Identifying and Correcting Signal Shift in DMSP-OLS Data

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Appendix

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1 Correlation of Nighttime Lights Maps from Remaining DMSP-OLS Satellites

This section performs the spatial cross-correlations described and carried out on the F16 DMSP-OLS satellite in the main text on the remaining DMSP-OLS satellites. Table S1 shows results from the F10 satellite, Table S2 from the F12 satellite, Table S3 from the F14 satellite, Table S4 from the F15 satellite, and Table S5 from the F18 satellite.

Table S1: F10 Satellite Interannual Pearson Correlations

Year:	1992	1993	1994
1992	X	0.527	0.554
1993		X	0.582
1994			X

Reviewing the correlations between the annual composites does not produce the same stark contrasts seen with the 2009 composite from F16, but still report some years that are less correlated with others, where further inquiry may reveal that shifts took place. For the F10 satellite, three years are not sufficient to detect a pattern of divergent correlation from one year to another. However, the correlations between the maps are lower than those for other satellites, suggesting that visual inspection for a shift is warranted.

Table S2: F12 Satellite Interannual Pearson Correlations

Year:	1994	1995	1996	1997	1998	1999
1994	X	0.574	0.568	0.557	0.521	0.521
1995		X	0.633	0.611	0.570	0.570
1996			X	0.635	0.597	0.597
1997				X	0.584	0.584
1998					X	0.960
1999						X

The F12 satellite correlations reveal 3 possible divergent years: 1994, where correlations with other years are all below 0.6 and 1998-1999,[1] where correlations with 1995-7 are slightly higher, but also below 0.6.

Table S3: F14 Satellite Interannual Pearson Correlations

Year:	1997	1998	1999	2000	2001	2002	2003
1997	X	0.564	0.570	0.584	0.562	0.598	0.561
1998		X	0.634	0.591	0.603	0.574	0.618
1999			X	0.634	0.637	0.591	0.643
2000				X	0.641	0.615	0.631
2001					X	0.620	0.657
2002						X	0.622
2003							X

For F14, the first year that is detected, 1997, also appears anomalous. But the correlations between 1997 and 1998 in both the F12 and F14 satellite are within 0.02 of one another, suggesting this may be a substantive decline in nighttime light intensity in the region, rather than a technical issue.

Table S4: F15 Satellite Interannual Pearson Correlations

Year:	2000	2001	2002	2003	2004	2005	2006	2007
2000	X	0.660	0.661	0.653	0.630	0.645	0.639	0.563
2001		X	0.670	0.640	0.624	0.645	0.635	0.561
2002			X	0.663	0.655	0.666	0.666	0.600
2003				X	0.652	0.665	0.653	0.575
2004					X	0.657	0.677	0.635
2005						X	0.682	0.582
2006							X	0.650
2007								X

[1] The two years are highly correlated, suggesting the 1999 composite came from a partial sample of 1999 observations. A review of work using the F12 1999 maps does not reveal any justification for this convergence.

In the F15 satellite coverage, it is 2007 that is anomalous. 2007 composites have the lowest correlations with six of the seven other years captured by the satellite. The correlations are also markedly lower than those found between the same years in the F16 maps.

Table S5: F18 Satellite Interannual Pearson Correlations

Year:	2010	2011	2012	2013
2010	X	0.632	0.497	0.528
2011		X	0.618	0.615
2012			X	0.629
2013				X

Finally, the F18 satellite shows a stark decline in correlation between the 2010 map and the 2012 and 2013 maps. This is likely a result of fighting during the Syrian Civil War (Peçanha et al., 2015), rather than a technical issue. The 2012 and 2013 maps are otherwise highly correlated with one another.

Overall, we observe that the first and last years covered by a DMSP-OLS satellite appear to have correlation patterns with the other years more suggestive of shift, warranting additional visual inspection. If scholars have the option of using maps from satellites that are not either in the first or last year of recording data (not available for 1992, 1994, 2009, 2010 and 2013), this will help to mitigate potential issues with signal shift.

2 Visual Inspection for Signal Shift from F16 Satellite Maps

We build on Figure 1 in the main article by evaluating whether a shift is evident when comparing the F16 2009 composite to composites from the F16 satellite other than 2007 in the same geographic space. Figure S1 compares 2009 to 2004, Figure S2 to 2005, Figure S3 to 2006 and Figure S4 to 2007. For each figure, the same control points as applied to shift 2009 data back in line with the 2007 composite are utilized to shift the 2009 map. This allows us to examine how broad an application of the control point technique using a single year baseline can be.

