presents the results of the baseline panel regression. This specification excludes spatial and temporal effects but includes local population and resource characteristics. The results indicate that siege, hybrid, and civil war conflicts are all significantly related to decreases in a municipality's sum of lights. Interpretation of the change in the sum of lights is taken as a percentage given by:

$$\%\Delta\text{SOL} = 100 \cdot (e^{\beta} - 1)$$

where β is the regression coefficient of interest. Municipalities that experienced siege and civil war conflicts had sums of light 51% and 54% lower, respectively, than municipalities that did not experience them. The hybrid type coefficient had the greatest magnitude and significance of the conflict types and was associated with a 63% lower sum of lights.

The baseline panel regression also finds that several population and resource features are related to sums of lights in the municipalities: larger populations are associated with higher sums of lights, whereas increasing the share of Bosnians or Serbs and fractionalization were associated with lower light sums. Proximity to highways (roads) had a positive association with ln(SOL), while elevation (ln(ele)) had a negative relationship.

The results of the baseline regressions, however, do not account for municipality characteristics, lagged effects of conflicts, or spatial spillovers. If sieges occur in heavily populated, urban areas (such as Sarajevo's municipalities) in each period of the war and do not occur in rural areas of lower population density, the retention or replacement of light infrastructure through the war will be interpreted as increases associated with the occurrence of siege because the municipality's population and urbanity characteristics are not considered in the model. The baseline panel regression also excludes effects from the joint incidence of conflict types and lingering impacts of previous conflict occurrences. Thus, the results presented in Table 5 and the percentage changes discussed above are unlikely to reflect the true effects of each type of conflict on the municipalities.

As has been discussed, a spatial autoregressive fixed-effects model with municipality fixed effects is employed to account for the issues associated with the simple panel regression. The SAR-FE model takes the following form:

$$\begin{aligned} \mathrm{lnSOL}_{m,p} = {} & \beta_0 + \beta_1 \mathrm{siege}_{m,p} + \beta_2 \mathrm{hyb}_{m,p} + \beta_3 \mathrm{civwar}_{m,p} + \beta_4 \mathrm{dircon}_{m,p} + \beta_5 \mathrm{conv}_{m,p} + \rho W\left(\mathrm{lnSOL}_{m-n,p}\right) \\ & + W(\varphi_1 \mathrm{siege}_{m-n,p} + \varphi_2 \mathrm{hyb}_{m-n,p} + \varphi_3 \mathrm{civwar}_{m-n,p} + \varphi_4 \mathrm{dircon}_{m-n,p} + \varphi_5 \mathrm{conv}_{m-n,p}) \\ & + \gamma_1 \mathrm{siege}_{m,p-1} + \gamma_2 \mathrm{hyb}_{m,p-1} + \gamma_3 \mathrm{civwar}_{m,p-1} + \gamma_4 \mathrm{dircon}_{m,p-1} + \delta_1 \mathrm{I\_3}_p + \delta_2 \mathrm{I\_2}_p + u_{m,p} \end{aligned}$$

where W represents the inverse distance spatial weights matrix and the ρ coefficient gives the effect of municipality *m-n*'s SOL on municipality *m*'s. Spatial autocorrelation is controlled over the ln(SOL), the conflict variables, and the error term[17]. The variables with a β coefficient are associated with conflict effects in period p and municipality m; those associated with a φ coefficient are spatially-lagged terms, where each observation is indexed by period p and the event occurring in a municipality lagged by *n*. γ-coefficient variables are the conflict lag variables. While conflict lags are included to account for the temporal behavior of the five types, period indicators are not included in the model due to the time-dependent nature of the conflict variables. Finally, δ-coefficient variables represent the interaction terms, with *I_3* giving 3-type combinations (one for each period) and *I_2* giving 2-type combinations (three for the first period, two for the second, and two for the third). A full list of the variables included in the regressions is located in Table A.2 of the appendix.

6. Results

The results of this analysis will be discussed in a specfic sequence. First, a brief overview of the signs and significance of the coefficient estimates from the SAR-FE regression will be given and translated into percentages from logarithm format. This will provide a clearer picture of the initial implications of the selected model. Then, two sensitivity tests and two additional model modifications will be conducted to verify and augment the results of the original SAR-FE specification. Finally, potential explanations for the coefficients that have been identified as significant predictors of the municipalities' sums of lights will be detailed in the next section.

[17] The autoregressive error term takes on the form $u = (I - \rho W)^{-1}\epsilon$, where ϵ represents the original, non-spatially weighted error. As has been mentioned previously, the necessity of controlling for error autocorrelation in night lights is discussed by Donaldson and Storeygard (2018).

Spatial Autoregressive Fixed Effects Model

Differentiating between direct and spillover effects has large implications for the results of this analysis; the inclusion of spatial and temporal controls alters the estimates on conflict variables and identifies significant spatial relationships between municipalities. The impacts of these spatial relationships are contained in the "Indirect" column in Table 6. One of the spatially lagged conflict types is found to significantly influence sums of lights in neighboring municipalities. Even where the spatial lags are insignificant, their inclusion affects the magnitudes and significance of the direct effects of the conflict types (in addition to the temporal lags and interaction variables).

Sum of lights also has significant spatial relationships: a given municipality's SOL is higher when its neighbors' SOLs are higher. Such spatial patterns in the spread of night light lights are expected. Consider, for example, Sarajevo: the economic activity of the central municipalities disperses into proximal municipalities. Thus, proximity to Sarajevo directly influences a contiguous municipality's sum of lights, as economic activity spills over into that municipality's borders.

Table 6: Spatial Autoregressive Fixed Effects Regression

	Direct	Indirect	Total
Conflict Types			
siege	-0.600	1.364	0.764
	(0.366)	(5.968)	(6.000)
hybrid	*-0.981****	*-18.980**	*-19.961**
	(0.300)	*(10.684)*	*(10.808)*
dirty conv.	-0.203	-2.175	-2.377
	(0.342)	(6.763)	(6.892)
civil war	*-0.659**	4.776	4.118
	(0.342)	(6.939)	(7.011)
conv.	*-0.769***	-15.380	*-16.150**
	(0.362)	(9.524)	*(9.564)*
Temporal Lags			
siege	0.104	0.100	0.205
	(0.332)	(0.331)	(0.656)
hybrid	*-0.835***	-0.804	*-1.639**
	(0.301)	(0.797)	*(0.950)*
dirty conv.	*0.439**	0.422	0.861
	(0.265)	(0.478)	(0.668)
civil war	-0.291	-0.281	-0.572
	(0.309)	(0.407)	(0.675)

Table 6 (cont): Spatial Autoregressive Fixed Effects Regression

	Direct	Indirect	Total
Interactions			
siege*hybrid*dirty conv.	-1.028	-0.990	-2.018
	(1.367)	(1.591)	(2.823)
siege*dirty conv.*civil war	-0.506	-0.487	-0.993
	(1.768)	(1.747)	(3.486)
siege*dirty conv.	1.522	1.466	2.988
	(1.119)	(1.720)	(2.568)
hybrid*dirty conv.	0.625	0.603	1.228
	(0.681)	(0.859)	(1.447)
siege*civil war	1.152	1.110	2.263
	(0.885)	(1.324)	(2.006)
dirty conv.*civil war	0.249	0.240	0.488
	(0.711)	(0.716)	(1.409)
siege*conv.	-0.339	-0.326	-0.665
	(0.914)	(0.912)	(1.800)
hybrid*conv.	*1.695***	1.632	*3.327**
	(0.607)	(1.636)	*(1.958)*
ρ		*0.515***	
		(0.234)	
Obs.			436
Wald χ^2			59.75*** (0.000)
Pseudo R^2			0.028

Note: Conventional conflict only occurs in the final phase of the war and therefore does not have a lagged term. The three-way interaction between siege, hybrid and conventional conflicts and the two-way siege interaction with hybrid conflict are omitted due to multicollinearity.
***p < 0.01, **p < 0.05, *p < 0.10

Results Overview

The baseline model identified siege and dirty conventional conflicts as variably significant predictors of ln(SOL). Neither siege nor dirty conventional conflicts are found to be significant in the SAR-FE model. Hybrid and civil war conflicts are both significant in this SAR-FE specification; conventional conflicts are also found to be significant. All of the conflict types, regardless of their significance, have negative signs on their direct effects estimates. Of the significant types, hybrid conflict has the largest effect on a municipality's sum of lights with an average decrease of 63%; civil war and conventional conflicts are associated with 48% and 54% decreases, respectively. The significance of the civil war coefficient, however, is low (10%).

