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Corruption and economic growth: new evidence from satellite data

Master's Thesis

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I have written this master's thesis independently. All viewpoints of other authors, literary sources, and data from elsewhere used for writing this paper have been referenced.

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Table of contents

Abstract

Literature regarding the consequences of corruption on economic growth have been relying on official macroeconomic indicators which is vulnerable to potential manipulation attempts by governments. This thesis aims to explore potential use of satellite night lights data in analysis of relationship between corruption and economic growth in post-Soviet region for the period 1995–2013. Empirical analysis makes use of several datasets, such as, lights-output proxy Z was generated using the National Geophysical Data Center data; Corruption Perceptions Index from Transparency International and V-Dem corruption index from Varieties of Democracy Dataset. Results of the generalized method of moments estimation on the panel data of 14 countries show that corruption has a significant negative effect on the growth rate of lights-output proxy Z and on the growth rate of real GDP per capita. This effect is non-linear and lights-output proxy Z demonstrated higher impact of corruption on economic growth as compared to the models using GDP measure, that can be explained by evidence on data reliability, manipulation of macroeconomic statistics and regime type of a country.

Keywords: *night lights data, corruption, economic growth, post-Soviet countries, panel data, generalized method of moment.*

1. Introduction

In 2016, the World Bank estimated the cost of corruption at over US$2.6 trillion, equivalent to 5% of global domestic product (GDP). Transparency International, which aims to give a voice to victims of corruption, points out that two out of five business executives pay bribes at some point when dealing with public institutions in developing countries (Ribeiro et al., 2018)

Corruption is a complex phenomenon that has been studied by several scholars to better understand it. The corruption literature branch has demonstrated the detrimental effect of corruption on economic growth, although this relationship is non- linear and with many caveats (Bardhan, 1997; Mauro, 1995). A critical factor in explaining different levels of corruption has been economic development, particularly income levels, measured in Gross Domestic Product (GDP) per capita variations. Authors have claimed that across countries, higher per capita income correlates with lower levels of corruption, although some researchers have questioned this correlation (Kaufmann, 1999), and several scholars have discovered the opposite. (Braun and Di Tella, 2004; Frechette, 2001). Numerous studies which investigated the link between economic growth and corruption, have exploited macroeconomic indicators and statistics reported by governments and/or international organizations. However, emerging studies indicate that these macroeconomic indicators and figures are not entirely reliable. For example, Martinez (2017) discovered the manipulation of GDP growth statistics in non-democracies by comparing self-reported GDP figures using night-light data.

Accordingly, existing research examining the link between corruption and economic growth would have own shortcomings due to data reliability issues, in particular, macroeconomic indicators. To overcome reliability and potentially manipulated data concerns, economists have proposed an alternative economic growth measure. For example, Henderson et al. (2012) used changes in night-light data as a measure of economic growth. They showed that light growth is a suitable proxy for GDP growth in the long run and also tracks short-term growth fluctuations. Rangel-Gonzalez and Llamosas-Rosas (2019) used satellite night-light data to measure economic activity in Mexico and discrepancies between estimated and official GDP to identify the unregistered economic activity. Therefore, this thesis aims to explore potential use of night light data to predict the relationship between corruption and economic growth. In this way, main advantage of use of satellite date, since the economic growth data obtained from satellite date is independent from any government body. This will be an important novelty and approach in the literature which studies the link between it and corruption.

The main focus of this research will be to examine the relationship between corruption and economic growth in a Post-Soviet region using satellite night-light data. The motivation behind the selection of countries is the limitation of obtaining a large amount of satellite data, so it was decided to conduct the estimations with a limited number of countries. The geographical coverage of the analysis is the former Soviet Union (FSU) countries with the exception of Russia due to its large area and high regional variation in terms of economic development. This region is highly relevant for the study of corruption and its consequences on economy for several reasons. First, according to corruption indices from Transparency International, corruption is a widespread problem in this group of countries. Second, according to The Quality of Government ranking (Charron et al., 2019), these countries have low levels of institutional quality such as rule of law, accountability, and transparency.

The thesis will be focused on examination of the effect of corruption on the rate of growth of lights-output proxy. I find that the direct effect of corruption on the rate of growth of generated lights- output proxy is statistically significant and that the effect is non-linear. Moreover, this effect is higher compared to the classical approach that uses GDP data.

To the best of the author's knowledge, this is the first study for the FSU region that systematically analyzes the relationship between corruption and economic growth. In this sense, this thesis also adds to the limited literature by estimating the effect of corruption of that sample of countries and comparing official GDP growth rates with the generated proxy.

The next chapter of the thesis reviews the relevant literature. It is followed by the “Data description” section, where night-lights and estimation data explained that used to conduct the research. The section “Methodology and empirical estimation” consist of several sub-sections: methodology behind the generation of lights-output output proxy; methodology of estimation of the impact of corruption on that proxy using generalized method of moments (GMM) approach; robustness checks; empirical results and their discussion. Eventually, Conclusion, References and Appendices are provided as separate sections

2. Literature Review

2.1. Measurement of corruption and its link with economic growth

The role of corruption, the abuse of public office for private gain, in limiting human development is now well established. However, the ability to validly and reliably measure the impact of corruption over time and across countries remains controversial. A definition of corruption that was introduced by Pope (2000) and then popularized by the World Bank and the IMF, namely "the abuse of public office for private gains," serves as a backdrop of my research.

As mentioned earlier, there are a variety of measurement tools for corruption. Hamilton and Hammer (2018) and Clark (2017) critically reviewed the validity, consistency, and content alignment of the six leading indicators used to measure corruption: including the two most popular: the Corruption Perceptions Index (CPI) and the Control of Corruption Governance Metric (CC). The authors made a comparative analysis between these and the other four, including the Government Effectiveness Governance Metric, the Global Corruption Barometer, the UN Survey of Crime Trends; and evidence on the measuring corruption (validity criterion). The result of the analysis is that these two composite subjective indicators are the best starting point for any empirical analysis because they are more comprehensive and thus more likely to capture all elements of corruption.

The Corruption Perceptions Index (CPI) is a freely available and cross-national measure of corruption from Transparency International. This index aims to measure the abuse of 'entrusted power for private gain' (Transparency International, 2011). Each country is given a score, which can range from 0 (extremely corrupt) to 100 (no corruption), and individual country scores are developed by aggregating and averaging normalized scores of 'corruption-related data' emanating from a variety of sources. The objective of the index is to provide a measure of the extent of corruption by bureaucrats and politicians in the public sector (Transparency International, 2011). The goal of the Control of Corruption Governance Metric (CC) measure, like the CPI, is to capture the extent to which public policymakers abuse their public office for private gain. The aim of the index is designed to capture the extent to which public power is exercised for private gain, including both small and large forms of corruption, as well as the "capture" of the state by elites and private interests (World Bank, 2010). Despite a formal definition that seems more focused on political corruption, the CC, like the CPI, is primarily composed of sources, some of which are identical to the CPI, that are concerned with measuring both political and bureaucratic corruption. In short, the CC is very similar to the CPI, although, unlike the CPI, one of its representative sources focuses exclusively on corruption by bureaucrats, which means that the bias toward non-elected officials may be somewhat more significant compared to the CPI. In addition, CC uses fewer representative sources (five versus eight), which means that it is somewhat less likely to consist of representative sources regarding the extent of 'political' corruption than CPI (Hamilton and Hammer, 2018).

In the literature, there are still two different approaches to the effects of corruption on an economy. They are illustrated by the wheel of economic growth, where corruption can be the "grease" or the "sand" for this wheel (Méon & Sekkat, 2005). This concept shows that corruption may have a positive or negative impact on economic growth, and it only considers the economic aspects of this phenomenon, ignoring ethical arguments. Many researchers have attempted to define the relationship between corruption and economic growth The exact channels through which corruption affects economic growth are not resolved empirically. However, the main channels used in researches include investment, human capital, and political instability (Mo, 2000; Mauro, 1995).

Approaches and frameworks that investigating the relationship between corruption and economic growth are still developing and remain a relevant topic for research. Gründler and Potrafke (2019), in their recent paper, used CPI data for 175 countries over the period 2012-2018 and re-examined the relationship between corruption and economic growth. The cumulative long-run effect of corruption on growth is that real GDP per capita declined by about 17% when the inverse CPI increased by one standard deviation. Authors claimed that the effect is particularly pronounced in autocracies and countries with low government effectiveness and rule of law, supporting the "weak form" of the "grease the wheels" hypothesis: affects to growth by reducing foreign direct investment and increasing inflation. The hypotheses about a non-linear relationship between corruption and economic growth using models estimated by the generalized method of moments (GMM) were empirically confirmed by Pluskota (2020) in her study. The author concludes parabolic linkage between those categories and provides exciting insights into the impact of corruption, where the maximum of a function of economic growth could be calculated in terms of the value of corruption. One result suggests that low levels of corruption can be beneficial to an economy. At the same time, too much corruption inhibits economic growth.

Another study by Ahmad et al. (2012) provides a linear quadratic empirical relationship between corruption and economic growth. The authors used the same empirical approach of the generalized method of moments (GMM). Their estimation shows that a decrease in corruption raises the economic growth rate in an inverted U-shaped manner. Their result is robust to alternative specifications of the econometric relationship. The authors claimed that the empirical literature reporting a linear relationship between corruption and economic development does not differentiate between growth-enhancing and growth-reducing levels of corruption. Therefore, new approaches are needed to examine the relationship between the categories.

