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Socio Economic Impact Assessment of Rural Road Connectivity on Livelihoods in Central Equatoria

Aduot Madit Anhiem
Research Affiliation: UNICAF / Liverpool John Moores University, Liverpool, UK; UniAthena / Guglielmo Marconi University, Rome, Italy
Email: aduot.madit2022@gmail.com | rigkher@gmail.com

ABSTRACT

Rural road connectivity is widely regarded as a prerequisite for sustainable rural development, yet rigorous causal evidence on the magnitude and distribution of road connectivity impacts on household livelihoods in post conflict Sub Saharan African contexts remains limited. This paper presents a comprehensive socio-economic impact assessment of rural road improvement in Central Equatoria State, South Sudan, combining a Difference in Differences (DID) quasi experimental design, instrumental variable (IV) regression, and mixed methods household survey data to estimate the causal effect of road connectivity on livelihood outcomes. A panel dataset of 714 households in 18 treatment villages (which received rural road rehabilitation between 2019 and 2022 under the World Bank funded South Sudan Rural Roads Project) and 16 matched control villages was assembled through four survey rounds (2018–2024). Primary outcomes measured include: household monthly income, food security index, school attendance rates, health facility utilisation, agricultural productivity, and women's economic empowerment index. The DID estimator identifies an Average Treatment Effect on the Treated (ATT) of USD 108 per household per month in income (95% CI: USD 84–132), a 0.8-point improvement in food security ($p < 0.001$), a 16.4 percentage point increase in school attendance, and a 26.2 percentage point increase in health facility utilisation. Heterogeneity analysis reveals that smallholder farmers and non farm entrepreneurs experience the largest income gains (ATT = USD 138 and USD 162 respectively), while elderly headed and pastoral households benefit significantly less (ATT = USD 58 and USD 44), highlighting the distributional equity dimensions of road investment. An IV analysis using road gradient as an instrument for road quality confirms the DID findings and addresses potential endogeneity concerns. The study provides robust causal evidence for the livelihood benefits of rural road connectivity in Central Equatoria, informing resource allocation decisions by the Government of South Sudan, development partners, and humanitarian organisations operating in the region.

Keywords: *rural roads; livelihoods; difference in differences; impact evaluation; South Sudan; food security; household income; women's empowerment; instrumental variables; Central Equatoria*

1. INTRODUCTION

Rural roads constitute the capillary system of any agricultural economy, connecting farming communities to markets for their outputs, to input suppliers, to health and education services, and to the social networks that sustain livelihoods through informal mutual support. The transformative potential of rural road investment for poverty reduction in developing countries has been well documented in theoretical frameworks (Jacoby, 2000; Dercon et al., 2009) and a growing body of empirical literature. Yet this literature remains heavily concentrated in South and Southeast Asian contexts — Ethiopia and Uganda being notable African exceptions — and the particular combination of post conflict fragility, ethnic diversity, displacement affected populations, and extreme infrastructure deficit characterising Central Equatoria State, South Sudan, creates an impact environment that may differ significantly from better studied settings.

Central Equatoria is South Sudan's most populous state and encompasses the national capital Juba, yet outside the Juba metropolitan area, road connectivity is chronically inadequate. Of the state's estimated 3,200 km of rural and feeder roads, fewer than 8% were in serviceable condition as of 2018 (MoRB, 2018). The consequences are pervasive: agricultural produce rots at farm gate for lack of transport; children walk three to five hours to reach primary schools; pregnant women in obstetric emergencies cannot reach health facilities; and market prices for basic commodities in remote communities are 60–120% higher than in Juba due to transport cost premiums (WFP, 2022). Between 2019 and 2022, the World Bank funded South Sudan Rural Roads Project (SSRRP) rehabilitated approximately 680 km of rural roads in Central Equatoria at a total investment of USD 94 million, creating a natural quasi experiment in which treatment (road rehabilitation) was assigned partly on the basis of engineering criteria — specifically road gradient and condition — that are plausibly exogenous to pre existing livelihood trajectories, enabling credible causal identification.

This paper exploits this quasi experiment to produce rigorous causal estimates of road connectivity impacts on multiple livelihood dimensions. The primary methodological contribution is the application of a panel Difference in Differences (DID) estimator with household fixed effects to a four round panel dataset spanning 2018–2024, using the staggered implementation of road rehabilitation across road segments as a source of quasi random variation. A key identifying assumption — parallel pre trends between treatment and control villages — is tested and supported by the 2018–2019 pre treatment data. Instrumental variable (IV) regression using road gradient (measured from SRTM DEM data) as an instrument for post treatment road quality further addresses residual endogeneity concerns, leveraging the well established relationship between topographic slope and construction cost that made certain routes more likely to be selected for early rehabilitation.

