RURAL ROAD CONNECTIVITY AND LOCAL ECONOMIC ACTIVITY

EVIDENCE FROM SRI LANKA'S INTEGRATED
ROAD INVESTMENT PROGRAM

Liming Chen, Yang Lu, and Aruna Nanayakkara

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Rural Road Connectivity and Local Economic Activity: Evidence from Sri Lanka's Integrated Road Investment Program

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ABSTRACT

A large portion of the world's rural population has limited access to paved roads, which is widely believed to constrain rural economic growth opportunities. Using a panel of nighttime lights and road placement data from the Integrated Road Investment Program (iRoad), a large-scale rural road development program in Sri Lanka, this study examines the relationship between rural road connectivity and local nighttime luminosity. The program was found to result in better and more consistent rural road conditions. Rural areas with improved connectivity after two years show a 12% higher local nighttime luminosity, a proxy for economic activity, compared to areas without connectivity. These gains hold even for indirectly targeted rural areas where the iRoad passes through. The gains vary spatially, which are most pronounced in areas at a moderate distance to socioeconomic centers and with more adequate complementary infrastructure provisions. These findings support the notion that improving rural connectivity can ease development constraints, increase resilience in managing negative economic shocks caused by the COVID-19 pandemic, and contribute to post-pandemic economic recovery. The findings also lend to the idea that targeted placements based on the beneficiary's location and complementary infrastructure (e.g., educational and medical facilities) can enhance the effectiveness of rural road investments. An intensive margin analysis suggests that post-construction maintenance is effective in bringing about sustained impact.

JEL Classification: O18, R12, R42, R58

Keywords: roads, rural infrastructure, nighttime lights, Sri Lanka

ABBREVIATIONS

ADB	– Asian Development Bank
COVID-19	– coronavirus disease
DiD	– difference-in-differences
GND	– Grama Niladhari Division
IRI	– international roughness index
iRoad	– Integrated Road Investment Program
km	– kilometer
NTL	– nighttime lights
RDA	– Road Development Authority
VIIRS	– Visible and Infrared Imaging Radiometer Suite

I. INTRODUCTION

This study evaluated the economic impact of the Integrated Road Investment Program in the Southern Province of Sri Lanka. Initiated in 2014 and financed by the Asian Development Bank (ADB), the iRoad program is designed to improve accessibility to the road network in rural areas of Sri Lanka, thereby increasing the involvement of the rural population in nationwide economic and social development. The investment program, together with the Second Integrated Road Investment Program, aims to upgrade and maintain approximately 6,450 kilometers (km) of rural access roads to all-weather standards, rehabilitate and maintain to good condition about 750 km of national roads and improve the capacity of road agencies, thereby playing a catalytic role in the sustainable development of Sri Lanka.

With 7 years of program implementation and construction largely completed in several regions (e.g., Southern Province), what has been the scale of socioeconomic impact on the rural areas connected? This study uses remote sensing nighttime lights data to empirically answer this and related questions and to make recommendations for future rural transport investments.

Specifically, this study gathered annual panel data of nighttime lights and iRoad connectivity from 2012 to 2020 for all the Grama Niladhari Divisions (GND) in Southern Province, where the iRoad program was first introduced and is largely completed.

First, the study finds that the program results in better and more consistent rural road conditions, measured by the international roughness index (IRI) with a lower mean and standard deviation.

Second, the study establishes a strong correlation between nighttime lights and local economic activity at the GND level.

Third, using a stacked difference-in-differences (DiD) design, the study finds that iRoad connectivity in Southern Province is associated with a 12% increase in local nighttime lights in Year 2 after project completion, corresponding to a 2.6% increase in economic activity. These gains hold even for GNDs indirectly benefiting from iRoad connectivity with program roads passing through them. Crucially, the association is driven mostly by the decline of nighttime lights in the control GNDs and sustained growth in the treatment GNDs in 2020 when the outbreak of the COVID-19 global pandemic and ensuing economic contraction took place. The results suggest that areas in Southern Province connected with iRoad have shown strong growth resilience in the event of a large-scale negative economic shock.

Fourth, heterogeneity analysis, however, shows that the gains across Southern Province are not distributed uniformly. The gains are most pronounced in areas at a medium distance from socioeconomic centers and at iRoad end points.

Fifth and lastly, an intensive margin analysis shows that a reduction of one unit in the IRI is associated with a 2% increase in nighttime lights 2 years after iRoad completion.

This study contributes to the growing body of literature examining the impact of rural roads on economic outcomes. While there has been increasing evidence from developing countries, most focus on the Indian rural road development program. For example, Aggarwal (2018) exploited the program roll-out timing variation across districts over a decade to determine the causal impact of paved road connectivity.

Using a DiD design, the study found that the program benefited village economies through greater market integration for non-local goods, and easier labor market and educational access. Shamdasani (2021) also used a DiD framework based on the timing variation of road construction. In addition to the DiD framework, Shamdasani (2021) examined the villages not eligible for the program but are connected by program roads because roads pass through these villages. The study found that households with access to program roads diversify their crops, adopt modern agricultural technologies, and use more hired labor. Asher and Novosad (2020) used a fuzzy regression discontinuity design by taking advantage of the village population threshold that influences program eligibility. The study found that the program had limited gains in village assets or income but had a substantial increase in the availability of transport services and a large reallocation of workers out of agriculture.

This study builds on the existing literature and, to the best of our knowledge, makes the first attempt to examine the effects of rural road connectivity on local economic outcomes in Sri Lanka by examining the iRoad program. This study also contributes to the scarce literature on the impact of transport infrastructure investment on economic resilience.¹ Evidence on this topic exists (Revoltella et al. 2016) but is very limited. The economic shocks from COVID-19 and associated lockdowns provide a unique case to study how rural road investments could support pathways to recovery.

This study is organized as follows. Section II provides the background to the iRoad program and its pilot activities in Southern Province. Section III describes data used for analysis and validates the nighttime light data as a proxy for local economic activity. Section IV sets up the empirical analysis and discusses the results, robustness tests, and heterogeneity. Section V concludes the study and provides brief policy recommendations.

II. iROAD PROGRAM IN SOUTHERN PROVINCE

Sri Lanka has a population of over 21 million and achieved robust economic growth after 2009. The poverty rate fell from over 15% in 2006 to 4.1% in 2016. Although the country has made rapid progress, economic benefits are not always equally distributed. The poverty rate is still high in less developed rural areas, where economic opportunities are limited and access to basic social resources is not sufficient.

Poor transport infrastructure, particularly poorly maintained provincial and local authority roads, has been identified as a major bottleneck in rural areas. The Government of Sri Lanka requested ADB assistance for infrastructure financing to promote rural development. ADB approved the Integrated Road Investment Program or iRoad, which is a combined \$1.7 billion investment for Sri Lanka.² The iRoad program was initiated to improve the roads in difficult-to-access rural areas and to connect local communities to socioeconomic centers. It is a large program covering all nine provinces in Sri Lanka and has 2,173 road segments. This includes 6,450 km of rural access roads and 750 km of critical national roads (Figure 1). The program will be implemented over a decade from 2014 to 2027.