Nonetheless, there are several studies in which the impact of corruption is not statistically significant (Huang, 2016), with a few showing that the existence of corruption can actually contribute to economic growth ("greasing the wheels" in inefficient regulatory framework) and, go deeper claiming that the costs incurred from measures taken by government action against corruption and bureaucracy are not always beneficial to economic growth (Tsanana et al, 2016; Huang, 2016).

2.2. Problem of reliability of the governmental or international organizations data

Because of its hidden nature, corruption and its effects are difficult to measure. The most significant criticisms leveled at such measurements in the international specific literature also highlight that, in most cases, the independence of the organizations undertaking the corruption measurements, the transparency of the data sources used, and the applied methodology are not ensured.

Nemeth et al. (2019) identified numerous risks that affect the scientific reliability and validity of international indicators that measure corruption. The organizations conducting the survey cannot be considered independent. Numerous factors influence corruption perceptions in addition to corruption. Jahedi and Mendez (2014) acknowledged that economic and cognitive factors might distract the subjective indicators, and these may show a negative correlation with the objective data. However, according to them, this is not a sufficient reason for disregarding the data sources. Hawken and Munck (2009) analysed and tested the validity of data on corruption using the full range of data sets employed in corruption research. The authors showed that different classes of data sources on corruption indicators, a distinction based on who assesses the level of corruption in a country, are based on different standards for assessing corruption and that the different standards do not apply consistently to all countries.

Moreover, they mention that the problem with the indicators is also simply adopted in CPI and the CCI indices. Systematic differences between indicators are disregarded in the selection of indicators used in these indices.

Other researches claim the problem of investigating the impact of corruption in the countries where it is ample. For example, Shukhova and Nisnevich (2017), measured the validity of corruption indices in their work and proved that in many cases, the methodology used to construct the index is not accessible to the extent that would allow independent researcher validation to be conducted. Pelizzo et al. (2017) conducted some correlation analyses that raise questions about the validity and reliability of the estimated level of corruption using Kazakhstan as an example. The authors found that corruption levels estimated by the Corruption Perception Index, the World Governance Indicators, and the Global Competitiveness Index are weakly and insignificantly related to one another and relatively unstable over time. The authors explain why international measures of corruption fail to assess and track changes in corruption levels in Kazakhstan. They suggest that this anomaly can be explained by three different reasons, namely that the country is so different from other places, that methodologies that work elsewhere do not work in the internal context, that the methods used to estimate corruption levels are wrong, and that the information processed to estimate corruption levels in Kazakhstan is misleading.

According to the challenge of determining whether the data is valid, researches tend to pit validation techniques against each other, rather than explain how to combine multiple approaches. One solution to that is Varieties of Democracy (V-Dem) corruption index is a new approach to the conceptualization and measurement of corruption (McMann et al. 2016). It is co-hosted by the University of Gothenburg and University of Notre Dame. V-Dem aggregates corruption indicators using a two-stage approach: using item response theory (IRT) measurement model and Bayesian factor analysis to aggregate corruption measures (McMann et al. 2016, p.15).

From the other perspective, the reliability problem applies to the measurement of official economic and financial statistics at the government level. Governments of all kinds have an incentive to exaggerate how well the economy is doing, on the basis of which manipulation of official economic statistics occurs. A strong democracy guarantees that opposition parties, the media, the judiciary, and the general public are free to scrutinize government figures. In more autocratic regimes, such checks and balances are largely absent

(Martinez, 2017). The execution of USSR officials responsible for the 1937 census after its unsatisfactory results serves as an extreme example (Merridale, 1996). A more recent example concerns Chinese Premier Li Keqiang's alleged acceptance of the unreliability of the country's official GDP estimates (Clark et al., 2017). Nevertheless, there is limited evidence on whether manipulation of growth figures is a common feature of modern authoritarian regimes and how this phenomenon is quantified.

2.3.Use of satellite data as a proxy for economic growth

A few years ago, scientists started looking for other approaches to undertake economic estimations. In addition to machine learning approaches to measuring challenging series such as corruption, some economists suggested the usefulness of an extraordinary proxy for economic activity: the amount of light that can be observed from outer space. For example, Henderson et al. (2012) used changes in "night lights" as a measure of economic growth. They showed that light growth is a convenient proxy for GDP growth in the long run and also tracks short-term growth fluctuations. Their estimates differ from the official data by up to three percentage points annually. Therefore, they prove that empirical analyses of growth using Lights no longer need to use countries as the unit of analysis.

Other economists used the same approach to measure human well-being (Ghosh et al. 2013), with the authors claiming that their estimates can be constructed as spatially disaggregated one-square-kilometer grids so that they can be aggregated to any desirable mapping unit. The alternative measure of the distribution of wealth across regions, called the Night Light Development Index (NLDI) (Elvidge et al., 2012), is often used in papers related to various economic estimators. It is an empirical measurement index of human development derived solely from nighttime satellite imagery and population density.

Other researchers use the same approach for more specific estimations. For example, Rangel-Gonzalez and Llamosas-Rosas (2019) used satellite nightlights to measure economic activity in Mexico and discrepancies between estimated and official GDP to identify the unregistered economic activity. The proposed econometric specification in this paper takes into account the fact that the relationship between nightlights and economic activity varies by sector when estimating the correlation between luminosity and economic activity. Similarly, a research group from Romania (Kinga et al. 2020) measured inequality and determined the Night Light Inequality Index (NLII) at the national level, based on the county-level Night Light Development Index (NLDI) values mentioned above, using the Gini coefficient for the empirical evidence. The values of the NLII range from 0 to 10, with 0 indicating perfect equality and 10 indicating perfect inequality.

In the most recent work, Jha and Talathi (2021) used the number of night lights per capita as a proxy for per capita income at the district level in India. They found that modern districts that were historically under direct British rule had 39.47% less night lights per capita compared to modern districts that were historically under indirect British rule. When looking at the growth pattern using satellite data from 1993 to 2013, directly ruled districts had a 1.84% lower annual growth rate than indirectly ruled districts. They mention that directly ruled districts were converging at a rate of 2% per year while indirectly ruled districts were converging at a rate of 5.7% per year (areas that were initially less developed were growing faster). All the estimates for different activities prove that satellite data can be used as an efficient proxy for empirical analysis. In discovering the relationship between corruption and economic growth using night lights data, it is also worth noting that electricity is essential for social and economic development. In the paper by Min (2015), electricity is likened to the "lifeblood of the modern economy" as most of the economic activities we see in the world today depend on a steady supply of electricity and a stable system to distribute it. Boräng et al. (2016) explained that the effect of democratic experience on electrification is indeed dependent on the level of corruption in the public administration. Democratic history is associated with a lower proportion of the population living in unlit areas only if a country has been able to reduce corruption to a certain level. In contexts with widespread corruption, a long experience with democracy has been shown to have no effect on the provision of electricity to the population.

Martinez (2017) discovered the manipulation of GDP growth statistics in non-democracies by comparing self-reported GDP figures with night-light data. He showed that the night-light elasticity of GDP is systematically larger in more authoritarian regimes. This autocracy gradient in elasticity is not explained by possible differences in a large set of country characteristics, including economic structure, urbanization, state capacity, or level of development. The gradient is larger when countries have a stronger incentive to exaggerate economic performance or when the institutions that constrain the manipulation of official statistics are weaker.

The author asserts that the magnitude of this manipulation is substantial. His estimates show that the most authoritarian regimes inflate annual GDP growth rates by a factor of 1.15-1.3 on average. Due to his concluding remarks, adjustment of the GDP growth figures for manipulation changes the understanding of relative economic performance at the turn of the XXI century and downplays the apparent economic success of countries with non-democratic forms of government. Moreover, his findings are a warning sign for scholars, policymakers, and other consumers of official economic statistics. They provide an incentive for the development and use of robust measures of economic activity and for the enforcement of international transparency standards such as the IMF's Dissemination Standards Bulletin Board (DSBB) (Martinez, 2017 p.28).

3. Data description

Empirical analysis makes use of datasets which are obtained from different sources.

First of all, night lights data from the National Geophysical Data Center (NGDC) of the National Oceanic and Atmospheric Administration (NOAA). The annual data from 1995 to 2013 (time series length of 19 years) has been used. This time interval was chosen because the Defense Meteorological Satellite Program (DMSP) data collected by US Air Force Weather Agency is only available until 2014 and it is easier to undertake the analysis due to required computing power comparing to Visible Infrared Imaging Radiometer Suite (VIIRS) data that is available for next years. Each satellite-year dataset is a grid in .tar format. reporting the intensity of lights as a six-bit digital number, for every 30 arc-second output pixel (approximately 0.86 square kilometers at the equator) between 65 degrees south and 75 degrees' north latitude (National Geophysical Data Center, 2010). Figure 1 summarizes the processing of the data. For the empirical estimations approximately 50 GB of the satellite data has been used. To get the proxy for economic activity author used the replication files form the code of the paper "Measuring Economic Growth from Outer Space" by Henderson et al. (2012) and applied additional R packages such as "lattice", "dplyr", "pdynmc", "plm" etc. for munging, calculating and estimating data with models in next chapters.