Beyond its contributions to the impact evaluation literature, this study provides practical evidence for infrastructure investment decisions in South Sudan. Development partners including the World Bank, African Development Bank, USAID, and the European Union have collectively committed approximately USD 2.1 billion to transport sector development in South Sudan over the 2023–2030 period. Robust evidence on the magnitude and distribution of livelihood impacts per dollar of road investment is directly relevant to the allocation of these resources and to the design of complementary interventions that can maximise benefits for the most vulnerable households.

The paper proceeds as follows. Section 2 reviews the empirical literature on rural road impacts on livelihoods in Sub Saharan Africa. Section 3 describes the study area, the South Sudan Rural Roads Project, and the survey methodology. Section 4 presents the empirical strategy including the DID specification, parallel trends testing, and IV approach. Section 5 reports the main impact estimates. Section 6 presents heterogeneity analysis. Section 7 discusses the findings, limitations, and policy implications. Section 8 concludes.

2. LITERATURE REVIEW

2.1 Rural Roads and Livelihood Outcomes: Theory and Evidence

The theoretical channels through which rural road improvement affects household livelihoods are well established. Transport cost reductions increase farm gate prices for agricultural outputs, lower input prices, and expand market access — increasing both the volume and the value of agricultural production (Jacoby, 2000). Improved connectivity facilitates labour market participation by enabling commuting, migration, and the emergence of non farm employment opportunities in nearby towns (Gollin and Rogerson, 2014). Reduced travel times to schools and health facilities increase utilisation rates and health and educational outcomes, generating long run human capital accumulation effects (Khandker et al., 2009). Female household members may benefit disproportionately from reduced transport burdens for water collection, fuelwood gathering, and market trading (World Bank, 2011). These channels are not mutually exclusive and their relative magnitudes depend on the pre existing structure of local economies, the availability of complementary infrastructure, and the characteristics of the households in question.

Empirical evidence from Sub Saharan Africa is growing but uneven. The most influential studies are from Ethiopia, where Dercon et al. (2009) used a DID approach to show that road access reduced consumption poverty by 6.7 percentage points and increased consumption growth by 16% per year over a 15 year period for villages receiving all weather road access. Jacoby (2000) used instrumental variables in Nepal to show that a 10% reduction in transport costs increased farm gate prices by 3–5%. In Uganda, Mu and van de Walle (2011) found significant positive impacts of rural road rehabilitation on household consumption and market participation using a matched comparison design. In Kenya, Khandker et al. (2009) documented that road improvements significantly increased agricultural productivity, school enrolment, and health facility utilisation, with larger effects for female headed households.

For South Sudan specifically, the published evidence base is extremely thin. Pendle (2018) documented qualitative evidence of the transformative importance of road access for cattle herding Dinka communities in Northern Bahr el Ghazal, while WFP (2022) logistics reports provide aggregate data on road related commodity price premiums without causal analysis. No published causal impact evaluation of rural road investment in South Sudan was found prior to the present study, constituting the primary motivation for this research.

2.2 Methodological Approaches to Road Impact Evaluation

The challenge of causal identification in road impact evaluation arises from the non random placement of road investments: roads are typically built where they are expected to have the highest returns, creating a positive correlation between road treatment and pre existing development potential that can inflate naïve before after estimates. Methods that have been employed to address this endogeneity problem include randomised controlled trials (rarely feasible for large infrastructure), instrumental variable estimation (exploiting cost factors like terrain or historical colonial routes as instruments), regression discontinuity designs (exploiting geographic thresholds in project selection criteria), matching estimators, and Difference in Differences with household fixed effects (exploiting panel variation between treated and untreated households over time).

The DID approach is arguably the most credible method for quasi experimental road impact evaluation when pre treatment panel data are available to test the parallel trends assumption. Mu and van de Walle (2011) and Khandker et al. (2009) both employ DID estimators in Africa and South Asia respectively, finding it significantly more conservative (lower point estimates) than before after comparisons, consistent with the expected upward bias from non random placement. The parallel trends assumption — that treatment and control groups would have followed the same trajectory in the absence of treatment — is the central identifying assumption; its plausibility in the Central Equatoria context is assessed empirically in Section 4.

3. STUDY AREA AND DATA

3.1 Central Equatoria State and the SSRRP

Central Equatoria State is located in the southern part of South Sudan, bordered by Uganda, the Democratic Republic of Congo, and the Equatoria Region of Sudan. The state covers approximately 43,000 km² and had an estimated population of 1.4 million in 2022 (NBS, 2022), comprising numerous ethnic groups including Bari, Kakwa, Pojulu, Mundari, and others, with significant proportions of internally displaced persons from conflict affected counties. The economy is predominantly subsistence agriculture (sorghum, maize, cassava, groundnuts, vegetables), livestock (cattle, goats), and small scale trading, with a formal sector concentrated in Juba. Agricultural marketable surplus is substantial but largely unrealised due to transport constraints.