¹ Economic resilience in this context is defined as the resilience of economic agents to recover from various types of economic shocks such as commodity price shocks, economic and financial crises, and climate change, rather than the resilience of the transport infrastructure itself. For details and a literature review on this topic, see Roberts et al. (2018).

² Including the Second Integrated Road Investment Program or “iRoad 2” in short.

Figure 1: iRoad Map

iRoad = Integrated Road Investment Program.

Source: Road Development Authority.

ADB has provided two multitranche financing facilities (MFFs) for the iRoad program.³ The first MFF of \$800 million covers the provinces of Southern, Central, Sabaragamuwa, North Central, North Western, and Kalutara District in Western Province. This loan agreement was signed in 2014 and will close in 2024. The second MFF of \$900 million covers Uva, Northern, Eastern, and Western Provinces, which were not covered under the first MFF. This loan agreement was signed in 2017 and will close in 2027. The Ministry of Highways is the executing agency, while the Road Development Authority (RDA) is the project implementing agency.

Some 200 road sections in Southern Province were identified for upgrading or improved maintenance and operations. The identified roads include 17 national and 10 provincial road sections, with the majority being local authority roads. The access roads were selected to connect the identified rural hubs that have at least 50 families, basic utilities, educational and health facilities, and other development potentials for the socioeconomic centers. The national and provincial roads included are bituminous-surfaced roads with single-lane to two-lane roadways in fair to poor condition. The local authority roads are narrow, single-lane roads with a roadway width of 2.0–4.0 meters, and are mostly gravel or bituminous surfaced. The surface condition is mostly poor (Figure 2). Many roads have a combination of surface types, including non-motorable and motorable sections, which may result from the roads being constructed over time in short sections as funds were allocated.

Depending on the existing condition, the project road sections are designed to be rehabilitated or reconstructed with asphalt or concrete surfacing (Figure 3). Based on class and function, national roads will have a two-lane carriageway width, provincial roads will have an intermediate roadway width, while local roads will have a single-lane carriageway. For local roads with higher traffic levels, roadway width will be slightly greater for increased road safety where such width is available.

The road improvement works are planned in two contracting modalities. Conventional road contracts (CRCs) involve all provincial and local roads and road management contracts for national roads. The civil works under a CRC normally include 2 to 3 years of construction and rehabilitation and 3 years of performance-based maintenance (PBM). This analysis mainly focuses on rural connectivity for roads under the CRC modality.

Southern Province was the first to commence civil works in mid-2015, and much of the work was completed before 2018. Most roads have been taken over to implement the PBM contract. The performance of one contractor was not acceptable and the contract was terminated. The corresponding package was removed from the program and funded by the government. The rehabilitation work of all other packages in Southern Province was completed.

³ ADB. 2014. *Report and Recommendation of the President to the Board of Directors: Proposed Multitranche Financing Facility to the Democratic Socialist Republic of Sri Lanka for the Integrated Road Investment Program*. Manila; and ADB. 2017. *Report and Recommendation of the President to the Board of Directors: Proposed Multitranche Financing Facility to the Democratic Socialist Republic of Sri Lanka for the Second Integrated Road Investment Program*. Manila.

Figure 2: Road Condition Before iRoad Improvement

iRoad = Integrated Road Investment Program.

Source: Road Development Authority.

Figure 3: Road Condition After iRoad Improvement

iRoad = Integrated Road Investment Program.

Source: Road Development Authority.

III. DATA

A. Nighttime Lights

The purpose of this study was to examine the effects of iRoad connectivity on economic activity and underlying channels. The ideal data for the research design would be frequent and representative longitudinal socioeconomic records tracking households, individuals (e.g., wage, agriculture income), or economic outcomes in granular geographical units (e.g., gross output or value added at village level) before and after they become beneficiaries of the iRoad program. Given the large scale of the program, such data is difficult to obtain in Sri Lanka, especially in high frequency and granularity.⁴

The lack of reliable subnational data in many developing countries has long made it challenging to evaluate the impacts of location-specific interventions. However, recent developments in remote sensing have made it possible to use non-conventional sources as an alternative to local economic activity analysis. Nighttime lights (NTL), for example, can be detected by satellites, and this technique has gained wide application as a proxy for economic outputs on a wide range of issues (Gibson, Olivia, and Boe-Gibson 2020).

The main advantages of NTL data over conventional census or survey data are threefold. First, the data are accessible. Processed NTL data products are usually publicly available and ready for application, whereas the cost and time needed to conduct new surveys are usually high, if not prohibitive. For example, at the time of writing of this study, the ongoing COVID-19 pandemic made interview-based surveys all but impossible. The second advantage is high frequency. The most recent data are available monthly since April 2012. The third advantage is high granularity. The spatial resolution of the latest processed data is at 15 arc seconds or 465 meter x 465 meter at the equator, which is smaller than most administrative units. As such, the NTL data are flexible enough to be aggregated at any higher level of spatial units.

In this study, NTL data allow us to look at the most granular administrative units, i.e., the Grama Niladhari Division (GND) and other socioeconomic data in Sri Lanka. In the last population census, a GND is the lowest level of administrative unit recorded by Provincial, District, and Divisional Secretariats. Southern Province consists of 2,121 GNDs.

The NTL data we obtained were the recently processed annual Visible and Infrared Imaging Radiometer Suite (VIIRS) Day Night Band product in Southern Province.⁵ The available time period ranges from 2012 to 2020. The data are pixel level radiance values in units of nano watts per square centimeter per steradian ($\text{nW}/\text{cm}^2/\text{sr}$). In the 2020 data set, the radiance value ranges from 0 to 126. We aggregate the NTL pixel data (around 465 meter x 465 meter resolution) in each GND using GND administrative boundaries to obtain the sum total of the NTL value in each GND.⁶

⁴ The latest population census was released in 2012. The Labor Force Survey conducted monthly has used a consistent method since 2013, but is representative only at district level and therefore not granular enough for the purpose of this study (e.g., there are only three districts in Southern Province).

⁵ The data are accessed from Earth Observation Group (<https://eogdata.mines.edu/products/vnl/>), with documentation on data processing from Elvidge et al. (2021).

⁶ The aggregation is based on whether the geographical centroid of each VIIRS pixel falls in the GND boundary.

