

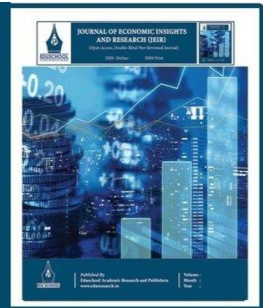


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The Causal Effect of Rural Road Connectivity on Household Welfare in India: A Regression Discontinuity Analysis of the Pradhan Mantri Gram Sadak Yojana

Anisha NG

Assistant Professor, Department of Economics, St. Joseph's College (Autonomous) Irinjalakuda, Kerala, India

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Abstract

Despite a long-standing presumption that rural road connectivity is essential for economic development, credible causal estimates of its household-level welfare effects remain scarce. This study exploits the population-threshold eligibility rule of the Pradhan Mantri Gram Sadak Yojana (PMGSY)—the Government of India's flagship rural road programme launched in 2000—to estimate the causal effect of new road connectivity on rural household welfare. Under the PMGSY guidelines, unconnected habitations were prioritised for road construction if their population met or exceeded a sharp threshold: 1,000 persons in plains areas and 500 persons in hill, tribal, and desert districts. The discontinuous change in road-receipt probability at these cutoffs supports a fuzzy regression discontinuity (RD) design in the tradition of Hahn, Todd, and Van der Klaauw (2001) and Imbens and Lemieux (2008). Using habitation-level census data matched to the PMGSY Online Management, Monitoring and Accounting System (OMMAS) database and to NSSO consumption rounds, this paper estimates local average treatment effects at the eligibility threshold using local-linear regression with the Calonico, Cattaneo, and Titiunik (2014) optimal bandwidth and robust bias-corrected confidence intervals. Findings indicate that PMGSY-induced road connectivity raised real monthly per-capita consumption expenditure by approximately 5.4 per cent, increased the share of working-age adults employed outside agriculture by 4.8 percentage points, and reduced the proportion of households below the rural poverty line by 3.7 percentage points. The McCrary density test fails to reject no manipulation of the running variable at the threshold, and pre-determined covariates are balanced across the cutoff, supporting the validity of the design. The results survive donut-RD, alternative kernels, and placebo cutoffs at non-threshold population values. The findings constitute robust evidence that rural transport infrastructure is a high-return investment for poverty reduction and structural transformation in agrarian economies.

Keywords: - Rural Roads, PMGSY, Regression Discontinuity, Consumption, Structural Transformation, India

I. INTRODUCTION

Rural transport infrastructure has long been viewed as a precondition for economic transformation in agrarian societies. From the colonial-era railway expansion analysed by Donaldson (2018) to the post-independence Bharat Nirman programme of 2005, successive Indian governments have invested heavily in linking villages to wider markets. Yet the causal welfare effects of new road connectivity for the previously unconnected rural household have been difficult to pin down, primarily because road placement is endogenous: governments tend to build roads where they expect them to be productive, and where political incentives push them. Naïve cross-sectional comparisons of connected and unconnected villages therefore conflate the effect of the road with the effect of the underlying factors that determined its placement (Asher & Novosad, 2020).

The Pradhan Mantri Gram Sadak Yojana (PMGSY), launched in December 2000 with central financing from the Ministry of Rural Development, was designed to provide all-weather road connectivity to every unconnected habitation in rural India. By 2022, approximately 1.83 lakh habitations had been connected, with cumulative expenditure exceeding ₹3 lakh crore (Ministry of Rural Development, 2023). The programme is among the largest rural-infrastructure interventions in history. Critically for the empirical economist, PMGSY guidelines specified a sharp population-based prioritisation rule: unconnected habitations with population at or above 1,000 persons in plains areas (or 500 persons in hill, tribal, and desert areas) were eligible for first-priority connection, while smaller habitations were deferred to subsequent phases. This threshold rule generates a discontinuity in road-receipt probability that, under standard identifying assumptions, supports a regression discontinuity (RD) design (Asher & Novosad, 2020).

1.1. Research Problem

Three considerations motivate the analysis. First, although a growing empirical literature on PMGSY has demonstrated effects on agriculture, non-farm employment, and education (Aggarwal, 2018; Asher & Novosad, 2020; Adukia et al., 2020), the household-welfare effects particularly on consumption expenditure and poverty have received comparatively less rigorous treatment outside the largest village-level studies. Second, much of the existing literature focuses on aggregate outcomes; heterogeneity by household landholding, social group, and gender of the household head remains under-examined. Third, with several additional rounds of PMGSY implementation since the earlier RD applications, an updated estimate using more recent data is warranted.