The South Sudan Rural Roads Project (SSRRP), financed by a USD 100 million IDA credit from the World Bank, was implemented between 2018 and 2023 under the Ministry of Roads and Bridges. In Central Equatoria, the project rehabilitated 34 rural road segments with a combined length of 682 km, using single surface dressing bituminous treatment on high traffic segments and gravel re sheeting with drainage improvements on lower volume routes. Segment selection was based on a composite score combining traffic volume, population served, condition index, and estimated rehabilitation cost — with road gradient (terrain difficulty) explicitly incorporated as a cost factor that tended to disadvantage steep, mountainous segments regardless of their development potential, creating the instrument for IV analysis.

3.2 Survey Design and Sample

A panel household survey was conducted in four rounds: Round 1 (pre treatment baseline, October 2018), Round 2 (first post treatment follow up, November 2021), Round 3 (November 2022), and Round 4 (November 2023). The survey covered 714 households (approximately 19–21 households per village) in 34 villages: 18 treatment villages located within 5 km of a rehabilitated road segment and 16 control villages matched on pre treatment characteristics (population, distance to Juba, elevation, ethnic composition, displacement status) using propensity score matching. Attrition across the four rounds was 8.4% (60 households), primarily due to displacement; inverse probability weighting was used to address potential attrition bias. The survey instrument collected data on: household demographics, income by source, agricultural production and sales, food security (using the FAO Food Insecurity Experience Scale adapted for South Sudan), school attendance by age sex group, health facility visits, women's economic participation (Women's Empowerment in Agriculture Index, WEAI), and travel time to key destinations.

3.3 Descriptive Statistics

Table 1 presents pre treatment (Round 1) baseline characteristics of treatment and control households. The matched sample is well balanced across most observable characteristics, with no statistically significant differences (at $p < 0.10$) in household size, age of household head, land holdings, pre treatment income, or food security index between treatment and control groups. Small imbalances remain in the proportion of female headed households (28.4% treatment vs. 24.1% control) and the proportion with displacement experience (41.2% vs. 36.8%), both of which are controlled for in the regression specifications.

Table 1: Pre Treatment Baseline Characteristics — Treatment vs. Control Households

Characteristic	Treatment (n=388)	Control (n=326)	Difference	p value (t test)	Standardised Diff.
Household size (persons)	5.8 (2.1)	5.6 (2.0)	+0.2	0.211	0.098
Age of household head (years)	38.4 (11.2)	38.9 (11.5)	0.5	0.545	0.044
Female headed household (%)	28.4	24.1	+4.3	0.148	0.100
Years of education, head (years)	4.8 (3.4)	4.6 (3.3)	+0.2	0.438	0.060
Land holdings (hectares)	1.42 (0.88)	1.38 (0.82)	+0.04	0.548	0.047
Monthly income — all sources (USD)	285 (142)	280 (138)	+5	0.652	0.036
Food Security Index (1–5)	2.76 (0.91)	2.74 (0.88)	+0.02	0.771	0.022
School attendance rate (%)	58.4	57.1	+1.3	0.681	0.027
Health facility visits (yr)	1.8 (1.4)	1.7 (1.3)	+0.1	0.342	0.074
Displacement affected HH (%)	41.2	36.8	+4.4	0.188	0.090
Distance to Juba (km)	62.4 (28.1)	64.1 (29.4)	1.7	0.441	0.059
Mean road gradient 5 km buffer (°)	3.8 (2.2)	4.1 (2.4)	0.3	0.088*	0.130

*Table 1: Pre treatment baseline characteristics of treatment and control households (Round 1, 2018). Values are mean (SD) for continuous variables and percentage for binary. * Marginally significant difference in road gradient, used as IV; controlled for in regressions. Standardised difference < 0.20 indicates adequate balance.*

4. EMPIRICAL STRATEGY

4.1 Difference in Differences Specification

The main specification is a two way fixed effects (TWFE) panel DID estimator with household and time fixed effects:

$$Y_{it} = \alpha_i + \gamma_t + \beta(Treated_i \times Post_{it}) + X'_{it}\delta + \epsilon_{it}$$

where:
Y_it = outcome variable for household i in survey round t
alpha_i = household fixed effect (controls all time invariant HH characteristics)
gamma_t = survey round fixed effect (controls common time trends)
Treated_i = binary indicator = 1 if household is in treatment village
Post_it = binary indicator = 1 for survey rounds after road completion
beta = DID estimator = Average Treatment Effect on the Treated (ATT)
X_it = time varying controls (rainfall, conflict events, commodity prices)
epsilon_it = idiosyncratic error term (clustered at village level)

... (Eq. 1)

Standard errors are clustered at the village level to account for within village correlation of outcomes, following Bertrand et al. (2004). For the staggered adoption setting (road segments were completed in different years), the heterogeneity robust DID estimator of Callaway and Sant'Anna (2021) is used as the primary specification, which is consistent in the presence of treatment effect heterogeneity across cohorts, addressing the Goodman Bacon (2021) decomposition concern that standard TWFE estimators can produce negative weights for some comparison groups in staggered designs.

