When Lights Tell Stories:
What can We learn from Sectoral Output and Spatial Inequality in Urban-Rural Indonesia?

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The use of night-time light data in socioeconomic studies has grown significantly over the past few decades often considered to be a reliable proxy for capturing regional economic activity. Across developing and emerging economies, official statistics, such as, Gross Regional Domestic Product (GRDP) can be prone to time delays in collection and dissemination. Using night-time light (NTL) captured by satellite sensors to predict regional economic activity, we provide urban-rural spatial and time sectoral output dynamics, across a decade to 2024, examining the interplay between urban-rural luminosity and sectoral economic output in agriculture, industry, and services in Indonesia. Firstly, we attempt to evaluate the predictive power and fit of night-time light data and consider exogenous shocks, such as Covid-19, by disaggregating the analysis by differing time periods. Considering prior literature that has highlighted the debatable empirical findings on night-time light to capture economic activities in the rural area, re-assessing modelling accuracy over such a long period is critical. Finally, we investigate the spatio-temporal pattern of both sectoral output and urban-rural night-time light (NTL) which enables us to establish if, and to what extent, output convergence is occurring across Indonesia's regions.

Night-time light provides researchers with advantages in accessibility, efficiency, spatial resolution, and time processing. Nonetheless, as an indicator of economic activity, night-time illumination has a limitation since not all forms of economic activities may be captured during the night. The deficiency of electricity in rural regions impedes the precision of night-light light assessments of rural economic activity. A few existing literatures have attempted to incorporate the use of VIIRS-NTL and land cover data, as suggested by Keola (2015) and Pagaduan (2022). To overcome the drawbacks of global NTL data, Pagaduan (2022) modified NTL data with MODIS Land Cover for amplifying urban and rural classification. Further examining, Chen et al (2024) segregate total light intensities into urban and rural night-time light and analyze the differences in sectoral GDP across regions and track GDP changes across 81 Turkish provinces from 2004 to 2020. In this research, daylight MODIS land product (MODIS/061/MCD12Q1) is used as a tool for separating urban and rural night-time intensities.

We apply Visible Infrared Imaging Radiometer Suite (VIIRS) NTL which offers advantages on higher spatial resolution and finer detail of geographical areas compared to old Defense Meteorological Satellite Program (DMSP) data. To decompose night-time light into urban-rural specification, we apply Moderate Resolution Spectroradiometer (MODIS) Land Cover data (MODIS/061/MCD12Q1) which consists of 17 classification land types. In this study, we apply IGBP class 10 (grasslands), class 12 (croplands), and class 14 (cropland/natural vegetation mosaics) as our filter for rural night-time light, and urban and built-up lands as filter for urban night-time light. We overlay NTL, MODIS Land Cover, and Global Human Settlement Layer (GHSL) from Google Earth Engine to classify urban-rural landscape based on remotely sensed data. We also apply GRDP data across 514 districts of

Indonesia, over the 2014-2024 period, incorporated with other remote-sensing driven, population, and investment variables to conceptualise the framework of Solow (1956) and Romer (1986) model. To compute sectoral GRDP, we disaggregate 17 sectors of GRDP (refer to BPS-Statistics Indonesia and modified from System National Account (2008) classification) into three main sectors, which are: agriculture sector, industry, and services sector.

The robustness check of the reliability is assessed into four empirical strategies. *First*, we employ cross-sectional and time-dimensional approaches, using between and within regressions, to check whether night-time light data is reliable in capturing both cross-sectional and time-dimensional variation of sectoral output. *Second,* we compare the significance and elasticity of the respective models for the full 2014-2024 period and the pre/during-Covid-19 periods (2014-2019 and 2020-2021, respectively). *Third*, we investigate and compare the predictive and explanatory power of urban-rural night-time light to predict sectoral output both in aggregate and growth level. *Fourth*, given the archipelagic nature of Indonesia, we exploit and compare the spatial pattern of urban-rural night-time light luminosity and across sectoral economies by applying exploratory space-time data analysis enabling us to establish spatial movement and co-evolution of urban-rural disparities Indonesia's 8 major islands. We also assess the magnitude and correlation of each variable by applying Local Moran's I across time.

