Web Appendix to "Measuring Economic Growth from Outer Space"

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April 2011

The Version 4 Defense Meteorological Satellite Program Optical Linescan System (DMSP-OLS) Nighttime Lights Time Series data used in this paper are available from the National Oceanic and Atmospheric Administration's (NOAA) National Geophysical Data Center (NGDC).[1] Key aspects of the data are discussed in the text. Here we give more details of a few of these aspects. The first has to do with lights that are recorded. As noted in the text, the sensor saturates at a level of light that is common in the cities of rich countries, resulting in top-coded values. At high latitudes no summer data can be used because sunlight is still contaminating images at local pass times of 8:30 pm to 10:00 pm. This effect is diminished closer to the equator. The data are subject to overglow or blooming, which means that lights tend to appear larger than they actually are, especially for bright lights and over water. Snow tends to magnify lights. Humidity is known to affect the performance of other sensors but has never been studied in relation to the DMSP-OLS. Many of these problems are not likely to be important in poorer countries, as there are few instances of top-coding, and many are tropical countries with no long summer nights, and virtually no snow in populated areas. In addition to spatial coverage and resolution, sensors also have spectral range and resolution. The DMSP-OLS sensor covers the visual-near infrared portion of the spectrum, from 500 to 900 nanometers. Different lighting technologies have different emissions profiles, but they all have substantial emissions in this range, because the human eye can only see radiation between approximately 380 and 750 nanometers. Further details about the lights data and processing can be found in Elvidge *et al*. (1997a, 1999, 2003, 2005, 2010), Lieske (1981), and Small *et al.* (2005).

Across all 17 years, an average of 3.5% of land-based pixels, representing 1.4% of land area, are missing data. As noted in the text, they are overwhelmingly at high latitudes, which is why we exclude areas above the Arctic Circle. Below the Arctic Circle, this phenomenon affects pixels representing 0.39% of land area. We exclude 22 country-years in which at least one constituent country-satellite-year was missing data for at least 5% of its land area.

Because de facto sensor settings may vary across satellites and as a satellite ages, Elvidge *et al.* (2009) perform an "intercalibration," relating the different satellite-years of data to each other, without tying them directly to physical quantities, based on the identifying assumption that lights in Sicily did not change between 1994 and 2008. Rather than use the formulas in Elvidge *et al.* (2009) to do that specific intercalibration, in statistical work we control for these problems with year fixed effects, which we find to be more readily interpretable.

As briefly reported in the text, in an experiment carried out for 18 days during the winters of 1996 and 1997, the settings of one of the satellites were altered so that a true radiance measure could be calculated with no top-coding (Elvidge *et al.* 1999). Settings alternated across these nights between low and high magnification in order to capture both intense and weak lighting. The resulting experimental radiance-calibrated dataset, averaged across all 18 days, is also distributed by NGDC. After a scaling factor is applied, each 30 arc-second pixel reports the radiance in Watts per cm^2 per steradian.

[1] Available at http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html. Accessed 22 January, 2010.

Since the grid for the radiance calibrated data is in principle the same as that for the annual composites, individual pixels can be compared across datasets. However, the real-world location of each pixel is measured with an error of approximately 2 km (Elvidge *et al.* 2004), so that the pixels in the two data sets don't exactly overlap. In Table A1, column 1, we report the results of a regression of the log of digital number from the most comparable of the 30 uncalibrated datasets (F-12, 1997) on the log of radiance, for the 8.7 million cells that are lit in both datasets. The elasticity is 0.587. We expect the elasticity is biased downwards because of measurement error from pixels not exactly overlapping. In the remaining columns, we run the same regressions after aggregating all lit cells into larger square cells, with the linear scale factor noted. So in column 2, 2-by-2 arrays of the original cells are merged to become cells with four times the original cell area, and in column 3, 5-by-5 arrays are formed. By column 3, there are still over six hundred thousand cells, but the elasticity now is close to one. Additional aggregation doesn't change the elasticity much.

Web Appendix Table 1: Radiance versus digital numbers

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	F-12 DN	F-12 DN	F-12 DN	F-12 DN	F-12 DN	F-12 DN	F-12 DN	F-12 DN
Radiance	0.58675***	0.79876***	0.94694***	0.97767***	0.98090***	0.97117***	0.95957***	0.95548***
	[0.00020]	[0.00039]	[0.00058]	[0.00072]	[0.00092]	[0.00125]	[0.00174]	[0.00198]
Constant	0.67421***	0.05970***	-0.62278***	-0.78730***	-0.78213***	-0.67790***	-0.55325***	-0.50717***
	[0.00076]	[0.00187]	[0.00333]	[0.00474]	[0.00679]	[0.01028]	[0.01599]	[0.01888]
Observations	8657670	2590447	606988	229774	93423	38013	14792	10848
R-squared	0.47	0.678	0.862	0.917	0.944	0.958	0.966	0.969
linear scale factor	1	2	5	10	20	40	80	100

Web Appendix References (papers not cited in main text)

Elvidge, Christopher D., Kimberley E. Baugh, Eric A. Kihn, Herbert W Kroehl, and Ethan R. Davis. 1997a. "Mapping of City Lights Using DMSP Operational Linescan System Data." *Photogrammetric Engineering and Remote Sensing*, 63: 727-34.