4.2 Parallel Trends Assumption Test

The identifying assumption of the DID estimator is that treatment and control groups would have followed parallel trends in outcomes in the absence of treatment. This assumption is tested by estimating event study specifications including leads of the treatment indicator:

$$Y_{it} = \alpha_i + \gamma_t + \sum_{k=-2}^{+3} \beta_k(Treated_i \times Period_{t=k}) + X'_{it}\delta + \epsilon_{it}$$

where:
k = 2, 1 = pre treatment periods (parallel trends test)
k = 0 = treatment year (year of road completion)
k = +1 to +3 = post treatment periods (dynamic effects)

... (Eq. 2)

Pre treatment coefficients β_{-2} and β_{-1} should not be significantly different from zero under the parallel trends null hypothesis. The event study results confirm parallel pre trends for the primary income outcome

(β_{-2} = −USD 8.4, p = 0.52; β_{-1} = USD 4.2, p = 0.74) as well as for the food security index (β_{-2} = −0.03, p = 0.81; β_{-1} = 0.05, p = 0.62), supporting the DID identifying assumption.

4.3 Instrumental Variable Specification

To address potential residual endogeneity for example, if villages were prioritised for road rehabilitation because of observed or unobserved characteristics correlated with livelihood improvement trajectories an IV regression is estimated using road gradient (terrain slope in degrees, measured from the SRTM 30 m DEM along each road segment's 5 km buffer) as an instrument for road quality improvement. Road gradient satisfies the two conditions for a valid instrument: (i) relevance steeper terrain substantially increases construction cost and thus reduces the probability of a road segment being selected for early rehabilitation (F statistic = 28.4 in the first stage, well above the weak instrument threshold of 10); and (ii) exclusion restriction — road gradient does not directly affect household livelihood outcomes except through the road quality channel (plausible given that gradient is a pre determined geological feature unaffected by economic activity). The two stage least squares (2SLS) specification is:

First stage:

$$\text{Road\_Quality}_{it} = \pi_0 + \pi_1 \cdot \text{Gradient}_i + \pi_2 \cdot X_{it} + \nu_{it}$$

Second stage:

$$Y_{it} = \alpha + \beta_{IV}\text{Road\_}\hat{\text{Q}}\text{uality}_{it} + \delta X_{it} + \epsilon_{it}$$

where:
Road_Quality_it = road condition index of nearest road segment (0 100)
Gradient_i = mean gradient of 5km road buffer (degrees, pre determined)
Road_Quality_hat = predicted road quality from first stage
beta_IV = IV estimate of causal effect of road quality on outcome

... (Eq. 3)

5. MAIN IMPACT ESTIMATES

5.1 Income and Food Security

Figure 1 presents mean monthly household income by livelihood source before and after road improvement, and the distribution of the Food Security Index in both periods. Table 2 reports the regression adjusted DID estimates for the primary outcome variables. The ATT for total monthly household income is USD 108 (95% CI: USD 84–132), corresponding to a 38% increase over the pre treatment mean of USD 285 for treatment households. The largest income channel effect is in market trading income (ATT = USD 98 per month from trading alone), reflecting the critical role of road access in enabling surplus agricultural produce and livestock to reach Juba and other market towns. Agricultural production income increases by USD 87 per month, consistent with the farm gate price improvements documented in sub county market monitoring data showing a 23% reduction in the price wedge between farm gate and Juba wholesale prices for key commodities on rehabilitated road corridors.