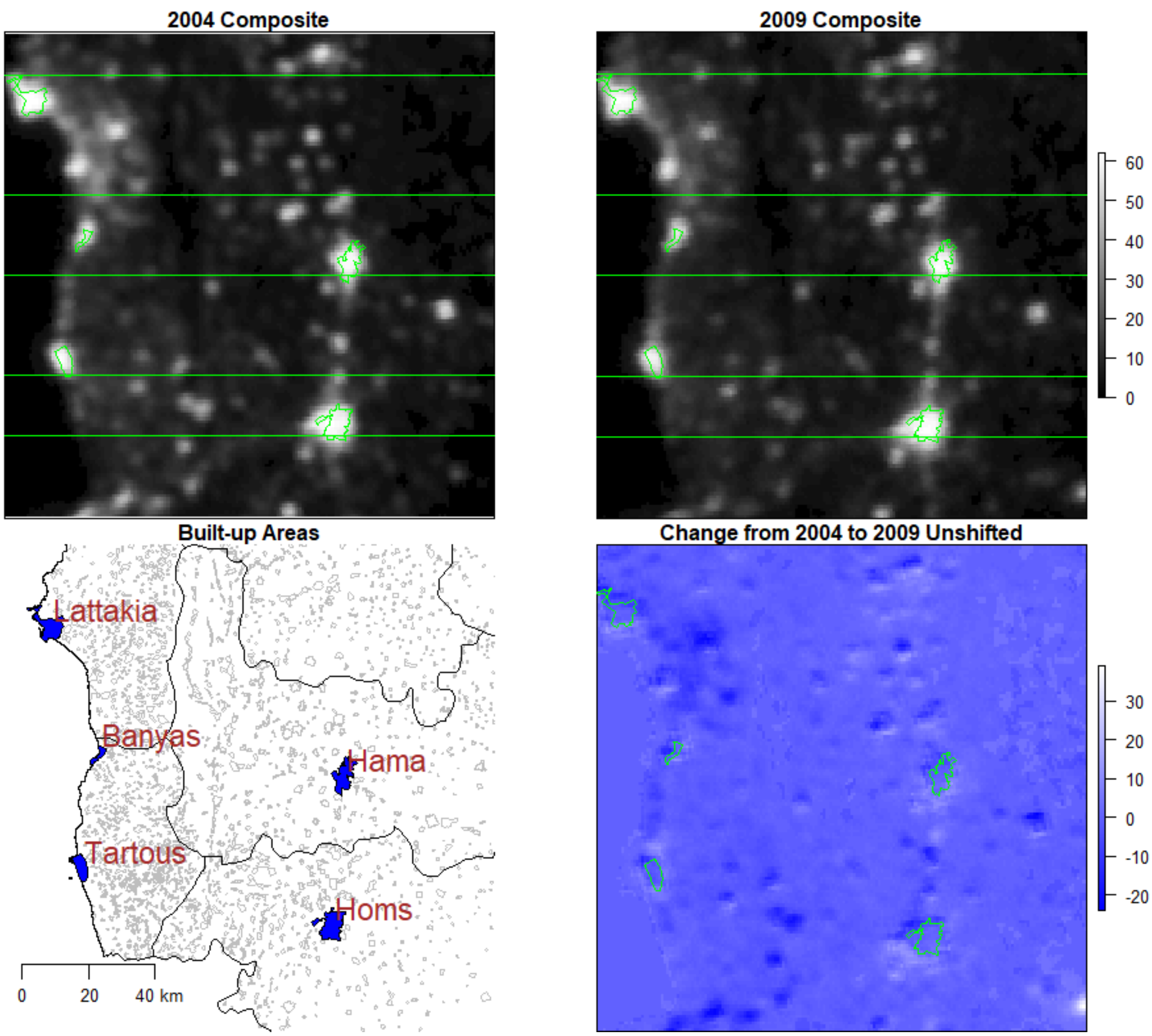


Figure S1: Evaluating Signal Shift in 2004 and 2009 F16 Composites

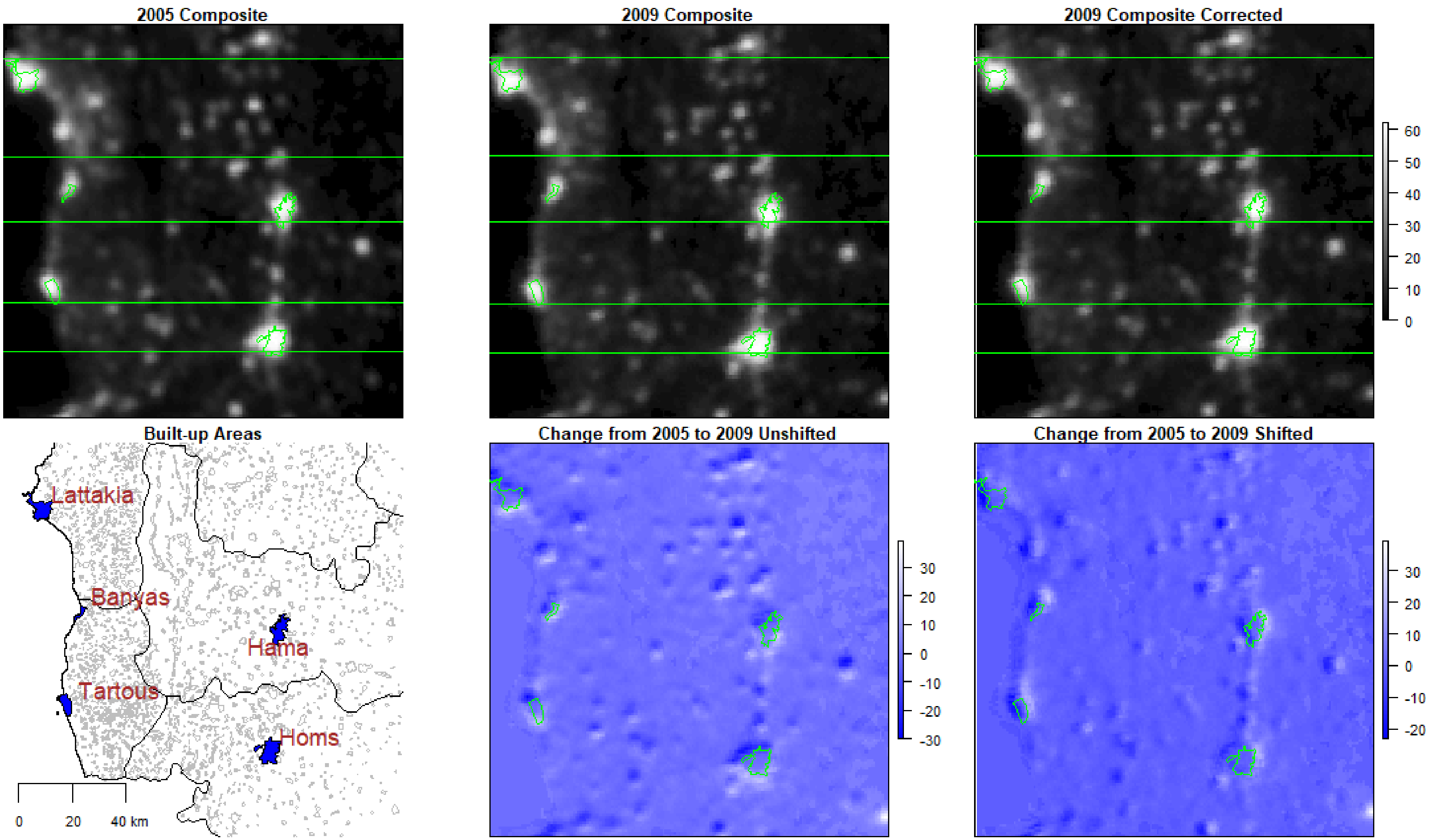


Figure S2: Evaluating Signal Shift in 2005 and 2009 F16 Composites

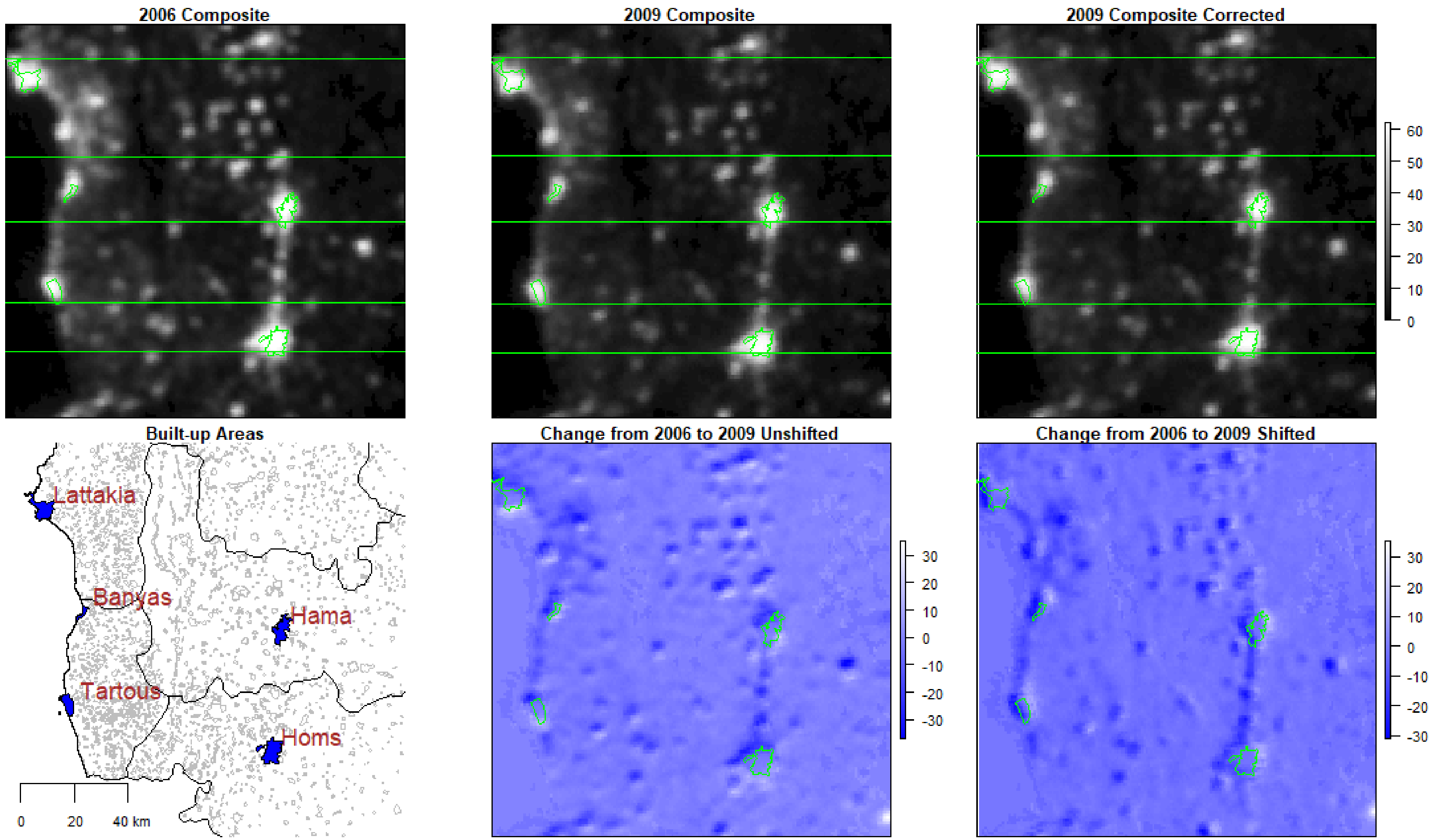


Figure S3: Evaluating Signal Shift in 2006 and 2009 F16 Composites

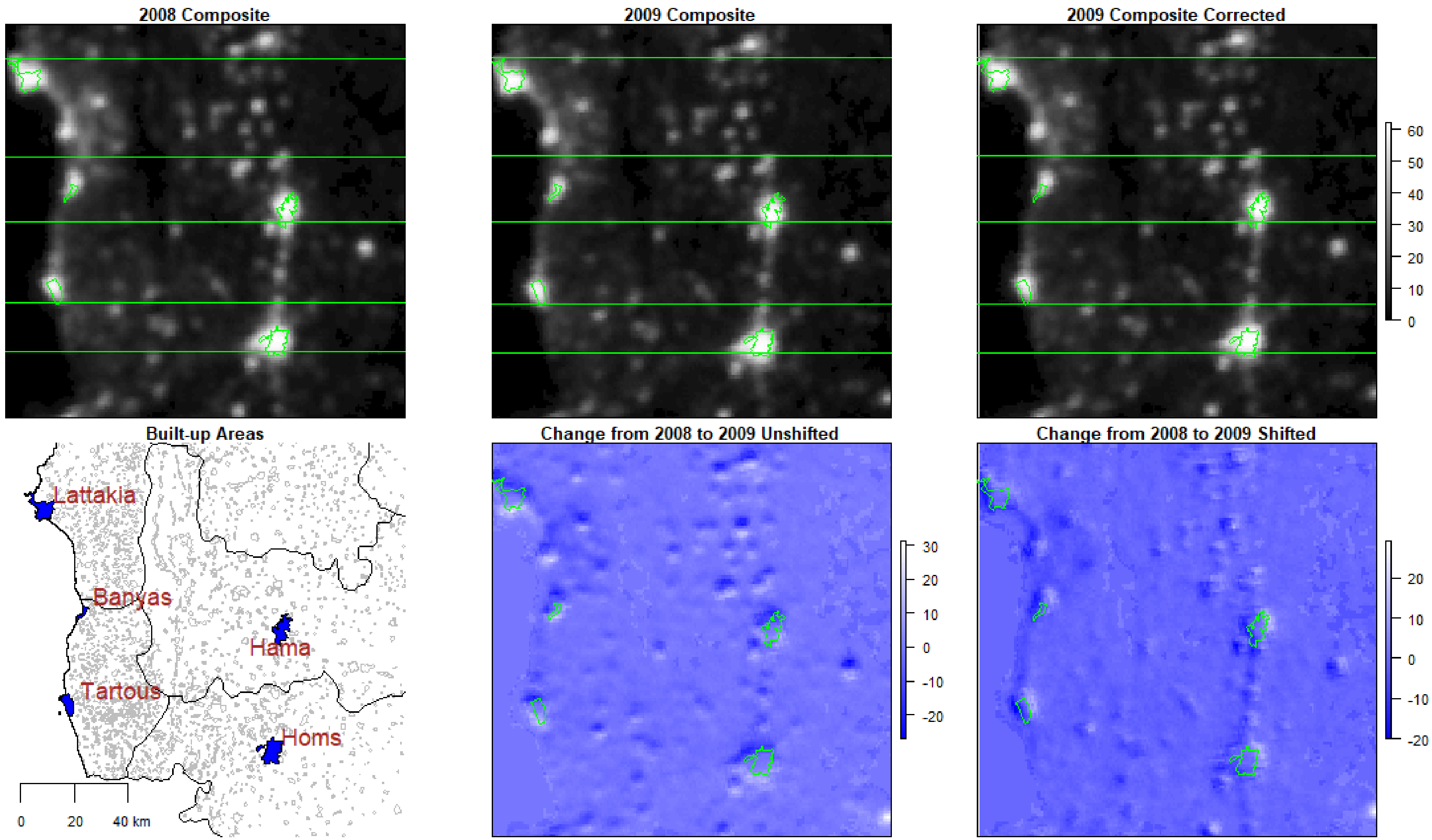


Figure S4: Evaluating Signal Shift in 2008 and 2009 F16 Composites

Examining Figures S2, S3 and S4 reveals little difference from Figure 1 in the main article. There is a noticeable shift from 2005, 2006 and 2008 to 2009 and the shift is evidently in the same direction as was observed from 2007 to 2009. Moreover, the correction applied using control points from 2007 and 2009 shows largely the same results for 2005, 2006 and 2008.[2] Effectively, the map shifts from a 2005-08 baseline to 2009.

More interesting is Figure S1, where no shift from 2004 and 2009 is observed. This lack of a shift follows a pattern seen in the F12, F14 and F15 satellites where the correlations for the first and final years of coverage of a satellite diverge from one another. In this case, it appears that, although the 2004 and 2009 maps diverged from one another by five years, the signal converged back to where it had been when the satellite began operation. Whether the F16 satellite began operating properly, shifted and then shifted back to the right place or the satellite corrected in 2005 only to falter in the last year of operation is beyond the scope of our study. However, the additional maps show that signal shift is not merely confined to a single composite within a single satellite and is likely present in multiple years and across multiple satellites.

[2] Although there does appear to be some more overcorrection than observed in the original figure.

3 Intercalibration between 2007 and 2009 Nighttime Lights Data

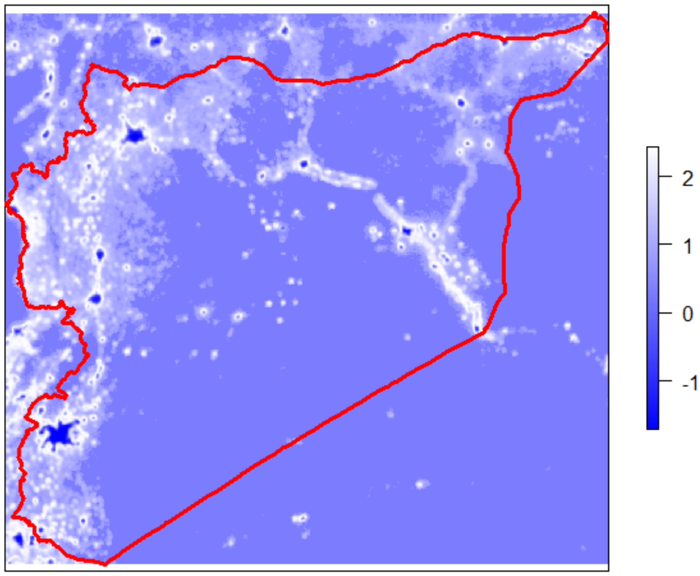
This section elaborates on the limited ability of intercalibration techniques to capture systematic shifts in the position of nighttime light images across annual maps. Intercalibration techniques are regression-based adjustments that standardize individual nighttime lights values across different years. Elvidge et al. (2013) calculate formulas for each year of DMSP nighttime lights data using Sicily in 1999 as the base image. The formulas for 2007 and 2009 are reproduced below:

$$DMSP2007_{ic} = 0.6394 + 0.9114 * DMSP2007 + 0.0014 * DMSP2007^2$$

$$DMSP2009_{ic} = 0.9492 + 1.0683 * DMSP2009 - 0.0016 * DMSP2009^2$$

When applied to 2007 and 2009 data, intercalibration produces limited change between the difference in intercalibrated nighttime lights from 2007 to 2009 and the differences produced in the original data. Figure S5 shows that light intensity differences in intercalibrated data deviate at most two DNs from the original, making a negligible change to the overall averages at the sub-district level. Moreover, the regression-based formula merely accounts for year-over-year changes within the same pixel and is not able to account for the possibility that pixels that correspond to a certain coordinate in space may shift over time. Even intercalibration techniques based on specific regions rather than global models (i.e. Liu et al., 2012) cannot account for such shifts. Thus, this article develops a technique for manually shifting DMSP images to correct systematic errors in geopositioning..

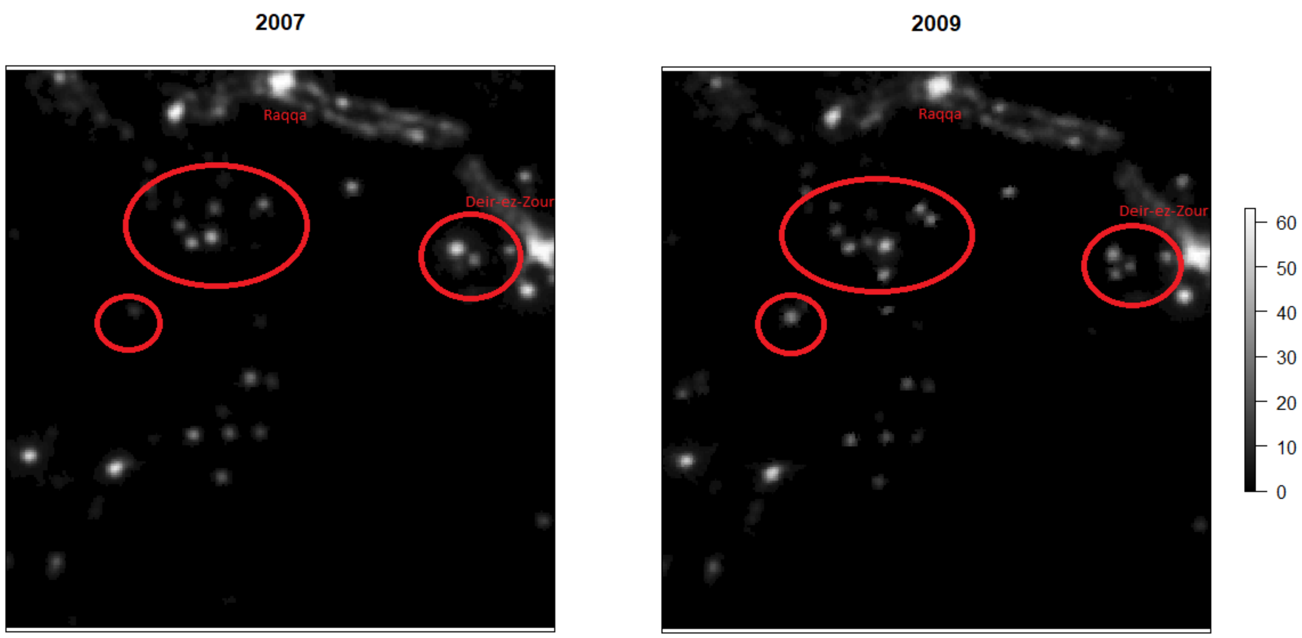
Figure S5: Change from original to intercalibrated differences from 2007 to 2009 DMSP-OLS data



4 Accounting for Gas Flares in De Juan and Bank's (2015) Analysis

Gas flaring occurs when natural gas is separated and burned off from crude oil prior to transport. The burn-off from gas flaring usually occurs at remote refining sites and tends to be bright and variable, with the potential for extremely bright light intensity appearing in some years, only to disappear entirely in the next year's composite (Elvidge et al., 2009). As such, averages from areas that include gas flares may report rapid declines and increases in nighttime light values over a fairly short period of time. While not a flaw in the data, this biases estimates that assume nighttime lights are only related to electrification or other forms of light emission. Figure S6 illustrates gas flaring in eastern Syria in 2007 and 2009. While the area south of al-Raqqa and west of Dayr al-Zur is mostly unpopulated desert, we see numerous high-intensity light emissions appear and disappear when comparing the two maps.