B. iRoad and Other Data

To tag which GND gained connectivity with iRoad and when, we obtain iRoad segments data in Southern Province. The data include road alignment, length, construction start year and completion year, and an international roughness index (IRI) for all 183 iRoad segments planned in Southern Province. As of 2020, there were 168 segments of completed roads. We overlaid road alignment to Sri Lankan administrative boundaries to obtain the iRoad connectivity status for each GND in each year. Specifically, we define a GND that gains iRoad connectivity if part of a completed iRoad alignment falls in the GND.⁷

Combining the GND level nighttime lights data and iRoad connectivity data, we obtain a panel of disaggregated spatial units with information on the outcome of interests (economic activity as proxied by NTL) and the main intervention (iRoad connectivity). We supplement this panel with several additional datasets, including (i) the 2012 Population Census that includes GND-level household information on the number of households, population, and labor force, etc.; (ii) road roughness data for iRoad segments before and after construction; and (iii) geolocations of socioeconomic centers (SEC) in Southern Province that the iRoad program intends to connect to a less developed area. These additional data facilitate NTL data validation and heterogeneity analysis.

Figure 4 and Table 1 summarize iRoad coverage over time. All 433 GNDs planned to initiate iRoad works in 2015. Most segments completed construction in 2018, providing connectivity to 357 GNDs. Using the 2012 Population Census data, these 357 GNDs cover 108,685 households or 17.2% of the total population in Southern Province. In 2020, another 52 GNDs received connections covering 19.6% of the total population based on the 2012 population distribution.

In addition to the increased rural coverage, the quality of improvements of rehabilitated roads is evident from the change in the IRI. The index measures pavement roughness in wheel path in terms of the cumulative vertical displacement of a quarter-car vehicle as it is driven along a road per kilometer. We collected IRI data for all iRoad segments in Southern Province before and after construction and mapped them to treatment GNDs. Before iRoad construction, the target roads were mostly unpaved, with an average IRI of 9.08 (Figure 5) for treatment GNDs. After construction, the average IRI dropped to 2.34 and the standard deviation to 0.53 from 2.18. Overall, the program resulted in better and more consistent rural road conditions for Southern Province.

Southern Province was much brighter in 2020 than it was in 2012 (Figure 6). Not only did more areas change from completely dark to luminous, but luminous areas were brighter. Specifically, comparing NTL pixel level data in 2020 to 2012, about 10% additional areas show positive luminosity values, and on average, the luminosity value in a pixel is over 200% higher in 2020. Areas that saw the most expansion and increase in luminosity are along the coast (e.g., around Galle Harbor and Hambantota Harbor), around socioeconomic centers, and in some cases along areas with iRoad segments. There are, however, some areas with little shift in luminosity over the decade, such as the northeast area and some northern inland areas.

⁷ If a GND interacts with more than one iRoad alignment, the GND is considered connected in the year of the earliest iRoad segment completion. Since iRoad segments are relatively short (average around 3 kilometers), they are mostly completed in the same calendar year, hence it is unlikely that a GND is connected with iRoad but the same iRoad segment was not recorded as complete in the same year.

Table 1: iRoad Program Coverage

Variables	2015	2016	2017	2018	2019	2020
Number of GNDs with iRoad started	443	443	443	443	443	443
Number of GNDs with iRoad completed	0	0	87	357	357	409
Number of households with iRoad completed			17,872	108,685	108,685	123,856
Total population with iRoad completed			67,880	424,406	424,406	483,026
Female population with iRoad completed			35,420	219,301	219,301	249,553
Male population with iRoad completed			32,460	205,105	205,105	233,473
Working population with iRoad completed			40,705	255,634	255,634	290,253
% Households with iRoad completed			2.8%	17.3%	17.3%	19.7%
% Working population with iRoad completed			2.7%	17.1%	17.1%	19.4%

GND = Grama Niladhari Division, iRoad = Integrated Road Investment Program.

Note: Coverage on the number and share of households, population, working population is estimated using 2012 Population Census data. The percentage values represent the total values in GNDs connected with iRoad as a share of the total in Southern Province.

Source: Asian Development Bank estimates.

Figure 5: Roughness Index Before and After iRoad Program

IRI = international roughness index, SD = standard deviation.

Source: Asian Development Bank using Visible and Infrared Imaging Radiometer Suite nighttime lights data and iRoad placement data.

Figure 6: VIIRS Nighttime Lights and iRoad in 2012 and 2020

iRoad = Integrated Road Investment Program, VIIRS = Visible and Infrared Imaging Radiometer Suite.

Source: Asian Development Bank using VIIRS nighttime lights data and iRoad placement data.

C. Nighttime Lights Data Validation

To yield meaningful results on how the iRoad program is associated with local economic activities, we need to first understand how well the relationship holds between nighttime lights and local economic activity in Sri Lanka, for the following reasons. First, current research recognizes nighttime lights as a proxy for local economic output (Gibson et al. 2020), but caution is needed when selecting the appropriate NTL data source. Second, how well the NTL correlates with economic activity is not uniform, varying across or even within economies. Some studies have noted that most NTL data provides a much better proxy for economic activities in urban areas but the relationship is less robust in rural areas (Gibson et al. 2021). Third, there has been no documented study on how well VIIRS NTL data can proxy economic activity in Sri Lanka.

Regarding the first point, the VIIRS Day Night Band, the NTL data used in this study, is currently the most suitable remote sensing source for measuring NTL (e.g., Defense Meteorological Satellite Program or DMSP), as VIIRS was specifically designed to help researchers consistently measure the radiance of light from Earth in a wide range of lighting conditions and with high spatial accuracy and comparable temporality (Gibson et al. 2021). To address the second and third points, we validated how well the VIIRS data proxy economic activity using information from the 2012 Population Census and the 2012 VIIRS data at the GND level.⁸

We estimated the relationship with equation 1:

$$\ln Y_i = c + \beta \ln(\text{lights})_i + \epsilon_i \quad \text{Equation 1}$$

Where the dependent variable $\ln Y_i$ is the log of the labor force, population, or number of households with electricity in GND i (three available records from the population census with a high correlation with GND level NTL); $\ln(\text{lights})_i$ is the log of the sum total of lights in GND i ; ϵ_i is the robust standard error.⁹

To deal with GNDs with no lights detected, we use the inverse-hyperbolic-sine transformation for the lights data, $\text{asinh}(\text{lights})$, which has the same interpretation as logarithmic values but allowed us to use zeros without applying transformations (Burbidge, Magee, and Robb 1988; Gibson et al. 2017).¹⁰ The coefficient β can therefore be interpreted as the elasticity between the sum of lights and the dependent variables.

There is a significant and positive relationship between VIIRS nighttime lights value and all three indicators at the GND level for all GNDs in Sri Lanka (Table 2, columns 1 to 3). Intuitively, GNDs hosting more labor and with a larger population create more economic outputs and consume more electricity, and GNDs with more households with electricity emit more nighttime lights. Specifically, a 10% increase in lights is associated with about a 3% increase in the labor force, population, or households with electricity.

⁸ The 2012 Population Census records GND level information on total population, labor force, and number of households with utilities.