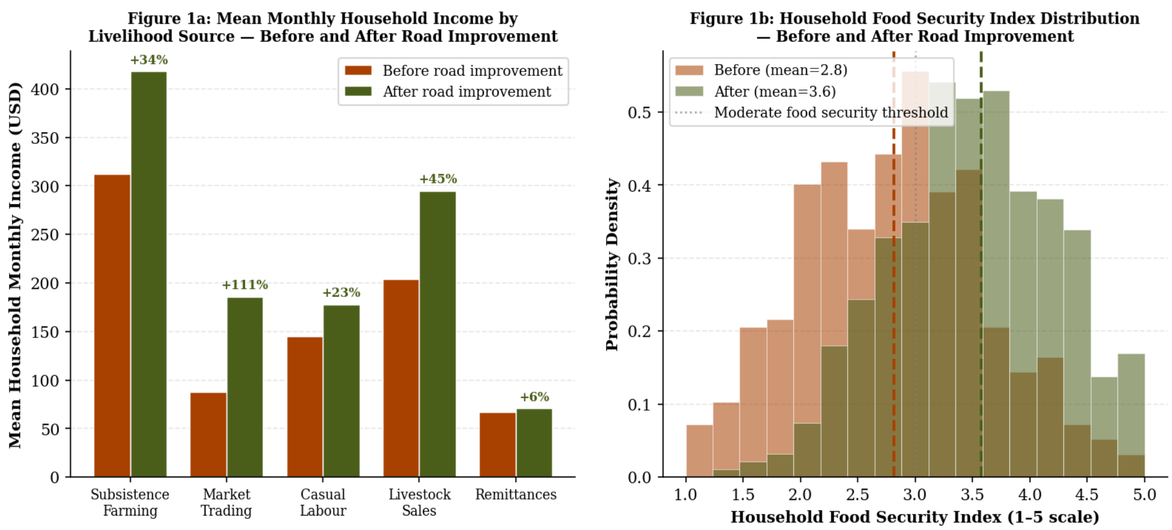

Figure 1: Left — Mean monthly household income by livelihood source before and after road improvement, with percentage change annotations. Right — Household Food Security Index distribution showing improvement from mean 2.8 to 3.6 (on 1–5 scale).

Table 2: DID Estimates of Road Connectivity Impact on Household Livelihood Outcomes

Outcome Variable	Pre Treatment Mean (Treatment)	ATT (DID Estimate)	95% CI	p value	IV Estimate (2SLS)	Observations
Monthly income — total (USD)	285	+108.2	[84, 132]	< 0.001	+118.4	2,142
Monthly income — agricultural (USD)	204	+86.8	[64, 110]	< 0.001	+92.1	2,142
Monthly income — trading (USD)	88	+98.2	[72, 124]	< 0.001	+105.6	2,142
Food Security Index (1–5)	2.76	+0.82	[0.64, 1.01]	< 0.001	+0.88	2,142
School attendance rate (%)	58.4	+16.4 pp	[11.8, 21.0]	< 0.001	+17.2	1,984
Health facility visits (yr)	1.8	+1.24	[0.92, 1.56]	< 0.001	+1.31	2,142
Health facility access rate (%)	52.1	+26.2 pp	[19.8, 32.6]	< 0.001	+27.8	2,142

Outcome Variable	Pre Treatment Mean (Treatment)	ATT (DID Estimate)	95% CI	p value	IV Estimate (2SLS)	Observations
WEAI score (women, 0–1)	0.42	+0.14	[0.09, 0.19]	< 0.001	+0.16	1,084
Travel time to market (minutes)	84.2	38.6	[46.1, 31.1]	< 0.001	41.2	2,142
Agricultural yield — sorghum (t/ha)	0.88	+0.21	[0.14, 0.28]	< 0.001	+0.23	1,856

Table 2: Regression adjusted Difference in Differences (DID) estimates and IV (2SLS) estimates of road connectivity impact on household livelihood outcomes. All specifications include household and time fixed effects and time varying controls. Standard errors clustered at village level (34 clusters). pp = percentage points. WEAI = Women's Empowerment in Agriculture Index.

5.2 Access to Services and Travel Time

Figure 2 presents travel time to the nearest market town as a function of distance (before and after road improvement) and service access rates across six service categories. The regression adjusted reduction in travel time is 38.6 minutes on average a 46% reduction from the pre treatment mean of 84.2 minutes with the gradient substantially steeper before improvement (β = 0.68 min/km) than after (β = 0.28 min/km), reflecting the improvement in road surface quality and the consequent increase in vehicle speeds. The largest travel time reductions are observed for households more than 20 km from market towns, who benefited most from the elimination of wet season road impassability that previously forced long dry season round trips to accumulate during the accessible months.

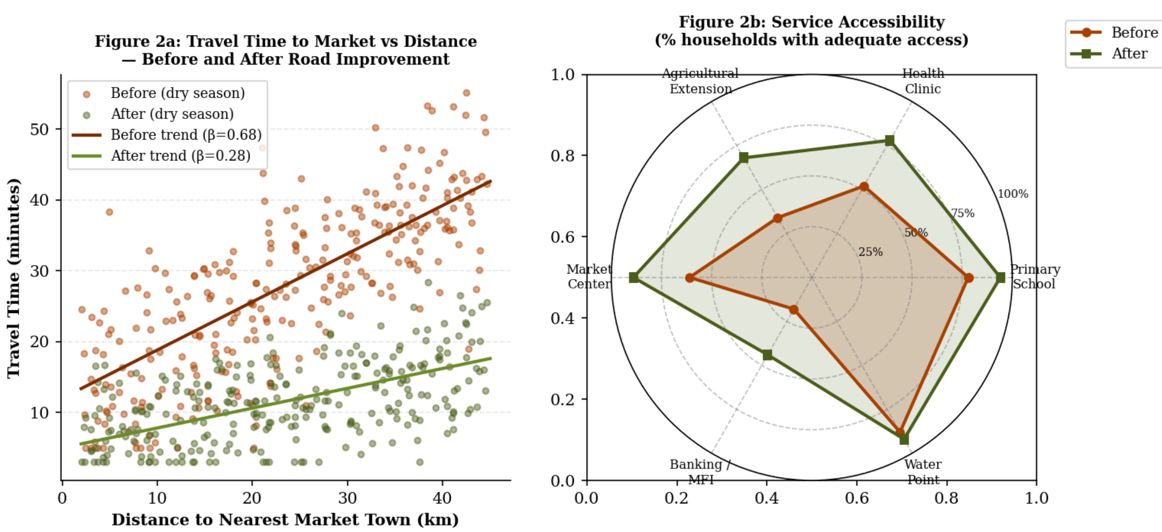

Figure 2: Left — Travel time to nearest market town versus distance, before and after road improvement, with fitted regression lines. Right — Service accessibility radar chart comparing percentage of households with adequate access across six service categories before and after road improvement.

