MONTHLY GDP ESTIMATION FOR JAPANESE PREFECTURES BY NIGHTTIME LIGHT AND LANDCOVER DATA

Jonggeol Park
Professor, Tokyo University of Information Sciences
2658501 4-1 Wakabaku Onaridi Chiba Japan
Email: amon@rsch.tuis.ac.jp

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ABSTRACT: In this study, VIIRS/DNB data and land cover data were utilized to estimate the monthly GDP of Japan's prefectures. The learning data consisted of six years from 2014 to 2019, while the validation data spanned three years from 2020 to 2022 for accuracy assessment. The time-series DNB data contained seasonal noise, such as snow, and irregular noise, such as clouds. Hence, the STL method was applied to eliminate noise components other than the artificial light source. Considering that GDP varies depending on the method of regional economic activity, we classified it based on the land cover ratio of prefectures and investigated its relationship with DNB. The results revealed that employing the regional classification and DNB trends proposed in this study proved more effective.

1. INTRODUCTION

Gross Domestic Product (GDP) is an indicator that represents the total economic activity within a country or region during a specific period. Economic activity encompasses all production of goods and services by businesses and individuals in that area. Therefore, GDP is a key measure to understand the entirety of economic activity. When the economy is doing well and there is increased production of goods and services by businesses and individuals, GDP goes up. Conversely, during economic downturns or events like pandemics, economic activity decreases, leading to a decrease in GDP.

GDP serves as a benchmark for assessing the health and growth of the economy and is used for evaluating economic trends. It plays a pivotal role in the decision-making process for governments, central banks, businesses, investors, and other economic stakeholders when planning for future strategies and policies. As such, the accurate and timely estimation of GDP is crucial, as it has a significant impact on many individuals involved in the economy.

Quarterly GDP preliminary reports and annual national economic calculations are published as indicators representing the overall economic situation of Japan. The publication frequency is quarterly for GDP preliminary reports and annually for national economic calculations. Additionally, regional economic calculations, reflecting the economic conditions of each prefecture, are also made available. However, the publication frequency for regional economic calculations is annual, with a lag of 2 to 3 years before the data is released. The primary reasons for this lag include data collection, processing, revisions, seasonal adjustments, adjustments for factors, and quality assurance.

Many studies have utilized nighttime satellite imagery to estimate economic activity and GDP more rapidly. Satellites like DMSP (Defense Meteorological Satellite) with its OLS (Operational Linescan System) and VIIRS (Visible Infrared Imaging Radiometer Suite) with its DNB (Day/Night Band) possess sensors in the visible and near-infrared spectrum (0.47–0.95 μm) that enable the observation of nighttime lights. This data has been used to estimate nighttime economic activity and population.

For instance, Welch and Zupko (1980) modeled nighttime light data from DMSP/OLS against socioeconomic indicators and found a strong correlation between light dome volume, population, and electricity consumption in 35 U.S. cities. Similar studies have been conducted in various regions worldwide, such as China, India, and multiple countries studied by Elvidge et al. (using DMSP/OLS). These studies have revealed strong correlations between nighttime lights, population, economic activity, and electricity consumption.

However, many of these studies did not adequately account for noise components in satellite data (such as atmospheric interference, clouds, and snow) or regional industrial characteristics, leading to lower accuracy in GDP and EPC (Electric Power Consumption) estimations.

Another factor that can be used to estimate economic growth is the transportation network and traffic volume. As economies grow, there is typically an increase in demand, which in turn leads to higher traffic volumes. This is because in growing economies, more goods and services are produced and distributed, resulting in increased logistics and people's movement. Therefore, there is a close relationship between transportation infrastructure and traffic volume with GDP. Efficient transportation infrastructure promotes economic growth and contributes to increased productivity by ensuring smoother logistics and mobility.

In this study, we used time-series DNB (Day/Night Band) nighttime light data to estimate the GDP of Japan's 47 prefectures. We focused on the relationship between traffic volume and GDP, using DNB data to factor in urban and road areas for GDP estimation. Urban areas were defined using a threshold of annual average DNB values, while road areas were identified using road data from national land information for national and express highways. The DNB data from the extracted urban and road areas were decomposed into trend, seasonal variation, and residuals using the STL (Seasonal-Trend Decomposition Procedure Based on LOESS) method to remove noise components such as clouds and snow.