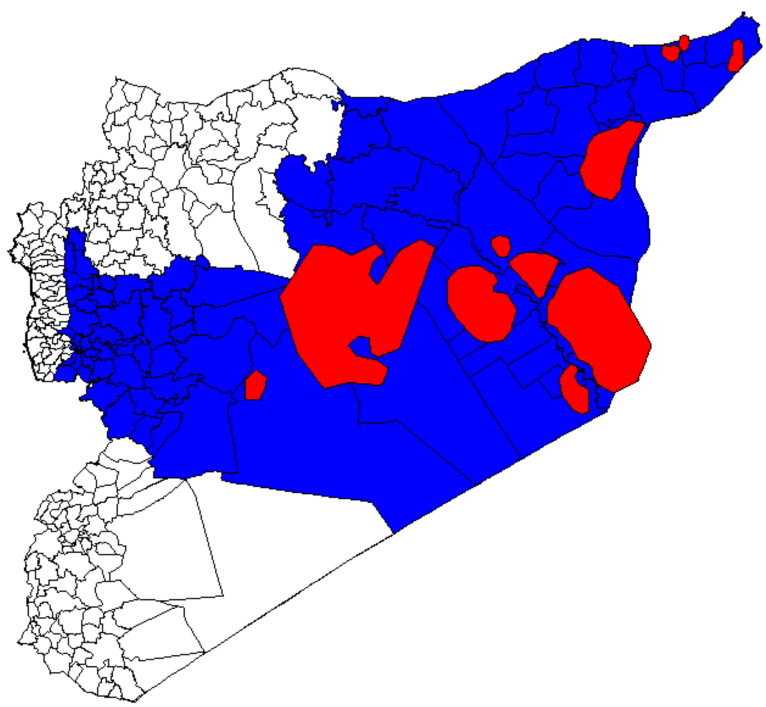
Figure S6: Gas Flaring in Eastern Syria (latitude 34-36, longitude 38-40)



Removing Gas Flare Regions

With respect to gas flares, De Juan and Bank (2015) state that they "did not possess detailed data on the exact location of oil and gas fields" and instead "identified five governorates with varying numbers of oil and gas fields" and excluded them from the analysis as a robustness check (100-101). Gas flaring occurs in remote, unpopulated desert areas in Syria, yet the governorates De Juan and Bank (2015) exclude contain large cities, including Homs and Hama, that were central to early violence. Thus, their technique for accounting for gas flares could also exclude evidence of an effect contrary to the one they find. Moreover, the exclusion is not necessary–the NOAA's website contains an extensive repository of country-level shapefiles for gas flare locations, compiled by Elvidge et al. (2009) from fifteen years of nighttime lights data.[3] We compare the sub-districts excluded by De Juan and Bank (2015) and the shapefile available from NOAA in Figure S7.

Figure S7: Overlay of areas excluded by De Juan and Bank (2015) due to gas flares (blue) and gas flares shapefile from NOAA (red).



Utilizing the shapefile available from NOAA to remove areas identified as having visible gas flares does not exclude any sub-districts, only removing some areas within sub-districts and allowing all the data to be analyzed free of interference from gas flare emissions. Results from this

[3] Available here: https://ngdc.noaa.gov/eog/interest/gas_flares_countries_shapefiles.html.

average are shown on model 3 of Table S6. Model 4 combines models 2 and 3, removing pixels with values in excess of 60 or higher and areas with gas flares. While both models 3 and 4 report a negative effect of nighttime lights change on violence, the substantive effect is reduced by over half, and significance falls below a p-value of 0.05. Even when adjusting for gas flares alone, the findings of the De Juan and Bank (2015) article are not wholly supported.

Table S6: Logistic Regression on Violence in Syria Adjusting for Saturation and Gas Flares

Dependent Variable:	25 or more deaths in sub-district (binary)			
	(1)	(2)	(3)	(4)
Gov. Employees	−0.012	−0.016	−0.013	−0.007
	(0.028)	(0.027)	(0.028)	(0.029)
Sunni	0.369	0.350	0.338	0.279
	(0.583)	(0.575)	(0.557)	(0.566)
'Alawi	−0.022	0.014	0.030	−0.027
	(0.547)	(0.552)	(0.482)	(0.459)
School Enrollment	−0.046	−0.021	0.000	0.014
	(0.113)	(0.110)	(0.106)	(0.122)
Border Dist. (log)	−0.003	0.059	−0.005	−0.097
	(0.471)	(0.470)	(0.430)	(0.469)
Urbanization	2.932***	3.034***	2.838***	2.899***
	(0.660)	(0.565)	(0.668)	(0.648)
Electrification	−0.008	−0.002	−0.002	0.000
	(0.100)	(0.102)	(0.103)	(0.135)
Pct. Unemployed	−0.009	−0.001	−0.001	−0.004
	(0.029)	(0.026)	(0.025)	(0.024)
Road Density	−2.590***	−2.388***	−2.314***	−3.530**
	(0.578)	(0.493)	(0.490)	(1.379)
Population (log)	1.932***	1.942***	1.917***	2.082***
	(0.701)	(0.670)	(0.629)	(0.490)
Lights Change (Original)	−0.464***			
	(0.121)			
Lights Change (No Saturated Pixels)		−0.432***		
		(0.142)		
Lights Change (No Gas Flares)			−0.304*	
			(0.161)	
Lights Change (Unsaturated No Flares)				−0.206*
				(0.113)
Constant	−1.791	−5.664	−7.036	−10.176
	(17.823)	(17.773)	(18.795)	(19.694)
Observations	247	247	247	247

Note: *p<0.1; **p<0.05; ***p<0.01. All models include first-level administrative (governorate) fixed effects and governorate-clustered standard errors.

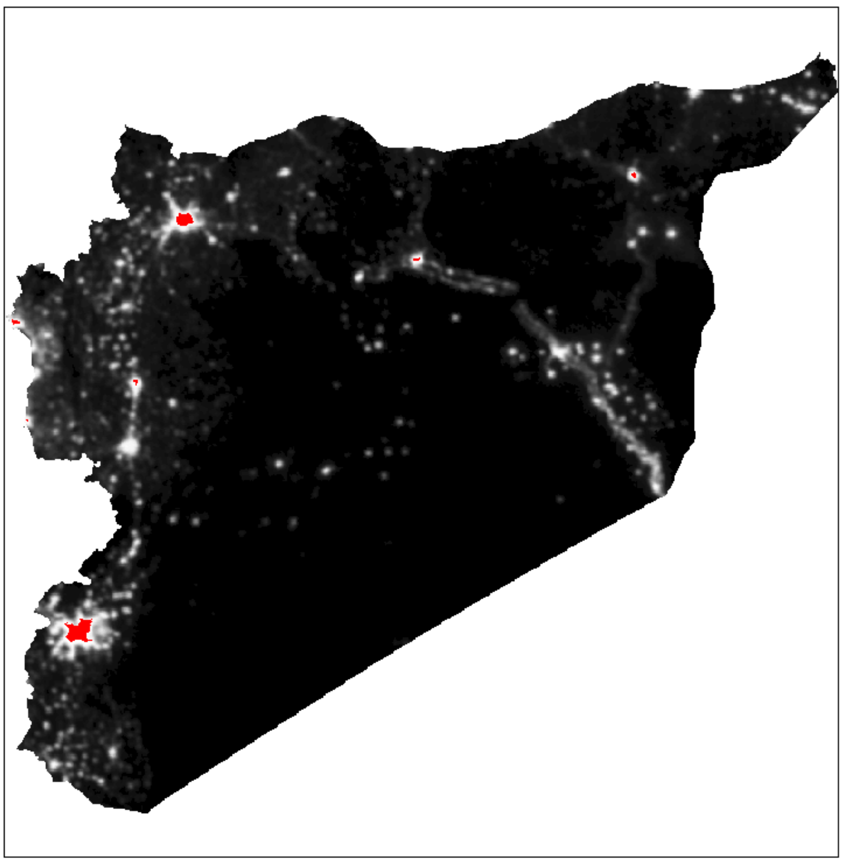
5 Accounting for Saturation in De Juan and Bank's (2015) Analysis

Saturation occurs when the nighttime lights measure for a given pixel reaches its maximum digital number, censoring variation in urban areas. The DMSP-OLS satellite is designed to scan clouds during both day and night, detecting both clouds and light emissions. As a result, light detection is generally set at the highest possible setting to detect moonlit clouds. The strategy for ensuring detection of low light levels reduces the ability to detect areas with high levels of light emission, such as cities. Thus, many cities have an unvarying DN of 63, the highest possible in DMSP-OLS data (Hsu et al., 2015).