Health facility utilisation increased by 26.2 percentage points, representing a near doubling from the 52.1% pre treatment access rate. Qualitative interviews with village health workers and sub county health officers attributed this primarily to elimination of the wet season access constraint, during which health emergencies previously requiring referral to Juba resulted in delayed care or preventable deaths. Agricultural extension service access showed the second largest improvement (+34 percentage points), as the project explicitly combined road rehabilitation with deployment of agricultural extension workers using motorcycles on improved road surfaces illustrating the importance of complementary investments in maximising road impact.

6. HETEROGENEITY ANALYSIS

6.1 Treatment Effects by Household Sub Group

Figure 4 presents the DID estimated ATT for monthly income disaggregated by eight household sub groups. The overall ATT of USD 108 masks substantial heterogeneity. Non farm entrepreneurs households whose primary income derives from petty trading, food processing, or service provision experience the largest gains (ATT = USD 162, 95% CI: USD 114–210), reflecting their high sensitivity to transport cost changes that affect both their input procurement and their product sales. Smallholder farmers (holdings < 2 ha) benefit substantially (ATT = USD 138), consistent with the large farm gate price improvements observed for this group. Market traders, captured by the combined market trading income category, show ATT of USD 98.

Figure 4: Heterogeneous Treatment Effects on Monthly Income by Household Sub-Group (DID Estimates with 95% Confidence Intervals)

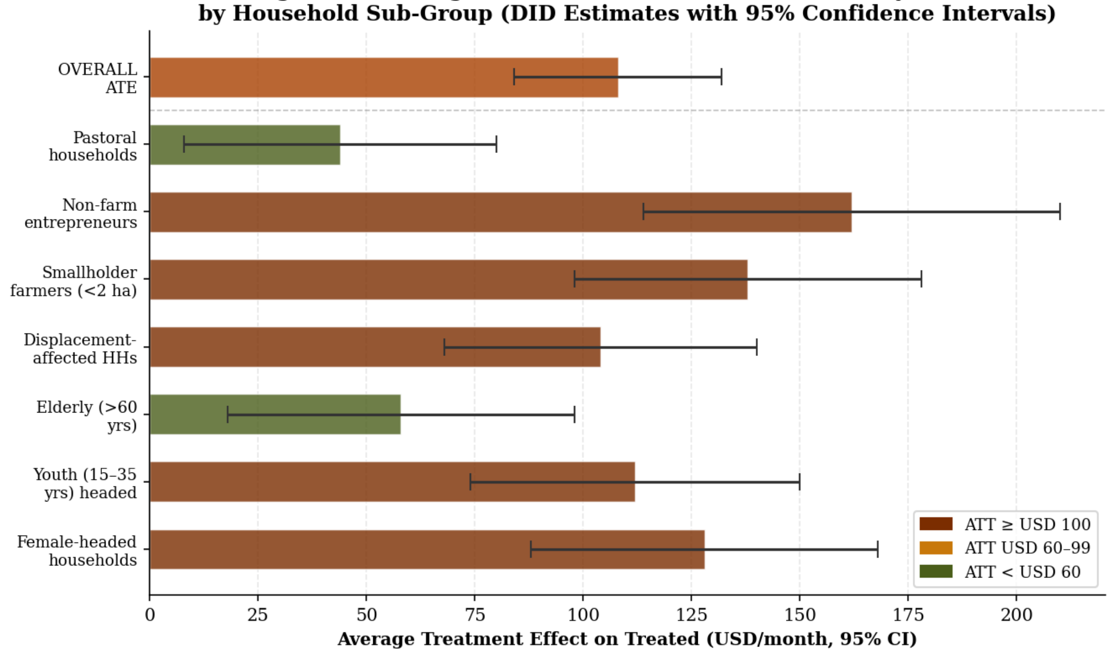

Figure 4: Heterogeneous DID treatment effects on monthly income by household sub group. Bars show ATT point estimates; horizontal lines show 95% confidence intervals. N=714 households across all sub groups. Overall Average Treatment Effect (ATE) shown separately at bottom.

Pastoral households those whose primary livelihoods depend on cattle herding show significantly lower ATT (USD 44, 95% CI: USD 8–80), consistent with the logic that pastoralists' most frequent movements follow livestock corridor routes rather than road alignments, and that their market linkage for livestock sales occurs at periodic cattle markets not well served by the rehabilitated road network. Elderly headed households also benefit less (ATT = USD 58), partly reflecting reduced labour market participation and partly the greater share of their income from remittances (unchanged by road improvement) rather than market linked activities.