One significant spatial lag and two significant temporal lags are identified in the SAR-FE model. Hybrid conflict alone has a significant indirect spatial effect. The estimated coefficient of -18.980 translates to a 100% decrease in sum of lights resulting from spillover effects. This result is likely compounded due to the spatial layout of the conflict types, where the occurrence of hybrid conflict in neighboring municipalities means that a given municipality experiences hybrid conflict both directly and indirectly. The significance of the indirect effect of hybrid conflict is low (10%). The magnitude of this coefficient is likely skewed by municipalities that experience light losses and have multiple neighbors that experience hybrid conflict simultaneously. Municipalities around Sarajevo, for example, are susceptible to this result, as all four of the capital's central municipalities experienced hybrid conflict during the first period of the war. The role of Sarajevo will be further investigated in the next subsection.

The temporal lag of the hybrid conflict variable is of smaller magnitude than the spatial lag but has greater significance. Municipalities that experience hybrid conflict in the first period of the war have average decreases of 57% during the second phase of the war. The lag of dirty conventional conflicts is similarly found to be significant at a low level and is positively associated with a municipality's sum of lights, generating a 55% increase.

Before discussing these results with respect to their components and providing potential explanations for the behaviors elucidated in Table 6, two tests are conducted to determine the sensitivity of the results to variations in the model. This allows for better interpretation of the results with the removal of inconsistent and spurious effects. These tests investigate the role of outlier municipalities to determine whether large cities are responsible for the effects identified by the above SAR-FE model. Then, an additional interaction term necessitated by the results of Table 6 is added in a third model modification. Finally, an evaluation of the first period is presented to better detail the effects of hybrid conflicts. In the following subsections, the model and results contained in Table 6 are referred to as the "original" SAR-FE model.

Sarajevo Exclusion

Interaction terms serve as a control in the SAR-FE model, but have low frequency of occurrence. To better understand the importance of the interaction terms and population- or urbanity-driven results, an SAR-FE model excluding the capital city[18] was evaluated over the remaining 105 non-central-Sarajevo municipalities. This eliminates the first period interaction term and the two-way siege interactions with hybrid and conventional conflicts. Futhermore, the occurrence siege conflict is eliminated in the first period (all sieges in this phase occurred in Sarajevo), and only two observations remain in third period. However, there are numerous non-Sarajevo municipalities that experienced siege conflicts in the second phase of the war.

The results of the Sarajevo Exlcusion regression are located in Table A.5 of the appendix. The estimated effects of siege conflicts are largely unaffected by the exclusion of Sarajevo. Hybrid, civil war, and conventional conflict retain their initial levels of significance and comparable coefficient magnitudes. The hybrid conflict lag and the hybrid-conventional interaction term are similarly unchanged. There are two notable changes that occur as a result of this specification: first, the dirty convential period lag loses its 10% significance—this suggests that its impact was concentrated in the four Sarajevo municipalities and driven by unobserved characteristics specific to the capital city. Second, the hybrid conflict indirect effect has become insignificant, while the conventional spillover is significant at the 10% level with a coefficient of -16.419 (which translates to a 100% decrease in SOL). This suggests that this specific spillover effect, whether resulting from hybrid conflict, conventional conflict, or some observed characteristic related to both, occurs in the third period (as the exclusion of Sarajevo associates them with conventional conflict, which only occurs in Period 3).

Ten-Municipality Exclusion

One extension of the Sarajevo Exclusion sensitivity test is the exclusion of ten municipalities that include the largest Bosnian cities (Banja Luka, Tuzla, Zenica, Ilidza, Mostar, and Bijelina in addition to the four initial Sarajevo exclusions). The full results are also located in Table A.5. Hybrid conflict is significant at the 5% level, while civil war and conventional conflicts retain the same levels of significance as in Table 6. The hybrid lag and the hybrid-conventional interaction similarly do not change in significance. All of the conflict types and the hybrid lag coefficients decrease in magnitude, while the interaction term increases in positivity. Once again, dirty conventional conflicts are insignificant. In this specification, however, the spillover effects from both hybrid and conventional conflicts are significant (though both are at

[18] This excludes the Sarajevo Centar, Sarajevo Novi Grad, Sarajevo Stari Grad, and Novo Sarajevo.

the 10% level) and are both associated with 100% decreases in a municipality's sum of lights. Possible explanations for the significance and magnitudes of the interaction terms will be provided in the Discussion section of this text.

The results of the original SAR-FE model are generally robust to the ten-municipality exclusion; this is a strict test on lights, as nearly one third of the population (according to pre-war levels) is excluded when these ten municipalities removed from the data. As with the Sarajevo Exclusion, the exclusion of ten municipalities with the largest Bosnian cities does not materially alter the conclusions reached from the results of the original SAR-FE model.

Hybrid Lag & Civil War Interaction

This variant of the SAR-FE model is motivated by the concurrence of civil war conflict and the hybrid lag variable. The results of Table 6 are inconclusive for Period 2 in that they indicate the existence of a potentially significant, unidentified interaction: it could be that civil war conflicts only have significant effects on a municipality's sum of lights when that municipality has already been devastated by hybrid conflict in the preceding period. Civil war conflict has a consistently low level of significance in the original SAR-FE model as well as the two exclusions examined previously.

A civil war-hybrid lag interaction is added to the original SAR-FE regression to isolate the independent effects of each variable. The results of this test are presented Table A.6 of the appendix and show that the independent civil war term is rendered insignificant. The hybrid lag term has a slightly smaller coefficient (now associated with 54% decreases in luminosity) but retains its original 5% significance; the interaction itself is also insignificant. The hybrid conflict term increases in significance relative to the results in Table 6, and siege conflicts become significant at a low level; the other results remain essentially unchanged. Only three municipalities that experienced hybrid conflict in the first period also experience civil war in the second period; overall, this augmentation of the model indicates that the Period 2 effects of conflict are driven by the hybrid lag rather than by the independent civil war term. When this interaction term is inserted into the two exclusion regressions run previously, the same patterns emerge, and civil war remains insignificant. Therefore, the results of this test indicate that the light losses in the second period are a derivative of the first-period hybrid effects, and civil war is entirely insignificant when it is considered with respect to the hybrid lag.

