Using deep learning and long-run reconstructed luminosity data to study declining towns

Extended Abstract

Long-run population decline, urban shrinkage, and the hollowing-out of smaller towns are now well-established features of many advanced and transition economies. In these places, low fertility, ageing populations, and selective out-migration have produced sustained reductions in economic activity outside major metropolitan centres. These dynamics are not new, with human urban history containing many examples of towns that have flourished, stagnated, or disappeared altogether. What remains contested is how best to **measure** these processes consistently over long time horizons and across many small spatial units, especially where administrative boundaries are coarse or change over time.

This paper revisits the question of **urban decline at the town level** using three decades of satellite-detected night-time lights (NTL), combined with recent advances in deep learning that substantially improve the spatial fidelity of early-generation NTL data. Building on prior work that used Defense Meteorological Satellite Program (DMSP) data to estimate trends in urban growth across the spatial hierarchy and in several countries, we reconstruct data from this purely first-generation (1G) military-oriented sensor by using a deep learning approach anchored to second-generation (2G) research-oriented VIIRS observations. The resulting **time-series spans 1992–2021** to both lengthen the period of analysis and sharpen inference about small and medium-sized towns, which are the type of spatial units where DMSP sensor limitations have historically been most binding.

The empirical focus is New Zealand, a country that provides a useful laboratory for studying town-level decline. New Zealand combines European-style settlement patterns and institutional continuity with a relatively sparse and geographically dispersed population. Its urban system includes a small number of dominant metropolitan areas alongside many provincial towns whose economic fortunes have diverged markedly over time. Importantly, the absence of large-scale conflict or administrative reorganisation allows long-run changes in luminosity to be interpreted more cleanly as reflecting demographic and economic processes rather than boundary changes. While the empirical setting is somewhat peripheral, the mechanisms examined—selective decline, persistence, and spatial re-concentration—are directly relevant to regions experiencing prolonged population loss.

Measurement Challenges in Long-Run Night-Time Lights Data

Night-time lights have become a standard proxy for local economic activity in regional science, development economics, and urban studies. However, their use for analysing **small spatial units over long horizons** raises well-known measurement challenges. The DMSP sensors that provide global coverage from the early 1990s were designed for meteorological purposes, not economic measurement. Although DMSP data are released on a fine output grid (approximately 0.7 km² at New Zealand's latitude), the underlying pixel footprint for the sensor is far coarser—around 25 km² at nadir and substantially larger off-nadir. This mismatch induces blurring (spatial smoothing), particularly around bright urban centres, causing light from large towns to spill into neighbouring areas and attenuating variation among smaller settlements.

These issues generate **spatially mean-reverting measurement error**, which is especially problematic when studying town-level outcomes. In the context of declining towns, such error biases estimated changes toward zero, masking genuine contraction and exaggerating persistence. Moreover, blurring causes nearby towns to merge into a single luminous mass, reducing the number of urban units that can be separately identified. Earlier analyses based solely on DMSP therefore faced a fundamental trade-off: long time-series coverage at the cost of diminished spatial resolution.

The introduction of the Visible Infrared Imaging Radiometer Suite (VIIRS) in 2012 marked a major advance. VIIRS offers much finer spatial resolution, on-board calibration, and no saturation at high brightness levels. However, its relatively short temporal span has limited its use for studying long-run urban dynamics. Therefore, recent work in remote sensing has sought to bridge this gap using various harmonization approaches to stitch together DMSP and VIIRS observations into a single long time-series.

In our analysis we use a deep learning–based super-resolution and cross-sensor calibration, producing reconstructed luminosity series that map the historical DMSP observations onto a VIIRS-like radiance scale, going back to the early 1990s. Unlike earlier harmonisation efforts that rely purely on cross-sectional calibration, temporal changes are incorporated, making the reconstructed long-run series particularly suitable for studying the dynamics of urban change.

Empirical Strategy and Town Definition

Our analysis constructs a consistent panel of urban areas observed annually from 1992 to 2021. Town boundaries are defined using a centre-outward growth algorithm applied to high-resolution built-up area layers, allowing urban extents to expand or contract over time while preventing artificial mergers caused by sensor blur. A key advantage of improved spatial resolution and reduced blurring with the reconstructed DMSP data is that **more towns can be analysed separately**: places that appeared as a single cluster under DMSP can often be distinguished once blurring that smears apparent light across truly unlit areas is reduced.

For each town, we focus on the extensive margin of luminosity to estimate (non-linear) trend growth rates. The long time horizon allows us to distinguish temporary shocks from persistent decline and to assess whether towns that enter a declining trajectory exhibit recovery, stabilisation, or continued contraction. Throughout, we compare results obtained using raw DMSP with the reconstructed data, to show how measurement flaws in 1G sensors may introduce data artefacts that affect inferences about urban change.

Findings: Persistence and Heterogeneity in Decline

Three broad findings emerge. First, the use of the reconstructed DMSP data reveals **stronger and more persistent decline** in a subset of small and medium-sized towns than is apparent in analyses based on the original DMSP data. Towns that appear stable when measured with raw DMSP often show gradual but sustained reductions in luminosity once blurring is corrected. This pattern is consistent with spatially mean-reverting measurement error attenuating estimated decline in earlier work.

Second, improved resolution with the reconstructed series increases the number of towns that can be tracked independently over time. In several regions, what appeared under DMSP as a stable medium-sized town is revealed to consist of a shrinking core and one or more satellite settlements with divergent trajectories. This heterogeneity is masked when towns are inadvertently merged by coarse imagery. The implication for regional analysis is that decline is often **more localised and uneven** than previously inferred.

Third, decline exhibits strong persistence. Towns that experience sustained reductions in luminosity over a decade rarely recover to their previous relative position, even when national economic conditions improve. This finding resonates with evidence on hysteresis in regional labour markets and the long half-life of population shocks. The contribution here is to show that such persistence is visible in remotely sensed economic activity over nearly thirty years, once measurement issues are addressed.

Relevance Beyond New Zealand

Although the empirical application is to New Zealand, the results speak directly to wider debates about shrinking regions and the future of small towns. In many parts of the world, demographic decline is no longer cyclical but structural. Understanding whether decline is gradual or abrupt, spatially diffuse or sharply localised, and reversible or persistent is central to debates about regional policy, infrastructure provision, and managed decline.

Methodologically, the paper contributes to a growing literature emphasising that **sensor resolution matters** for regional inference. Studies that rely on long DMSP series without accounting for spatial smoothing risk understating both decline and divergence. Deep learning–based reconstructions offer a partial solution, allowing researchers to retain temporal depth while improving spatial accuracy. For regions where long-run decline predates the VIIRS era—these methods open new possibilities for empirical analysis.

Conclusion

This paper revisits long-standing questions about declining towns using improved night-time lights data that combine temporal reach with enhanced spatial resolution. By extending analysis over the three decades from 1992 to 2021 and reducing sensor-induced blurring, we show that urban decline is more persistent, more heterogeneous, and more spatially concentrated than suggested by earlier DMSP-based studies. While the application is to New Zealand, the findings and methods are directly relevant more broadly to regions grappling with sustained population loss. Methodologically, the paper highlights the importance of aligning research questions with the measurement properties of the data used to answer them—a lesson that extends well beyond night-time lights.