Economic disintegration and spatial inequality- fine-tuning the impact of location using remote sensing data for former Yugoslavia

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Abstract

The present research applies satellite data to augment official economic performance measures such as gross domestic product (GDP) and gross regional product (GRP) on low geographical scales for the countries in the former Yugoslavia. The overall objective of this research is to illustrate the economic performance on local levels with a focus on analyzing the consequences of economic disintegration following the breakup of Yugoslavia. We extend a recent statistical framework (Henderson 2012) which uses nighttime lights to augment official economic performance measures by using observable nighttime light into space. Our framework are estimating economic performance and growth at small geographical units in a context with areas experiencing periods of economic decline.

Introduction

The problem of measuring economic growth has stimulated research in economic geography and economics for many decades (Gallup et al., 1999; Maddison, 1995; Barro, 1991). Despite continuously revised and more encompassing research on global comparisons of income and economic activity using conventional data (time series or panels measured at country level) it is difficult to find reliable data for all countries on lower administrative levels. Apart from the lack of data on low administrative levels, a number of studies have pointed out serious measurement errors in GDP growth (Nordhaus, 2006; Henderson, Storeygard and Weil, 2012). Relative to developed economies, in many developing and emerging economies a much smaller share of economic activity is conducted within a formal sector, the degree of economic integration and price equalization across regions is lower, and, most significantly, the government statistical infrastructure is weaker. These factors make the calculation of nominal GDP (total value added, in domestic prices) difficult.

Satellite remote sensing missions are generally designed for specific applications such as vegetation classification or weather forecasting. The Defense-Meteorological Satellite Program-Optical Line Scanner (DMSP-OLS) was designed to observe clouds at night; however, its sensor can also detect the presence of light at night on Earth. The DMSP-OLS sensor is sensitive enough to detect streetlights and even saury fishing vessels at sea (Sei-Ichi, et al. 2010). The lighting detected by the DMSP-OLS is almost entirely the result of human activities, emitted from settlements, shipping fleets, gas flaring or fires from swidden agriculture. Therefore, nighttime light imagery serves as a unique view of the earth's surface, which highlights human activities.

Recent studies conducted by economists have paid attention to human generated nighttime light data and tried to associate these with economic growth in order to overcome estimation errors (Elvidge, et al., 1997; Sutton and Costanza, 2002; Doll, Muller and Morley, 2006; Ghosh, et al., 2010; Henderson et al., 2012; Ebener, et al., 2005; Chen and Nordhaus, 2011; Keola et al., 2015; Melander et al. 2015; Lessman and Seidel, 2017; Wu, 2018). These studies have made attempts to advance research in two directions; firstly estimations of the level of economic activities, and secondly disaggregation of economic activities into smaller administrative/non-administrative areas that lack official statistics.

This research begins with a framework for estimating gross domestic product with NTL from DMSP-OLS based on Henderson (2012) in the countries of the former Yugoslavia during the period 1992-2013. The objective is to estimate the level of economic activities on district levels. The Henderson (2012) framework is elaborated and extended to augment estimates of level of economic performance on national and subnational areas to account for spatial difference in estimated GDP and GRP between and within the countries once to consist of Yugoslavia.

Remote Sensing Data and Economic Analysis

Our principle aim is to estimate economic performance using data observed from space. In this section, we consider, in publishing order, selected studies that use remote sensing data to analyze economic activities on the ground, examining their methodologies, results, advantages, and drawbacks. A wealth of studies confirms a strong relationship between NTL and economic activity in a single year (Croft, 1978; Doll et al., 2006; Ebener et al., 2005; Sutton and Costanza, 2002; Sutton et al., 2007). In cross-sectional analysis, NTL tends to have a stronger relationship with GDP than population (Elvidge et al., 1997; Zhou et al., 2015b). Across a diverse group of 21 countries, lit area and GDP follow a log-linear relationship with an R2 of 0.97 (Elvidge et al., 1997). The linkage of lit area and, more typically, derivatives of SOL with economic activity allows mapping and estimation of GDP from NTL at a range of scales in places where no standard accounts data exists, as exemplified by the production of the first-ever 1×1 decimal degrees global map of GDP (Doll et al., 2000). Although Sutton et al. (2007) argue that NTL can only crudely, if still significantly, estimate sub-national GDP due to its coarse spatial and spectral resolution, it has been used to accurately predict household level wealth in local levels (Weidmann and Schutte, 2016; Jean et al., 2016).

Croft (1978) was among the first to point out that NTL reflects human economic activities on the ground. This led (Elvidge, et al. 1997) to estimate population, GDP (PPP $), and electricity usages in lit areas. Coefficients of log-log, or growth rate relationship, between population, GDP, and electricity and area lit were found to be very high (0.920, 1.159, and 1.178) from a single year cross-sectional analysis of 21 countries. Using area lit instead of sum of observed light intensity makes (Elvidge, et al. 1997) unique from later studies. This study reveals that a statistically significant relationship between night-time light and activities on the ground can be established. Its biggest drawback, however, lies in its inability to account for the fact that activities may also spread upwards as well as outwards.