First Period Isolation

The first period is advantaged in analysis because it is unaffected by previous conflict occurrences and can therefore be analyzed for independent effects; this is not true of the second and third period, for which events of the preceding periods may affect those which occur later. Thus, to better understand the dynamics of hybrid conflict, which is the only significant conflict type in the first period of the war, the SAR-FE model can be restricted to a two-period analysis of Period 0 and 1, where only siege, hybrid and dirty conventional conflicts and the interaction of the latter two (the three-way and other two-way interactions are omitted due to multicollinearity) are evaluated. The estimated direct impact of hybrid conflict in the first period is larger than that of the full-period model (associated with an 81% decrease in sum of lights at 5% significance); the indirect impact has a smaller coefficient value (-13.415 at 5% significance) that translates to a spillover effect of magnitude similar to that of the original SAR-FE model (after the ln-conversion, both estimate 100% decreases). The results of this test suggest that the effects of hybrid conflict are largest and most significant in the first period of the war as the direct coefficient magnitude decreases in the full-period model. This is consistent with the descriptive statistics on light losses that show larger losses occurring during the first period of the war—the first-period hybrid coefficient is larger than the coefficients of the third-period conventional and the overall hybrid term.

7. Discussion

When the sensitivity tests and hybrid lag-civil war augmentation are factored into the interpretation, the SAR-FE model indicates that hybrid and conventional conflicts are associated with municipal light losses and are significant inhibitors of economic activity. Low significance was attributed to civil war conflicts in the original model, but the inclusion of its interaction with the lagged hybrid variable in a modified model rendered its independent effect (as well as the interaction term) insignificant. Both the spatial and temporal lags of hybrid conflict were found to be significant throughout the analysis.

Hybrid-type conflicts occur in both the first and third periods of the war; however, the component events that define hybrid conflicts are not the same in both periods. The conflict characteristics[19] that comprise first-period hybrid conflict include captured, recaptured and pockets; the events that define third-period hybrid conflict are pockets, threatened and war crimes. Conventional conflict occurs only in the third period and involves captured, recaptured and contested events. Thus, there is overlap in the conflict events that compose first-period hybrid and conventional conflicts but no temporal overlap. There is temporal overlap between third-period hybrid and conventional conflicts, but they do not share component events.

The descriptive statistics contained in Table 2 indicated that average losses in sums of lights were largest in the first period of the war; slow recovery occurred during the second and third periods (as shown by the positive means), but light losses were still incurred in those phases of the war by some municipalities (as evinced by the negative minimum values in the change statistics). Explanations for these patterns of destruction with respect to hybrid and conventional conflicts can be attributed to both the underlying component events that constitute both types of conflict and the period-specific goals of the war.

As was outlined in Section 4, the goals of warring parties in the first period involved the acquisition of territory and the strengthening of those positions. This involved both military combat to expel opposing forces as well as genocide of the civilian body. The third period of the war involved less ethnic cleansing as groups attempted to curry favor from the international community, which would eventually arbitrate the peace deal between the opposing parties. Maintaining assets acquired in previous periods and inflicting damage on enemy forces dominated this final phase of the war.

In terms of constituent events, first-period hybrid conflicts and third-period conventional conflicts share one particularly notable feature that likely drives the severity of consequential night light losses: both possess captured and recaptured components. Captured and recaptured both indicate transfers of control between warring parties in one period; the latter indicates that two transfers occurred over the same period. In a war where airstrikes and resultant large-scale destruction are limited due to internationally imposed no-fly zones, the captured and recaptured components provide an intuitive explanation for light losses where destruction is restricted to the ground.

[19] Table 3 contains the full listing of component events by period of occurrence for each of the five types of conflict.

The transfer of control of municipality X from Aggressor A to Aggressor B in a captured component incentivizes the destruction of municipality X's resources by Aggressor A in their retreat to minimize the assets available to Aggressor B once the forcible transfer of power is complete. Likewise, the recaptured component, which involves a second transition, now from B to A (or potentially B to C), incentivizes Aggressor B to destroy assets available in municipality X so that the successor to control cannot utilize those resources in the future. This pattern applies to both to hybrid conflict in Period 1 and conventional conflict in Period 3. Furthermore, where ethnic cleansing served as a means of establishing control over a municipality, it is likely that the occurrence of captured and recaptured components, and therefore of hybrid and conventional conflicts, resulted in genocide and mass emigration. Thus, hybrid and conventional conflicts are associated with light loss through both the destruction of light-generating infrastructure and severe population loss.

The components of third period hybrid conflict are expected to generate similar patterns of destruction, if to a possibly lesser extent, as they include threatened and war crimes components, which also involve infrastructure (now specifically through shelling and bombardment) and population (again through ethnic cleansing) losses, respectively. While the first and third period hybrid conflicts differ in components, the underlying pattern of destruction is similar.

The interaction between hybrid and conventional warfare, which only applies in Period 3 and occurs in five municipalities, has a positive and significant effect on sums of lights. When the overall impact is calculated, however, the sum of their calculated coefficients ($\beta_2 + \beta_3 + \delta_2$ to sum the coefficients on hybrid, conventional, and their interaction in that order and as specified in the original SAR-FE specification) is -0.055, which translates to a 5% decrease in the sums of lights in municipalities that experience both hybrid and conventional conflicts. Thus, there seems to exist a tempering effect when both types of conflict occur. This could be a result of patterns of component occurrence when both conflicts are present. For example, if the components associated with heavy resource destruction and a large civilian death toll, such as war crimes, captured and recaptured components, do not occur as frequently where both hybrid and conventional conflicts occur, decreases in SOL might be less severe than in municipalities where captured and recaptured events occur with greater frequency under the presence of only conventional conflict.

The mechanisms of conflict discussed above are consistent with the literature on the economic impact of civil war. The broad categories of hybrid and conventional conflict each involve specific avenues through which violence affects economic activity. The dual losses incurred with population outflow and resource destruction are distinct inhibitors of productivity, trade, and social order. Extreme reductions in the labor force result from ethnic cleansing and refugee movement; decreased productivity of the labor force that remains in a war-torn municipality is inevitable amid conflict as a result of physical and psychological stressors. The capital stock these regions is depleted due to deliberate resource destruction via the control change mechanism discussed above. Government expenditures are allocated to the war, rather than productive activities—it is also a possibility that funds that did remain would be directed away from regions controlled by opposing parties, which depends on the hybrid and conventional conflict occurrence patterns. The disruption of trade patterns and economic relationships also results from these power shifts and damaging events; seizures and subsequent re-seizures of supply lines interrupts trade both within the municipality and outside of it.

These effects may not be as pronounced in municipalities where control does not shift and deliberate, excessive destruction of resources and human life does not occur. While siege, dirty conventional, and civil war conflicts are by no means "good" or productive, they may not inhibit everyday business operations to the same extent that hybrid and conventional conflicts do. Moreover, if heavy losses are sustained in population *or* infrastructure, but not both[20], with the occurrence of siege, dirty conventional, or civil war conflict, municipalities that experience them might exhibit smaller decreases in light levels from destruction than hybrid and conventional conflicts, which simultaneously and repeatedly involves losses in both dimensions.

Limitations & Future Extensions

The use of the spatial autoregressive model with fixed effects is not without its disadvantages, many of which result from limitations imposed by the time characteristics of the

[20] Not that both do not occur simultaneously—the distinction is that "heavy" losses may occur in one or the other, or "light" losses may occur in both, whereas hybrid and conventional conflicts are more likely to generate "heavy" losses in both.

data. While the model could otherwise account for variables discussed as "time-invariant" in preceding sections, the record styling of casualties and mine placement as wartime aggregates impairs the model's ability to account for these variables. A similar problem exists with respect to non-death population changes, such as ethnic fractionalization and population. One conciliatory factor is that the relevant literature on the Bosnian civil war finds municipal fractionalization effects to be singificant only during the beginning of in the war (Costalli and Moro, 2012; Weidman, 2011). While the impacts of population change from refugees and casualties cannot be addressed due to time invariance in the data, the effects of initial population size are considered by the two exclusion tests.