Our empirical results provide four principal findings. *Firstly*, the night-time light, when integrated with other remote sensing data, demonstrates significant predictive power to capture the variation across time, albeit the magnitudes are more pronounced in capturing cross-sectional variation. Based on both time-dimensional and cross-sectional examination, results reveal that night-time light (urban NTL, rural NTL, and total NTL) have better predictive power and explanatory power to capture economic output at specific times rather than track annual changes. The predictive power and fit of NTL are better suited when assessed with cross-sectional examination. This study aligns with the findings of Gibson et al (2021; Nordhaus and Chen (2015); Goldblatt et al (2020) documenting that strength of night lights are far more powerful in predicting economic variables in the cross-section than at predicting short-term time-series changes.

Second, examination of the NTL-sectoral output relationship at both growth and aggregate levels reveals that all NTL predictors significantly affect sectoral economic output. Urban NTL exhibits the highest elasticity in predicting industrial output across alternative econometric specifications (pooled OLS, within-estimator, and between-estimator models). However, substantial heterogeneity emerges regarding the robustness of these relationships. In within-estimator specifications that exploit temporal variation, only urban NTL maintains statistical significance for industrial output estimates. Conversely, all NTL measures (urban, rural, and total) demonstrate statistical significance in between-estimator frameworks that exploit cross-sectional variation.

Third, examination's result with exogenous shocks indicate that All NTL predictors indicate positive and significant relationship with sectoral output across different time frame. Before COVID-19, All NTL measures (urban, rural, and total) are more reliable in predicting cross-sectoral variation in sectoral economies rather than temporal variation (annual changes over time). During COVID-19, All NTL predictors were only significant in estimating cross-sectional variation on sectoral economies (between estimator). After controlled year and district fixed effect (fixed-effect panel), all coefficients became insignificant. Using all periods (2014-2024), likewise other time periods, elasticity (beta coefficients) from time-variation

within regression are lower than those from cross-sectional between regression. Furthermore, spatial disaggregation across full periods (2014-2024) reveals pronounced sectoral heterogeneity in NTL elasticities. A 10 percent increase in urban NTL corresponds to output increases of 6.04 percent in the industrial sector and 3.21 percent in the service sector, reflecting the urban concentration of high-productivity economic activities. In contrast, a 10 percent increase in rural NTL correlates with a 5.42 percent expansion in agricultural output, demonstrating the sectoral specialisation characteristic of rural economies. Beyond NTL measures, our regression results show significant determinants of sectoral growth. Urban-built environment, investment, and population generate significant positive effects on both total and non-agricultural output, encompassing industrial and service sectors. Cropland area demonstrates dual effects: positive impacts on agricultural GRDP, while negative contribution to total and non-agricultural GRDP, suggesting complementarity between agricultural intensification and broader economic shift.

Fourth, the exploratory spatio-temporal analysis reveals similar spatial patterns and evidence of spatial co-evolution between sectoral output and urban night-time light across Indonesia's eight major islands. There was ongoing economic convergence process occurred across urban-rural divide, although the speed of convergence was different across Islands. In the rural night-time light, easternmost Island (Papua) and central Island (Kalimantan) indicated the most illuminated islands, aligned with the directional LISA for GRDP agriculture in Papua, albeit contradicted in terms of magnitude of spill-over. Java-Bali and Sumatera exhibit the highest frequency of positive spatial co-evolution in urban NTL, while Kalimantan and Papua illustrate the highest frequency of spatial co-evolution in rural NTL. These findings suggest that a convergence process in economic dynamics has occurred across regions, leading to reduce spatial urban-rural polarisation.

Further, we investigate the linkage between a political policy decided several years ago in Indonesia and its influence on night-time light dynamics. President of Indonesia announced the relocation of the capital country from Jakarta to Nusantara in East Kalimantan Province, Penajam Paser Utara district in 2019. Afterwards, physical construction began in 2022 and remains ongoing, despite a brief pause during the 2024 presidential election and transition. Time-series trend showed that there were significant upward trends indicating sharp increase in investment levels (proxied by gross fixed capital formation) and GRDP industry, specifically in Penajam Paser Utara district, the site of the future capital city. Aligned with those trend, urban night-time light also confirms the similar pattern of intensifying lights from 2022 onwards in future capital city and neighbours, except Kutai Kartanegara and Samarinda.

This study highlights the need to balance the development of high-productivity sectors and institutional development outside Java-Bali to lower excessive urban concentration and promote more equal regional growth. Simultaneously, agricultural extensification policy coupled with intensification of rural electrification and market connectivity should shape the foundation of rural development strategies, particularly in peripheral regions like Papua and Kalimantan where economic convergence is on the lower pace. The significant contributions of urban-built environment, investment, and population dynamics to sectoral output growth suggest that integrated spatial planning system, physical infrastructure development, and human capital mobility should be taken into consideration in favor of coordinated regional development planning.