Sutton and Costanza (2002) instead use the sum of the intensity of NTL to estimate GDP, or as they term it, a measure of marketed economic output and land cover to estimate ESP (Ecosystem Services Product), a type of non-marketed value. However, as they try to establish country specific coefficients between NTL and GDP (PPP $) using single year data, the relationship is a ratio generated by simple division. These country specific coefficients are then used to produce one square kilometer GDP for each country. Using coefficients determined at country-level on finer sub-national administrative areas is, as stated by the authors, an improvement to the general body of research on the subject related to estimation of local economic performance using NTL.

Doll et al. (2006) estimate the relationship between the sum of nighttime light and the available GRP of 11 countries in the EU and USA. The elasticity of GRP on the sum of night-time light is estimated to be between 0.049 and 0.210 in these regions, excluding outliers. Outliers are generally capitals or large cities that have different or higher elasticity when compared to the rest of domestic regions. The elasticity of these outliers is determined separately from the rest of the regions within the countries. Only the Netherlands and Greece are found to an elasticity applicable nationwide. This shows that elasticity of night-time light and GRP vary in most countries. For this reason, it is important to be cautious when using night-time light to directly estimate the level of GRP of a sub-national region without official data.

Ghosh et al. (2010) divide economic activities into commerce/industry and agriculture. They assume agriculture does not emit observable NTL. They try to overcome the limitation of single year cross-sectional data by grouping together countries and sub-national administrative areas by ratios of the sum of NTL and value-added. Cross-sectional regression is used to determine specific coefficients for each group. Non-lit area is accounted for from Landscan[1]. The population grid is used to assign agricultural output to sub-national geographic areas. Apart from limitations coming from a single analysis, this study is also limited because assigning agricultural value-added according to a population grid at a one square kilometer scale is not likely to adequately reflect the reality. In most societies besides

[1] http://web.ornl.gov/sci/landscan/

subsistent societies, a small number of people work in agriculture to produce food not only for themselves but also for the population of other towns and cities.

Chen and Nordhaus (2011) document a positive relationship between nighttime lights and GDP at the level of grid cells of 1×1 decimal degrees.

Single year analysis is common among the studies discussed so far. In addition to the high cost to acquire processed data in the past, the fact that NTL data should not be compared between different years is likely to be the main obstacle to time-series analysis. This is not to say that NTL must not be compared over time. Levels of NTL between 0 and 63 depend on sensor settings that vary over time, across satellites, and due to the age of a satellite. Henderson et al. (2012) deal with this limitation by introducing time-variant effects in panel analysis. Moreover, panel analysis makes it possible to take into account differences among countries. Multi-year analysis in particular allows one to limit analysis on growth without having to deal explicitly with scale invariability. We extend the statistical framework of Henderson et al. (2012) to account for economic performance in smaller geographical areas. We also make use of many direct and indirect suggestions offered in previous studies. The relative underuse of DMSP-OLS data for studying such trends represents an unusual gap in the research particularly since sensor issues like saturation can limit the data's practicality for studying brightly lit urban areas. NTL data from DMSP-OLS cannot resolve further brightening in areas where lights have already reached the sensor's saturation point, when the observed digital number (DN) value reaches 63 (Small et al., 2005). Thus, DMSP-OLS data may actually prove more valuable for studying places where lights have not yet reached the saturation point, which are often non-urban areas, and places where lights are dimming rather than continuously brightening.

Bruederle and Hodler (2017) studies the relationship between NTL and human development at small geographical areas and conclude that nighttime lights are also a good proxy for local human development when using a research design that exploits cross-country variation between small spatial units.

Nighttime light have been used to estimate the level of the informal activities the economy using Cambodia as study area. Tanaka and Keola (2017) demonstrate that data on nighttime light are particularly useful in capturing informal activity. Given the cross-section data on formal and informal activity across regions, their approach is applied to estimate the shadow economy in Cambodia. Their approach relies crucially on nighttime light to estimate the shadow economy. Their results provide evidence for the growth of informal activity in Cambodia is larger than that of formal activity, thereby leading to a growing share of informal activity over time in Cambodia.

Data and Methods

In this section we describe the main dataset used in the estimations; DMSP-OLS Nighttime lights.

DMSP Night-time Lights

The United States Air Force has operated their Defense Meteorological Satellite Program (DMSP) for more than 40-years. The program is based on a series of orbiting satellites whose primary function is to monitor weather. The daytime records of the sensor are exclusively from sunlight reflected from clouds or the earth's surface and thus, of limited use outside of weather forecasting. When the earth's surface is at night, however, the electromagnetic energy sensed by the system is mostly a product of human light emitting activities. Croft (1978) was, to the best of our knowledge, the first to acknowledge that night-light data could be used to measure economic activity.

The DMSP Operational Line Scan (OLS) sensors operate at an 830 km altitude with a sun synchronous near polar orbit with a revisiting time of 101 minutes. The OLS is an oscillating scan radiometer which generates images with a swath width of approximately 3000 km. With fourteen orbits per day, each OLS is capable of generating global daytime and night-time coverage of the earth every 24 hours.