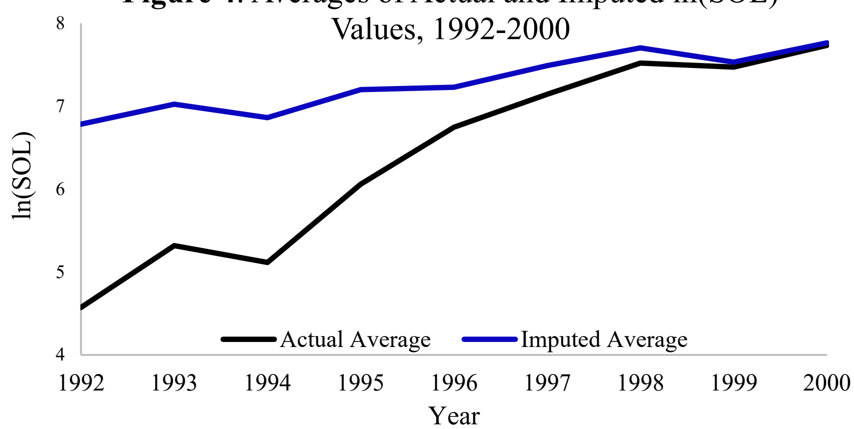
This issue of omitted demographic and utilities variables cannot be remedied by the use of random effects instead of fixed effects, which would be a natural strategy to account for these characteristics, as the data do not meet the requirements for such analysis. The critical factor that prevents the use of random effects is the assumption that individual effects are uncorrelated with the independent variables. This is untrue of both the conflict and demographic variables—consider siege conflicts, for example: onset is related to urbanity, which fixed effects do take into account. Urbanity is related to fractionalization and ethnic composition—urban areas tend to be more ethnically diverse and have higher fractionalization scores. Fixed effects are necessary to control for these interrelated municipality effects that impact patterns of conflict incidence. A mitigating factor in this limitation is that the original Principal Component Analysis conducted by Becker *et al*. did take these time-invariant features into consideration in the process of identifying these conflict types. Thus, the conflict definitions have some inherent weighting of the regional characteristics that are omitted from the SAR-FE regressions.

One final consideration that merits discussion is the behavior of spillover effects identified as significant in the model. While such indirect impacts of conflict are expected and motivate the use of a spatial autoregressive model, the size of the coefficients is surprising. The magnitudes of these estimates for indirect effects could capture the impacts of omitted variables, as has been dicussed. This feature is reflected in the low Pseudo R^2 value for the SAR-FE models. Alternatively, where hybrid and conventional conflict occur in contiguous municipalities, it could be the case that effects are magnified where multiple conflict events occur. This is also related to inseparability of conflict types; overlap within their definitions in combination with clustering effects might magnify the estimates of spillovers.

Research Extensions

A natural avenue for future research that could mitigate some of the limitations of this study is the longitudinal extension of the spatial model. This would require some reformatting of the conflict data and a reassessment of appropriate time periods for analysis, but postwar evaluation could integrate time-variant demographic features, casualty counts, and mine placement, the effects of which are expected to persist after the official end of the conflict. Figure 4 compares the imputed and actual averages of ln(SOL)[21] for Bosnia's municipalities throughout the war and five years[22] after its conclusion. The convergence of the imputed and actual values in 2000 indicates that recover does occur in the postwar period, though lagged effects of conflict persist for at least five years after the war. The evaluation of recovery patterns by conflict type with the inclusion of demographic and utilities variables made time-variant by this expansion of the time horizon would be a valuable extention of these findings.

Figure 4: Averages of Actual and Imputed ln(SOL) Values, 1992-2000



8. Conclusion

Conflict is widely acknowledged to be a suppressant of economic activity, and the economic literature on civil war outlines numerous mechanisms by which such effects are

[21] The calibration process for 2000 is included in Tables A.3.2 and A.3.3 of the appendix; Table A.4.1 contains the regression coefficients and model structure for the postwar imputation regressions.
[22] The effects of conflict on economic activity are generally found to last several years after violence ends. Kothari *et al*. (2020) and Gates *et al.* (2012) both find differences of five years, as appears to be the case in Bosnia. Rohner *et al.* (2013) look four years post-conflict in Uganda and also find persistent effects of interethnic violence.

realized. This investigation contributes to this literature by identifying the importance of differentiating between types of conflict in which the mechanisms of economic suppression assume varying roles and weights. This paper utilizes a new conflict dataset on the Bosnian civil war and DMSP-OLS nighttime light imagery to examine the differential economic consequences of the five types of conflict that dominated the war. The use of a spatial autoregressive model with municipality fixed effects identified both temporal and spatial spillovers of conflict as significant determinants of economic activity.

Distinguishing between characteristics of conflict offers a valuable means of investigating the differential economic outcomes of civil war. The conclusions of this research are consistent with the theory and empirical findings of the civil war literature. Destruction from mines (Andersson *et al.,* 1995) and shelling, losses in the labor force from out-migtraion (Kondylis, 2009; World Bank World Development Indicators), and a lack of foreign investment (European Bank of Reconstruction and Development) are fundamental elements of the five-mechanism framework (Collier, 1999) that outlines the economic costs of conflict. The literature also identifies significant lagged effects of war (Kothari *et al.*, 2020; Gates *et al.*, 2012; Rohner *et al.*, 2013). This research finds both instantaneous and (temporally and spatially) lagged consequences of conflict; furthermore, it identifies that these consequences were most severe in municipalities that experienced hybrid and conventional conflicts.

Hybrid and conventional conflict types exert large direct and indirect effects on economic activity. The other three types of conflict were not consistently significant across the sensitivity tests and model augmentations employed to verify the results. Wartime descriptive statistics indicated that, on average, municipalities experienced decreases in SOL in the first period of the war and growth of SOL for the remainder of the war. The magnitudes of the estimated impacts of the significant types of conflict reflected this pattern. Hybrid type conflicts were associated with 62% decreases in SOL in municipalities that experienced such conflict, while the estimated indirect effects on neighboring municipalities predicted 100% decreases in sums of lights; the lagged effects of hybrid conflict were associated with 54% decreases in municipalities that experienced this type of conflict in Period 1. The two-period model that isolated first-period impacts found an average SOL decrease of 80% within a municipality and predicted the same level of spillover effects as the full-period model. Conventional conflicts were associated with

54% decreases in SOL. The joint occurrence of both hybrid and conventional conflicts in Period 3 had lesser effects than the independent occurrence of either type.

The impacts of hybrid and conventional conflict on economic activity are attributed to shifts in municipality control that are unique to those types of conflict. These changes in control were theorized to incentivize deliberate and excessive destruction of resources and to instigate the perpetration of ethnic cleansing. These findings provide evidence of significant differences in the economic implications of violence depending on the types of conflicts experienced by municipalities over the course of the war. These characteristics are related to period-specific goals of warring parties, and the techniques employed to realize these goals are ingrained in the definitions of the five types of conflict.