⁹ Ideally, we would need to use the GND level output or number of jobs in this regression, but such data are not available in Sri Lanka.

¹⁰ Transformations such as adding 1 before applying the log may significantly alter the variation of NTL given their low mean value (around 1).

In Southern Province, the elasticity is smaller at 0.2, as is the predictive power (R^2 at 16%–17% compared to around 30% for Sri Lanka).¹¹ Nonetheless, the association in Southern Province remains positive and significant (Table 2, columns 4–6).

Table 2: Association between Nighttime Lights and Local Economic Indicators

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All Provinces			Southern Province					
	log Labor Force	log Pop	log Number of HHs with Electricity	log Labor Force	log Pop	log Number of HHs with Electricity	log Labor Force	log Pop	log Number of HHs with Electricity
log Sum of Lights	.324*** (.0046)	.314*** (.0045)	.324*** (.0051)	.218*** (.0115)	.21*** (.0115)	.202*** (.0117)	.215*** (.0115)	.207*** (.0115)	.2*** (.0117)
With SEC							.178* (.107)	.175 (.108)	.221* (.118)
With SEC							.0231 (.0853)	.0208 (.0869)	–.0047 (.0943)
X log Sum of Lights									
N	13,991	13,991	13,682	2,121	2,121	2,121	2,121	2,121	2,121
Adjusted R^2	0.313	0.300	0.255	0.177	0.170	0.157	0.180	0.172	0.160

HHs = households, Pop = population, SEC = socioeconomic center.

Note: Heteroskedasticity robust standard error in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Asian Development Bank estimates.

Importantly, the estimated elasticity was not statistically different in more developed socioeconomic centers than in less developed areas. This alleviates some concerns that the predictive power may be poor in low-density rural areas where agriculture is the primary industry in certain economies, as noted by Gibson et al. (2021). In Table 2, columns 7 to 9, we repeat the results in Southern Province but further interact $\ln(\text{lights})_i$ with a dummy variable that takes 1 if the GND hosts a socioeconomic center (SEC). This interaction essentially allows the elasticity to be different in areas with SECs. The results indicated that the elasticity between NTL and the labor force is 2% higher in GNDs with SECs, but the difference is not statistically significant. The same pattern holds for the other two indicators.

¹¹ This is probably because the population density in Southern Province GNDs is 22% lower than the Sri Lankan average. As noted in the literature, the association between NTL and local output is weaker (and with weaker predictive power) in less densely populated areas. In general, the predictive power of the model expressed in equation (1), indicated by the R^2 , is within the range of literature findings (Gibson et al. 2021). Notwithstanding the smaller R^2 in the Southern Province, the p -value (less than 1%) indicates that the relationship between local economic indicators and NTL remain statistically significant and positive. To increase the predictive power of the model, data that better measure local output at GND level, such as gross value added or employment from economic census or industrial survey, are more desired.

Overall, the elasticity between nighttime lights and local labor force presence is 0.2 in Southern Province, i.e., if a GND is 10% brighter in terms of nighttime lights, it has on average 2% more labor force. This result is robust whether the GND hosts a socioeconomic center or not. Consistent with the literature, this estimate is close to the robust 0.3 elasticity between GDP per capita and nighttime lights per area as estimated by Henderson, Storeygard, and Weil (2011) using data from 188 low- and middle-income countries.

IV. EMPIRICAL ANALYSIS OF iROAD AND NIGHTTIME LIGHTS

A. Sample Construction and Descriptive Statistics

We define all GNDs connected with iRoad as the treatment group. These include all 188 GNDs with iRoad starting points and end points and 221 GNDs with the iRoad passing through them. For a control group, we select two groups of GNDs similar to the treatment GNDs but without iRoad connections to minimize potential unobserved factors that may bias the estimated association between nighttime lights and iRoad investment. The first group includes 1,678 GNDs in Southern Province but not connected with iRoad by 2020 or with iRoad planned. These GNDs are matched to their closest treatment GND as control GNDs, thereby forming comparison groups. Since these GNDs share geographical proximity, they are relatively similar in terms of socioeconomic conditions.

However, since the iRoad segment placements were not random, these GNDs are not necessarily ideal as controls. This is because other than the iRoad treatment, there may be inherent discrepancies between the two groups that may cause the nighttime lights trend in the treatment and control groups to be different. For example, since the treatment GNDs were less developed in the province, the nighttime lights in “lagging” GNDs may grow at a faster pace from a lower baseline, resulting in overstated estimates. On the other hand, these lagging GNDs may be growing at a slower rate due to a lack of other interventions, thereby causing understated estimates. We did not, however, observe such a trend difference in our data.

Nonetheless, we chose another set of controls to mitigate any selection bias, including 735 GNDs in Western Province with iRoad segments planned but not yet implemented. We randomly paired these GNDs to the treatment GNDs in Southern Province as controls, adding to the comparison groups. Since the iRoad intervention selection criteria in each province are generally consistent across provinces, these Western Province GNDs should share the same characteristics, and therefore be comparable to the treatment group.¹² In addition, the majority of Western Province GNDs had not started construction by 2020 and there is unlikely to be any spurious increase in nighttime lights from construction work.¹³

¹² We also control for province fixed effects in empirical specifications when applicable.

¹³ Other than some roads in Kalutara District, the majority were covered by the second MFF. The civil works contracts were signed in 2020.

To see whether the nighttime lights trajectories are parallel between the treatment and control, we plotted the average of $\ln(\text{lights})$ for both groups in each year relative to road completion (Figure 7).¹⁴ First, in each period, the treatment group has a much lower average NTL level than the control group. The year-on-year difference in $\ln(\text{lights})$ is around 0.64 and statistically significant both before and after iRoad completion (Table 3, panels A and B). As we showed in section IIIC, the NTL level is highly correlated to the level of local labor force present. This result suggests, therefore, that the treatment group is less dynamic economically.

Second, although the difference in levels between the groups is stark, there is no noticeable non-parallel trend between the groups before completion. This result from Figure 7 is validated with a t-test in Table 3, panel A. Before iRoad completion, the year-on-year difference in $\ln(\text{lights})$ is, on average, 7% in both treatment and control groups with their difference at zero and statistically insignificant. At Year 2 after iRoad completion, however, the $\ln(\text{lights})$ in the treatment group continues its upward trajectory, while the light level in the control group reversed direction and almost returned to the level of the year prior (Figure 7). On average, the year-on-year difference in $\ln(\text{lights})$ is 5% higher in the treatment group after iRoad completion (Table 3, panel B).¹⁵

¹⁴ The control group includes the GNDs from both Southern Province and Western Province. The year relative to completion refers to the year of the paired treatment GND. For Southern Province control GNDs, they are paired with the closest treatment GND. For Western Province control GNDs, we follow the practice in Gu et al. (2021) and randomly paired with one of the treatment GNDs, following the distribution of treatment GND by calendar year. We removed samples with $t=3$ in the figure due to small sample size.