Images are processed at the National Oceanic and Atmospheric Administration's (NOAA) National Geophysical Data Center (NGDC). Processing removes pixels for observations of the moon lit half of the lunar cycle, locations where the sun sets late in the summer (e.g. the Scandinavian countries), places with auroral activity (high latitude regions), and areas covered with clouds. The remaining observations for each operating satellite sensor are averaged to produce a satellite-year dataset. The operational temporal resolution is then one year.

Images from the system have been openly available since 1973 but were periodically overwritten to free storage capacity. Thus, data are digitally archived and available only since 1992. The processed data is distributed to the public through NOAA or NGDC Internet portals.

The intensity of lights is coded in a grid format as six-bit digital numbers (DN). The range is between 0 (no light) and 63In essence, we have followed the setup according to Henderson et al (2012). The average valid nights for each satellite year are 39.2 and datasets currently exist for 30 satellite years.

What can be observed?

In 1994, NGDC began producing annual global cloud-free composites of nighttime lights (Elvidge et al., 1997). These products have been used for a multitude of applications, for example, spatial modeling of population density and economic activity, quantification and comparison of global urban land uses, discrimination of urban rural population distributions, estimation of infrastructure density, assessment of losses of agricultural land, and several more. The OLS detects radiances down to the $5E^{-10}$ W $cm^{-2}sr^{-1}$ range which makes it possible to detect artificial sky brightness and most types of bulbs used for external lightning (Elvidge, 2007). In Figure 1 we provide an example from the study area that illustrates the spread and intensification of nighttime lights for the period 1992—2012 based on three overlaid maps. The usefulness of DMSP-OLS data is evident as it clearly reveals urban sprawl, infrastructure development, and general economic expansion. However, there are a few interesting observations to highlight. The main cities in the observed emit nighttime light at the three observations with the exception of Sarajevo where the urban area indicates that light omission during 1992 was limited. Several places with green colored light can be observed meaning that light was only observed in 2002. These places can be noted in Bosnia-Hercegovina and Macedonia.

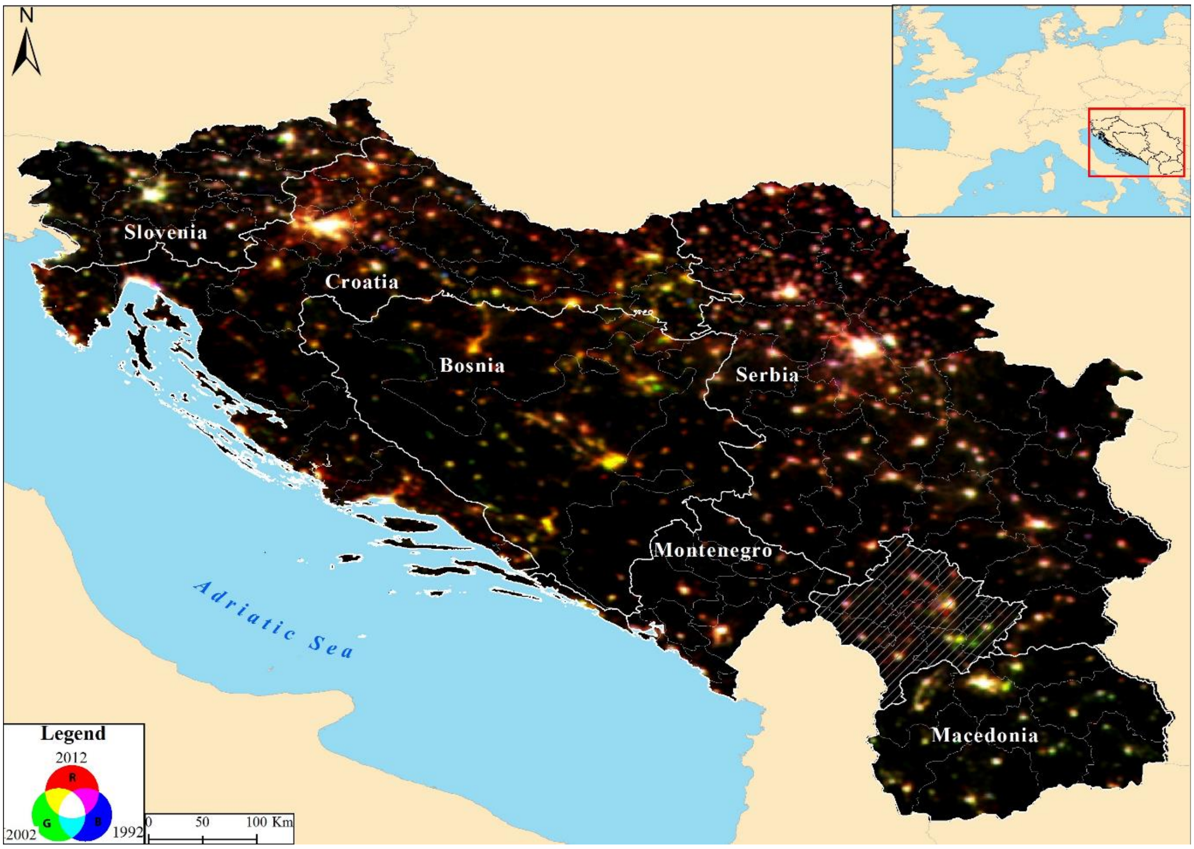

Figure 1. Nighttime light observed 1992, 2002 and 2012

The shortcomings reported for the technical equipment are coarse spatial resolution, lack of on-board calibration, lack of systematic in-flight gain changes, limited dynamic range, six-bit quantification, and signal saturation in urban centers (Elvidge, 2007). A large part of research using night-time lights are undertaken in context with growing economic activities, fast urbanization and infrastructure development particularly in recent years China have been studied using night-time light (Yi et al., 2014; Tan, 2017; Xiang and Tan, 2017)