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Appendix

Table A.1: Data Sources

Bosnian civil war conflict data	Becker *et al* (2018)
Bosnia census, 1991	Federal Bureau of Statistics, Federation of Bosnia and Herzegovina
Bosnia municipalities boundaries, 1991	Andreas Berger
Montenegro boundaries	European Environment Agency
Montenegro census, 1991	Statistical Office of Montenegro, Statistical Yearbook 2011, Review by Municipalities (Ch. 26)
Serbia boundaries	MIT GeoWeb (file originally from Stanford)
Serbia census, 1991	Statistical Office of the Republic of Serbia, Census 2011, Comparative Overviews
Industry & Mining Workers	Statistical Yearbook of Yugoslavia, 1991
DMSP-OLS night lights	National Oceanic and Atmospheric Association
World Topography Map	World Bank

Table A.2: Regression Variables

Imputation Regressions: variables used to calculate the 1992 pre-war values for Bosnia as well as the 1992-2000 no war comparison. The SAR-FE models *only* use the 1992 imputation as a pre-war measure; the war period sums of lights are calculated using the actual values between 1992-1995.

$\ln(imp_{m,t-1})$	Natural log of the imputed value of SOL for municipality *m* in year *t-1*
$[\ln(pop)]^2$, ln(pop)	Natural log of population in 1991 and its square; population is highly correlated with lights and is thus is a valuable predictor of ln(SOL) in the imputation process
ln(ele)	Natural log of elevation; serves as a topographical control in the imputation regression
ln(dwe)	Natural log of the number of dwellings in municipality *m* in 1991; serves as a measure of light-emitting infrastructure in a region
ln(ind)	Natural log of the number of industry and mining workers in municipality *m* in 1991; serves as a measure of local economic activity and is a light-emitting industry

Baseline Panel Regression: this regression identifies preliminary relationships between conflict types and lights as well as demographic and regional features that are swept out of the SAR-FE model.

SOL	Sum of lights of municipality *m* in year *t.* These are composed of pixels that take a value between 0-63 on a luminosity scale, where 63 represents maximum saturation and 0 is minimum light detection (no emission).
ln(SOL)	The natural log of the sum of lights for municipality *m* in year *t.* The distribution of SOL is heavily skewed right, while ln(SOL) better approximates a Gaussian distribution. These values are used in the period-weighting equations to approximate light values for the periods of the war as defined by Becker *et al*. (2018)
ln(death)	Natural log of the number of casualties for municipality *m* over the course of the war. It is as a post-war total and is time-invariant in this analysis.
frac	Ethnolinguistic fractionalization—measures degree of ethnic heterogeneity depending on shares of ethnic groups (see footnote 11). It is taken pre-war and is time-invariant.
share_bos, share_serb, share_croat	Share of Bosniaks, Serbs, and Croats in municipality *m.* Like frac and ln(death), the shares are measured once (pre-war) and are time-invariant.
mines	Post-war mine count in a municipality.
Utilities: all utilities are taken as pre-war measures and are time invariant. - power: presence of power plants - armory: presence of armory - extr: presence of mines for mineral extraction - roads: presence of roads (road density in Becker *et al,* 2018) - junc: presence of transportation junction	

SAR-FE Regressions: These models cannot include the demographic and topographic features listed in the baseline panel regression table. ln(SOL) is the same as that in the baseline panel regression.

$siege_{m,p}$ [*siege123_1*]—siege conflicts occur in all three periods of the war with different components. They are correlated with ethnic heterogeneity and urbanity (Becker *et al.,* 2018[23]) **$siege_{m-n, p}$**: spatial lag of the siege variable; applied in all periods. **$siege_{m, p-1}$**: temporal lag of the siege variable; occurs in Periods 2 and 3.
$dircon_{m, p}$ [*dircon12_1*]—dirty conventional conflicts occur in the first and second periods of the war with different components. They are associated with low frac (high homogeneity) and power (Becker *et al.,* 2018). **$dircon_{m-n, p}$**: spatial lag of the dirty conventional variable; applied in Periods 1 and 2. **$dircon_{m, p-1}$**: temporal lag of the dirty conventional variable; occurs in Periods 2 and 3.
$hybrid_{m,p}$ [*hybrid13_1*]—hybrid conflicts occur in the first and third periods of the war with different components. They are correlated with low share_serb (relating to the use of ethnic cleansing) and are negatively related to power and junc (Becker *et al.,* 2018). **$hybrid_{m-n, p}$**: spatial lag of the hybrid variable; applied in Periods 1 and 3. **$hybrid_{m, p-1}$**: temporal lag of the hybrid variable; occurs in Period 2.
$civwar_{m, p}$ [*civwar2_1*]—civil war conflicts occur in the second period of the war. They are related to ethnic cleansing, armory, and power (Becker *et al.,* 2018). **$civwar_{m-n, p}$**: spatial lag of the civil war variable; applied in Period 2. **$ciwar_{m, p-1}$**: temporal lag of the civil war variable; occurs in Period 3.
$conv_{m, p}$ [*conv3_1*]—conventional conflicts occur in the third period of the war. They differ from dirty conventional conflicts largely due to different third-period goals (Becker *et al.,* 2018). There is no temporal lag, as this conflict only occurs in Period 3. **$conv_{m-n, p}$**: spatial lag of the civil war variable; applied in Period 3.
3-Way Interactions—valued at 1 when a municipality experiences all three possible conflict types one period. **I_all_1** [***$siege_{m,p}$*$dircon_{m, p}$*$hybrid_{m,p}$***]: interaction between Period 1 conflict types; occurs in 4 municipalities. **I_all_2** [***$siege_{m,p}$*$dircon_{m, p}$*$civwar_{m,p}$***]: interaction between Period 2 conflict types; occurs in 1 municipality. **I_all_3** [***$siege_{m,p}$*$hybrid_{m, p}$*$conv_{m,p}$***]: interaction between Period 2 conflict types; occurs in no municipalities.
2-Way Interactions—valued at 1 when a municipality experiences two conflict types in a given period. **I_SH_13** [***$siege_{m,p}$*$hybrid_{m,p}$***]: interaction between siege and hybrid Periods 1 and 3; occurs in 4 municipalities in Period 1 and none in Period 3. **I_SD_12** [***$siege_{m,p}$*$dircon_{m,p}$***]: interaction between siege and dirty conventional in Periods 1 and 2; occurs in 4 municipalities in Period 1 and 2 in Period 2. **I_HD_1** [***$hybrid_{m,p}$*$dircon_{m,p}$***]: interaction between hybrid and dirty conventional in Period 1; occurs in 8 municipalities. **I_SCW_2** [***$siege_{m,p}$*$civwar_{m,p}$***]: interaction between siege and civil war in Period 2; occurs in 3 municipalities. **I_DCW_2** [***$civwar_{m,p}$*$dircon_{m,p}$***]: interaction between civil war and dirty conventional in Period 2; occurs in 4 municipalities. **I_SCV_3** [***$siege_{m,p}$*$conv_{m,p}$***]: interaction between siege and conventional in Periods 3; occurs in 2 municipalities. **I_HCV_3** [***$hybrid_{m,p}$*$conv_{m,p}$***]: interaction between hybrid and conventional in Period 3; occurs in 5 municipalities.

[23] For greater detail on the identification of the conflict types and their relation to the demographic and topographical features, see Becker *et al* (2018). To see the components for each conflict type and each period, see Table 3.