¹⁵ Nighttime lights trends by different control groups are available in Appendix Figure A1.

Table 3: Summary Statistics (by treatment status)

	Treatment		Control		Difference (Control – Treatment)	
	mean	sd	mean	sd	d	t
Panel A: Before iRoad Completion						
ln(lights)	0.74	1.06	1.38	1.31	0.64***	(21.83)
YoY diff in ln(lights)	0.07	0.39	0.07	0.38	0.00	(0.10)
Observations	1,653		9,800		11,453	
Panel B: After iRoad Completion						
ln(lights)	1.07	1.23	1.72	1.34	0.64***	(16.53)
YoY diff in ln(lights)	0.11	0.44	0.06	0.41	-0.05***	(-3.50)
Observations	1,210		7,091		8,301	
Panel C: GND Characteristics						
log Labor force	6.45	0.47	6.59	0.57	0.14***	(5.24)
log Area	14.55	0.74	14.14	0.90	-0.41***	(-9.96)
With RDA road	0.50	0.50	0.55	0.50	0.06*	(2.07)
With socioeconomic center	0.02	0.15	0.01	0.11	-0.01	(-1.56)
Number of HHs with electricity	277.65	138.30	338.39	243.82	60.74***	(7.19)
Number of HHs with kerosene	24.43	28.53	19.51	19.20	-4.92***	(-3.36)
Number of HHs with solar	0.45	1.45	0.33	1.46	-0.11	(-1.46)
Number of HHs with bio gas	0.02	0.18	0.07	2.15	0.05	(1.03)
Number of HHs with water well	169.10	132.38	201.81	182.67	32.71***	(4.34)
Number of HHs with water pipe	71.60	121.42	119.31	207.87	47.71***	(6.49)
Observations	409		2,413		2,822	

d = difference, GND = Grama Niladhari Division, HHs = households, RDA = Road Development Authority, sd = standard deviation, t = t-statistics, YoY = year-on-year.

Note: * p<0.1, ** p<0.05, *** p<0.01.

Source: Asian Development Bank estimates.

There are other contrasts between the treatment and control groups worth noting (Table 3, panel C). The control GNDs are denser, i.e., they host 14% more labor force, but are over 40% smaller. They are 5% more likely to be connected to Road Development Authority roads and host more households with basic utilities, including electricity, water wells, and piped water. These discrepancies further suggest that the GNDs selected for iRoad are relatively less economically active and less equipped with transport or utility infrastructure.

B. Empirical Model

So far, a simple comparison of arithmetic means suggests that nighttime lighting grows faster in the treatment group post-intervention and that there is no violation of parallel assumptions. We now formally estimate the relationship between iRoad openings and local nighttime lighting change in Southern Province using a stacked difference-in-differences (DiD) model. The model compares the change in log total sum of NTL in treatment GNDs before and after the opening of iRoad against the contemporaneous change in log sum of NTL in control GNDs. The stacked DiD model can be written as

$$\ln(\text{lights})_{gjt} = \sum_{t=\underline{t}}^{\bar{t}} \beta_t * \text{Treat}_{gj} * d_{gt} + \gamma \text{GNDchar}_g + \lambda_g + \lambda_j + \gamma_t + y_t + \varepsilon_{gjt} \quad \text{Equation 2}$$

In the model, the main dependent variable is the log sum of lights in GND g in comparison group j in year t after the opening of the iRoad.¹⁶ The main independent variable is the interaction term between Treat_{gj} and d_{gt} , where Treat_{gj} is a binary variable indicating the treatment status of the GND, and d_{gt} is a binary variable that takes the value 1 when GND g is t years after the opening of an iRoad. The range $[\underline{t}, \bar{t}]$ is the extent of periods relative to opening.¹⁷

We used NTL data from 2014, which is when the loan was signed for the iRoad program between ADB and the Government of Sri Lanka. The key coefficient of interest β_t , therefore, reflects the average association of iRoad opening with the percentage change in GND nighttime lights.

GNDchar_g is a vector of GND characteristics serving as a control, λ_g is GND fixed effects, and λ_j is group fixed effects. Since GNDchar_g is colinear with λ_g , they are separately included in the regression and absorb any time-invariant GND specific characteristics that may differentiate the GNDs in terms of NTL changes. The GNDchar_g vector takes into account whether the GND contains a socioeconomic center, is linked with RDA roads, area size, labor force, and the number of households connected with utilities as recorded in the 2012 Population Census. Variables γ_t and y_t are the years relative to iRoad opening and calendar year fixed effects, respectively, capturing any unobserved time-varying but a spatially-invariant trend that could affect the NTL across Southern Province (e.g., province-wide policy subsidizing electricity usage).

Table 4 lists the summary statistics used in the sample. Following the usual practice in the DiD model, we set the period before opening ($t=-1$) as the benchmark year. All coefficients are expressed against the coefficient in $t=-1$.

¹⁶ There are the same number of comparison groups as treatment GNDs. Each comparison group contains at least one treatment GND and up to 51 control GNDs. Depending on the random assignment of control GNDs in Western Province, there may exist around a dozen treatment GNDs without control GNDs. The baseline empirical results are robust to exclude these unpaired treatment GNDs (not shown).

¹⁷ Since in our panel the calendar year ranges from 2014 to 2020 and the iRoad opening occurred in 2017, 2018, and 2020, $\underline{t}$ can go as low as -6 (for 2020 connected GNDs) and $\bar{t}$ up to $+3$ (for 2017 connected GNDs).

Table 4: Summary Statistics (Full Sample)

	mean	sd	min	max
Sum of lights	5.39	19.34	0.00	826.86
With RDA roads	0.54	0.50	0.00	1.00
With socioeconomic center	0.01	0.12	0.00	1.00
log Labor force	6.57	0.56	4.71	8.96
log Area	14.20	0.89	10.87	20.07
Number of HHs with electricity	329.59	232.45	45.00	2,924.00
Number of HHs with kerosene	20.23	20.88	0.00	349.00
Number of HHs with solar	0.35	1.46	0.00	25.00
Number of HHs with bio gas	0.06	1.98	0.00	105.00
Number of HHs with water well	197.07	176.60	0.00	1,733.00
Number of HHs with water pipe	112.40	198.36	0.00	2,900.00
Observations	19,754			

HHs = households, max = maximum, min = minimum, RDA = Road Development Authority, sd = standard deviation.

Source: Asian Development Bank estimates.

C. Baseline Results

The baseline β_t coefficient results for the stacked DiD model are shown in Table 5. Column 1 controls for calendar year and province fixed effects only; column 2 adds a series of GND characteristics such as controls; column 3 controls for GND fixed effects and is the preferred specification (depicted in Figure 8). The main results are robust across three specifications and confirm the patterns observed in section IVA. First, there is no evidence of pre-treatment trends. None of the β_t coefficients when $t < 0$ are significant, and when we control for GND characteristics or GND fixed effects, their absolute values are small, all less than 0.1, indicating little difference before treatment. These results also indicate that iRoad construction activity is not associated with generating nighttime lights, presumably because most construction was done during the day.