Generally, the relative underuse of DMSP-OLS data for studying such trends represents an unusual gap in the research particularly since sensor issues like saturation can limit the data's practicality for studying brightly lit urban areas. DMSPOLS cannot resolve further brightening in areas where lights have already reached the sensor's saturation point, when the observed digital number (DN) value reaches 63 (Small, Pozzi, and Elvidge 2005). Thus, DMSP-OLS data may actually prove more valuable for studying places where lights have not yet reached the saturation point, which are often non-urban areas, and places where lights are dimming rather than continuously brightening.

Modell and Results

Henderson et al. (2012) show that growth of nighttime lights is strongly related to aggregate economic growth on the ground. Our analysis start with estimating the level of economic activities for the countries in South-East Europe plus Czech Republic, Hungary and Slovakia on national levels.

Henderson et al. (2012) developed an analysis to study the relationship between NTL and real GDP to study growth. Keola et al. (2015) added land cover to account for economic activities which emit less or none NTL such agriculture and forestry in less developed Asian and African countries. In this paper, we attempt to estimate the nominal GDP with just NTL and its byproducts. We believe this is justifiable for following reasons. First, per capita GDP (current) of former Yugoslavia was higher than $3,000 in 1979, and surpassed $4,000 in 1989. Thailand, the richest country by per capita GDP in Indochinese peninsula only achieved this in 2009 (Word Development Indicators). Per capita electricity consumption in any regions of former Yugoslavia is also higher than in Thailand in 2014 Word Development Indicators (). We think much more economic activities in former Yugoslavia regions emit NTL, than in poorer Asian and African countries, so there is less necessity to use land cover data in estimation of regional GDP. Second, all regions considered in this paper belong to the same country before breaking up, and therefore shared, and still share, more similar characteristics of how energy is used and affect GDP. Third prices are somehow closer in these regions than among different countries globally. Our estimation framework, adapted from Henderson et al. (2012) can be described as equation (1):

$$(1) \qquad \gamma_{jt} = \hat{a}NTL_{jt} + \hat{b}(NTL/NTL\_Area)_{jt} + d_t + e_{jt}$$

where …γ_{jt} is the true nominal GDP of country j in time t. NTL_{jt} and $(NTL/NTL\_Area)_{jt}$ are the level of observed night-time light and lit area at corresponding country and time. d_t and e_{jt} stands for year effect, and error term.

The model relates nominal GDP to level of NTL and level of NTL adjusted by lit area observed by satellite plus time-invariant effects and an error term. The second explanatory variable is introduced to capture the agglomeration effect of NTL by deflating NTL with lit area. d_t is needed to account for different level of observed NTL arising from different satellites and their settings. Regression results of parts or whole of equation (3) are shown in appendix. For country level, it is difficult to distinguish choose which specification to use in extra sample (subnational) prediction. We chose specification (3) because it suppresses overestimation of NTL in regions without agglomeration and therefore generate results closer to official statistics when aggregated to national level.