Table A.3.1 Satellite Calibration

$F12_{m,t}$	SOL for municipality *m* in year *t* captured by the F12 satellite (1994-1999)
$F10_{m,t}$	SOL for municipality *m* in year *t* captured by the F10 satellite (1992-1994)
$F14_{m,t}$	SOL for municipality *m* in year *t* captured by the F14 satellite (1999-2003)

Table A.3.2: Satellite Calibration Regressions

	F10 to F12				**F14 to F12**
	Bosnia		Serbia & Montenegro		Bosnia, Serbia & Montenegro[24]
	Linear	*Quadratic*			
$(F10\ SOL)^2$		*-0.0001****	*-0.00001****	$(F14\ SOL)^2$	*-4.01e-06****
		(0.00002)	*(3.32e-06)*		*(8.90e-07)*
F10 SOL	*0.876****	*1.370****	*1.403****	F14 SOL	*1.318****
	(0.045)	*(0.072)*	*(0.036)*		*(0.011)*
Constant	*168.572****	36.285	-60.153	Constant	*42.868**
	(36.479)	(33.637)	(57.259)		*(22.931)*
Obs.	109	109	179	Obs.	864
Adj. R^2	0.778	0.858	0.976	Adj. R^2	0.988
F-Stat.	(1, 107) 379.17***	(2, 106) 328.27***	(2, 176) 3620.32***	F-Stat.	(2, 861) 34434.20***
RMSE	318.69	254.46	451.68	RMSE	369.69

Table A.3.3: Satellite Calibration Equations

Serbia & Montenegro, F10	$F12_m = -60.153 - 0.00001(F10_m)^2 + 1.403(F10_m)$
Bosnia[25], Serbia & Montenegro, F14	$F12_m = 42.868 - (4.01e^{-06})(F14_m)^2 + 1.318(F14_m)$

Figure A.3.1: Bosnia Calibration Linear Fit

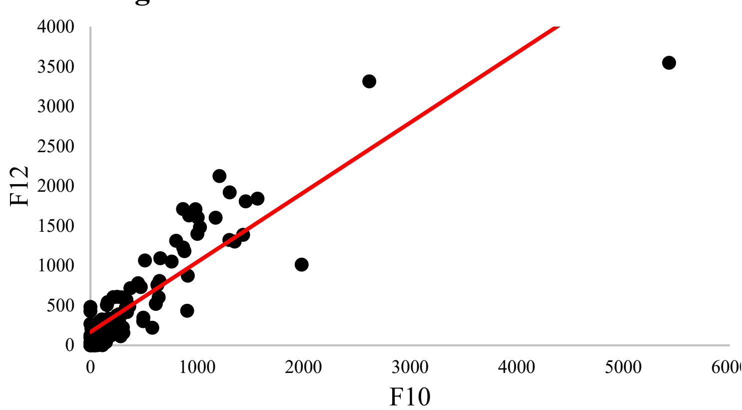
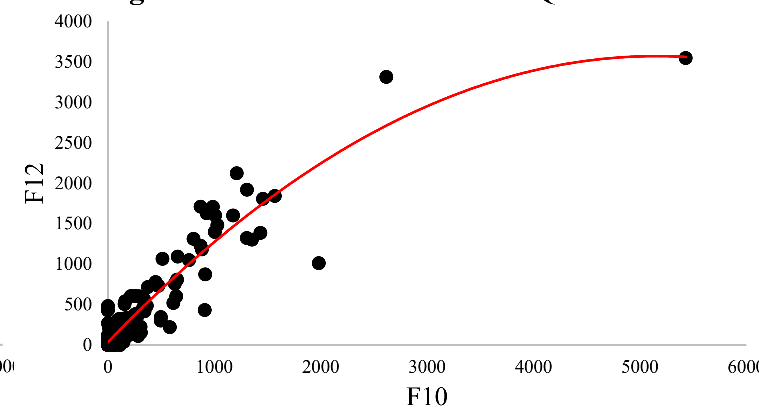


Figure A.3.2: Bosnia Calibration Quadratic Fit



[24] The post-war calibration for the F14 satellite is conducted only using the quadratic model, as was the Serbia-Montenegro F10 calibration. It is also done jointly as 2000 shows convergence of the average sums of lights between imputed and actual values. The F10-F12 calibration was performed separately when the divergence of the average sums was large.

[25] The equation for the Bosnia F10-F12 regression is included in the body of the text.

Imputation Equation: $\ln(imp_{m,t}) = \alpha_0 + \alpha_1 \ln(SOL_{m,t-1}) + \alpha_2[\ln(pop_m)]^2 + \alpha_3 \ln(pop_m) + \alpha_4 \ln(ele_m) + \alpha_5 \ln(dwe_m) + \alpha_6 \ln(ind_m) + \varepsilon$

Table A.4.1: Imputation Regression Coefficients 1 (1992-2000)

	1992	1993	1994	1995	1996	1997	1998	1999	2000
$\ln(imp_{m,t-1})$		*0.770****	*0.821****	*0.887****	*0.980****	*0.609****	*0.822****	*0.913****	*0.818****
		(0.040)	*(0.032)*	*(0.028)*	*(0.018)*	*(0.031)*	*(0.051)*	*(0.028)*	*(0.027)*
$[\ln(pop)]^2$	*-0.449****	0.029	*-0.054**	-0.035	*-0.052**	*0.087***	*-0.082***	*0.044***	0.003
	(0.070)	(0.041)	*(0.030)*	(0.023)	*(0.015)*	*(0.026)*	*(0.029)*	*(0.017)*	(0.016)
ln(pop)	*10.167****	-0.529	*1.220**	0.726	*1.158****	*-1.763***	*1.842***	*-0.906***	0.040
	(1.478)	(0.874)	*(0.633)*	(0.504)	*(0.323)*	*(0.555)*	*(0.626)*	*(0.368)*	(0.338)
ln(ele)	*-0.531****	0.006	*-0.168****	0.013	0.007	*-0.126****	-0.020	*-0.046***	*0.093****
	(0.074)	(0.044)	*(0.032)*	(0.027)	(0.017)	*(0.028)*	(0.036)	*(0.020)*	*(0.019)*
ln(dwe)	*0.215**	-0.007	0.065	0.019	-0.010	0.058	0.017	*0.068***	-0.037
	(0.117)	(0.059)	(0.045)	(0.035)	(0.023)	(0.038)	(0.046)	*(0.027)*	(0.025)
ln(ind)	*0.216***	0.077	-0.003	-0.001	0.001	0.047	0.004	-0.038	*0.040**
	(0.099)	(0.052)	(0.040)	(0.031)	(0.020)	(0.034)	(0.041)	(0.023)	*(0.022)*
constant	*-50.321****	3.540	-5.204	-2.913	*-6.139****	*11.843****	*-8.736***	*5.124***	0.325
	(7.847)	(4.575)	(3.319)	(2.631)	*(1.683)*	*(2.886)*	*(3.261)*	*(1.909)*	(1.762)
Obs.	179	179	179	179	179	179	179	179	179
Adj. R^2	0.703	0.894	0.938	0.954	0.982	0.194	0.874	0.957	0.949
F-Stat.	85.180***	252.01***	445.97***	614.18***	1616.54***	317.89***	207.23***	653.81***	548.79***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
RMSE	0.834	0.448	0.339	0.267	0.171	0.287	0.349	0.200	0.189

Note: The 1992 regression does not have a preceding year term as night light data is only available beginning in that year. The coefficients are calculated from the Serbia & Montenegro regressions of $\ln(SOL)_{m,t}$ on $\ln(SOL)_{m,t-1}$ and the other listed variables. The Bosnia regressions are recursive, using the imputed value from year *t-1* in the regression for year *t*.