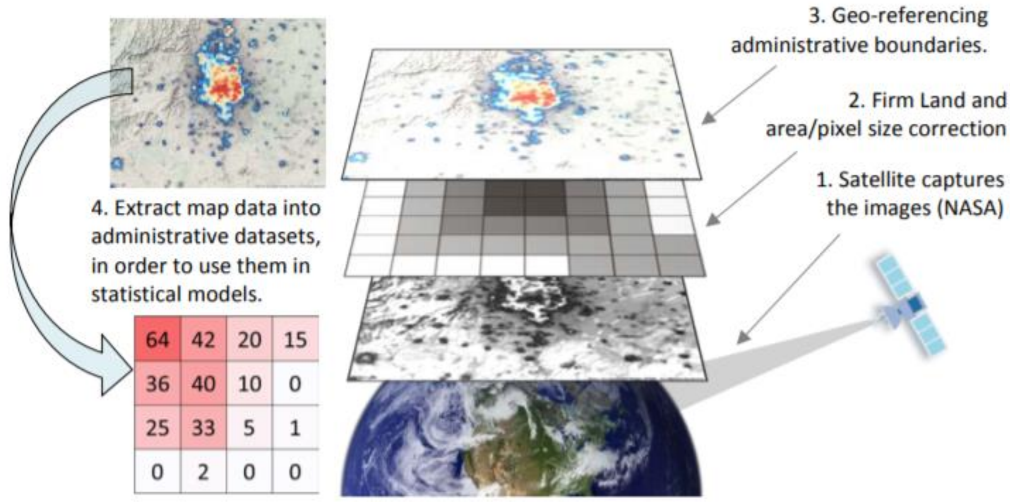

Figure 1. Graphical Description of Data Processing

Source: Rangel-Gonzaleza and Llamosas-Rosas (2019)

Because of the computational difficulties of getting large amount of the data from satellite, it was decided to conduct the estimations using a sample of a limited number of countries. Geographical coverage of analysis will be the Post-Soviet countries (former Soviet Union countries) except Russia due to its large area and high regional variation in terms of economic development. This region is highly relevant for studying corruption and its consequences on economy for several reasons. First, according to corruption indices from Transparency International, corruption has been a widespread problem in this group of countries. Second, according to The Quality of Government ranking (Charron et al., 2019), these countries have low level of institutional quality such as rule of law, accountability and transparency. Considering the legacy of a totalitarian past, the strategically important geographical location, and the various cultural and political determinants of corruption this sample of countries is interesting to study. Due to lack of these certain institutional setting, country officials may not reveal accurate statistics about macroeconomy and business environment. Hence, these conditions make these countries suitable laboratory for empirical analysis of the relationship between corruption and economic growth. For the lights-output proxy I obtained panel data of 14 countries for 19 years' timeframe.

Appendix A shows main variables for 14 countries that have been obtained using abovementioned data and replication files. Description of the lights data can be found in Appendix B.

For empirical estimations, I included several independent variables which are obtained by using various datasets such as Transparency International, World Bank, IMF and V-DEM (Varieties of Democracy) datasets. Primary independent variable for proxying corruption obtained from Corruption Perception Index (CPI, from Transparency International) and V-DEM corruption index. CPI measure is available starting from 1995 and old indices were multiplied by 10 to get the same estimation value over the time. V-DEM corruption index is available for all years and was multiplied by and subtracted from 100 to get the same estimation value as the CPI measure: from 0 to 100 and higher index level indicates lower corruption level of a country.

Scholars appear to agree on different sets of macroeconomic indicators to be used for investigating the impact of corruption on economic growth. For example, Mo (2001) and Pelligrini and Gerlagh (2004) used for their analysis control variables such as government expenditures, investment-output ratio, and population growth rate to analyze the impact of corruption on growth. I also include electricity consumption and trade openness ratio and substitute the GDP with my lights-output proxy as independent variable. Primary information about the variables is presented in Appendix B.

4. Methodology and empirical estimations

4.1. Generating lights-output proxy

Night light satellite data have been already used by past studies as a proxy for economic activity. For example, in regions for which no GDP data are available, at the sub-national level, or for regions in which GDP measurement is of poor quality, for example in some developing countries as in the paper by Henderson et al. (2012).

This proxy gives the data on the regions and their intensity of night lights. Specifically, I examine to what extent changes in the intensity of night lights are correlated with local economic growth. As, for example, in the paper by Ishizawa et al. (2016) for the Central America region. I used the same econometric approach to evaluate the relationship between artificial night lights and real GDP over time as in paper by Chen and Nordhaus (2010). The basic assumption is that there are measures on nightlights intensity and standard output for each grid cell (or country), and that these are measured with error. The analysis was conducted at the country level in both of the abovementioned papers. For that the nightlights grid data were before summed up to obtain country level values using shape files for each country separately. Figure 2 illustrates the difference between number of observed night lights for Estonia in 1992 and 2013. Comparative illustrations for all 14 countries are in Appendix E.

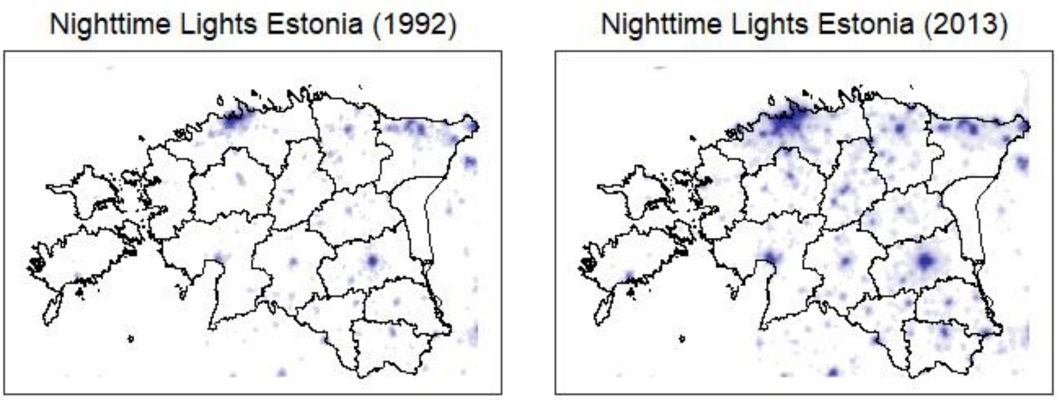

Figure 2. Comparison of night light in Estonia
Source: author's own compilation.

The variable *y* is the logarithm of the true output (GDP), m is the logarithm of the night lights intensity (number of nightlights observed divided by area), and ε and ξ are the measurement errors for standard output and intensity, respectively. In addition, I assume a structural relationship between intensity of nightlights and true output as in Ishizawa et al. (2016), with a coefficient of β (elasticity of nightlights to true output) and an error term u. There are measurements of each variable in one country *i* over the year *t*, an asterisk denotes the true value:

$$y_i = y_i^* + \varepsilon_i \text{ (1)}$$

$$m_i = m_i^* + \xi_i \text{ (2)}$$

$$m_i = \beta y_i^* + u_i \text{ (3)}$$

Equations (1) and (2) are the error processes for output and nightlights intensity, respectively. Equation (3) is the data-generating process for intensity of nightlights as a function of true output. Using this equations, lights-output proxy from these relationships is obtained as follows:

$$Z_i = (1/\beta) \times m_i \text{ (4)}$$

where Z_i is the log of lights-output proxy and β is the consistently estimated coefficient from the equation (3). I observe the long-term growth (time series length of 18 years), therefore β coefficients are high and significant. The results of estimation are in the Appendix D.

For example, model predictions using lights-output proxy compared to observed GDP growth in case of Georgia are in Figure 3.

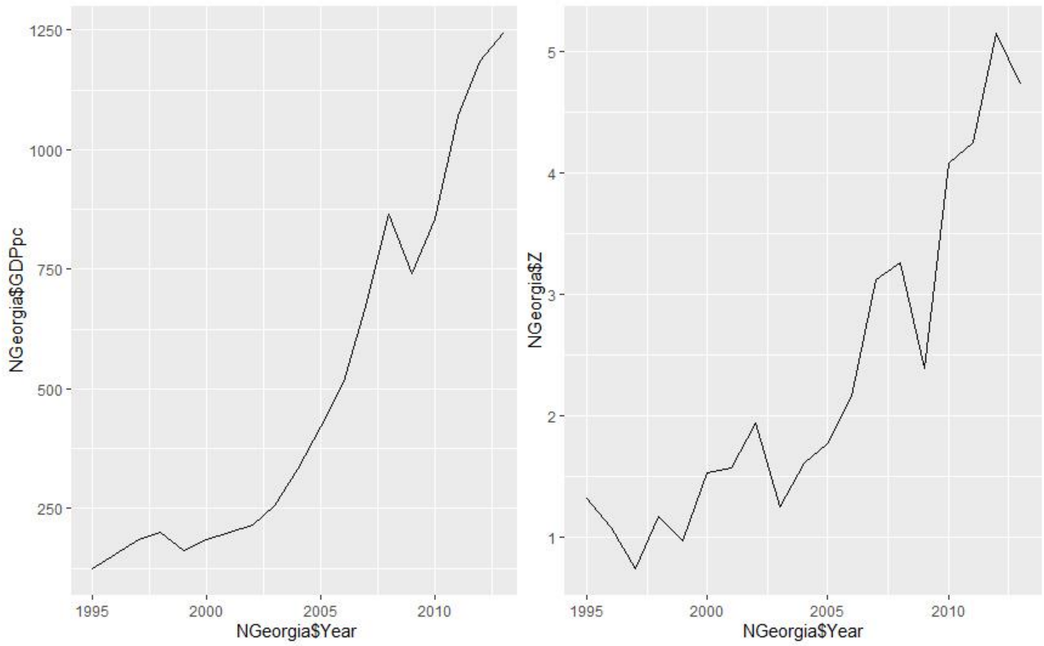

Figure 3. Comparison of growth lights-output proxy Z and GDP in Georgia (1995-2013)
Source: author's own compilation.