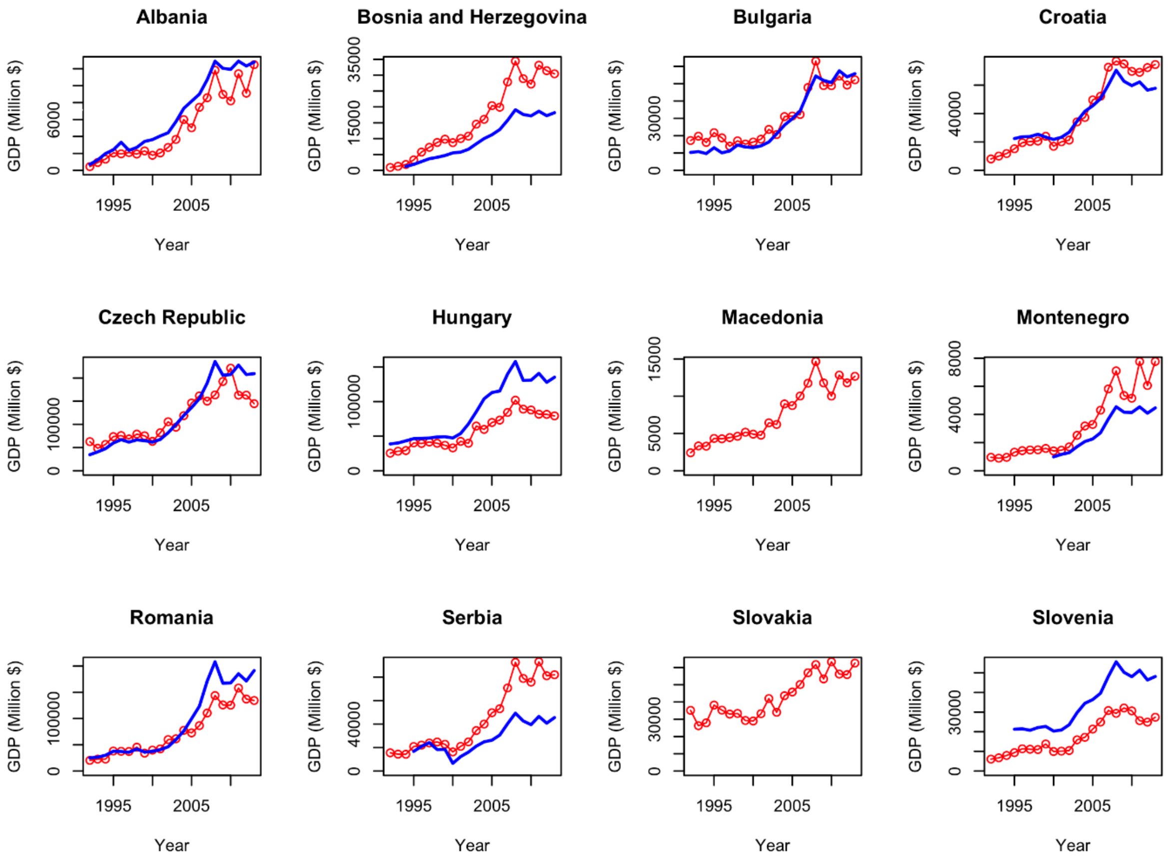

Figure 2. Real and Estimated GDP for South-East Europe plus Czech Republic, Hungary and Slovakia

Figure 2 combine two types of data; the real blue line represents official figures from World Development Indicators (current GDP in million US$ and the dotted red line is authors' estimations covering the period 1992- 2013. The figure show the fit for the countries used to estimate the results. Several countries within former Yugoslavia, the estimated levels of GDP are overestimated compared with the official data. The estimated results for Bosnia and Hercegovina, Montenegro and Serbia provide higher levels especially in the later part of studied period (2007-2013). Slovenia provide the opposite direction with the estimated GDP data providing underestimated results with official data.

The strength of observed nighttime light is normalized to between no light of 0 to strongest light of 63 and time fixed-effects were actually used by Henderson et al. (2012) to principally address this inconsistency.

	Dependent variable:		
		log(gdp)	
	(1)	(2)	(3)
log(ntl)	1.0201***		0.9825***
	(0.0292)		(0.0298)
log(ntl/ntl_area)		2.1244***	0.5578***
		(0.3647)	(0.1449)
factor(year)1992	10.4010***	17.3228***	9.3286***
	(0.4185)	(1.1344)	(0.4900)
factor(year)1993	10.2305***	17.9674***	9.2958***
	(0.4270)	(1.0621)	(0.4777)
factor(year)1994	10.3625***	17.7609***	9.4323***
	(0.4084)	(1.0295)	(0.4617)
factor(year)1995	10.2553***	17.7761***	9.2503***
	(0.4070)	(1.0487)	(0.4710)
factor(year)1996	10.3166***	17.8201***	9.2996***
	(0.4079)	(1.0568)	(0.4735)
factor(year)1997	10.2398***	17.7190***	9.1978***
	(0.4101)	(1.0738)	(0.4789)
factor(year)1998	10.1005***	17.6104***	9.0193***
	(0.4157)	(1.1025)	(0.4891)
factor(year)1999	10.2290***	17.4384***	9.0963***
	(0.4124)	(1.1314)	(0.4944)
factor(year)2000	10.1675***	17.8027***	9.2230***
	(0.4006)	(1.0016)	(0.4573)
factor(year)2001	10.2615***	17.7096***	9.2571***
	(0.4019)	(1.0392)	(0.4668)
factor(year)2002	10.4038***	17.7377***	9.3662***
	(0.4023)	(1.0600)	(0.4720)
factor(year)2003	10.6284***	18.1718***	9.6407***
	(0.4029)	(1.0299)	(0.4652)
factor(year)2004	11.0395***	18.8232***	10.1638***
	(0.3971)	(0.9569)	(0.4450)
factor(year)2005	10.9062***	18.5539***	9.9394***
	(0.4036)	(1.0177)	(0.4629)
factor(year)2006	11.1840***	18.8588***	10.2586***
	(0.3996)	(0.9891)	(0.4538)