***p < 0.01, **p < 0.05, *p < 0.10

Table A.4.2: 1992 Actual vs. Imputed Difference Statistics:

	ln(SOL)	SOL
minimum	-2.543	-215.15
median	2.202	839.733
maximum	7.892	6168.636
mean	2.203	1338.847
standard deviation	1.931	1378.995
variance	3.727	1.90e06

These differences are taken by subtracting the actual 1992 value from the imputed 1992 value. Table A.4.2 and Figure 2 show that on average, the actual, war-impacted light levels are much lower than the imputed values.

Table A.5: SAR-FE Sensitivity Tests

	Sarajevo Exclusion			Ten-Municipalities Exclusion		
	Direct	Indirect	Total	Direct	Indirect	Total
Conflict Types						
siege	-0.628	-10.499	-11.127	-0.662	-13.537	-14.199
	(0.433)	(11.403)	(11.509)	(0.442)	(11.211)	(11.323)
hybrid	*-0.834***	-13.303	*-14.138**	*-0.770***	*-12.677**	*-13.446**
	(0.296)	(8.468)	*(8.562)*	*(0.301)*	*(7.674)*	*(7.763)*
dirty conv.	-0.248	-7.997	-8.244	-0.222	-7.362	-7.585
	(0.362)	(9.198)	(9.356)	(0.367)	(8.230)	(8.389)
civil war	*-0.631***	7.280	6.649	*-0.619**	6.226	5.607
	(0.355)	(7.136)	(7.227)	*(0.361)*	(6.601)	(6.690)
conv.	*-0.846***	*-16.419**	*-17.265**	*-0.791***	*-16.538**	*-17.329**
	(0.372)	*(9.480)*	*(9.513)*	*(0.381)*	*(9.240)*	*(9.269)*
Temporal Lags						
siege	0.142	0.145	0.287	0.055	0.051	0.107
	(0.376)	(0.407)	(0.772)	(0.404)	(0.380)	(0.782)
hybrid	*-0.785***	-0.800	-1.585	*-0.736***	-0.688	-1.424
	(0.322)	(0.803)	(0.983)	*(0.329)*	(0.705)	(0.901)
dirty conv.	0.451	0.460	0.910	0.474	0.443	0.917
	(0.280)	(0.528)	(0.733)	(0.289)	(0.507)	(0.719)
civil war	-0.369	-0.376	-0.745	-0.442	-0.413	-0.855
	(0.316)	(0.478)	(0.734)	(0.338)	(0.502)	(0.767)
Interactions						
siege*dirty conv.*civil war	-0.172	-0.176	-0.348	-0.056	-0.053	-0.109
	(1.814)	(1.850)	(3.661)	(2.000)	(1.867)	(3.867)
siege*dirty conv.	1.161	1.183	2.344	1.081	1.009	2.090
	(1.161)	(1.600)	(2.580)	(1.179)	(1.444)	(2.467)
hybrid*dirty conv.	0.589	0.600	1.189	0.518	0.484	1.002
	(0.705)	(0.913)	(1.536)	(0.721)	(0.815)	(1.473)
siege*civil war	0.965	0.984	1.949	0.829	0.774	1.603
	(0.926)	(1.302)	(2.074)	(1.240)	(1.363)	(2.507)
dirty conv.*civil war	0.221	0.225	0.447	0.207	0.193	0.400
	(0.726)	(0.762)	(1.474)	(0.736)	(0.705)	(1.429)
hybrid*conv.	*1.743***	1.776	*3.518**	*2.020***	1.886	*3.906**
	(0.620)	(1.758)	*(2.081)*	*(0.688)*	(1.851)	*(2.191)*
ρ		*0.523***			*0.500***	
		(0.231)			*(0.233)*	
Obs.			420			396
Wald χ^2			53.40***			51.81***
			(0.000)			(0.000)
Pseudo R^2			0.034			0.052

Note: Conventional conflict only occurs in the final phase of the war and therefore does not have a lagged term. The three-way interactions between siege, dirty conventional, and hybrid conflict and siege, hybrid, and conventional conflict and the two-way siege interactions with dirty conventional conflict and hybrid conflict are omitted due to multicollinearity.

***p < 0.01, **p < 0.05, *p < 0.10

Changes between the original SAR-FE and the two exclusion models are, overall, minor. The most notable feature is the change in significance of indirect effects. The exact source of conflict spillovers in the third period is unclear, but they appear to result from both hybrid and conventional conflicts.

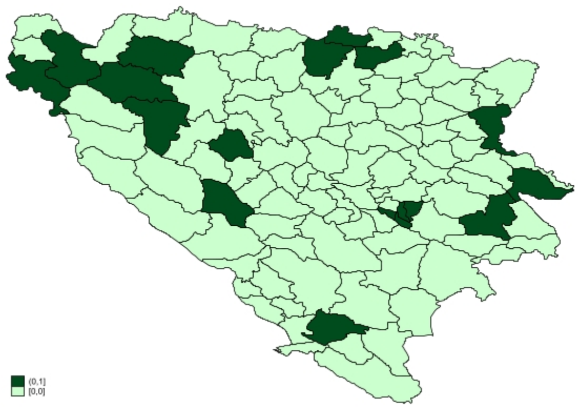
Table A.6: Hybrid Lag-Civil war Interaction

	Direct	Indirect	Total
<u>Conflict Types</u>			
siege	*0.366**	1.380	0.774
	(0.366)	(5.935)	(5.966)
hybrid	*-0.985****	*-18.847**	*-19.832**
	(0.300)	*(10.611)*	*(10.734)*
dirty conv.	-0.214	-2.513	-2.727
	(0.343)	(6.803)	(6.934)
civil war	-0.578	5.079	4.501
	(0.392)	(6.974)	(7.067)
conv.	*-0.768***	-15.333	*-16.101**
	(0.361)	(9.475)	*(9.514)*
<u>Temporal Lags</u>			
siege	0.104	0.099	0.204
	(0.332)	(0.327)	(0.652)
hybrid	*-0.777***	-0.740	-1.516
	(0.331)	(0.758)	(0.949)
dirty conv.	0.420	0.400	0.819
	(0.268)	(0.463)	(0.661)
civil war	-0.281	-0.267	-0.548
	(0.310)	(0.398)	(0.669)
<u>Interactions</u>			
hybrid lag*civil war	-0.328	-0.312	-0.640
	(0.780)	(0.790)	(1.543)
siege*hybrid*dirty conv.	-1.037	-0.988	-2.025
	(1.367)	(1.580)	(2.808)
siege*dirty conv.*civil war	-0.478	-0.456	-0.934
	(1.768)	(1.724)	(3.466)
siege*dirty conv.	1.537	1.464	3.002
	(1.119)	(1.715)	(2.559)
hybrid*dirty conv.	0.658	0.626	1.284
	(0.685)	(0.871)	(1.456)
siege*civil war	1.112	1.059	2.170
	(0.890)	(1.290)	(1.987)
dirty conv.*civil war	0.192	0.183	0.375
	(0.723)	(0.707)	(1.420)
siege*conv.	-0.331	-0.315	-0.647
	(0.914)	(0.900)	(1.789)
hybrid*conv.	*1.649***	1.570	*3.219**
	(0.617)	(1.592)	*(1.929)*
ρ		*0.512***	
		(0.235)	
Obs.			436
Wald χ^2			59.90***
			(0.000)
Pseudo R^2			0.029

Note: Conventional conflict only occurs in the final phase of the war and therefore does not have a lagged term. The three-way interaction between siege, hybrid and conventional conflicts and the two-way siege interactions with dirty conventional conflict and hybrid conflict are omitted due to multicollinearity.