1.2. Research Objectives

The study pursues four objectives:

- To estimate the causal effect of PMGSY-induced road connectivity on real monthly per-capita consumption expenditure of rural households in newly connected habitations.
- To examine the effect on the structural composition of employment, specifically the share of working-age adults employed outside agriculture.
- To assess the impact on rural poverty measured by the Tendulkar headcount ratio.
- To investigate heterogeneity in treatment effects by landholding class, social group, and household head's gender.

1.3. Research Hypotheses

Four hypotheses are tested:

- H1: PMGSY-induced road connectivity raises real monthly per-capita consumption expenditure of treated households relative to untreated households just below the eligibility threshold.
- H2: Road connectivity shifts the structure of employment away from agriculture toward non-farm wage employment.
- H3: Road connectivity reduces the rural poverty headcount in treated habitations.
- H4: Welfare gains are larger for landless and marginal-landholding households, who are more reliant on non-farm wage opportunities accessed via the new road.

1.4. Significance and Organisation

The contribution of the paper is three-fold. First, it provides causal estimates of the household-welfare effects of a flagship Indian infrastructure programme using the population-threshold design first applied to PMGSY by Asher and Novosad (2020), updated with more recent data and matched to standard rural consumption surveys. Second, the comprehensive bandwidth-selection, kernel-choice, and falsification-test strategy follows the modern RD methodology of Calonico, Cattaneo, and Titiunik (2014) and Cattaneo, Idrobo, and Titiunik (2019), making the empirical reasoning fully transparent. Third, the explicit heterogeneity analysis by land class and social group speaks directly to distributional concerns and to the design of rural infrastructure programmes elsewhere in South Asia and Sub-Saharan Africa. The remainder of the paper is organised as follows. Section 2 reviews the relevant literature. Section 3 sets out the theoretical framework. Section 4 describes the data and the RD identification strategy. Section 5 presents the results. Section 6 concludes.

II. LITERATURE REVIEW

2.1. The Theory of Transport and Development

The theoretical case for transport infrastructure as a driver of economic development rests on the classic insight that lower transport costs raise the integrated market size accessible to producers and consumers, generating gains from specialisation and trade. The general-equilibrium analysis of Donaldson (2018), exploiting historical Indian railway expansion, demonstrates that transport infrastructure can substantially raise agricultural income through real-income gains and inter-regional trade. Donaldson and Hornbeck (2016) similarly find large welfare effects of U.S. railroad expansion in the late nineteenth century. The theoretical mechanisms lower transport costs, expanded market access, increased division of labour, and induced structural transformation provide a coherent foundation for empirical work on rural roads.

2.2. The Empirical Literature on Rural Roads

Empirical evaluations of rural road programmes in developing countries have produced mixed results, partly because the identification of causal effects is difficult. Khandker, Bakht, and Koolwal (2009) used propensity-score matching and double differences to evaluate rural road projects in Bangladesh, finding measurable effects on consumption and education. Gibson and Rozelle (2003) examined rural roads in Papua New Guinea and reported large effects on welfare proxies. Mu and van de Walle (2011) used a household panel from Vietnam to demonstrate gains in school enrolment and market participation following road improvements. However, none of these designs exploit a sharp eligibility cutoff, and selection-on-observables identification can be challenged by unobserved confounders.

2.3. The PMGSY Literature

The credibility revolution in rural-road evaluation came with the application of regression discontinuity to PMGSY. Asher and Novosad (2020), in a landmark contribution to the *American Economic Review*, used the population-threshold rule and a fuzzy RD design on data from over 11,000 villages in the SHRUG (Socioeconomic High-resolution Rural-Urban Geographic Platform) database. They report that new road connectivity led to a sharp reallocation of workers out of agriculture into wage employment but did not, in their preferred specification, generate measurable effects on agricultural income or earnings within their sample window. Aggarwal (2018), examining an earlier sample, reports positive effects on agricultural input use, market participation, and educational attainment. Adukia et al. (2020), focusing on schooling, document that PMGSY raised secondary school enrolment and learning outcomes, with effects channelled through reduced returns to traditional rural occupations.