factor(year)2007	11.4614***	19.1054***	10.5383***
	(0.3983)	(0.9867)	(0.4525)
factor(year)2008	11.2966***	18.6263***	10.2125***
	(0.4077)	(1.0931)	(0.4832)
factor(year)2009	11.2756***	18.4662***	10.1771***
	(0.4050)	(1.0997)	(0.4834)
factor(year)2010	10.7862***	17.6704***	9.5019***
	(0.4176)	(1.2257)	(0.5226)
factor(year)2011	11.0825***	18.3549***	9.9464***
	(0.4121)	(1.1290)	(0.4946)
factor(year)2012	10.8719***	17.7635***	9.6084***
	(0.4153)	(1.2109)	(0.5175)
factor(year)2013	11.0710***	18.2253***	9.9087***
	(0.4115)	(1.1447)	(0.4983)
Observations	201	201	201
R^2	0.9997	0.9979	0.9997
Adjusted R^2	0.9996	0.9977	0.9997
Residual Std. Error	0.4499 (df = 178)	1.1545 (df = 178)	0.4334 (df = 177)
F Statistic	24,800.4000*** (df = 23; 178)	3,759.0130*** (df = 23; 178)	25,612.9200*** (df = 24; 177)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 1: Regression results

Table 1 provides the regression results for the national GDP estimations presented in Figure 2.

There are three models (all with year effects)

(1) log(gdp) = a*log(ntl)

(2) log(gdp) = a*log(ntl/area)

(3) log(gdp) = a*log(ntl)+b*log(ntl/area)

(2) with is normalized by area performs obviously the worst. For the other models we need the fourth digits to see (3) performs slightly better than (1). In a brief, (3) account for both scale and density of NTL.

Estimating Gross Regional Product for Sub National Levels

In this section we estimate the Gross Regional Product for sub national levels of the countries in former Yugoslavia to evaluate the performance of our models.

Figures 3 and 4 show 1992 and 2013 sum of nighttime light for district levels for countries in former Yugoslavia.

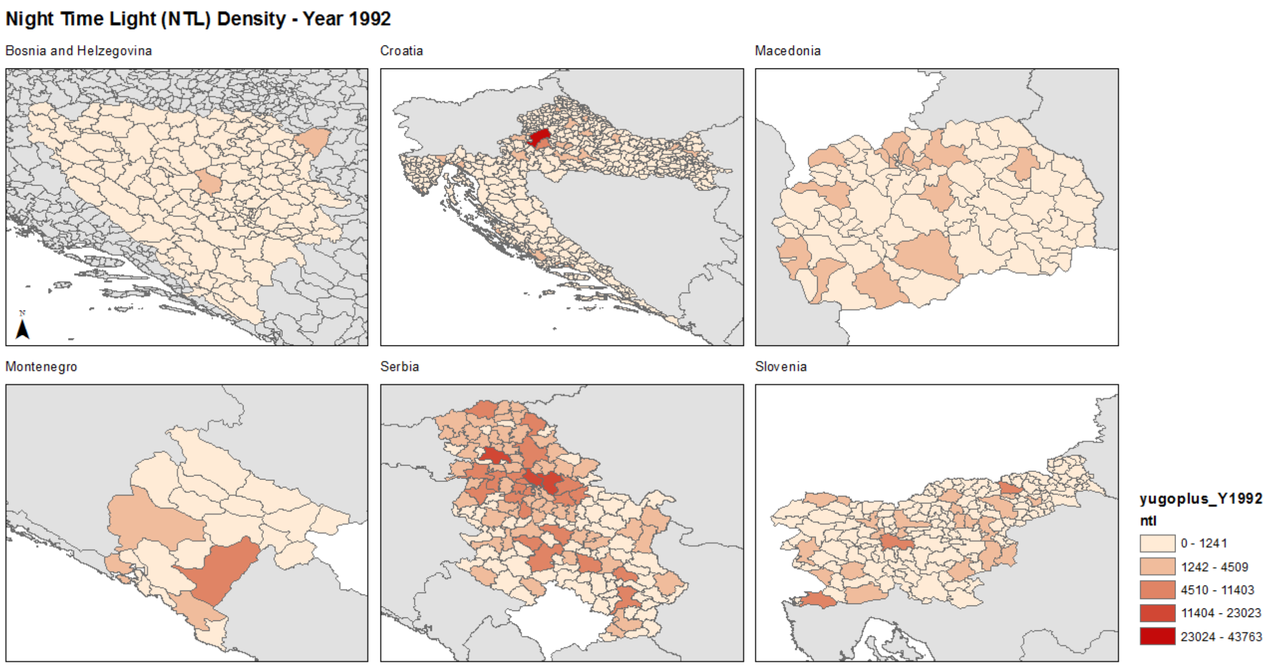

Figure 3. Sum of Light on district level 1992[2]

The nighttime light on district level for the entire set of countries are on rather low levels with Bosnia and Hercegovina and Macedonia showing the lowest levels. Serbia indicate relatively larger sum of light levels compared with the rest of the areas. Capital Zagreb in Croatia emit the same levels of nighttime light as Serbian Capital Belgrade.