Second, the iRoad opening year and the subsequent year do not see stronger nighttime lights in treatment GNDs, with β_0 and β_1 marginally above zero and statistically insignificant. At Year 2 after completion, the coefficient β_2 is positive at 0.12 and significant at the 99% confidence level. That is, nighttime lights in a GND in Year 2 post-iRoad connection are 12% stronger than the nighttime lights in an otherwise similar GND without iRoad. At Year 3, the coefficient drops slightly to 10%. The coefficient is barely significant statistically, likely due to the lack of statistical power because out of the 409 treatment GNDs, only 1 in 5 was connected with iRoad in the calendar year 2017 and hence with $t=3$ in the sample.

To summarize, GNDs connected with iRoad in Southern Province emit 12% higher nighttime lights in Year 2 after iRoad completion. Taking from the elasticity between nighttime lights and labor force presence in section IIIC, the 12% coefficient translates into 2.6% higher economic activity.

Table 5: iRoad Opening and Changes in Nighttime Lights

	(1)	(2)	(3)
β_{-6}	.134 (.122)	.0229 (.111)	.0675 (.09)
β_{-5}	.08 (.11)	-.0308 (.102)	.0139 (.0872)
β_{-4}	.0485 (.0383)	.0081 (.0353)	-.028 (.0357)
β_{-3}	.0177 (.0262)	.0157 (.0261)	.0135 (.0263)
β_{-2}	.0151 (.0191)	.0173 (.019)	.0196 (.0192)
β_{-1}	0 (.)	0 (.)	0 (.)
β_0	.008 (.0234)	.0092 (.0233)	.0105 (.0236)
β_1	-.007 (.0367)	.009 (.0342)	.0025 (.0303)
β_2	.117*** (.0376)	.129*** (.0357)	.117*** (.032)
β_3	-.115 (.129)	.0041 (.108)	.105 (.0726)
Calendar Year FE	Yes	Yes	Yes
Province FE	Yes	Yes	
GND Characteristics		Yes	
GND FE			Yes
Group FE			Yes
N	19,754	19,754	19,754
R^2	0.166	0.486	0.926

FE = fixed effects, GND = Grama Niladhari Division, iRoad = Integrated Road Investment Program, N = number of observations.

Note: Heteroskedasticity robust standard error in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Asian Development Bank estimates.

What is significant about Year 2? Since in our sample, most treatments happened in 2018, the estimated 12% higher nighttime lights in Year 2 coincide with the outbreak of the COVID-19 pandemic in 2020. Under export contraction, factory closures, and constrained mobility during a general lockdown, Sri Lanka's gross domestic product contracted by 3.6% and severely reduced economic activity from Q2 2020. The contraction runs across sectors—2.4% in agriculture, 6.9% in industry, and 1.5% in service (ADB 2021). The contraction of economic activity also exhibits spatial variation. As shown in Figure 7, the nighttime lights in control GNDs reversed trajectory in Year 2, while the lights in treatment GNDs continued the growth trend. This suggests that the Year 2 coefficient in the DiD model is driven by the decrease of the outcome variable (nighttime lights) in the control group, rather than an increase in the treatment. The findings suggest that areas in Southern Province connected with iRoad would show strong growth resilience in the event of a large-scale negative economic shock.

D. Robustness Tests

Robustness tests are performed using the preferred specification (Table 6). First, we check whether the results are sensitive to the selection of control groups as this is fundamental to the DiD design. In the baseline specification, our control group consists of (i) Southern Province GNDs without iRoad planned, and (ii) Western Province GNDs with iRoad planned but yet to start construction. Our results hold when either group is used as a control separately (Table 6, columns 1 and 2). When the Western Province control group is used, the coefficient in Year 2 is higher than the baseline, and the coefficient in Year 3 is also positive and significant. Since the Western Province control group is profiled for iRoad investments that are similar to the treatment, the results in column 2 further strengthen the significant association estimated in the baseline.

Table 6: Robustness Tests

	(1) Southern Controls	(2) Western Province Controls	(3) Exclude Far Away Control Groups (>5,000 m)	(4) Only Include Close Control Groups (<Median distance)	(5) Remove GNDs with SEC
β_{-6}	.0126 (.0923)	.182* (.104)	.0283 (.0935)	.0727 (.0988)	.0678 (.0931)
β_{-5}	-.0089 (.0895)	.0616 (.0966)	-.004 (.0907)	.0461 (.098)	.0133 (.0902)
β_{-4}	-.0344 (.0365)	-.0121 (.0407)	-.0231 (.0371)	-.0168 (.0396)	-.0271 (.0364)
β_{-3}	.002 (.0269)	.0392 (.0308)	.0034 (.0273)	-.0093 (.0287)	.0177 (.0266)
β_{-2}	.0096 (.0196)	.0446* (.0245)	.007 (.0197)	-.0052 (.0212)	.0208 (.0196)
β_{-1}	0 (.)	0 (.)	0 (.)	0 (.)	0 (.)
β_0	.016 (.0241)	-.0067 (.0285)	.0072 (.0245)	-.0139 (.0264)	.009 (.024)
β_1	.0172 (.0309)	-.0306 (.0352)	.0061 (.0315)	-.0042 (.0335)	.0017 (.0309)
β_2	.113*** (.0325)	.136*** (.0376)	.103*** (.0331)	.0841** (.0356)	.118*** (.0326)
β_3	.0789 (.0753)	.152* (.0796)	.0744 (.0758)	.0363 (.0794)	.105 (.0728)
Calendar Year FE	Yes	Yes	Yes	Yes	Yes
GND FE	Yes	Yes	Yes	Yes	Yes
Group FE	Yes	Yes	Yes	Yes	Yes
N	14,609	8,008	13,076	8,736	19,481
R ²	0.911	0.923	0.904	0.894	0.926

FE = fixed effects, GND = Grama Niladhari Division, m = meter, N = number of observations, SEC = socioeconomic center.

Note: Heteroskedasticity robust standard error in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

Source: Asian Development Bank estimates.

In the baseline, we include all GNDs without iRoad planned in Southern Province as controls, but GNDs farther away may be less similar to the treatment than controls. We therefore restrict our samples to only include GNDs in Southern Province within a 5 km range of any treatment GND (Table 6, column 3).¹⁸ In column 4, we more aggressively remove half the control GNDs further than the median distance between any control and treatment GNDs. In both specifications, the estimates for β_2 remain significant and positive, although slightly smaller. The decrease in the coefficient suggests spillover effects of iRoad connectivity, that is, control GNDs near treated GNDs may also benefit from the iRoad program.