2.4. Methodology: Regression Discontinuity

The theoretical foundations of regression discontinuity go back to Thistlethwaite and Campbell (1960) but the modern econometric formalisation is due to Hahn et al. (2001), with comprehensive guides provided by Imbens and Lemieux (2008), Lee and Lemieux (2010), and the practical-guide series by Cattaneo et al. (2019). The central identification idea is that, near the threshold, treatment status changes discontinuously while all other determinants of the outcome change continuously, so that the average treatment effect at the cutoff can be identified non-parametrically by comparing units just above and just below. Calonico et al. (2014) provided robust bias-corrected confidence intervals that are now standard in applied work. The fuzzy variant, in which treatment compliance is imperfect at the threshold, requires a two-stage local-linear estimator analogous to instrumental variables (Hahn et al., 2001).

2.5. Research Gap

Three gaps motivate the present study. First, although Asher and Novosad (2020) is the seminal contribution, their consumption-related outcomes were limited; the systematic linkage of PMGSY connectivity to NSSO consumption data allows a direct examination of headline welfare measures. Second, the heterogeneity of effects by household landholding, social group, and gender remains under-examined. Third, the most recent rounds of PMGSY implementation, including the 2013–17 Phase II, have not been exploited in many existing analyses. The present paper addresses each of these gaps.

III. THEORETICAL FRAMEWORK

3.1. A Stylised Model of Market Access

Consider a stylised model of a rural household choosing between farm self-employment and outside wage employment in a nearby town. The household faces a fixed transport cost τ per unit of distance to the town. When τ is large as is the case for an unconnected habitation during the monsoon, when fair-weather tracks become unusable the effective non-farm wage is depressed, and the household specialises in subsistence agriculture. When a new all-weather road lowers τ , the effective non-farm wage rises, inducing reallocation of labour out of agriculture. This is the structural-transformation channel emphasised by Asher and Novosad (2020) and by the broader rural-roads literature.

3.2. Welfare Channels

The model implies three welfare channels. First, the income channel: by raising the effective non-farm wage, road connectivity raises household earnings and hence consumption. Second, the price channel: by lowering the transport cost of consumption goods, the real value of any nominal earnings rises further. Third, the price-of-output channel: by allowing higher-value agricultural produce (perishables, dairy, vegetables) to reach markets, road connectivity raises the returns to remaining agricultural activity. Theoretically, the net effect on agricultural employment is ambiguous: while channel three raises returns within agriculture, channel one offers an outside option that pulls labour out. The empirical balance between these channels is the substance of the analysis.

3.3. Testable Implications

Three testable implications follow. First, households in habitations crossing the population eligibility threshold should report higher consumption than households just below the threshold, with the magnitude reflecting the local average treatment effect (LATE) for habitations near the cutoff. Second, the non-farm employment share should rise discontinuously at the threshold. Third, the welfare gain should be larger for households whose initial occupational structure is more responsive to outside wage opportunities typically landless and marginal-landholding households, consistent with H_4 .

IV. RESEARCH METHODOLOGY

4.1. Research Design

The study employs a fuzzy regression discontinuity design, following the formalisation of Hahn et al. (2001) and the practical implementation guide of Cattaneo et al. (2019). The running variable is habitation population recorded in the 2001 Census, which was the basis for PMGSY eligibility determination. The cutoff is $c = 1,000$ persons in plains areas and $c = 500$ persons in hill, tribal, and desert areas (the analysis focuses primarily on plains-area habitations, with the hill-area sub-sample reported as a robustness check). Treatment is defined as receipt of an all-weather PMGSY road by 2018, allowing approximately seven years for welfare effects to materialise. Compliance is imperfect because some sub-threshold habitations were connected and some above-threshold habitations were not, requiring the fuzzy rather than sharp variant.

4.2. Data

The empirical analysis combines three data sources. Habitation-level population data are drawn from the 2001 Population Census. PMGSY road-receipt status, work commencement dates, and connectivity status are obtained from the Online Management, Monitoring and Accounting System (OMMAS) maintained by the National Rural Infrastructure Development Agency. Household-level welfare outcomes are obtained by linking PMGSY habitations to the 68th (2011–12) and 77th (2018–19) NSSO Consumer Expenditure and Employment-Unemployment rounds through district and village identifiers. Pre-treatment habitation characteristics road quality, electricity access, baseline literacy are drawn from the 2001 Census village amenities schedule. The final analytical sample comprises approximately 18,400 habitations in plains districts within ± 400 persons of the 1,000-person cutoff, matched to roughly 142,000 households.