The figure shows the similarity of the growth in both GDP per capita and Z, but the growth of the Z proxy is sharper and more volatile comparing to GDP growth. This proxy will be used as an independent variable for estimating a dynamic panel data model in next section.

4.2. Estimating the effect of corruption on economic growth

The violation of exogeneity assumption makes OLS estimators inconsistent and creates the problem of endogeneity. A potential endogeneity problem arises due to reverse causality e.g. economic growth may affect corruption levels. However, the direction of this effect is unclear. Higher economic growth may increase the availability of rents, making corruption more profitable, but it also increases the amount of resources that can be devoted to controlling corruption. In both cases, corruption would be correlated with the error term in the random effects model (REM) and the estimates would be biased. If economic growth increases (decreases) corruption, the regression coefficients of the linear and quadratic terms for corruption would be biased upward (downward). To overcome this difficulty, several authors in the past have included an instrumental variable and performed a two-stage least squares (2SLS) regression. In theory, this is a perfectly valid procedure. In practice, however, it is very difficult to find a valid instrument. The two-dimensionality of the panel data creates two types of errors that affect the performance of the estimates. One relates to cross-sectional observations and the other to time-series observations (e.g., country-specific error may overstate the estimates in our sample). Apart from these errors, the inclusion of lagged dependent variable also worsens the problem of serial correlation; to overcome the problem of bias and endogeneity, I use the generalized method of moments (GMM) in this study, apart from REM as in Ahmad et al. (2012), Swaleheen (2011), Pluskota (2020) and others.

I estimate a dynamic panel data model. To specify my structural econometric model, first extend the traditional cross section model into a panel data model as follows:

$$Z_{i,t} = \alpha_0 + \alpha_1 \mathrm{CORR}_{i,t} + \sum \beta_j \mathrm{X}_{ijt} + \mu_{it} \quad (5)$$

where $Z_{i,t}$ is the dependent variable - log of intensity-output proxy, CORR is the explanatory variable - corruption index: CPI or V-DEM. X_{ijt} is a column vector of exogenous control variables and includes: government expenditures to GDP ratio (EXGDP), FDI to GDP ratio (FDIGDP), export plus import to GDP ratio (OPENNESS), kilowatt hour per capita consumption (KWHPC) and population growth rate (POPGR). Primary information about this variable and their descriptive statistics with correlation matrix can be found in Appendix B and Appendix C respectively.

Subscript i is used to present the country (i = 1, 2,…...,n), j for control variables (j = 1, 2,…., m) and t is used for time (t = 1, 2,…..,T), and μ is an error term. The focus of the study is on the impact of corruption on economic growth, so α1 is the coefficient of main interest. As both CPI and V-DEM corruption indices are interpreted so that higher value of them indicates lower corruption level in a country, so I expect that the positive sign (α_1< 0) supports the hypothesis that corruption 'greases the wheels'; whereas negative sign of the coefficient of corruption (α_1> 0) implies that corruption 'sands the wheels'.

For my panel, I expect the marginal effect of corruption on growth to change as the incidence of corruption increases. To test for this nonlinearity, I add squared corruption (CORR^2) as an explanatory variable. A negative sign will support the hypothesis that at a high, level of incidence corruption is more decentralized and growth-reducing. A positive sign indicates that the relationship between corruption and its effect on growth is low.

Arellano and Bond (1991) present a method (AB first difference GMM method) suitable for estimating this dynamic model for a panel of countries whose data are available for a short period (N is large and T is small). Applying the definition of a growth rate of the intensity-output proxy ($Z_{i,t} = \log Z_{i,t} - \log Z_{i,t-1}$) and rearranging terms and adding squared corruption (CORR^2) as an explanatory variable, the estimating equation in the AB first difference GMM method is the structural equation in first difference:

$$\begin{aligned}\log Z_{i,t} - \log Z_{i,t-1} \\ &= y_2(\log Z_{i,t} - \log Z_{i,t-2}) + y_3(CORR_{i,t} - CORR_{i,t-1}) \\ &+ y_3(CORR^2_{i,t} - CORR^2_{i,t-1}) + \beta_j(X_{ijt} - X_{ijt-1}) + (\varepsilon_{i,t} - \varepsilon_{i,t-1})\end{aligned}$$

With μ eliminated, the AB method uses internal instruments for each of the first differenced explanatory variables. For exogenous explanatory variables, the first differenced term $(X_{ijt} - X_{ijt-1})$ is instrumented by itself. In the case independent variable, $(\log Z_{i,t} - \log Z_{i,t-2})$ can be instrumented by $\log Z_{i,t-2}$ under the assumption that $E[\log Z_{i,t-S}, (\varepsilon_{i,t} - \varepsilon_{i,t-S})] = 0$ for $S > 2$; $t = 3, \ldots$, i.e., that current lights-output proxy are uncorrected with the level of corruption (and other endogenous variables) two periods ago.

4.3. Empirical results

Table 1 below represents estimation results of the difference GMM model. Table includes columns with lagged natural logarithm of the independent variable (lights-output proxy Z), explanatory variable CORR and the lists of exogenous explanatory variables and control variables; parameter estimates of the model and their significance. In the end of the table various tests of the estimated models are presented. Column 1 and column 2 resulting models with lights-output proxy Z as independent variable. In the last column (3) the same estimations are performed but using classical natural logarithm of the GDP per capita as independent variable.

Table 1. Difference GMM (Arellano–Bond first difference GMM) estimation results using CPI

	(1)	(2)	(3)
Lagged lnZ	0.5429 (***)	0.0113	
Lagged lnGDPPC			0.6543 (***)
CPI	0.0142 (***)	0.0432 (***)	0.0071 (**)
CPI^2		-0.0003 (**)	
FDIGDP	0.0076	0.0061	0.0075
EXGDP	-0.0115 (*)	-0.0149 (*)	-0.0014
OPENNESS	-0.0023	0.0038	0.0024(*)
POPGR	0.0364 (*)	-0.008	0.0124(**)
KWHPC	0.0001	0.0005	0.0001
Wald test(*p*-value)	0.0	0.0	0.0
J-statistic (*p*-value)	0.0425	0.1994	0.0347
H0:AR(1) is absent (*p*-value)	0.04038	0.0112	0.0389
H0:AR(2) is absent (*p*-value)	0.2394	0.3651	0.4574
No. of observations	266	266	266
No. of countries	14	14	14

The asterisks ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively

Source: author's calculations

First model passes the test for the absence of the AR-2 process in the differenced error term, J-statistic and the Wald tests. Results with estimation using CPI index in the GMM specification show even higher coefficient and significance at 1%. Corruption has a negative effect on my lights-output proxy. A one-standard-deviation increase (an improvement) in the CPI index raises the natural log of Z (Output) by 0.168% (obtained by multiplying 0.0142, the slope coefficient, by 12.704, the standard deviation of the CPI index in Table 3). That mean that output Z increase on average by 6.8% if we increase our CPI index on approximately 12 positions, i.e. from the level of the CPI of Tajikistan to the level of Moldova (Table 4). Comparing to the model with GDP per capita as independent variable (column 3), where the same increase in CPI level tends to increase of the GDP per capita on 9%.

I reject no autocorrelation of order 1 and cannot reject no autocorrelation of order 2. There is evidence that the Arellano–Bond model assumptions are satisfied. I re-estimated the GMM system model in Table 1 column 2 by adding the coefficient on squared corruption - CPI^2 - to check the sign of the coefficient. The results are reported in column 2. This model passes the test for the absence of the AR-2 process in the differenced error term and the Wald test. The J-statistic is higher because the model has been extended, but since this test for over identifying restrictions and this model has a p-value of 0.1994, which is not far from 0, I assume that over identifying restrictions are consistent in this case. When squared corruption is added as an explanatory variable, the coefficient on corruption is significantly larger (compare column 1 with column 2). The estimated effect of corruption in that case has higher value and statistically significant: a one-standard-deviation increase (an improvement) in the CPI index raises the natural log of Z by 0.548% (Output Z increase on 54.8% with increase of CPI on average 12-13 points).

4.4. Robustness check

Table 2 below represents estimation results of the difference GMM model but using V-DEM corruption index instead of CPI to see the impact of corruption on economic growth. Column 1 and column 2 resulting models with lights-output proxy Z as independent variable, column 3 – GDP per capita.