5.1 Identifying Saturated Pixels

We find saturation to be an issue in DMSP-OLS measures of Syria's urban areas. 532 of the pixels in the 2007 iteration of the nighttime lights data and 322 of the pixels in the 2009 data for Syria have digital numbers of 63. While saturated pixels make up less than 1% of total pixels in Syria, they take up much of the major metropolitan areas of Aleppo and Damascus and several other cities, such as Latakia, Hama, al-Raqqa and al-Hasaka (see Figure S8). These metropolitan areas were home to 38 percent of Syria's population, according to the 2004 census, and were the site of 44 percent of all deaths in the Syria Tracker outcome data used by De Juan and Bank (2015). Pixels with values of exactly 63 in 2007 can only decline or stay the same in 2009, ensuring lower values than non-saturated pixels for areas containing more than a third of Syria's population and nearly half of the deaths in the conflict. Even positive changes in pixels at values approaching 63 in 2007 may still be depressed if the values become saturated in 2009. Thus, the presence of saturated or close-to-saturated pixels would bias toward finding negative changes in digital numbers and suggest that saturated areas were more likely to experience load shedding, even if that may not have been the case.

Figure S8: DMSP-OLS F16 2007 Composite with 63 DN pixels in red



As a first step towards resolving this issue, we exclude all pixels with digital numbers above 60 in 2007 from the analysis. The results, shown in model 2 on Table S6 in the previous section of this appendix are largely identical to those of De Juan and Bank (2015) (whose findings are replicated in model 1 of Table S6), suggesting that results from non-saturated areas of Syria were consistent with De Juan and Bank's (2015) hypothesized relationship. However, given that saturated pixels are excluded from the analysis and were home to much of the Syrian population and much of the violence, it is important to account for variation in brightly lit areas. We present a technique to do so later in this section.

5.2 Capturing Variation in Nighttime Lights in Brightly Lit Pixels

Excluding pixels with digital numbers above 59 does not solve the problem of saturation. It merely restricts analysis to means calculated from unsaturated pixels. This can significantly alter the nighttime lights values for important urban units of analysis. For example, in Jaramana, a sub-district in suburban Damascus, nearly all pixels are saturated, giving it a near-zero value for nighttime lights change. Yet newspaper reports state that this primarily Druze and Christian suburb experienced considerable load shedding (Zaman al-Wasl, 2009), and it records fewer than 25 deaths in the Syria Tracker data, suggesting that saturation unduly favors estimation of load shedding's positive effect on violence.

To adjust for the presence of saturated pixels in urban areas, Ziskin et al. (2010) develop a Global Radiance Calibrated Nighttime Lights data-set. The radiance-calibrated images come from data collected at multiple gain settings, rather than the usual, high gain setting of DMSP-OLS satellites (Elvidge et al., 1999). Collecting at multiple settings allows for detection of imagery that would otherwise be saturated, which is then reported on an extended digital number scale. Thus, while high gain results top out at 63, the radiance calibrated pixel values may extend as high as

2,500, based variance in urban lights. This product is then blended with the non-saturated pixels to create a single mapped image.[4]

Though they address saturation issues, global radiance calibrated lights data impose their own limitations. The data is limited in temporal range (available only for 1996, 1999, 2000, 2003, 2004, 2006, 2010 and 2011), meaning that we cannot exactly replicate De Juan and Bank's (2015) independent variable with this data. However, using the closest years in this dataset, 2006 and 2010, remains consistent with the underlying concepts being tested. The 2006 data merely changes the baseline year during which load shedding did not take place.[5] While De Juan and Bank (2015) suggest load shedding largely ended after 2009 (97), official figures and newspaper reports state that it continued (al Bunni, 2010; Syria Report, 2011b), meaning that using 2010 images would not affect the analysis. A second issue is verification with the saturated images in 2010. The 2010 radiance-corrected data is available from the same satellite as the 2006 radiance-calibrated data, F16. However, no publicly available saturated maps exist for 2010 from the F16 satellite. Thus, we cannot verify what the outcome would have been had we differenced nighttime lights averages from 2006 to 2010. De Juan and Bank (2015) do include difference from 2006 to 2009 in their study, showing largely the same effect. Given our qualitative evidence, we believe that had non-radiance calibrated F16 data been available for 2010, we would still observe the direction and significance of the relationship De Juan and Bank (2015) find using 2009 F16 data.

A final issue is scaling. Because values for urban areas fluctuate as high as 2,000, the substantive differences in digital numbers may be of higher magnitude than differences in non-saturated

[4]The product is freely available here: https://ngdc.noaa.gov/eog/dmsp/download_radcal.html. Radiance-calibrated data is not a "stationary" product because including variation in nighttime lights due to short-term events, such as forest fires. Yet the difference between non-stationary and stable products is negligible. We find a 0.985 correlation between non-saturated areas in the 2006 "stable" DMSP map and the same areas in the radiance-calibrated map.

[5]In fact, as Beides et al. (2009, 29) note that load shedding began in earnest in 2006, it may be more accurate.

areas (which can only range from 63 to -63). While a simple difference of average values for radiance calibrated maps of 2006 and 2010 may provide useful new information, the differences in previously saturated areas may appear disproportionately large to those in other areas. Thus, in addition to taking simple differences, we also log pixel values in 2006 and 2010 and take the difference of those, to standardize the changes between lights in the radiance-calibrated data. The results when utilizing radiance-calibrated data are presented in Table S7.

Results from Table S7 show a reversal in direction of the substantive effect found by De Juan and Bank (2015). When utilizing radiance-calibrated images, the effect of differences in light intensity from before to during periods of load shedding is positive and significant. However, the effect loses significance after addressing the scaling issues posed by radiance calibrated data, in models 3 and 4. Nevertheless, we can say that incorporating changes to account for saturation in nighttime lights in many of Syria's urban areas casts doubt upon the association between clientelism and violence posited by De Juan and Bank (2015).

Table S7: Logistic Regression on Violence in Syria with Radiance-Calibrated DMSP-OLS Data

Dependent Variable:	25 or more deaths in sub-district (binary)			
	(1)	(2)	(3)	(4)
Gov. Employees	−0.011	−0.011	−0.008	−0.008
	(0.028)	(0.028)	(0.026)	(0.026)
Sunni	0.428	0.432	0.385	0.389
	(0.579)	(0.579)	(0.581)	(0.578)
’Alawi	0.130	0.133	0.075	0.060
	(0.432)	(0.433)	(0.400)	(0.393)
School Enrollment	0.044	0.044	0.053	0.046
	(0.128)	(0.128)	(0.133)	(0.130)
Border Dist. (log)	−0.216	−0.218	−0.281	−0.267
	(0.413)	(0.413)	(0.415)	(0.423)
Urbanization	2.879***	2.895***	2.608***	2.567***
	(0.620)	(0.613)	(0.498)	(0.507)
Electrification	0.013	0.014	0.023	0.019
	(0.123)	(0.123)	(0.157)	(0.145)
Pct. Unemployed	0.006	0.006	0.003	0.003
	(0.026)	(0.026)	(0.023)	(0.023)
Road Density	−0.970	−0.930	−1.905***	−1.974***
	(0.625)	(0.638)	(0.464)	(0.447)
Population (log)	1.997***	1.994***	2.013***	2.016***
	(0.672)	(0.672)	(0.641)	(0.639)
Lights Change (2010 from 2006 saturation adjusted)	0.039***			
	(0.007)			
Lights Change (2010 to 2006 sat. adj. no flares)		0.040***		
		(0.008)		
Log Lights Change (2010 from 2006 saturation adjusted)			1.522	
			(1.833)	
Log Lights Change (2010 to 2006 sat. adj. no flares)				1.091
				(1.615)
Constant	−13.816	−13.842	−15.500	−14.345
	(22.040)	(22.150)	(23.267)	(22.014)
Observations	247	247	247	247

Note: *p<0.1; **p<0.05; ***p<0.01. All models include first-level administrative (governorate) fixed effects and governorate-clustered standard errors.