[2] Montenegro is treated as a separate unit of analaysis

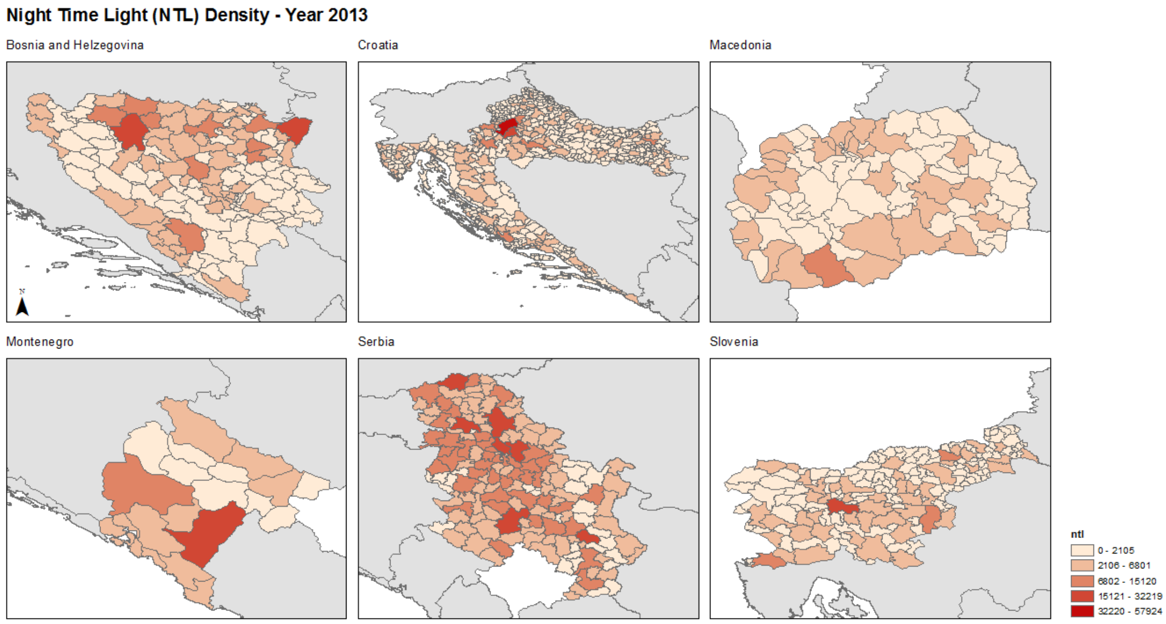

Figure 4. Sum of Light on district level 2013

About 20 years later, the sum of light for nighttime light in the former Yugoslavia indicate growth in all countries. All countries are experiencing higher levels of light. Nighttime light data provide information in two dimensions. Area lit increases with new night-time emission in previously dark places and light intensity increases when additional light sources emerge on top of existing sources.

The estimates for Gross Regional Products are illustrated in Figure 5 and 6 with estimates from 1992 and 2013.

Figure 5 provides results based on the estimations on gross regional products on district level based on the national model described earlier in the research. The estimations for 1992 show large parts of Bosnia and Hercegovina lacking data. This is due to low or non-existing levels of nighttime light, this observation also holds for parts of Croatia, especially the parts of the country neighboring Bosnia and Hercegovina. For Serbia, Montenegro and Slovenia the spatial distribution of the GRP are relatively evenly distributed.

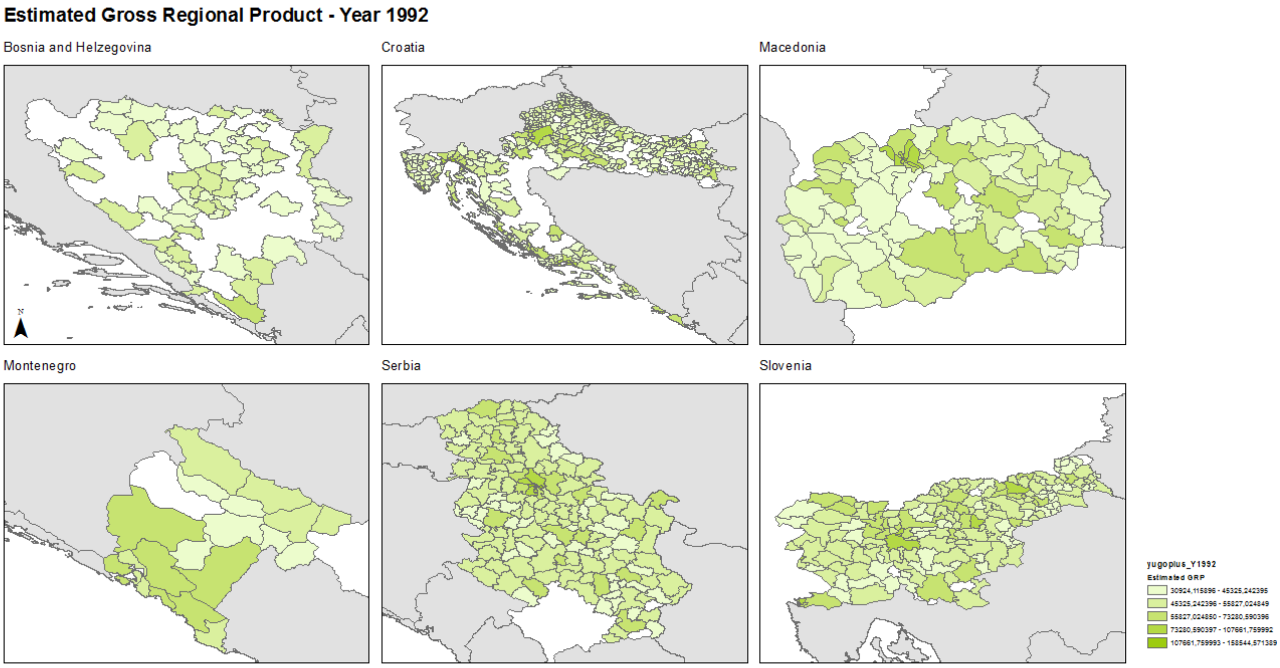

Figure 5. Estimated Gross Regional Product 1992

When it comes to the last year of the model estimates 2013 the results indicate recovery for area lacking estimates in 1992.