Table 2. Difference GMM (Arellano–Bond first difference GMM) estimation results using V-DEM index

	(1)	(2)	(3)
Lagged lnZ	0.7390 (***)	0.0037	
Lagged lnGDPPC			0.7458(***)
VDEM	0.0021 (***)	0.0262(**)	0.0012(*)
$VDEM^2$		-0.0002(*)	
FDIGDP	0.0051	0.005	0.0021
EXGDP	-0.0155 (**)	-0.0116(*)	-0.0014
OPENNESS	-0.0012	-0.0013	0.0124(**)
POPGR	-0.0950	0.0128	-0.0214(**)
KWHPC	0.0003	0.0008	0.0001
Wald test(*p*-value)	0.0	0.0	0.0
J-statistic (*p*-value)	0.0425	0.1994	0.0056
H0:AR(1) is absent (*p*-value)	0.0404	0.0112	0.0012

H0:AR(2) is absent (*p*-value)	0.2394	0.3651	0.2714
No. of observations	266	266	266
No. of countries	14	14	14

The asterisks ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively

Source: author's calculations

The result using V-DEM index shows smaller coefficients for corruption. However high significance at 1% level is still observed. A one-standard-deviation increase (an improvement) in the VDEM index raises the natural log of Z (Output) only by 0.067% (obtained by multiplying 0.0020874, the slope coefficient, by 31.708, the standard deviation of the V-DEM index). That mean that increase of the V-DEM index by 31-32 points tends to cause only to 6.7% increase in output Z. The $CORR^2$, using VDEM index (in column 2) is statistically significant and negative in sign as expected: a one-standard-deviation increase (an improvement) in the V-DEM index raises the natural log of Z by 0.781% (Output Z increase on 78.1% with increase of V-DEM on average 31-32 points).

Column 3 parameter estimates displays the impact of increase in V-DEM index on 30 points increase of GDP per capita only by 3.8 %. However, the coefficient on corruption is statistically significant at 10% level and has a positive sign indicating that corruption is growth reducing.

4.5. Discussion

From results above the corruption has an ample effect on economic growth and this effect is negative. Re-estimated models with $CORR^2$ supports finding that the effect of corruption on the lights-intensity proxy is negative and, furthermore, that the marginal effect of a change in the level of corruption Z declines with an increase in level. The coefficient for squared corruption is significant when measured by CPI (1% significance) and V-DEM index (5% significance). However, the sign for squared corruption is negative in all specifications, rejecting hypothesis based on Shleifer and Vishny (1993) that corruption is more growth reducing at higher levels because of how corruption is organized and supporting the hypothesis by Swaleheen (2011) that with regard to how the effect of corruption changes with its level (measured by squared corruption), it supports that the impact is changing with the incidence of corruption (different levels of corruption has different effects on growth). For my sample of countries, the effect of a change in the corruption can be calculated including CORR[2] as an explanatory variable in equation 5 and taking derivative:

$$\frac{\partial lnZ}{\partial CPI} = 0.0432 - 2 \times 0.0003 \times CPI \quad (7)$$

Equation (7) shows that when the level of corruption is allowed to vary in the sample of my countries, corruption is not growth reducing at all levels. When CPI reaches 72, corruption has no effect on growth at the margin. Beyond this level, corruption is actually growth reducing. At its highest incidence in my sample, i.e., in the case of Turkmenistan which has the lowest CPI at 17, corruption is greatly growth reducing.

The figure 4 illustrates positive slope of the parabolic relationship between corruption and economic growth and provides the growth maximizing level of corruption, which is 72 according to GMM estimations using CPI measure:

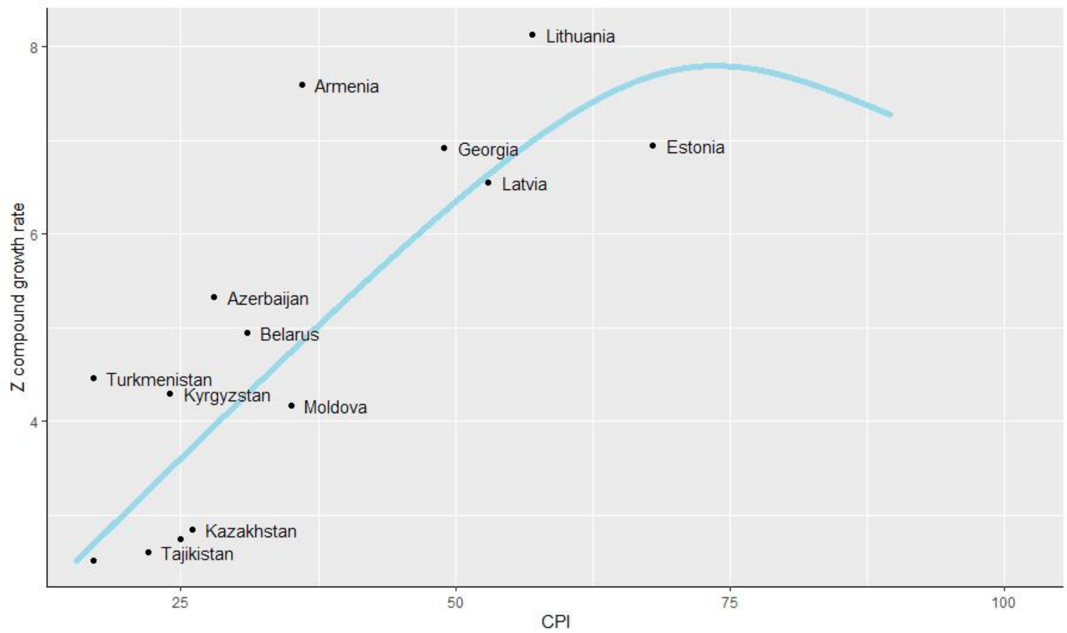

Figure 4. Growth maximizing level of corruption

Source: compiled by author

The models that used output proxy Z demonstrated higher impact of corruption on economic growth compared to models using GDP measure, that can be explained by evidence on data reliability, overestimation of the GDP, governmental accounting differences etc. For example, Martinez (2017) estimated that the most authoritarian regimes inflate yearly GDP growth rates on average by a factor of 1.15-1.3 %. and the economic success of non-democracies in recent years has been manipulation. Sample of my countries mainly includes such countries. Table 4 reports measured growth rates of lights-output proxy, GDP per capita and their difference.

Table 3. Comparison of output growth rates

Country	CPI (2013)	Z growth rate	GDP per capita growth rate	Δ_{gr}
Lithuania	57	8.13	4.46	-3.67
Estonia	68	6.95	4.50	-2.44
Latvia	53	6.55	4.61	-1.94
Ukraine	25	2.75	1.57	-1.18
Moldova	35	4.17	3.02	-1.15
Georgia	49	6.92	5.96	-0.96
Armenia	36	7.60	6.89	-0.71
Belarus	31	4.95	5.47	0.52
Kyrgyzstan	24	4.29	5.58	1.29
Kazakhstan	26	2.85	4.28	1.43
Tajikistan	22	2.61	4.93	2.32
Turkmenistan	17	4.47	6.90	2.43
Uzbekistan	17	2.52	5.77	3.25
Azerbaijan	28	5.33	9.56	4.24

Source: compiled by author.

From the table 3, we can compare how correlated the level of corruption and the difference between growth rates are. In my sample, Baltic trio including Estonia, Latvia and Lithuania are post-soviet countries with highest CPI and negative difference between actual GDP growth rate and generated lights-output proxy Z, while at the same time, at the bottom of the table are the countries with the lowest level of the CPI and at the same time with the largest difference in growth rates. Correlation between the differences in growth rates and CPI measure is -0.821, that proves high relationship between them.

When we look at the positive difference values between growth rates in the final column, these values belong to the countries which have authoritarian government style with very weak institutional setting. This could be attributed to the several factors. First, these less democratic countries might have inflated their economic growth rates since availability of public interest data is highly dependent on the regime type and authoritarian regimes tend to be less transparent than democratic ones (Hollyer et al., 2011). Political role of information is huge in authoritarian regimes, thus, there is a high likelihood of manipulation of macroeconomic statistics in these regimes for purpose of maintaining the power (Wallace, 2016). As a result, potentially manipulated macroeconomic statistical indicators would not show themselves in reality as concrete and physical developments. Second, even if the money is spent for specific investments, this may not be fully realised due to widespread corruption (Lehne et al., 2018). Indeed, according to CPI reported in Table 4, these countries have very low corruption rating. Eventually, taxpayers' money would disappear and end up in the corrupt hands, and hence, promised developments may not take place as it was caught (or not observed) in night lights data.

5. Conclusion

In this thesis I presented evidence that corruption has a direct effect on growth, that effect is negative and non-linear. To judge the relative importance of the effect of corruption, we now can compare effects of a one standard deviation change in the explanatory variables (CPI or V-DEM index) on both the growth rate of the generated lights-output proxy and the growth rate of real GDP per capita. Models with CPI results that output Z increase on average by 6.8% if we increase our CPI index on approximately 12 positions, i.e. from the level of the CPI of Tajikistan to the level of Moldova. Comparing to the model with GDP per capita as independent variable the same increase in CPI level tends to increase of the GDP per capita on 9%. That can be explained by evidence on data reliability, manipulation of macroeconomic statistics and regime type of a country.

I re-estimated the GMM system model by adding squared indices to check for the sign of the coefficient. With the negative sign, the model proves that the effect of corruption is parabolic and that the marginal effect of a change in the level of corruption on the growth rate declines with a decrease in corruption (increase in the level of corruption index). All models pass the tests for the absence of AR-2 process in the differenced error term, Wald and the Sargan–Hansen J tests. Models estimation using V-DEM index of corruption proves that impact of corruption is robust.