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Elvidge, Christopher D., Ruth Hobson, Ingrid L. Nelson, Jeffrey M. Safran, Benjamin T. Tuttle, John B. Dietz, and Kimberley E. Baugh. 2003. "Overview of DMSP-OLS and Scope of Applications." In *Remotely Sensed Cities*, ed. Victor Mesev, 281-99. London: Taylor & Francis.

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Elvidge Christopher D., David M. Keith, Benjamin T. Tuttle, and Kimberley E. Baugh. 2010. "Spectral Identification of Lighting Type and Character." *Sensors*, 10(4): 3961-3988.

Lieske, R.W. 1981. "DMSP primary sensor data acquisition." *Proceedings of the International Telemetering Conference*, 17:1013-20.

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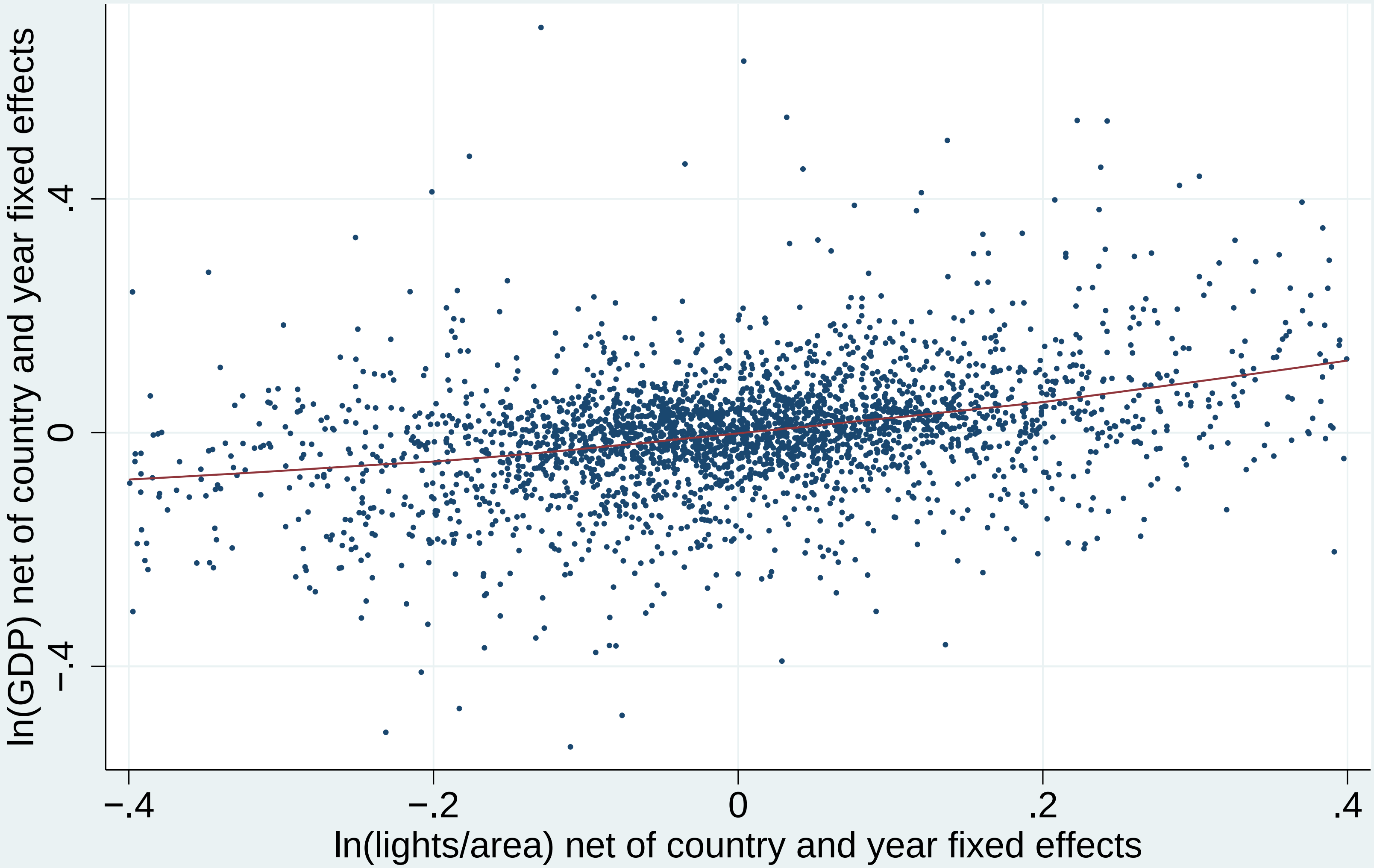
Figure A1. GDP versus lights: restricted interval panel



notes: 1. bandwidth = .8; 2. excludes 5% of country−years to the left and right