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# Monitoring Economic Development from Space: Using Nighttime Light and Land Cover Data to Measure Economic Growth

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**Summary.** — This study demonstrates estimations of economic activities on global, national, and subnational levels using remote sensing data, with a focus on developing economies. It extends a recent statistical framework which uses nighttime lights to estimate official income growth by accounting for agriculture and forestry which emit less or no additional observable nighttime light. The study argues that nighttime lights alone may not explain value-added by agriculture and forestry. By adding land cover data, our framework can be used to estimate economic growth in administrative areas of virtually any size.


*Key words* — remote sensing, economic growth, land cover, MODIS, gross domestic product, gross regional product

## 1. INTRODUCTION

The problem of measuring economic growth has stimulated research in economics and economic geography for many decades (Barro, 1991; Gallup, Sachs, & Mellinger, 2009; Maddison, 1995). The traditional approaches of estimating growth aim to measure changes in economic activities at national or global scales. However, the subnational dimensions of change in economic activities are also important, particularly in order to understand the interactions between local progresses/failures and those at higher geographical scales. In fact, development issues operate at intrinsically different spatial and temporal scales. Despite continuous revisions of knowledge, methodologies, and techniques for measuring income and economic activity using conventional ground survey-based data, reliable yearly statistics at the national level are often a luxury. Many poor countries lack both the resources and the capacity to acquire such reliable data, despite decades of international statistical support. The UN Statistical Commission has supported a standardized system of national accounts (SNA) since 1953, yet even today many developing countries do not regularly produce the full SNA due to capacity and cost constraints. A number of studies have actually pointed out potentially serious measurement errors in growth figures, particularly in developing and emerging economies (Henderson, Storeygard, & Weil, 2012; Johnson, Larson, Papageorgiou, & Subramanian, 2013; Nordhaus, 2006; Ravallion & Chen, 1999).

Since the early days of satellite remote sensing, its accessibility, quality, and scope have been continuously improving, making it a rich data source with a wide range of applications. Although there are a few examples of remote sensing to be found in the social sciences, developments have, on the whole, been less pronounced than in the natural sciences (Hall, 2010). This has historically been attributed to (a) the need for inhouse remote sensing expertise which is rarely found in social science departments, (b) the fact that many of the variables of interest in contemporary social science research are not directly observable from space, and (c) the very high costs for data acquisition.

Satellite remote sensing missions are generally designed for specific applications, often earth sciences related, such as vegetation classification and weather forecasting. The Defense-Meteorological Satellite Program-Optical Line Scanner (DMSP-OLS), launched in the early 1970s, was designed to observe clouds at night for weather forecasting purposes. However, its sensor was soon found to be very good at detecting the presence of light at night on Earth (Croft, 1978). The DMSP-OLS sensor is sensitive enough to detect street lights and even saury fishing vessels at sea (Saitoh *et al*., 2010). The lighting detected by the DMSP-OLS is largely 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 (Figure 1).

Recent studies conducted by economists have paid more attention to artificial nighttime light data and efforts have been made to associate these observations with economic growth in order to cope with estimation errors (Chen & Nordhaus, 2011; Doll, Muller, & Morley, 2006; Ebener, Murray, Tandon, & Elvidge, 2005; Elvidge *et al*., 1997; Ghosh, Powell, Elvidge, & Baugh, 2010; Henderson *et al*., 2012; Sutton & Costanza, 2002). These studies have made attempts to advance research in two directions: (a) estimation of a consistent and objective level of economic activities, such as PPP, real GDP, and nominal GDP, and (b) disaggregation of these measures into smaller administrative/non-administrative areas where official statistics are otherwise lacking or unavailable. While these existing studies pushed literature forward greatly by showing potential applications of remote sensing data in economics, the remote sensing data accumulated since 1970s are tremendous and many more uses remain to be explored. The main limitations of these existing studies is their overdependence on nighttime lights and therefore their tendency to underestimate economic activities that emit less or no additional nighttime light as they grow. This is particularly troublesome in