The evidence from this study demonstrates the statistical importance of corruption and shows the possibilities of studying this phenomenon for subsequent research using updated data or exploring each country separately.

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APPENDIX A

Table of lights, 2013

Country	Mean number of observations per pixel	Sum of the light values (millions)	Mean of the light values	Captured area (km^2)
Armenia	534	141,913	81	29,690
Azerbaijan	567	447,346	34	86,235
Belarus	257	1,371,270	19	207,069
Estonia	679	429,876	59	45,489
Georgia	630	222,266	70	69,844
Kazakhstan	763	2,851,084	9	2,730,536
Kyrgyzstan	527	288,682	115	198,649
Latvia	202	313,518	12	64,710
Lithuania	364	423,037	30	65,016
Moldova	1966	186,683	164	33,907
Tajikistan	268	181,085	55	142,113
Turkmenistan	321	684,509	67	489,593
Ukraine	1342	3,338,343	140	601,362
Uzbekistan	731	1,139,535	117	447,555

Source: author’s own compilation

APPENDIX B

Main information about the data

Code	Variable	Description
sumlights	Sum of the light values	Sum of the light values in area (in millions)
meanobsperpix	Mean number of observations per pixel	Mean number of observations per pixel that went into the aggregated image for a time period in a given area
area	Area	Area of a region captured using a shape file of an area
meanlights	Mean number of the lights	Mean of the light values in a given area
lightsarea	Intensity of light on an area	Intensity of light on an area as sum of lights to area ratio
Z	Lights-output proxy	Generated lights-output proxy measure of economic activity
GDPPC	Gross Domestic Product per capita	Gross Domestic Product per capita in USD
CPI	Corruption Perception Index	Corruption Perception Index, multiplied by 10 for all old format indices to get the same estimation value.
VDEM	V-DEM Corruption Index	V-DEM Corruption Index measure, multiplied by and subtracted from 100 to get the same estimation value as CPI. From 0 to 100 (higher value indicates lower corruption presence)
EXGDP	Government expenditures to GDP	Government expenditures to GDP ratio
FDIGDP	FDI to GDP	Foreign direct investments to GDP ratio
OPENNESS	Import plus export to GDP ratio	Openness of the economy ratio: import plus export to GDP ratio
KWHPC	Kilowatt hour per capita	Kilowatt hour per capita consumption in a country
POPGR	Population growth rate	Population growth rate of a country

Source: author’s own compilation

APPENDIX C

Descriptive statistics and correlation for selected variables

	ln(Z)	ln(GDPPC)	CPI	VDEM	EXGDP	FDIGDP	OPENNESS	KWHPC	POPGR
Average	2.722	23.116	31	35	15.972	6.124	99.795	2617.402	0.093
Median	2.81	23.125	26	17	16.608	4.655	94.904	2250.321	-0.232
Maximum	3.466	26.19	68	96	32.014	55.076	181.59	6689.368	2.823
Minimum	1.782	20.573	15	4	5.941	-0.963	36.619	1050.244	-3.758
Standard deviation	0.323	1.296	12.704	31.789	4.815	6.544	29.585	1147.985	1.231
Correlation									
	ln(Z)	ln(GDPPC)	CPI	VDEM	EXGDP	FDIGDP	OPENNESS	KWHPC	POPGR
ln(Z)	1		-	-	-	-	-	-	-
ln(GDPPC)	0.04	1	-	-	-	-	-	-	-
CPI	0.46	0.02	1	-	-	-	-	-	-
VDEM	0.49	0.15	0.85	1	-	-	-	-	-
EXGDP	0.78	0.03	0.46	0.47	1	-	-	-	-
FDIGDP	-0.28	-0.01	-0.07	-0.11	-0.29	1	-	-	-
OPENNESS	0.25	-0.1	0.45	0.36	0.27	0.06	1	-	-
KWHPC	0.23	0.52	0.61	0.52	0.22	0.06	0.45	1	-
POPGR	-0.27	-0.08	-0.57	-0.53	-0.26	0.11	-0.04	-0.24	1

Source: author's own compilation

APPENDIX D

Generating lights-output proxy results

	β	Z	R^2 (within country)
Armenia	0.5449 (***)	25.92	0.8908
Azerbaijan	0.1646(**)	31.28	0.4542
Belarus	0.3094(***)	46.64	0.2997
Estonia	0.2441(**)	94.76	0.2819
Georgia	0.6729 (***)	4.78	0.8529
Kazakhstan	0.4734(*)	5.76	0.3954
Kyrgyzstan	0.1245(**)	8.65	0.4875
Latvia	0.2289 (**)	35.08	0.3059
Lithuania	0.3145(**)	84.62	0.3458
Moldova	0.6454 (***)	42.57	0.6847
Tajikistan	0.2456 (**)	8.19	0.3498
Turkmenistan	0.3456 (*)	8.55	0.3458
Ukraine	0.3478(*)	43.71	0.2587
Uzbekistan	0.5749(**)	19.18	0.3145

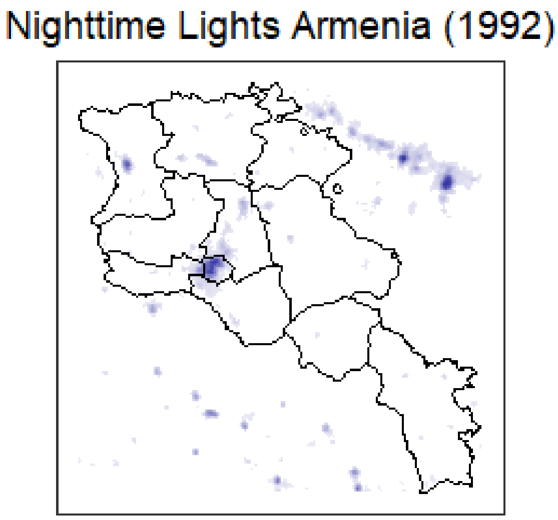
Note: Sample of 14 countries from 1995 to 2013

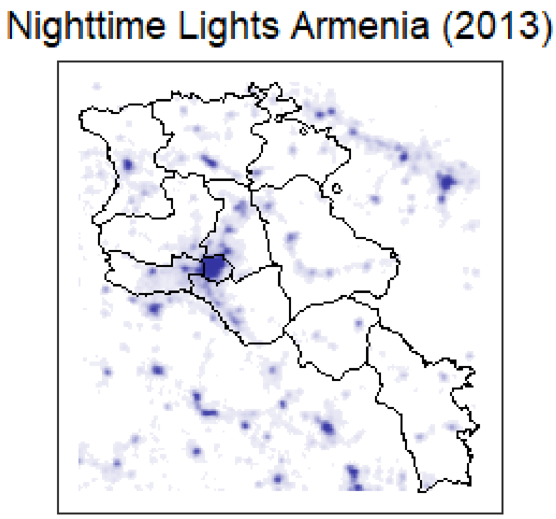
The asterisks ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively

Source: author's own compilation

APPENDIX E

Comparative illustrations for the sample of countries





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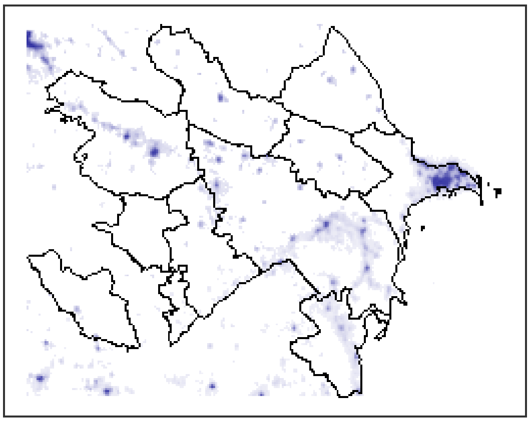

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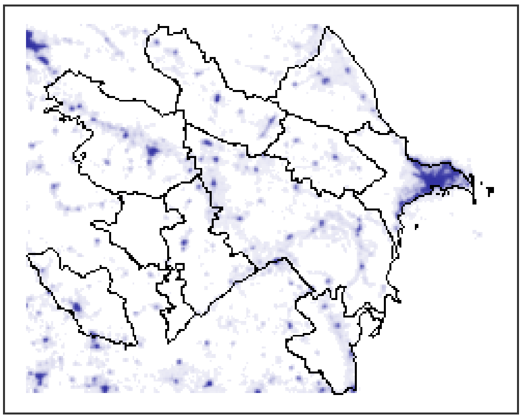