We also considered that nighttime light usage may vary based on regional land use characteristics. Therefore, we conducted unsupervised clustering based on each prefecture's land cover ratio, dividing them into four groups, and verified the accuracy of GDP estimation for each group. Finally, we compared our research methodology with existing methods to assess the effectiveness of this study.

2. DATA

2.1 VIIRS/DNB

The Visible Infrared Imaging Radiometer Suite Day/Night Band (VIIRS/DNB) is a highly advanced instrument installed on Earth-observing satellites like Suomi National Polar-orbiting Partnership (NPP) and Joint Polar Satellite System (JPSS) series.

For our research, we utilized VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1, made available through Google Earth Engine. We specifically used the "avg_rad" band to represent the luminance values within the DNB dataset. The "avg_rad" has a resolution of 500 meters and is measured in nWatts per square centimeter per steradian (nWatts/cm²/sr). The data was collected and analyzed from January 2014 to June 2022.

2.2 Monthly GDP

The disclosure of monthly GDP data for each prefecture takes more than a year because of the time required to collect and process the data. To address this delay, Yamazawa et al. (2022) conducted a regression analysis using factors like the steel industry production index, general construction statistics, and the tertiary industry activity index to swiftly estimate GDP. The estimation outcomes were then adjusted to match the quarterly gross prefectural product and the national real GDP. Given the aim of rapid GDP estimation in our study, we utilized the data provided by Yamazawa et al. instead of relying on the data published by the Cabinet Office. We obtained data spanning from April 2014 to March 2020, with the unit of measurement being 1 trillion yen.

2.3 MCD12Q1

The Terra and Aqua combined Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type (MCD12Q1) Version 6.1 data product provides global land cover types at yearly intervals. The MCD12Q1 Version 6.1 data product is derived using supervised classifications of MODIS Terra and Aqua reflectance data. It classifies the Earth's surface into various land cover categories like forests, croplands, grasslands, wetlands, and urban areas. This dataset is crucial for diverse applications including environmental monitoring, land management, and ecological research.

3. FLOW OF THIS RESEARCH

Figure 1 illustrates the workflow of our study. We begin by extracting urban and road areas from VIIRS/DNB data. Urban areas are identified using thresholds based on the average DNB values during summer and autumn, while road areas are determined using road information from national land data, specifically selecting highways and national roads, and creating masks. Data extraction is performed on the DNB data for all time periods.

Since DNB time-series data contains noise components like monthly variations, clouds, and snow, we employ the STL (Seasonal-Trend Decomposition Procedure Based on LOESS) method to separate it into trend, seasonal patterns, and residuals.