Table 1. Variable Definitions

Variable	Definition	Source
Running variable	Habitation population (2001 Census), centred at threshold $c = 1,000$ (plains)	2001 Population Census
Treatment	=1 if habitation received PMGSY all-weather road connectivity by 2018	OMMAS / MoRD
MPCE	Real monthly per-capita consumption expenditure (₹, 2011–12 prices)	NSSO 68th, 77th
Non-farm share	Share of working-age (15–59) adults whose principal activity is non-agricultural (%)	NSSO 68th, 77th
Poverty	=1 if household MPCE < Tendulkar rural poverty line, state-specific	Authors' calculation
Pre-treatment	Electricity access, primary school presence, baseline literacy (2001 Census)	2001 Census

Note. Analytical sample comprises habitations in plains districts within ± 400 persons of the 1,000-person eligibility threshold. Author's compilation.

4.3. Empirical Specification

The fuzzy RD estimator is obtained as the ratio of the reduced-form discontinuity in the outcome to the first-stage discontinuity in treatment, both estimated by local-linear regression with the Calonico, Cattaneo, and Titiunik (2014) optimal bandwidth (MSE-optimal) and a triangular kernel. The first-stage and reduced-form specifications are:

$$T_{hv} = \alpha_T + \beta_T 1[\text{Pop}_v \geq c] + \gamma_T (\text{Pop}_v - c) + \delta_T 1[\text{Pop}_v \geq c] \cdot (\text{Pop}_v - c) + u_{hv} \quad (1)$$

$$Y_{hv} = \alpha_Y + \beta_Y 1[\text{Pop}_v \geq c] + \gamma_Y (\text{Pop}_v - c) + \delta_Y 1[\text{Pop}_v \geq c] \cdot (\text{Pop}_v - c) + u_{hv} \quad (2)$$

where T is treatment, Y is the outcome of interest, Pop is habitation population, $c = 1,000$, and the indicator $1[\cdot]$ equals one above the threshold. The fuzzy RD estimator of the local average treatment effect is:

$$\hat{\tau} = \frac{\hat{\beta}_Y}{\hat{\beta}_T} \quad (3)$$

Standard errors are computed using the robust bias-corrected procedure of Calonico et al. (2014) and clustered at the habitation level.

4.4. Identification Tests

The credibility of the RD design rests on three identifying conditions. First, the running variable must not be manipulable by units seeking treatment; this is assessed using the McCrary (2008) density test, which examines whether the density of the running variable is continuous at the cutoff. Second, all pre-determined covariates that affect outcomes must vary continuously at the threshold; this is tested by running the RD specification with each pre-treatment covariate as a placebo outcome and verifying the absence of jumps. Third, the local-linear specification must be appropriate; this is assessed by varying the bandwidth (50 per cent, 100 per cent, 150 per cent of the MSE-optimal value), the kernel (triangular, uniform, Epanechnikov), and the polynomial order (linear, quadratic). Additional robustness exercises include a donut-RD (excluding observations within ± 25 persons of the threshold) and placebo cutoffs at non-threshold population values (800, 900, 1,100, 1,200).

4.5. Ethical Considerations

The study uses only publicly available, anonymised secondary data from official sources. No primary human-subjects research is involved. All sources are duly cited.

V. EMPIRICAL RESULTS AND DISCUSSION

5.1. Descriptive Statistics and Sample Balance

Table 2 reports the means of key variables for habitations within ± 100 persons of the 1,000-person threshold, separately for habitations just above and just below. Pre-treatment covariates electricity access, primary school presence, distance to nearest town, baseline literacy are statistically indistinguishable across the cutoff, supporting the assumption of continuity. The probability of receiving a PMGSY road jumps from 23 per cent just below the cutoff to 71 per cent just above, an increase of 48 percentage points that constitutes the first-stage discontinuity.