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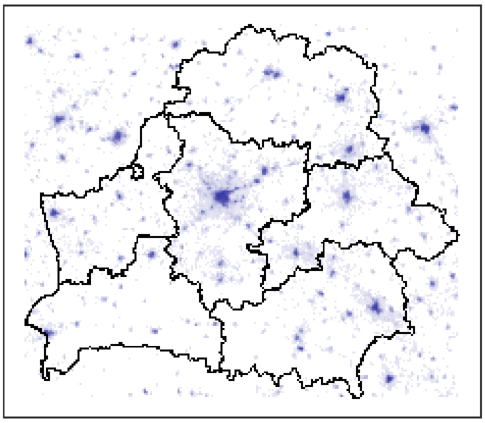
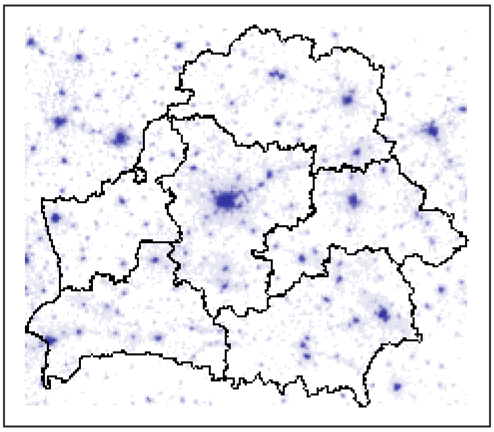
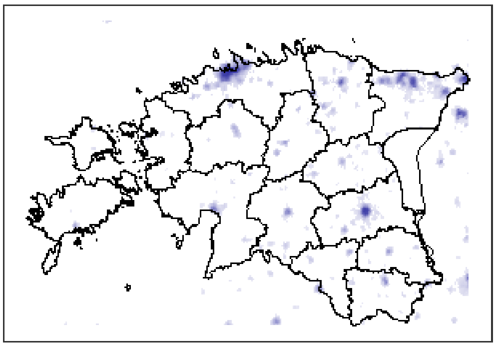


Nighttime Lights Belarus (2013)



Nighttime Lights Estonia (1992)



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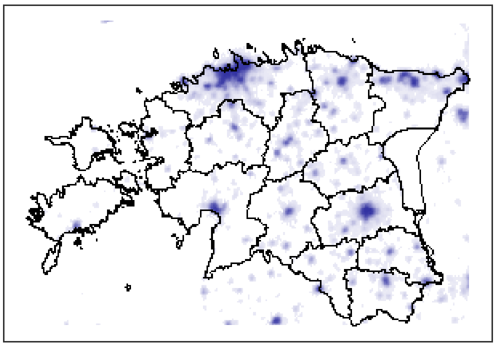

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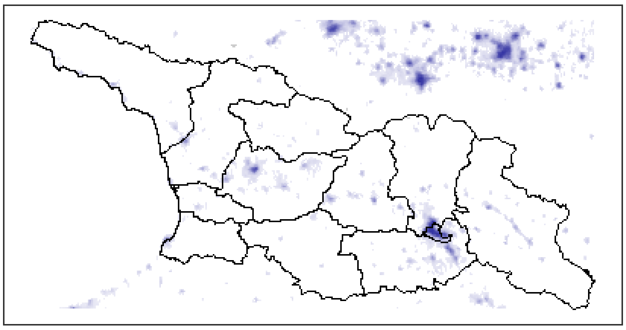

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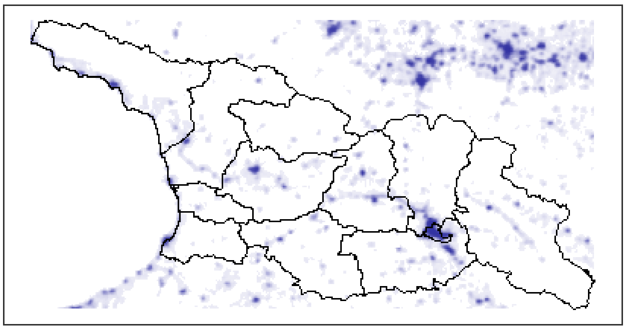

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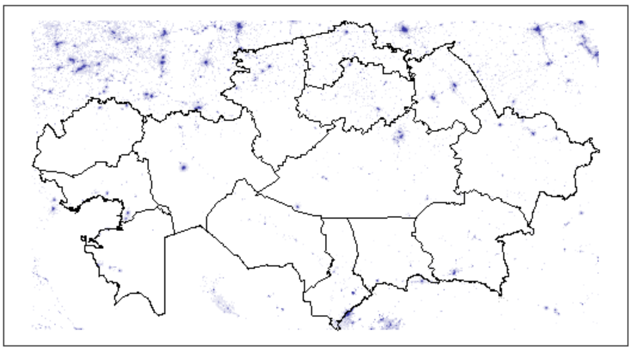

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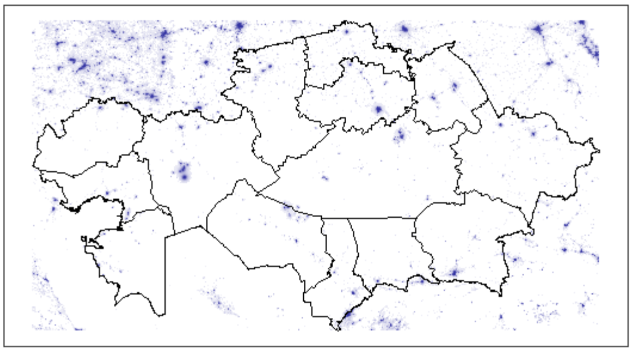
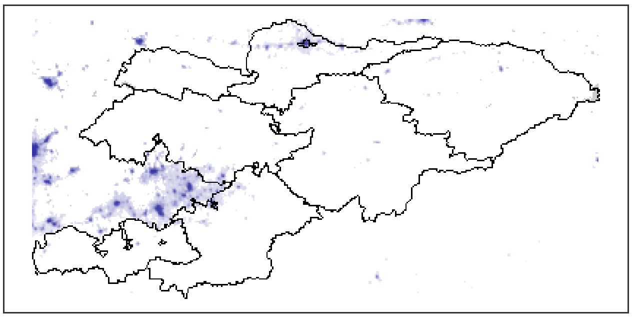


Nighttime Lights Kyrgyzstan (1992)



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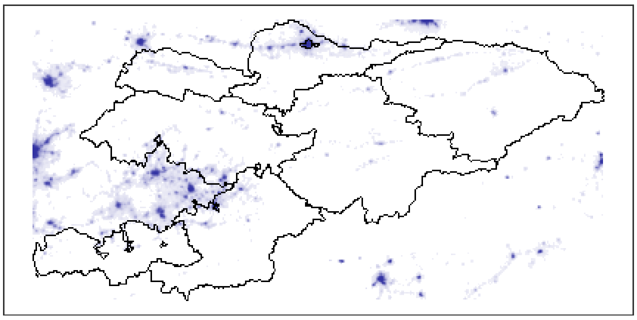
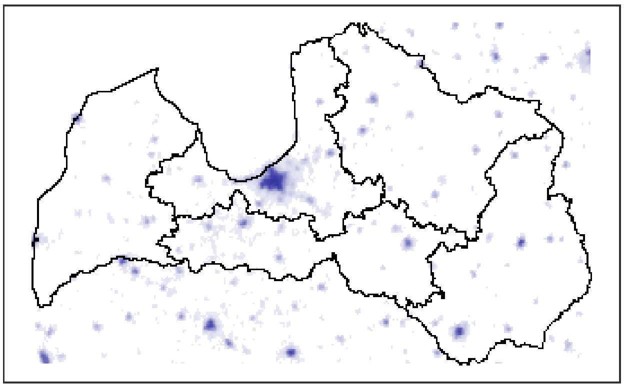


Nighttime Lights Latvia (1992)



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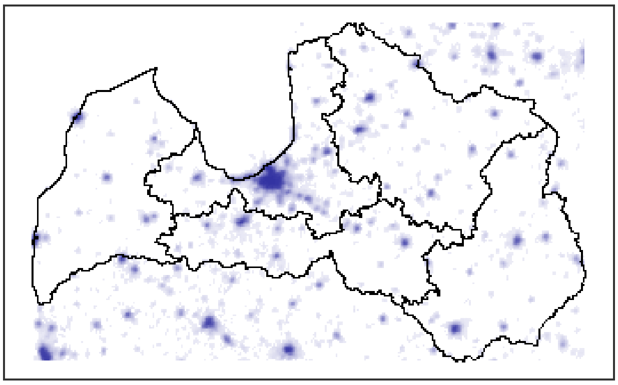

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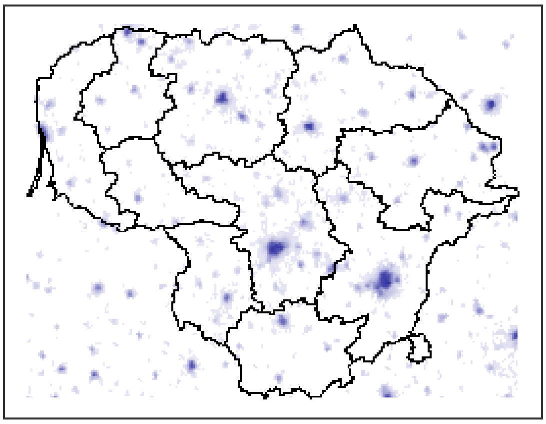