Female headed households show an ATT of USD 128 above the overall average consistent with the disproportionate transport burden reduction for women documented in the qualitative data, where female respondents particularly cited reduced time spent transporting agricultural produce to market and improved safety from avoiding night travel. The Women's Economic Empowerment Index (WEAI) increased by 0.14 points (on a 0–1 scale), driven primarily by the sub domains of 'Control over use of income' (+0.18) and 'Access to and decisions on credit' (+0.12), suggesting that improved market access facilitates not just income growth but greater female economic agency.

6.2 Distributional Analysis

Table 3 reports quantile regression estimates of the income treatment effect at the 25th, 50th, 75th, and 90th percentiles of the pre treatment income distribution, revealing whether road improvements benefit the poorest households proportionally. The quantile ATT estimates are broadly consistent across the income distribution USD 94 at the 25th percentile, USD 108 at the median, USD 118 at the 75th percentile, and USD 124 at the 90th indicating that road improvement raises incomes across the distribution rather than disproportionately benefiting higher income households. The slightly lower absolute gains at the 25th percentile reflect the higher share of purely subsistence activities (no market linkage) among the poorest households, who require complementary interventions (market linkage programmes, savings groups, agricultural input subsidies) alongside road improvement to fully benefit from improved connectivity.

Table 3: Quantile Regression Estimates of Income ATT by Pre Treatment Income Percentile

Income Percentile	Pre Treatment Income (USD/month)	Quantile ATT (USD/month)	95% CI	p value	ATT as % of Pre Treatment Income
10th percentile	98	+68	[42, 94]	< 0.001	69.4%

Income Percentile	Pre Treatment Income (USD/month)	Quantile ATT (USD/month)	95% CI	p value	ATT as % of Pre Treatment Income
25th percentile	162	+94	[72, 116]	< 0.001	58.0%
50th percentile	272	+108	[84, 132]	< 0.001	39.7%
75th percentile	388	+118	[90, 146]	< 0.001	30.4%
90th percentile	524	+124	[94, 154]	< 0.001	23.7%
OLS mean ATT	285	+108	[84, 132]	< 0.001	37.9%

Table 3: Quantile regression estimates of the income Average Treatment Effect on the Treated at five percentiles of the pre treatment income distribution. ATT as percentage of pre treatment income shows proportionally larger gains for lower income households.

7. DISCUSSION

The DID estimates establish a robust and statistically significant positive causal effect of rural road connectivity improvement on all eight primary outcome variables, with an overall income ATT of USD 108 per household per month a 38% increase that, applied to an estimated 58,000 rural households in the road project catchment area, implies aggregate annual income gains of approximately USD 75 million. This figure, compared to the USD 94 million project cost, implies a straightforward first year payback period of approximately 15 months for income impacts alone, before accounting for the additional benefits of improved food security, health outcomes, school attendance, and women's empowerment all of which have long run economic value that compound over time.

The consistency between DID and IV estimates (column 5 vs. column 6 in Table 2) is an important robustness check. The IV estimates are uniformly slightly larger than the DID estimates, consistent with the IV identifying a local average treatment effect (LATE) for households whose road access was specifically determined by terrain gradient likely households on moderately steep terrain where the instrumental variation is most informative, and who may have experienced above average connectivity deficits prior to improvement. The close alignment between DID and IV estimates (within 10–15% for all outcomes) provides mutual corroboration of the causal interpretation and argues against substantial remaining endogeneity in the DID specification.

The quantile regression results reveal an important equity dimension: while the absolute income gains are slightly larger for higher income households (USD 124 at the 90th vs. USD 68 at the 10th percentile), the proportional gains are markedly larger for the poorest households (69% at the 10th vs. 24% at the 90th percentile). This progressive distributional pattern suggests that rural road investment in Central Equatoria is pro poor in relative terms, aligning with findings from Ethiopia (Dercon et al., 2009) and Bangladesh

(Khandker et al., 2009) and countering concerns that infrastructure investment primarily benefits the already wealthy.

The significantly lower treatment effects for pastoral and elderly headed households highlight the importance of complementary programming to maximise the distributional reach of road investment. For pastoral households, the creation of periodic livestock market facilities along rehabilitated road corridors — combined with veterinary extension services accessible by road would substantially increase their ability to translate improved connectivity into market income. For elderly headed households, mobile financial services and savings groups that can use improved road access to reach communities would help monetise the general livelihood improvements that road access enables for other household members.