***p < 0.01, **p < 0.05, *p < 0.10

Table A.7.1: Period 1 Conflict Maps

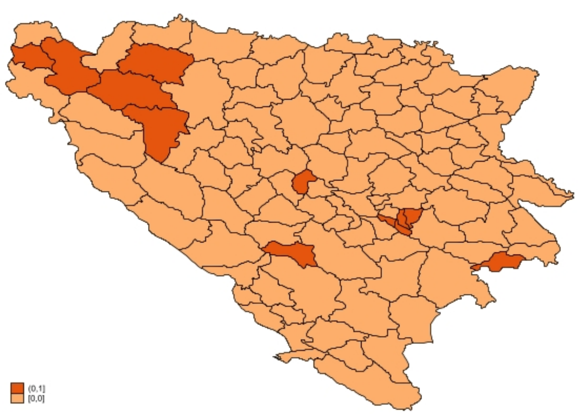


<u>Hybrid</u>

Hybrid conflicts are noticeably clustered in regions of incidence. It is likely that this clustering contributes to the magnitude of the estimated coefficient for indirect effects of hybrid conflict. This map also shows the locations of the Period 2 hybrid lag.

<u>Siege</u>

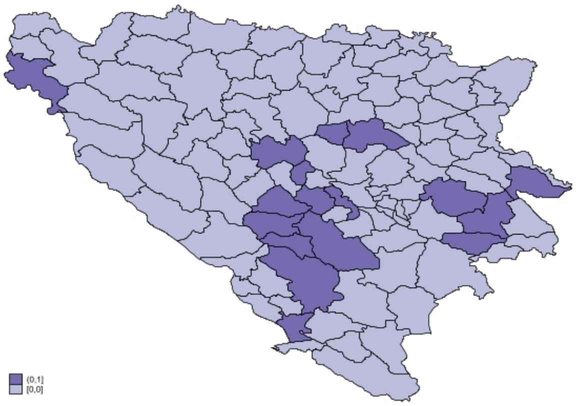
First-period siege conflicts occurred only in the central Sarajevo municipalities.



<u>Dirty Conventional</u>

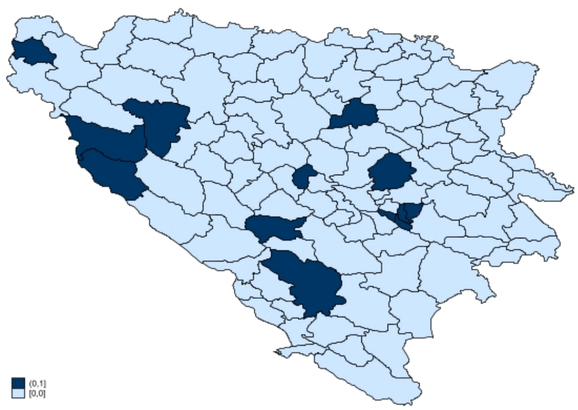
First-period dirty conventional conflicts exhibit heavy clustering, often in regions that simultaneously experienced hybrid conflict.

Table A.7.2: Period 2 Conflict Maps



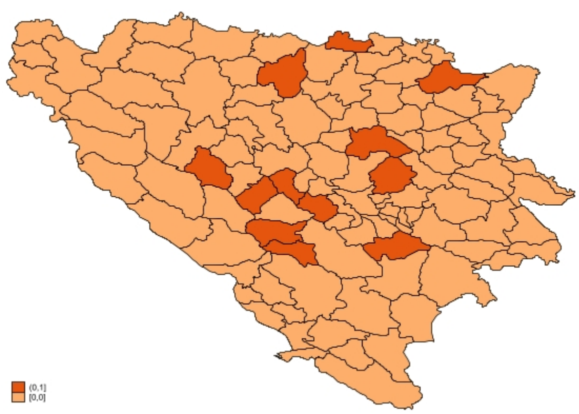
Civil War

Civil war conflicts exhibit strong clustering patterns and would be expected to have a heavy spatial component. However, they are found to be insignificant in the analysis when their interaction with the lagged hybrid term is considered. These conflicts occur only in the second phase of the war.



Siege

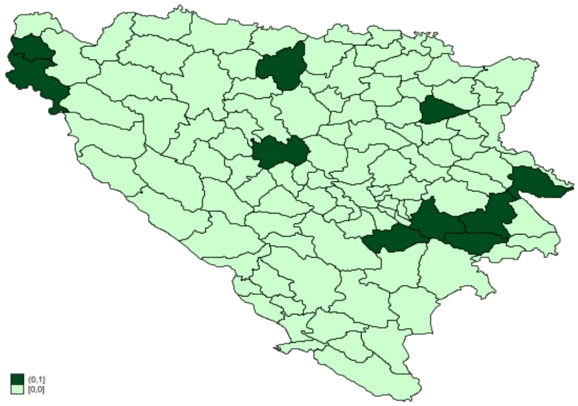
Second-period siege conflicts were more widespread than those of the first period, which only occurred in the Sarajevo municipalities.



Dirty Conventional

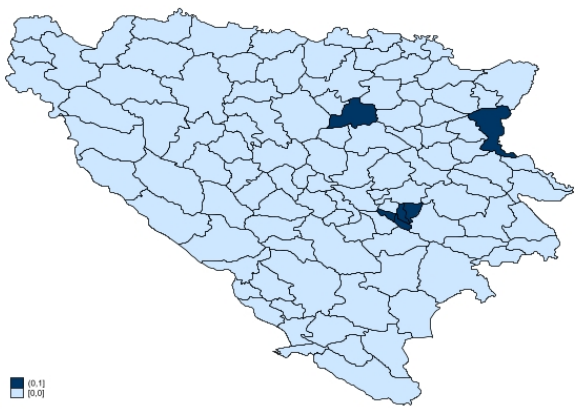
Dirty conventional conflicts in the second phase of the war show light clustering in the center of the country and largely occur in municipalities that did not experience this conflict type in Period 1.

Table A.7.3: Period 3 Conflict Maps



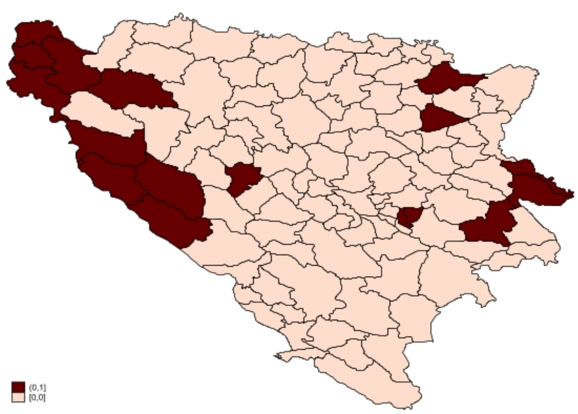
Hybrid

Hybrid conflicts again appear to have a spatial determinant in their pattern of occurrence. Several of the regions that experience hybrid conflict in Period 3 also experience conventional conflict. Not all regions that experienced hybrid conflict in the first period also experienced it in the third.



Siege

In the third period of the war, siege conflicts only occurred in three municipalities outside of Sarajevo.



Conventional

Conventional conflicts also exhibit spatial clustering. Like hybrid conflicts, conventional type conflicts were consistently significant and negatively associated with sums of lights. Some specifications also identify significant spillover effects from conventional conflicts. This conflict type occurred only in the third period of the war.