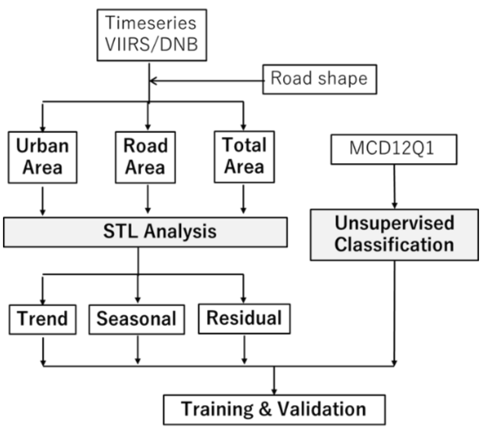


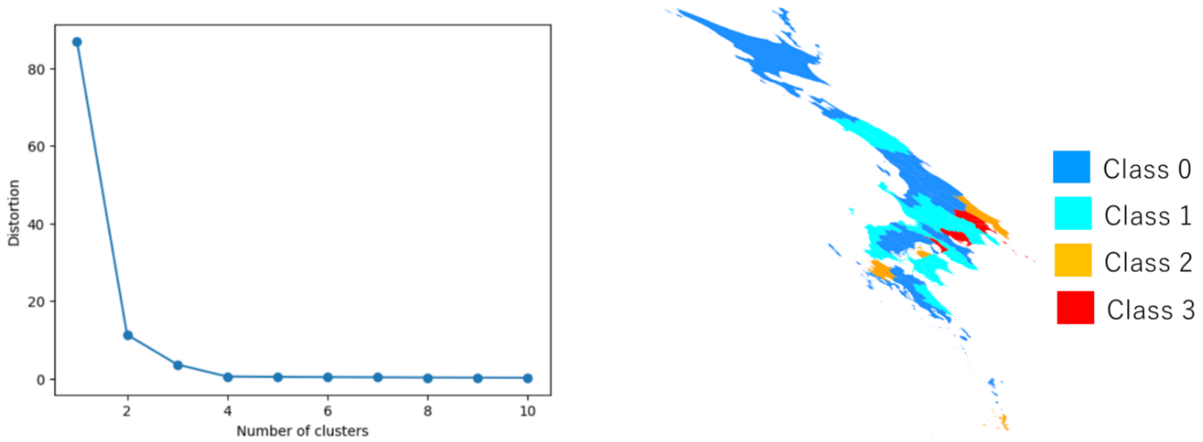
Figure 1. Data processing flow

Next, we categorize Japan into four groups based on the proportion of land cover for each prefecture. We create separate learning models for each group and compare their accuracy using validation data. This process helps us evaluate the precision of our models for different land cover characteristics across regions.

4. RESULT

4.1 Unsupervised classification

Figure 2 shows the unsupervised classification results using the K-means method based on the land cover area ratios for each prefecture. To determine the optimal number of clusters, we examined the Sum of Squared Errors (SSE) values against the number of clusters. The point at which the SSE value significantly decreases indicates an effective number of clusters. A smaller SSE value implies a better model with less distortion.



2.1 Change in distortion value depending on the number of classes, 2.2 Classification results based on land coverage
Figure 2. Classification results using K-means method using land cover rate

4.2 Separation of Trend, Seasonal and Residual Using STL

The monthly composite VIIRS data undergoes corrections for factors such as clouds, snow, and moonlight, but completely eliminating their influence is challenging. The noise components within VIIRS data can be broadly categorized into seasonal and non-seasonal factors. Seasonal factors include the influence of clouds during the monsoon season and snow during winter. The DNB (Day/Night Band) values decrease due to cloud cover and increase due to snow. Non-seasonal noise components are attributed to effects like clouds and atmospheric conditions.

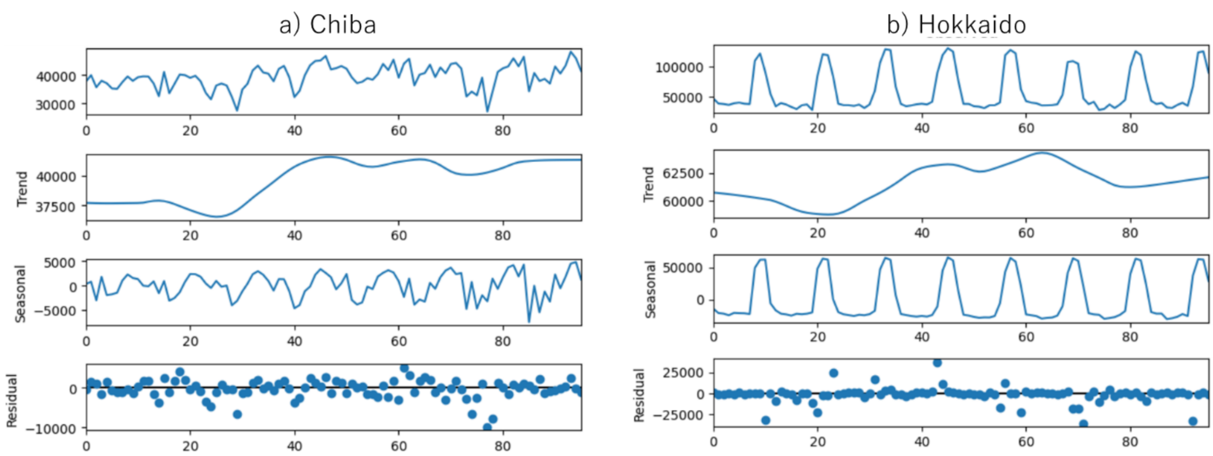


Figure 3. The DNB for Chiba and Hokkaido, and the results of the three-component separation using STL

To address this, we decomposed the time-series data using the STL (Seasonal and Trend decomposition using LOESS) method to extract trends, seasonal variations, and irregular components. Figure 3 shows an example of the time-series DNB data for urban areas in Chiba Prefecture and Hokkaido, which have been decomposed using STL into trends, seasonal, and irregular components.