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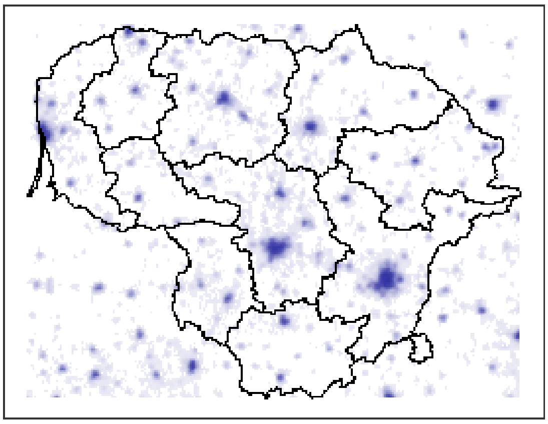
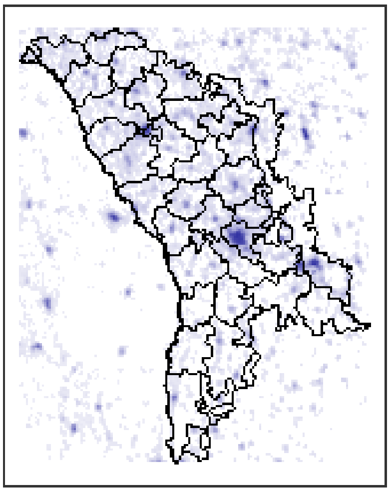


Nighttime Lights Moldova (1992)



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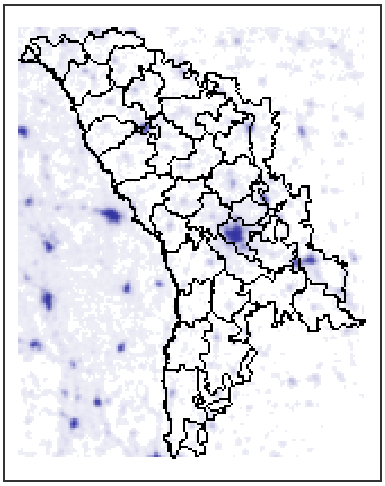

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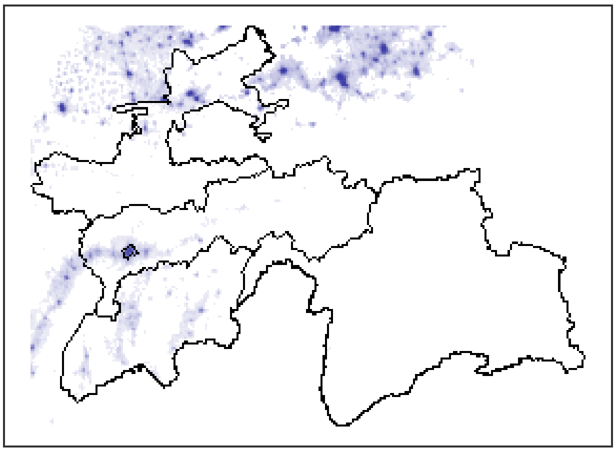

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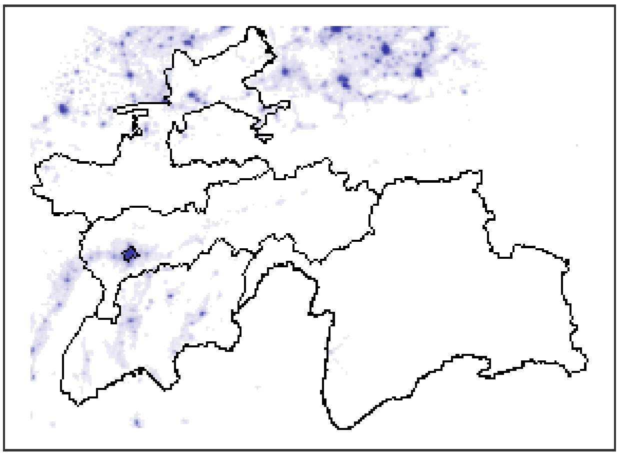

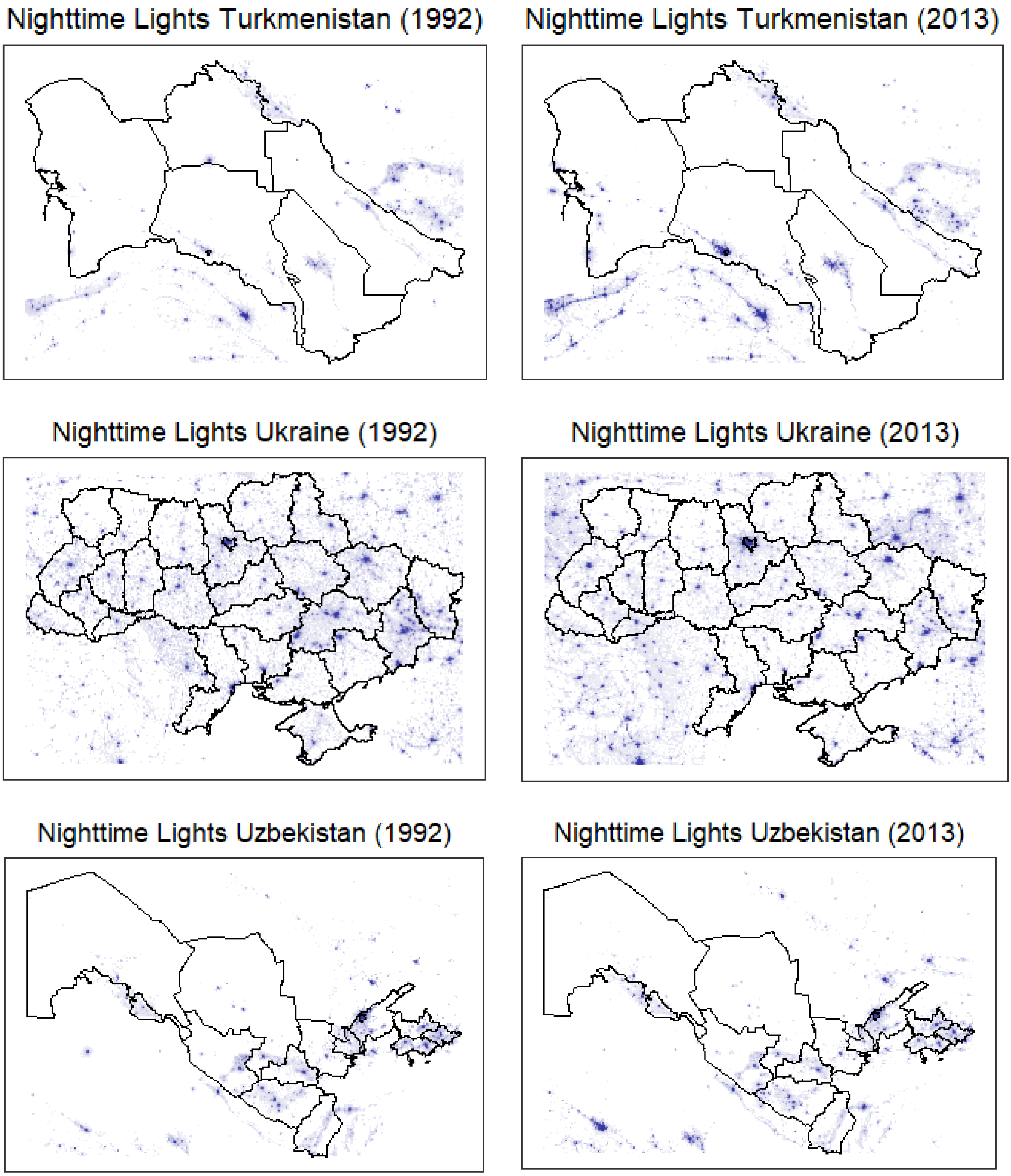

Source: author’s own compilation

Resümee

Korruptsioon ja majanduskasv: uue tõendid satelliidiandmetes

Danyl Denysenko

Korruptsiooni mõju majanduskasvule uurinud kirjandus on tuginenud ametliku statistika poolt avaldatavatele makroökonoomilistele indikaatoritele, mis võivad olla mõjutatud valitsusepoolsetest manipuleerimistest. Käesoleva magistritöö eesmärgiks on uurida satelliitide abil kogutud öötulede andmete kasutusvõimalusi uurimaks seoseid korruptsiooni ja majanduskasvu vahel post-Sovietlikes riikides perioodil 1995-2013. Empiirilises analüüsis kasutatakse erinevaid andmestikke: USA Rahvusliku Geofüüsikalise Andmekeskuse öötulede andmete alusel genereeritud kogutoodangu lähend; korruptsiooni taseme mõõtmiseks Transparency International korruptsiooni tajumise indeks ning Demokraatia Mitmekesisuse Andmestiku (Varieties of Democracy Dataset) V-Dem korruptsiooni indeks. Üldistatud momentide meetodi hindamine 14 riigi paneelandmete abil näitas, et korruptsioonil on oluline mõju nii öise valgustuse andmete alusel tuletatud kogutoodangu lähendi kui ka per capita SKP kasvule. Vastav seos on samas mittelineaarne ja öötulede andmete alusel tuletatud kogutoodangu lähendi kasutamisel oli korruptsioonil suurem mõju majanduskasvule võrreldes traditsioonilise SKP mõõdiku kasutamisega. Viimast tulemust võiks selgitada andmete usaldusväärsuse küsimustega osades analüüsi kaasatud riikides, makroökonoomiliste statistika manipuleerimisega ja eri riikide poliitilise režiimi tüüpidega.

Võtmesõnad: *öötulede andmed, korruptsioon, majanduskasv, post-Sovietlikud riigid, paneelandmed, üldistatud momentide meetod*

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24/05/2021