6 Re-examining De Juan and Bank (2015) with Conditional Fixed Effects and without Clustering Standard Errors

Our replication was somewhat complicated by inconsistencies in model specification and output in the original study by De Juan and Bank (2015). Their article presents a conditional fixed effects logistic model as the main model for drawing their inference (100). The authors note on the same page that they ran a governorate-level unconditional fixed effects model when clustering standard errors at the governorate level. We could not find this model in their appendix. While footnote 10 in their article notes that, “Wherever possible, we have clustered standard errors at the governorate level,” only one model in the Appendix, a negative binomial regression on table AVIII, employs clustering.

We believe such a correction is vital for spatial analysis, as the study of sub-national repression is subject to spatial autocorrelation—dependence of values of the dependent variable on values of the dependent variable from neighboring observations (Gledistch and Ward, 2008). Clustering standard errors relaxes the assumption of independence between specified categories of observations (Greene, 2003). In this case, it ensures that sub-districts within the same governorate were considered interdependent by the model. We speculate that De Juan and Bank (2015) did not employ this specification because using the ‘xtlogit’ command in STATA does not allow for conditional fixed effects logistic regression models with clustered standard errors.

The models in our main article specify logistic regressions using unconditional governorate fixed effects and cluster standard errors at the governorate level because we believe it is imperative to account for spatial autocorrelation in sub-national analysis. In this section, we specify the conditional fixed effects without clustering standard errors employed in De Juan and Bank's (2015) main article and reproduce Table 2 in our article.

Table S8: Logistic Regression on Violence in Syria Applying Corrective Shift - Conditional Fixed Effects, No Clustered Standard Errors

Dependent Variable:	25 or more deaths in sub-district (binary)				
	(1)	(2)	(3)	(4)	(5)
Gov. Employees	-0.010	-0.013	-0.007	-0.011	-0.006
	(0.020)	(0.019)	(0.021)	(0.019)	(0.020)
Sunni	0.282	0.371	0.187	0.355	0.206
	(0.709)	(0.689)	(0.708)	(0.682)	(0.698)
'Alawi	-0.040	-0.028	-0.061	-0.010	-0.039
	(1.009)	(0.949)	(0.998)	(0.935)	(0.975)
School Enrollment	-0.049	-0.020	-0.002	-0.009	0.008
	(0.160)	(0.158)	(0.160)	(0.157)	(0.158)
Border Dist. (log)	0.000	-0.054	-0.038	-0.095	-0.085
	(0.307)	(0.304)	(0.310)	(0.303)	(0.307)
Urbanization	2.681***	2.401***	2.767***	2.341**	2.666***
	(0.946)	(0.914)	(0.963)	(0.909)	(0.954)
Electrification	-0.010	0.010	0.001	0.011	-0.001
	(0.106)	(0.108)	(0.121)	(0.108)	(0.118)
Pct. Unemployed	-0.007	-0.002	-0.003	-0.001	-0.002
	(0.053)	(0.050)	(0.053)	(0.050)	(0.053)
Road Density	-2.428**	-1.727*	-3.528**	-1.787*	-3.287*
	(1.219)	(1.083)	(1.795)	(1.084)	(1.707)
Population (log)	1.758***	1.676***	1.912***	1.720***	1.900***
	(0.440)	(0.443)	(0.466)	(0.445)	(0.466)
Lights Change (Original)	-0.434***				
	(0.145)				
Lights Change (Shifted)		-0.263*			
		(0.159)			
Lights Change (Shifted, No Saturation)			-0.271**		
			(0.113)		
Lights Change (Shifted, No Flares)				-0.185	
				(0.151)	
Lights Change (Shifted, No Sat. No Flares)					-0.192 *
					(0.103)
Observations	247	247	247	247	244

Note: *p<0.1; **p<0.05; ***p<0.01. All models include first-level administrative (governorate) fixed effects.

Table S8 reproduces results from the main article without clustering standard errors and including conditional rather than unconditional fixed effects at the governorate level. There are slight changes to the coefficients and generally smaller standard errors. The results are broadly similar to those presented in the main article. Several of the coefficients in Table S8 retain some significance, but broadly suggest that when adjusting for the shift and gas flares, De Juan and Bank's (2015) suggested relationship is at least inconsistently significant.

The findings in this section require a broad caveat. The standard errors, as shown, do not take spatial autocorrelation into account because there is no clustering for standard errors. This omission generally biases toward finding significance. Thus the estimates in the main article should be treated as more reliable.

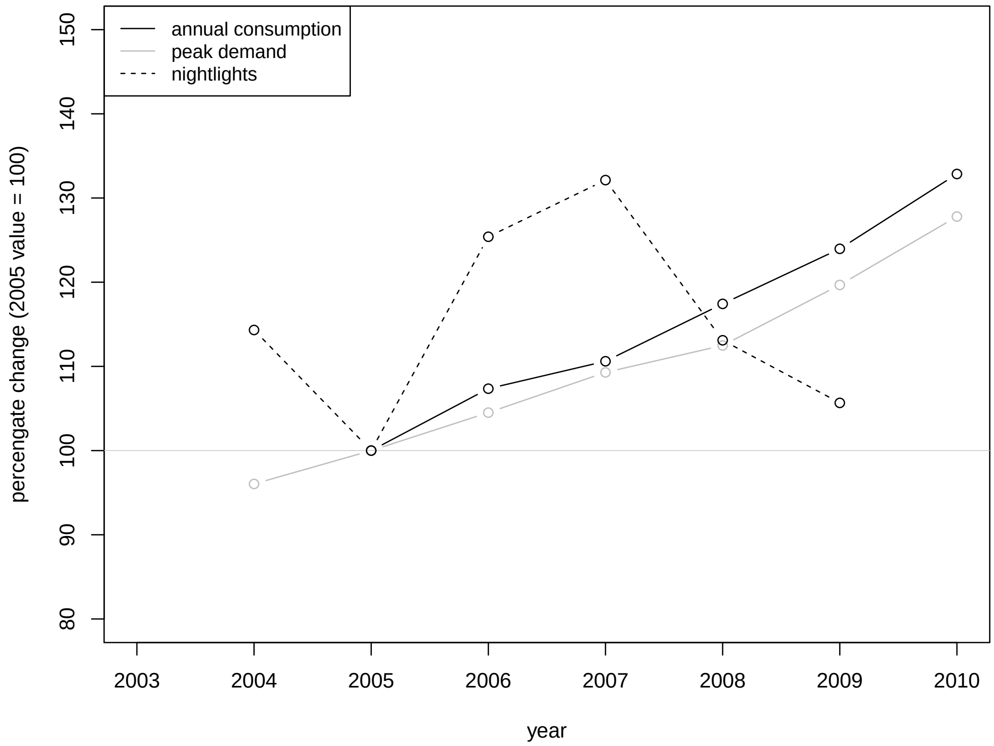
7 Changes in Electricity Demand and Consumption Across Time

In addition to the validity concerns raised in the main text—namely, that 'Alawi-dominated areas of the coast experienced the most load shedding, according to the uncorrected nighttime lights data—the data on actual electricity consumption suggests that load shedding accounted for a very small percentage of total changes in power consumption. According to the Syrian government ministry in charge of energy, the Public Establishment for Electricity Generation and Transmission (PEEGT), aggregate power consumption in Syria *increased* 9.8 percent between 2007 and 2009, with load shedding only constituting 1.4 percent of total energy demand in 2007 and 1.1 percent of total demand in 2010. This stands in contrast to a 20.0 percent *decrease* in total nighttime lights emissions in the DMSP-OLS nighttime lights data and suggests a disconnect between nighttime lights imagery and power consumption at the aggregate level. Trends in total annual power consumption, annual nighttime light emissions, and annual peak demand are displayed in Figure S9.[6]

Given the opaque nature of the Syrian regime, an observer might be skeptical about statistics provided by PEEGT. Yet there is reason to believe that these figures are not subject to the same obfuscation as official pronouncements on sensitive topics like the role of ethnic identity in public life or the ethnic composition of the army and security services. Power generation fell within the set of topics on which critical discussion was possible in pre-2011 Syria; the regime allowed criticism of the public institutions providing electricity and ministers themselves spoke openly about these shortcomings. A leading Communist newspaper, *Kassioun*, repeatedly published critical reports

[6]The peak demand figure given here differs from the one in De Juan and Bank (2015) because it uses actual figures, from PEEGT (2010), for 2009, rather than projections by Beides et al. (2009). Data on power consumption in Figure S9 come from PEEGT (2010), nightlight emissions data are taken from National Oceanic and Atmospheric Administration (2013), and peak demand data come from Beides et al. (2009, 83) and PEEGT (2010).