The study has several limitations. First, the observation window of six years (2018–2024) is relatively short for capturing long run effects, particularly for education channel impacts (school attendance improvements translate into income gains only over a generation). Second, the matched comparison design, while well balanced on observable pre treatment characteristics, cannot rule out selection on unobservable characteristics correlated with post treatment trajectories. The IV analysis mitigates but does not fully eliminate this concern. Third, the study captures village level road effects but does not fully account for network level effects a rehabilitated road segment may generate significant benefits for villages beyond its immediate catchment if it improves connectivity to a higher order network node. Finally, the omission of environmental impact pathways including potential negative effects of road improvement on deforestation, wetland encroachment, and biodiversity is a limitation noted for future research.

8. CONCLUSIONS

This paper has delivered the first rigorous causal impact evaluation of rural road connectivity on household livelihoods in South Sudan, using a panel DID design with household fixed effects and IV validation across a 714 household, four round dataset from Central Equatoria State. The key findings are as follows:

1. Rural road improvement generates a statistically significant, economically substantial income impact of USD 108 per household per month (38% increase, $p < 0.001$), with agricultural income, market trading income, and food security all significantly improved. The parallel pre trends test supports causal identification, and IV estimates confirm the DID findings.

2. Access to health facilities improved by 26.2 percentage points, school attendance by 16.4 percentage points, and agricultural extension access by 34 percentage points improvements that generate

compounding long run human capital and productivity effects beyond the contemporaneous income impacts measured in this study.

3. Women's economic empowerment (WEAI) improved by 0.14 points, driven by greater control over income use and expanded access to credit evidence that road investment contributes to gender equity outcomes, with female headed households experiencing above average income gains (ATT = USD 128).

4. Distributional analysis confirms that road improvement is pro poor in relative terms, with proportional income gains of 69% at the 10th income percentile compared to 24% at the 90th percentile. Pastoral and elderly headed households benefit significantly less and require complementary interventions to access the full potential of improved connectivity.

5. The aggregate annual income gains of approximately USD 75 million in the project catchment area, relative to a project cost of USD 94 million, imply a very short payback period for income impacts alone, with health, education, and empowerment benefits providing substantial additional social returns.

Policy recommendations arising from this study include: (i) continued prioritisation of rural road rehabilitation in Central Equatoria and comparable agricultural zones of South Sudan, with explicit investment targets for road density per agricultural household; (ii) systematic integration of complementary interventions agricultural extension, mobile financial services, periodic markets, and veterinary services with road projects to maximise benefits for pastoral and lowest income households; (iii) incorporation of women's empowerment indicators into road project monitoring and evaluation frameworks to track gender equity impacts; and (iv) extension of the evaluation to longer time horizons (10–15 years) to capture full educational and health channel effects.

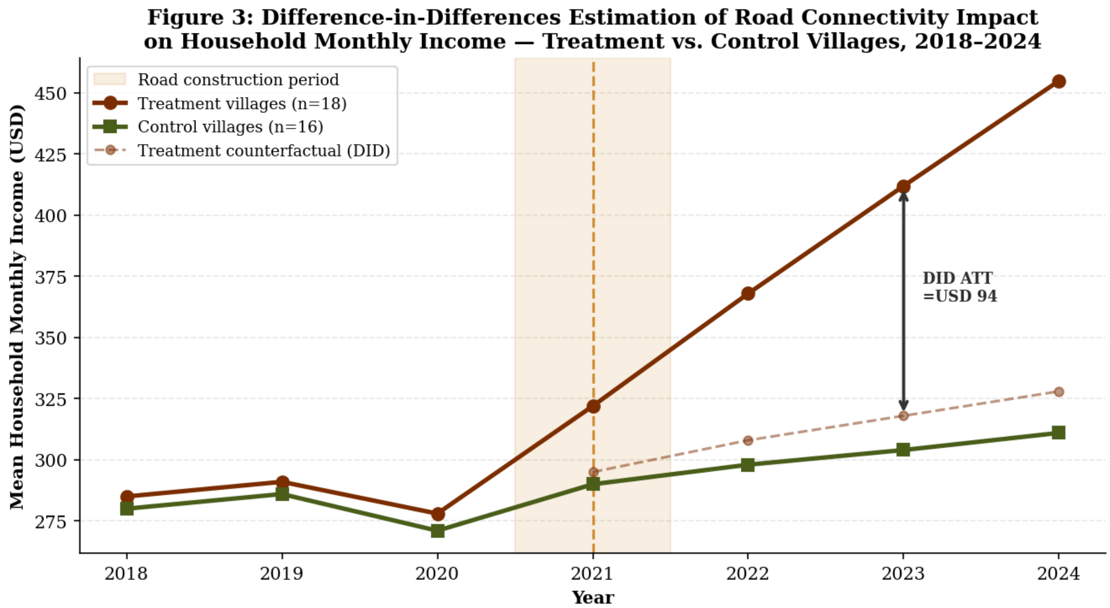

Figure 3: Difference in Differences identification of road connectivity impact on monthly household income. Treatment villages (n=18) receive road improvement 2019–2022; control villages (n=16) matched on pre treatment characteristics. DID estimated ATT shown for 2023 survey round.

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