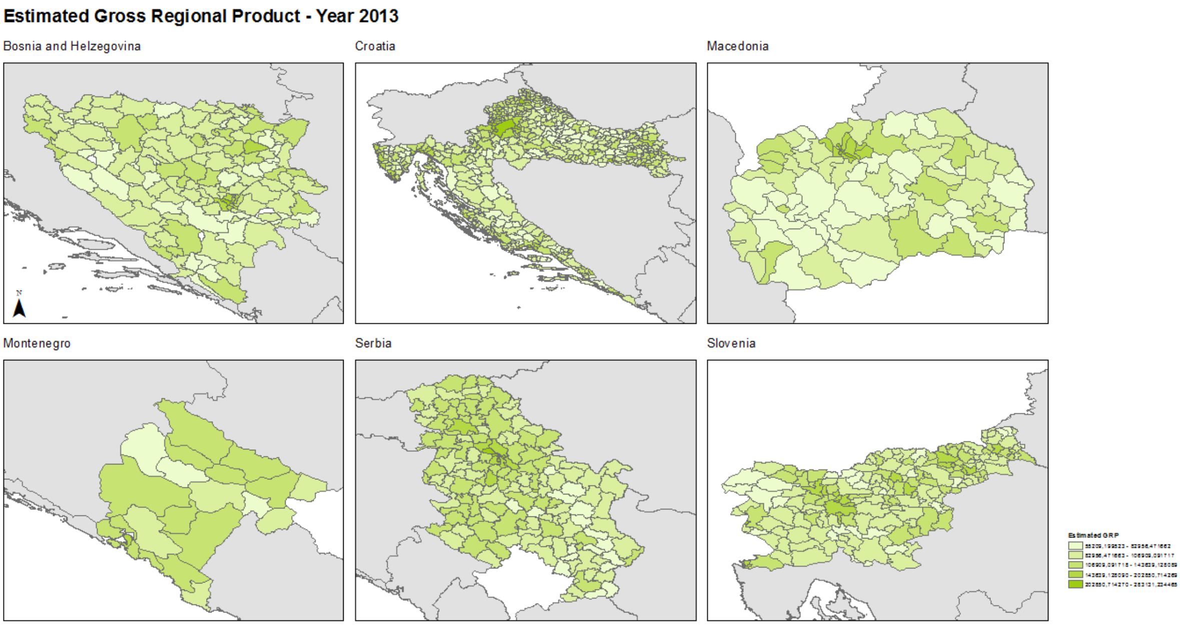

Figure 6. Estimated Gross Regional Product 2013

Cluster-outlier analysis

Cluster-outlier analysis of the GRP was used to estimate spatial cluster among the districts in each country based on inverse distance weight (IDW) (Cai et al., 2017). The cluster-outlier field has been recognized with a statistically significant level (i.e., 0.05 level or so on); those are fell into cluster of high values (HH), cluster of low values (LL), outlier in which a higher values is surround by lower ones (HL), and outlier in which a lower values is surrounded by higher values (LH). The z scores and p values were then computed to measure of statistical significance. A high positive z score would prefer the surrounding features that have similar values (either high values or low values) and low negative z score (critical value as ± 1.96±1.96 or 2.58) indicating a statistically significant (0.05 level or 0.10 level) spatial outlier consistence.

Discussion

Monitoring of economic activities should provide longitudinal information in a standardized and regular manner at different geographical scales. Planning and directions of public investment are dependent on accurate statistical measurements. Based on the information provided, stakeholders are enabled to make decisions and identify areas with large variation in production and productivity and target these areas through directed investments. Estimates should therefore be provided as early as possible during the economic cycle and updated periodically.

This research presents a model for estimating economic performances on subnational levels growth using satellite data. The application of remote sensing data in economic analysis is in the very early stages and has largely been limited to observations of night-time light.

Furthermore, for more than forty years the design of the OLS has not changed significantly, and OLS data have relatively coarse spatial resolution, limited dynamic range, and lack in-flight calibration (Elvidge, et al. 2013).

Despite the limitations mentioned above, this article provides advancement in how to monitor economic development from space. First, our study provides a unique spatial and temporal perspective of change in economic activities in a context of disintegrated economic system and conflicts. Second, it provides a truly geographical perspective with high detail in observations and low scale coverage that permits analysis at several scales. The model output can be aggregated to arbitrary geographical spatial units such as nations but, more importantly, it can also be used for studying functional regions that challenge administrative borders.

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