Figure S9: Percentage change in nightlights, power consumption, and peak demand in Syria



about electricity provision, and solicited and published an official response from the Minister of Electricity's office (al Bunni, 2009a; Khamis, 2009). Moreover, the Minister of Electricity, Ahmad Kayali, noted in a September 2009 speech covered by the official state newspaper, *al-Thawra*, the existence of major transmission losses and the fact that power outages had occurred at peak consumption times for several years. He promised that no outages would occur during Ramadan and had made a similar promise about nighttime power cuts during students' exam times the previous year ('Eissa, 2008; Hula, 2009). Finally, several international organizations have found the same data from PEEGT credible enough to make it the basis of their reporting and recommendations, including the World Bank (Beides et al., 2009), European development agencies working to improve the Syrian power grid (Hafner et al., 2012), and specialized commercial news monitoring publications (Syria Report, 2011c). The government's openness to criticism and the widespread use of these figures by relevant technical arms of international agencies together suggest that the government power generation figures are not subject to manipulation that would undermine their reliability.

8 Explaining Contrasting Results in the Syrian Case

This section argues that patron-client relations did play a central role in structuring patterns of contention—but not through the mechanisms posited by De Juan and Bank (2015). Energy policy, like the state's approach to basic public goods generally, does not evince the patterns of favoritism claimed by De Juan and Bank (2015). Rather, qualitative evidence suggests that power cuts were ephemeral and affected many regime clients, while the major shifts in energy distribution and subsidization in the late 2000s were not targeted toward any particular segment of society. By contrast, extra-institutional ties between regime members and social actors, which are clustered within non-Sunni ethnic groups, constituted the predominant form of access to state-controlled resources; exclusion from these channels of access constituted the critical factor pushing communities towards rebellion.

8.1 Energy provision and patronage

Provision of electricity and other basic public goods in contemporary Syria constitutes one of the few areas of state-society interaction not dominated by clientelistic logics. Since the Ba'th Party's ascent to power in the 1960s, the Syrian state has provided basic infrastructure and subsidized essential goods to its citizens as part of the Party's historical aim of creating a rural and working class coalition against old landed classes. To this end, it undertook a massive electrification campaign and made itself the sole provider of all fuels to consumers (Batatu, 1999, ch. 12). The electrification campaign evinced some ethnic favoritism in how it was rolled out; Balanche (2006, 60) observes that many 'Alawi areas of the coastal region received electrical, phone, and road access before their (Sunni) Turkman and Christian neighbors. Yet by the 2000s, electricity ceased to constitute a luxury good available only to regime clients. Over 97 percent of Syrians had access to the public electric grid in the last census taken before the uprising (Central Bureau of Statistics, 2004), and an independent urban planner with extensive access to government statistics and local field sites estimated that over 95 percent of spontaneous urban settlements had electricity access, even though extension of power to these areas was formally illegal (Hallaj, 2012, 4). The same is true of other measures of access to public goods like central water and sewage services, which were widely available and evinced no ethnic bias in patterns of provision.[7]

The Syrian government's approach to fuel subsidies underscores the programmatic nature of energy policy. As part of the Ba'th social contract, the government heavily subsidized energy products for all consumers. Fuel oil (used for heating) and cooking gas were sold for less than half of the cost of production, and electricity and gasoline were significantly discounted, as well (Barout, 2012, 129). This heavy energy subsidization was singled out for cuts in the early 2000s, but the modalities through which subsidies were scaled back reinforce the notion that energy policy is a poor measure for patronage. This campaign to rein in subsidies began in 2008, when the government increased the consumer fuel oil price from 25 percent of cost to 90 percent, but attempted to blunt the impact of this move by distributing coupons to all families allowing them to purchase 1000 liters of fuel at a steep discount (Syria Report, 2009). This scheme resulted in massive fraud and increased winter power cuts because many families sold their coupons and switched to electric heating in order to take advantage of continued subsidization of electricity, in addition to the illegal hookups to the power grid common in spontaneous urban areas (al Bunni, 2009b). To reduce load shedding the following winter, the government set the price of fuel at 71 percent of cost and an-

[7]Eighty-nine percent of residents of Sunni Arab-majority towns had access to central water supplies, versus 87 percent for 'Alawi-majority towns, with central sewage rates at 75 percent and 62 percent, respectively. The differentials can be put down primarily to 'Alawi-majority towns being in more rural areas (calculated from Central Bureau of Statistics (2004) and Khaddour and Mazur (2018)).

nounced a 220 US Dollar annual heating subsidy for all families earning below a generous income ceiling, which included over 98 percent of state employees. The government further raised this subsidy in January 2011 (Syria Report, 2009, 2011a).

Did power cuts follow a similar, programmatic logic? Objective data on this question are hard to come by. Official pronouncements state that load shedding was carried out programmatically, but do not constitute strong evidence in favor of this conclusion because the regime has an interest in characterizing the policy this way whether it was programmatic or not. However, qualitative evidence from a range of local sources other than the regime suggest that the central state did not systematically favor its clients in terms of electricity provision. State load shedding policy spared city centers power cuts, but other areas faced cuts—regardless of the composition of their population.[8] The Sunni core of Latakia city, for example, whose residents have a history of tension with the Asad regime, was spared cuts under the logic of "supporting tourism," while its 'Alawi periphery faced such cuts (al Bunni, 2009b). In Damascus, cuts also appeared to affect regime-favored populations populations, to the extent that those populations were outside the city center. Affected areas included ('Alawi) Mezze 86,[9] (Druze and Christian) Jeremana, Dahiyat Qudsayya (populated heavily by state workers), and Mashru' Dummar (populated mostly by the business elite), in addition to the poor Sunni suburbs that would spearhead the uprising in Damascus (al Bunni, 2009a; DP News, 2010; Zaman al-Wasl, 2009). Similar patterns were in evidence in Homs, with cuts to 'Alawi neighborhoods and wealthy Sunni peripheral neighborhoods, in addition to poorer peripheral Sunni neighborhoods (al Bunni, 2009b; al Hamawi, 2009). Finally, several newspapers reported that poorer peripheral areas of cities were subjected to longer cuts than wealthier ones, but

[8] Author (Mazur) personal correspondence with Ali Hamzeh, Professor of Electrical Engineering at Al-Ahliyya Amman University, Jordan, September 16, 2017. See also al Bunni (2009b).

[9] De Juan and Bank (2015) specifically mention Mezze 86 as being part of regime patronage networks and this being a reason for its quiescence (102).

noted that published schedules were not followed and placed the blame for this on the caprice of individual government employees holding the keys to turn electricity on and off (al Hamawi, 2009; Diab, 2010). Taken together, these reports suggest that load shedding in the Syrian electricity grid during the late 2000s was subject to some non-programmatic influences, but falls far short of being a state policy of selective public goods distribution.

8.2 Informal ties, patronage, and ethnicity

Whereas energy supply policy in Syria has followed a largely programmatic logic in recent decades, a great many other state-controlled resources could be accessed only through extra-institutional networks between regime members and social actors. Real political power and access to state-controlled goods inheres in these informal networks (Batatu, 1999, 206). Through the 1980s, the security services and state institutions formed the primary channels of access to state-controlled resources. For example, security officers and senior regime figures enriched themselves by plundering state budgets, securing lucrative import monopolies for family members, and taking payments to overlook smuggling of goods and subsidized fuel (Seale, 1988, 455). Average citizens exploited ties to state and Party officials and heads of labor syndicates, such as the Peasants' Union, to obtain civil service jobs, permission to open businesses or travel abroad, and privileged access to goods like agricultural inputs (al Mashhour, 2017, 19). These patterns continued, broadly speaking, throughout the 1990s and 2000s, and economic opening following Bashar al-Asad's accession to the presidency in 2000 widened the set of elite regime clients. Al-Asad's relatives and a small group of businessmen used their ties to the regime to carry out crony privatization of state-owned enterprises and obtain monopolies over entire industries. The President's cousin, Rami Makhlouf, exemplifies members of this new class. He headed a small group awarded a monopoly over the country's entire mobile phone market and boasted in a 2010 interview that another holding company of his touched 60 percent of the entire Syrian economy. Though this was surely an exaggeration, it demonstrates the scale of ambition and type of control this class understood itself to have over the country (Barout, 2012, 72-73).

While many of these networks extended into Sunni communities (Bishara, 2013, 311), access to state-controlled resources was highly stratified on an ethnic basis. The upper ranks of the regime, the military, and the powerful security services were heavily dominated by 'Alawis (Bou Nassif, 2015). Moreover, the large number of 'Alawis in the military and security services facilitated extensive regime monitoring of 'Alawi local communities and also gave those communities greater access to state-controlled goods (Khaddour, 2013, 11). Similar trends are in evidence for public employment; 58 percent of the workforce in 'Alawi-majority towns is employed in the public sector, compared to 28 percent of the workforce in Sunni Arab-majority towns and 31 percent nationally (calculated from Central Bureau of Statistics (2004), Khaddour and Mazur (2018)).