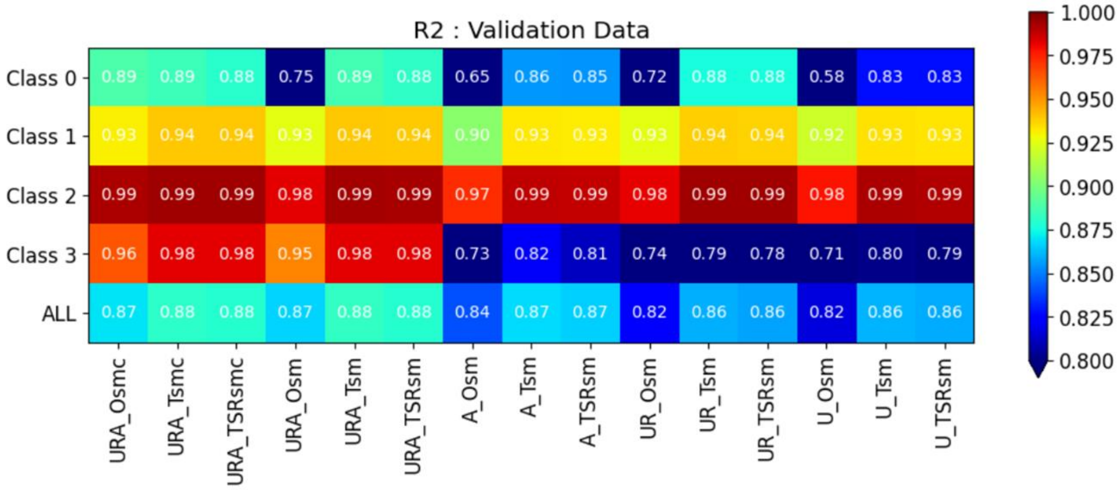
The x-axis represents time in months, while the y-axis represents the total DNB values for the urban areas. In Hokkaido, the DNB values increase significantly during winter due to the scattering of light caused by snow, leading to a seasonal variation with lower values in summer and higher values in winter. The trend data shows a decrease from 2014 to 2015, followed by an increase from 2016 to the summer of 2019, with a slight decrease again in 2020.

4.3 GDP estimation using class-based DNB

This study conducted accuracy validation using the following combinations to estimate GDP:

1. Class-based processing (Class 0-3, ALL)
2. Combinations of DNB regions (Urban: U, Road: R, ALL: A)
3. Combinations of DNB STL processing (Trend: T, Seasonal: S, Residual: R, None: O)

The training period covered six years from April 2014 to March 2019, while the validation period spanned three years from 2020 to 2022. Figure 4 presents the accuracy validation results for the validation data using a six-year training model. The model that utilized all prefectures without regional distinctions performed the worst, with an average R2 value of approximately 0.85. Among the class-based distinctions, Class 3, which includes Tokyo, had lower accuracy, while Class 2, which includes Chiba, Ibaraki, and Kagawa, exhibited the highest validation accuracy. Regarding the combinations of DNB data processing, it was found that using both urban and road regions yielded higher accuracy compared to using only urban regions. Furthermore, the use of STL for component separation demonstrated better accuracy compared to using raw DNB data.



U: Urban area, R:Road area, A:Urban+Road,
O:Original Data, T:Trend of STL , S: Seasonal of STL
s: Sum of DNB in target area, m: mean of DNB in target area, c: number of pixels in target area

Figure 4 Accuracy verification by DNB combination

5. CONCLUSION

This study conducted regression analysis using VIIRS/DNB data for the rapid estimation of GDP in the 47 prefectures of Japan. DNB data were utilized only for urban and road regions to eliminate the influence of the non-economic area of each prefecture. To remove noise components present in the time-series monthly DNB data (seasonal and residual components) and extract trend components, the STL method was employed. It was assumed that the light from urban areas varies depending on the land cover use of the region. The 47 prefectures were classified into four categories based on land cover rates, and GDP estimation using DNB was performed accordingly. Furthermore, a comparison was made between using the entire area for estimation and using individual models for each category.

In comparing the explanatory variables for regression analysis, it was found that using the total and average values for urban and road regions resulted in better accuracy. Additionally, in terms of the scope of application for regression analysis, using models tailored to the industrial characteristics rather than a single model for the entire area was found to be effective.

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