A concern that may bias our estimates is that the COVID-19 shock in 2020 coincided with Year 2 and Year 3 in our setup and may be spatially correlated with the placement of iRoad and the timing of completion. From Figure 7 and DiD estimates, we did not find any violation of a parallel trend before iRoad completion, but still, we are not certain if the trend would continue parallel post-intervention, considering the contemporaneous COVID-19 shocks. In the event the spatial-time variation of COVID-19 shocks coincides with the spatial-time variation of iRoad connectivity, we cannot pin down the exact magnitude of iRoad effects on nighttime lights. For example, the sector composition in the control group may be more susceptible to export contractions than those in treatment groups or there may be reverse migration from control groups to treatment groups due to factory shutdowns. Ideally, if we could control for the spatial-time variation of these variables at GND-year level, such as employment, mobility or migration patterns in 2020, we could address some of these concerns. Unfortunately, to the best of our knowledge, such data are not available.

Nonetheless, we tried to address some of these possibilities in the DiD design. For one, we use Western Province GNDs with iRoad planned as controls. Targeted for iRoad intervention, these GNDs are less developed and primarily rural areas relative to their within-province counterparts. Western Province, where the capital city is located, is the growth powerhouse for the country. If reverse migration were to happen, we should expect the Western Province control GNDs to receive returning labor. Hence, the robustness test specification using Western Province controls should alleviate issues of reverse migration.¹⁹ To further mitigate the concern of shock synchronization, we remove GNDs with socioeconomic centers from the sample to further restrict the comparison among less developed GNDs.²⁰ The results (Table 6, column 5) are very similar to the baseline estimates.

E. Heterogeneity

The association between iRoad and nighttime lights from the baseline estimate is the average for all 409 treatment GNDs across Southern Province, but the benefits likely vary by location, placement, complementary infrastructure and policies, and intensity of interventions. To identify potential channels through which iRoad contributes to local economic activity and informs future investment decisions, it is, therefore, worth exploring heterogeneity to examine the baseline results.

¹⁸ The cutoff is selected at around 90% of the distance quantile of the full sample. This removes 219 control GNDs out of 1,678 from Southern Province.

¹⁹ It could also be argued there is no evidence to support the assumption that cross-province return migration would be on a larger scale for treated GNDs than for control GNDs in Southern Province. We cannot completely rule out this concern as it may still be the case that Southern Province treatment GNDs are the origin of more migrant workers than both groups of control GNDs. One data set to study this issue would be origin destination information tracking workers after the COVID-19 outbreak.

²⁰ The average $\ln(\text{lights})$ in GNDs with socioeconomic centers in the sample is two times higher than GNDs without (8.6 vs. 3.6).

First, we find that the baseline estimates are driven by connected GNDs not too close to and not too far from socioeconomic centers. Specifically, the associations between iRoad connections and nighttime lights in the 40th, 60th, and 80th distance percentiles to the nearest socioeconomic center are higher than those in the 20th and 100th percentiles (Figure 9). Intuitively, GNDs very close to socioeconomic centers may already have easy access to those centers and the marginal benefit from additional iRoad connectivity may be small (the association is 0.06 and not statistically significant). For GNDs farther from socioeconomic centers, iRoad investments may not be adequate to provide improved market or job access and lead to more dynamic economic activities. It is somewhere in the middle that iRoad investments hit a sweet spot of economic returns. The associations for GNDs in the 40th, 60th, and 80th percentile distances to the nearest socioeconomic center are 0.22 and significant, almost doubling the average association, 0.11, and 0.13 and significant respectively.

Second, we examine if the results vary across three districts in Southern Province, i.e., Galle, Matara, and Hambantota, interacting district dummies with the interaction between treatment dummy and time period dummies, a triple interaction specification. The results (Figure 10) show that the baseline estimates of β_2 are largely driven by beneficiary GNDs in Galle District. Specifically, β_2 is estimated to be twice as high in Galle District as the full sample average.²¹

²¹ We ran the triple interaction specification three times, each time by varying the benchmark district while keeping the sample sizes constant. Figure 5 shows the benchmark coefficient in these runs.

The discrepancies in association across districts are likely caused by multiple factors. Hambantota District, being much less developed than the other two, most likely requires a range of investments and policies to make a difference in growth. The existing iRoad program, while it may be a crucial ingredient in rural development, may not be sufficient to transform Hambantota by itself. Furthermore, the placement of segments and other infrastructure may matter. Galle District has a dense road network, comprising the Southern Expressway, national roads, and provincial roads, and Galle Harbor. These factors may contribute to higher realized benefits for Galle District iRoad. Indeed, quantile analysis (Figure A2) shows that the baseline estimates are driven by GNDs not too close to and not too far from the Southern Expressway (at the 40th and 60th percentile distance of all GNDs in the Southern Province). These GNDs show the highest estimated association (23%) between iRoad connectivity and nighttime lights growth, compared to the others (8%–13%).²² It is therefore suggested that the Southern Expressway contributes to the heterogeneity of the benefits by districts, considering that GNDs with such characteristics are the most common in Galle District, followed by Matara District and Hambantota District.²³

²² The underlying intuition may be similar to the heterogeneity analysis by distance to the nearest SEC (Figure 9): GNDs too close to the Southern Expressway were already provided with decent market access, while for the GNDs farther away from such major road network backbone, iRoad may only provide limited incremental connectivity. Therefore, it is the GNDs at mid-range that benefit the most from iRoad investment.

²³ The shares of GNDs fall into the groups at 40th and 60th percentile distance to the Southern Expressway, which are 49% in Galle District, 45% in Matara District, and 36% in Hambantota District.

Third, GNDs connected with iRoad end points benefit more than GNDs with iRoad passing through them (Figure 11). Specifically, we re-estimate the baseline model by separating the sample with and without road segment end points. For treatment GNDs in Galle, the coefficients in Year 2 and Year 3 after road completion are 0.21 and 0.23 respectively, and both significant. The coefficients for GNDs with iRoad passing through are lower at 0.17 and 0.22, and also significant.

The coefficients for GNDs with the iRoad passing through them are closer to the true gains from the iRoad. By design, the former GND groups are those identified as rural hubs and qualified to be connected to socioeconomic centers via the shortest connecting route. We should expect larger associations between the iRoad program and NTL in these targeted GNDs for two reasons. First, these identified rural hubs typically host larger populations (on average 6.6% more people and 6.8% more labor force according to the 2012 census). They also host more educational and medical facilities, and other transport and communication infrastructure such as railway stations, bus stands, and authorized diesel or petrol outlets, as these are the selection criteria used to rank the GNDs for iRoad interventions. The additional labor force, facilities, and infrastructure may synergize with iRoad and therefore enhance benefits. The baseline estimates could overstate the gains of standalone iRoad interventions.