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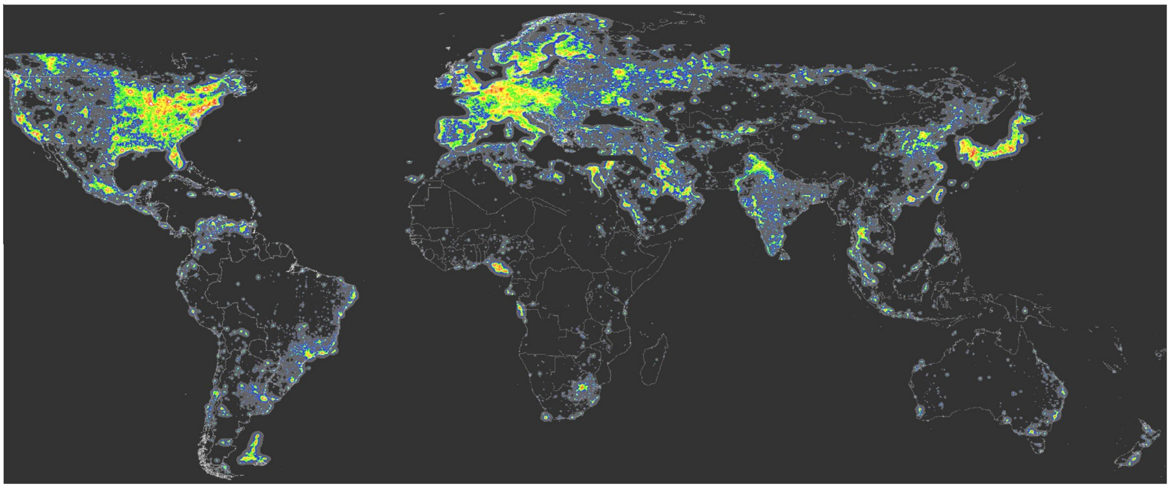

Figure 1. *A global view of nighttime lights year 2012 from the DMSP (Defense Meteorological Satellite Program).*

developing economies which often have a larger share of agriculture or forestry and therefore weaker linkages with nighttime lights.

The principle aim of this paper is to explore another potential remote sensing data source, namely land cover. The rest of this paper is structured as follows. Section 2 summarizes applications of remote sensing data in economic analysis thus far, before discussing some potential improvements. Section 3 reviews the data used in the analysis conducted in this paper, with a particular focus on remotely sensed land cover data. Section 4 sets estimation models by extending a framework developed by Henderson *et al.* (2012) and discusses the estimated results. Section 5 concludes.

## 2. REMOTE SENSING DATA AND ECONOMIC ANALYSIS

Our principle aim is to estimate economic growth 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 and examine their methodologies, results, advantages, and drawbacks in turn. Croft (1978) was among the first to point out that nighttime light reflects human economic activities on the ground. This led Elvidge *et al.* (1997) to estimate population, GDP (PPP $), and electricity usage in lit areas. Through a single year cross-sectional analysis of 21 countries 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, respectively). Using area lit instead of sum of observed light intensity makes Elvidge *et al.* (1997) unique from most of the later studies. This study reveals that a statistically significant relationship between nighttime 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 upward as well as outward.

Sutton and Costanza (2002) instead use the sum of the intensity of nighttime light 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 nighttime light 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. It is obvious that this will produce many sub-national administrative areas without GDP, as there are many areas without observed nighttime lights. Nevertheless, the introduction of ESP to account for economic activities that may not be captured by nighttime lights is highly suggestive. Using coefficients determined at the 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.

Doll *et al.* (2006) estimate the relationship between the sum of nighttime light and the available Gross Regional Product (GRP) of 11 countries in the EU and states in USA. The elasticity of GRP on the sum of nighttime 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 remaining domestic regions. The elasticity of these outliers is determined separately from the rest of the regions within each country. Only the Netherlands and Greece are found to have one consistent elasticity applicable nationwide. This shows that elasticity of nighttime light and GRP varies in most countries. For this reason, it is important to be cautious when using nighttime lights 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 that agriculture does not emit observable nighttime light. 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 nighttime lights and value-added. Cross-sectional regression is used to determine specific coefficients for each group. Non-lit area is accounted for by grid population data from Landscan. [1] The population grid is used to assign agricultural output to sub-national geographic areas. Apart from limitations coming from a single-year 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 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.

Single-year analysis is common among the studies discussed so far. In addition to the high cost to acquire processed data in