8.3 Regime action, ethnicity, and violence

Vital state-controlled goods could only be accessed through informal channels, and these channels were disproportionately open to 'Alawis and members of other minority ethnic groups. This political situation is the central social feature that impelled challenge, rather than a short-run drop in local public service delivery. Demonstrators in the city of Dar'a made this point emphatically, differentiating their demands from those relating to basic needs and services. When regime spokeswoman Bouthaina Shaaban announced tax cuts and salary increases for government employees in response to Dar'a protests in early 2011, demonstrators took to the street and famously chanted, "Oh Bouthaina, oh Shaaban, the Hawrani[10] is not hungry, we want freedom!" (Leenders, 2013). Implicit in these calls for political change was a demand to end rule by an autocratic regime drawn overwhelmingly from a single ethnic group, and patterns of contention reflected this fact; challenge came primarily from Sunni local communities and regime violence targeted those same communities.

De Juan and Bank (2015) largely discount the role of ethnicity in patterns of violence, but a more careful reading of the data suggests that ethnic identity played a central role in these patterns. Their quantitative analysis finds no effect of ethnic composition on violence, and they argue that ethnic considerations "did not play a prominent role in the early phase of the uprising in Syria but gradually gained in importance as fighting became more intense" (99). This characterization is incorrect on two accounts. First, it has an 'urban bias' (Kalyvas, 2004); protests occurring in many cities during the first six months of the uprising were largely non-violent and disavowed sectarianism, but violent incidents with a strong ethnic dimension occurred over the same period, particularly in small cities and rural areas (e.g., attacks on regime forces and subsequent regime massacres of Sunni civilians in Baniyas and Jisr al-Shughur, Barout (2012, ch. 7)). Second, the period covered by De Juan and Bank (2015) – from March 2011 through November 2012—includes a full year of civil war, during which ethnic considerations were central to dynamics of conflict. By late 2011, the country was in a state of civil war by any reasonable definition; significant swathes of Syrian territory began falling out of regime control and the fatality count in the Syria Tracker data reached 4147 by November 1, 2011, and 6054 by the end of 2011 (compared with 39,461 fatalities through November 2012) (Bishara, 2013, 199).

[10] Dar'a residents mostly hail from the Hawran region to which this demonym refers.

Sunni Arabs made up the overwhelming majority of fatalities in the data, but De Juan and Bank (2015) are unable to discern this trend in their quantitative analysis because their measure of ethnic identity is over-aggregated, to the sub-district level. When the level of measurement for challenger fatalities is shifted down from the sub-district to the town, a stark ethnic pattern emerges: 99.5 percent of deaths through November 2012 were in Sunni Arab-majority towns, with 0.2 percent occurring in Kurdish-majority towns, 0.1 percent occurring in 'Alawi-majority towns, and the remaining 0.2 percent occurring in towns where other groups constitute the majority (see the "Town-Level Ethnicity Data and Coding of Syria Tracker deaths" section of this appendix for further coding detail).

It is important to bear in mind the limitations of the town-based ethnicity statistics—the data only capture the majority ethnic identity of a town and individual death data are joined to the town nearest their geolocation. This means that non-Sunni Arab challengers in urban centers, which are all Sunni Arab-majority, would erroneously be coded into the Sunni Arab category. Moreover, these challengers faced the same repressive techniques as the Sunni Arabs alongside whom they turned out to demonstrate. But these non-Sunni Arab demonstrators represented a small fraction of the crowds demonstrating in the central squares of Sunni Arab-majority cities. Non-Sunni Arabs came primarily as 'delegations' from nearby 'Alawi or Isma'ili villages or as individuals and small groups of non-Sunni Arab urban residents attending demonstrations outside their home neighborhoods. And even this sort of participation was dampened significantly after August 2011, when contention became increasingly violent and the rhetoric of some anti-regime clerics and activists became openly sectarian and anti-'Alawi (Bishara, 2013, ch. 8).

The movement of non-Sunni Arabs to central urban spaces to protest sheds light on an important mechanism through which patronage attenuated challenge. 'Alawi community members linked to the regime acted as its eyes and ears on the ground, making it difficult for ’Alawi anti-regime activists to hold demonstrations in their own neighborhoods (Shabo et al., 2015, 11). Moreover, when non-Sunni Arabs did organize demonstrations in their home localities, they were typically subjected to repression not by the regime, but by members of their own community. For example, the Druze city of al-SuwaydaÊ¿ is one of the few majority non-Sunni cities to have sustained anti-regime demonstrations in spring and summer 2011. Rather than send its own security agents to repress demonstrations, as it did in other cities with sustained demonstrations, the regime largely outsourced this violence to local community members, who blocked the path of demonstrations coming to the city center and beat protesters to disperse them (Ezzi, 2015).

Long-run, informal patronage structures also functioned to attenuate challenge in Sunni Arab locales. The activists who spearheaded early demonstrations in urban centers tended to be young, educated, and not directly linked to the patronage structures historically used by the regime (e.g., state employment, corporatist peak organizations, and informal relations between local security branch heads and local notables) (al Mashhour, 2017, 26-27). In the city of Dayr al-Zur, for example, the regime drew on traditional patronage relations to limit challenges in the early months of the uprising. Security officers held meetings with local notables to “calm the street” and filmed demonstrations to look for state employees in the crowds (Zafir, 2013). Demonstrations, as a result, remained small and composed primarily of a young, educated elite. Mass participation, including that of poor residents who would presumably be most affected by subsidy cuts, occurred only following the regime’s use of violence against local community members in early June 2011, more than two months after the beginning of demonstrations. In other words, in Dayr al-Zur, regime actions and not material deprivation or the decay of public services played the crucial role in getting the worst-off residents out onto the streets (Bishara, 2013, 152; al Mashhour, 2017, 32).

To sum up, the most important causes of challenger deaths in the first eighteen months of the Syrian uprising and civil war were intimately tied to patronage, but this patronage had little to do with the delivery of basic public services. Rather, the regime's favoritism of 'Alawis for military, security, and public service positions created a network that would monitor and squelch dissent, as well as a corporate association with the regime that impelled many 'Alawis to stand by it, regardless of the individual returns to this support. At the same time, the case of Dayr al-Zur illustrates how the patronage networks structured contention, with those most vulnerable to public service fluctuations joining the uprising only following the regime's use of violence—and for reasons unrelated to fluctuations in public service delivery.

9 Town-Level Ethnicity Data and Coding of Syria Tracker deaths

To make qualitative inferences in the preceding section of appendix, we utilize town-level ethnicity data that records the ethnic identity of the majority of a town's residents for all Syrian towns, the administrative level below the sub-district (n=5204) (Khaddour and Mazur, 2018).

Ethnic composition of the public workforce, discussed in the "Informal ties, patronage, and ethnicity" sub-section, is calculated by pairing data from the last census before 2011 (Central Bureau of Statistics, 2004) with the town-level ethnic data. This technique allows only a rough estimation of ethnic representation in the public workforce because the ethnicity database it records only the majority identity of a town, not the identity of individuals. Yet there is reason to think that public employment figures generated using it constitute a conservative estimate for 'Alawis; under the Ba'th, many 'Alawis moved from their ancestral villages to Sunni Arab-majority cities, like Damascus and Homs, and occupied a disproportionate share of public jobs in ethnically diverse cities coded in this database as Sunni Arab.

The disaggregated data on deaths by town majority ethnicity, discussed in the "Regime action, ethnicity, and violence" sub-section of the main text join the Syria Tracker fatality data[11] with the Syria Town Database (Khaddour and Mazur, 2018). The deaths in the Syria Tracker data are geocoded to a latitude and longitude, and we coded the deaths as occurring in the town nearest the geolocation. We did this by finding the Syria Tracker record's 'nearest neighbor' in the town data using the 'Distance Matrix' command in QGIS.

Of the 43,331 deaths recorded in the Syria Tracker database through December 1, 2012, 99.5 percent of deaths are in Sunni Arab majority towns, with 0.2 percent occurring in Kurdish towns,

[11] Individual-level Syria Tracker data downloaded from https://kasshout.carto.com/me?utm_source=Footer_Link&utm_medium=referral&utm_campaign=Embed_v1&utm_content=kasshout, accessed November 17, 2017,

0.1 percent occurring in 'Alawi majority towns, and the remaining 0.2 percent occurring in towns where other groups constitute the majority. This figure corrects for the 3652 deaths in the Damascus and Homs suburbs that are mis-coded into the 'other minority' category; 2625 deaths are pulled into Dahiyat Qudsayya that actually occurred in Qatana, a suburb of Damascus, and 1027 in Mazra' al-Wa'r that occurred in al-Wa'r neighborhood of Homs. We are confident that these are a mis-codings because the sub-district variable in the Syria Tracker data puts them in the latter locales (adjacent to the 'other minority' locales into which the geolocation places them), and we have no qualitative evidence of deaths on this scale occurring in the towns into which these deaths are pulled by geolocation. In addition, 33 deaths in several other minority towns (Fairuza and Zaidal near Homs and Sahnaya just outside Damascus) are also likely spillover from conflict in the cities. For lack of specific evidence documenting this, however, those deaths are not recoded.

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