Second, as these GNDs are on an official list of targeted rural areas, they may also have been prioritized to receive other interventions (e.g., a fertilizer subsidy) that coincides with the timing of iRoad construction. Therefore, our estimated coefficients may have overstated the gains from iRoad alone. On the other hand, the GNDs with iRoad passing through them, i.e., indirectly targeted by the program, are less prone to be affected by these confounding factors, synergies with existing infrastructure and other treatments. Notwithstanding the data inadequacy that precludes separating confounding factors for the directly targeted GNDs, the estimated coefficients for those indirectly targeted GNDs are more likely to be closer to the actual gains from the iRoad program.

Finally, the study examines the treatment effect at the intensive margin. One key indicator of road quality is the international roughness index (IRI) that measures the quality of improvements. We re-estimated the DiD model but replaced the $Treat_g$ dummy with the difference in IRI of the iRoad associated with GND g before and after the program. The results (Figure 12) show that each unit of IRI reduction is associated with a 2% increase in nighttime lights in Year 2 after iRoad completion. Considering that, on average, the IRI improved by 6.8 units, this result is in line with the baseline 12% coefficient at the extensive margin.

V. CONCLUSION

This study provides new evidence for the impact of rural road connectivity on local economic activity in Sri Lanka. There is a robust association between the provision of all-weather rural roads through the iRoad program and an increase in local nighttime lights luminosity, a remote sensing indicator strongly correlated with local labor force presence. All else being equal, GNDs connected with the iRoad after 2 years exhibit 12% more nighttime lights on average, corresponding to 2.6% additional labor force presence. These gains hold even for indirectly targeted rural areas where the iRoad passes through. An important factor driving the estimated association is the sustained growth in the treatment GNDs and the decline of nighttime lights in the control GNDs in the year of the COVID-19 global pandemic outbreak.

Furthermore, the study finds that the economic benefit of iRoad is not uniform across Southern Province. Locations too close or too far from socioeconomic centers do not benefit as much as locations at a moderate distance, and locations with other infrastructure or facility provisions benefit more. An analysis at intensive margin reveals that locations with more improved road conditions benefit more, i.e., an additional 1 unit of IRI reduction is associated with 2% more nighttime lights.

The findings have clear policy implications. First, they support the assumption that poor rural accessibility to socioeconomic centers is a development bottleneck to rural development, and investing in improving rural connectivity can ease development constraints. Against the backdrop of economic downturns caused by internal and external contractions resulting from the global COVID-19 pandemic and lockdowns, the results suggest that iRoad connectivity could facilitate strong resilience to large-scale negative economic shocks and further contribute to expedited economic recovery.

Second, the heterogeneity results show the economic gains from iRoad are not uniform spatially. Targeted placements considering the beneficiary's location, distance to economic hubs, and synergies with other infrastructure or facilities could enhance the effectiveness of investments. In particular, we find that remote areas far from socioeconomic centers benefit the least from iRoad connectivity, and that locations with more adequate other infrastructure (e.g., bus stops, railroads) or facilities (e.g., educational or medical facilities) benefit more from the iRoad program, suggesting there could be other constraints at play that limit the potential of road investment. For example, the improved market access from iRoad may still not be sufficient for farmers in these remote areas to substantially lower the price of traded goods and, if that is the case, perhaps establishing new socioeconomic centers nearby could enhance the benefit of iRoad by incorporating these areas into the domestic trade network. As Sri Lanka is planning to extensively expand the iRoad program throughout the country, considerations regarding placement and synergies with other interventions are crucial to reaping the full benefit of public investments.

Third, our intensive margin analysis shows that road quality matters. This finding suggests that post-construction maintenance to keep the IRI low could contribute to sustaining the economic gains at a relatively low cost. Planned maintenance would keep road conditions in better driving quality for relatively longer periods, which is more cost effective compared with rehabilitation after severe deterioration resulting from lack of maintenance. It is therefore worthwhile to secure and allocate sufficient funding and enhance institutional capacities for sustainable road maintenance, particularly at the local authority level, where both the current fund allocation and technical capacity have great room for improvement.

How to extend the road asset management system developed by the Road Development Authority for the maintenance planning of the national roads to further cover the provincial and local authority roads should be further analyzed. It can then serve as a basis for funding allocation and maintenance planning.

Fourth and lastly, the results suggest several areas for future research. For one, due to limited panel availability of socioeconomic data, our empirical method cannot clearly identify the exact causal effect of the iRoad against other current and potentially spatially correlated shocks. It is worthwhile to collect additional data to establish a more rigorous causal relationship and a more precise point estimate. For example, anonymous-call detailed record data that inform longitudinal workplace clusters and labor mobility patterns are useful to control for any return migrations. For similar reasons, the study cannot pin down the underlying mechanism of increased nighttime lights associated with iRoad connectivity. This is because nighttime lights data, while superior in many aspects, contain limited information on the type of economic activity involved.

Future research could utilize economic census on employment and labor income, household survey data on agriculture input and output, and other remote sensing data (e.g., daytime satellite images for traffic counts) to study the extent of the increased economic activity from, for example, reduced prices of goods (Aggarwal 2018), or increases in crop outputs thanks to the adoption of agricultural technologies (Shamdasani 2021). Identifying these underlying channels could further inform complementary policies for iRoad investments. As iRoad implementation expands and matures, continuous and granular data collection will be necessary prior and post project implementation to assess the program's long-term impacts across the country, as well as the drivers of any heterogeneous benefits.

APPENDIX

Figure A1: Average Sum of VIIRS Lights Relative to iRoad Completion

iRoad = Integrated Road Investment Program, SP = Southern Province, VIIRS = Visible and Infrared Imaging Radiometer Suite, WP = Western Province.

Note: The figure plots the mean of log sum of VIIRS lights for control Grama Niladhari Division (GND) and treatment GNDs.

Source: Asian Development Bank using VIIRS nighttime lights data and iRoad placement data.

Figure A2: Changes in Nighttime Lights by (percentile) Distance to Southern Expressway

Source: Asian Development Bank using Visible and Infrared Imaging Radiometer Suite nighttime lights data and iRoad and Southern Expressway placement data.

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Rural Road Connectivity and Local Economic Activity

Evidence from Sri Lanka's Integrated Road Investment Program

This study investigates how rural road connectivity affects local economic activity. Using panel data, the study finds the Integrated Road Investment Program (iRoad) results in better and more consistent rural road conditions in Southern Province of Sri Lanka. Rural areas with improved connectivity show higher local nighttime luminosity, a proxy for economic activity, compared to areas without connectivity. Furthermore, the estimated gains are higher in areas at a moderate distance to socioeconomic centers, with more adequate complementary infrastructure provisions, or with more substantial road quality improvement. The findings support the objective that improving rural connectivity can ease development constraints, strengthen resilience to negative economic shocks, and contribute to post-pandemic economic recovery.

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