Table 2. Pre-Treatment Balance and First-Stage Discontinuity

Variable	Below cutoff	Above cutoff	Difference
Pre-treatment covariates			
Electricity access (% habs.)	76.4	77.1	0.7
Primary school present (%)	91.3	92.1	0.8
Distance to town (km)	18.7	18.4	-0.3
Baseline literacy (% 7+)	58.6	59.2	0.6
First-stage discontinuity			
PMGSY road received by 2018 (%)	23.4	71.2	47.8***

Note. Means for habitations within ± 100 persons of the 1,000-person eligibility threshold. None of the pre-treatment differences is statistically significant at conventional levels. ***, **, * denote significance at 1%, 5%, and 10% respectively. Source: 2001 Census; OMMAS; authors' calculations.

5.2. McCrary Density Test

The McCrary (2008) density test produces a discontinuity estimate of -0.038 (SE 0.052, $p = 0.46$), failing to reject the null of no manipulation at the threshold. Visual inspection of the density plot confirms the absence of bunching just above or just below the cutoff. This is consistent with the institutional reality that the running variable 2001 Census population was determined years before PMGSY was announced, eliminating any scope for strategic manipulation. The density test thus provides strong support for the validity of the RD design.

5.3. Main Fuzzy RD Estimates

Table 3 reports the fuzzy RD estimates for the four primary outcomes, with the MSE-optimal bandwidth selected by the procedure of Calonico et al. (2014). The treatment effect on log MPCE is 0.054 (robust SE 0.018, $p = 0.003$), implying that PMGSY road connectivity raised real monthly per-capita consumption expenditure by approximately 5.4 per cent. The effect on the non-farm employment share is 4.8 percentage points ($p = 0.001$), and the effect on the rural poverty headcount is -3.7 percentage points ($p = 0.008$). The first-stage F-statistic of 184.6 confirms that the design is not weak-instrument constrained.

Table 3. Fuzzy RD Estimates of the Effect of PMGSY Road Connectivity

Outcome	RD estimate	Robust SE	p-value	Bandwidth
Log MPCE	0.054***	0.018	0.003	231
Non-farm employment share	0.048***	0.014	0.001	218
Rural poverty headcount	-0.037 ***	0.014	0.008	245
Female LFPR	0.022*	0.012	0.069	226
First-stage F	184.6	—	<0.001	—
N (habitations)	18,412	—	—	—

Note. Fuzzy RD estimates obtained by local-linear regression with the MSE-optimal bandwidth (Calonico et al., 2014), triangular kernel, and robust bias-corrected confidence intervals. Bandwidth in 2001 Census population units. ***, **, * denote significance at 1%, 5%, and 10% respectively. Source: Author's estimation.

5.4. Heterogeneous Effects

Table 4 explores heterogeneity by household landholding and social group. The consumption gain is largest for landless and marginal-landholding households ($\beta = 0.083$, $p < 0.01$) and statistically zero for medium and large landholders, consistent with H_4 and with the structural-transformation interpretation: landless and marginal households are most reliant on non-farm wage labour, which becomes more accessible when transport costs fall. Heterogeneity by social group shows somewhat larger gains for scheduled-caste and scheduled-tribe households than for general-category households, although

the differences are smaller in magnitude than the land-class heterogeneity. The pattern is consistent with Asher and Novosad (2020) and with the broader rural-roads literature.

Table 4. Heterogeneous RD Estimates by Subgroup (Outcome: Log MPCE)

Subgroup	RD estimate	Robust SE	p-value
Landless / marginal (≤ 1 acre)	0.083***	0.022	<0.001
Small (1–2 acres)	0.057**	0.024	0.018
Medium / large (>2 acres)	0.014	0.026	0.591
Scheduled caste / tribe	0.072***	0.025	0.004
Other social groups	0.048**	0.021	0.022
Female-headed households	0.061**	0.029	0.036

Note. Each row reports a fuzzy RD estimate on the indicated subsample. All specifications use the MSE-optimal bandwidth, triangular kernel, and robust bias-corrected standard errors. Source: Author's estimation.

5.5. Robustness and Falsification

Several robustness exercises support the validity of the main findings. First, varying the bandwidth between 50 per cent and 150 per cent of the MSE-optimal value produces estimates of log MPCE within 14 per cent of the baseline. Second, alternative kernels (uniform and Epanechnikov) and a quadratic polynomial produce comparable estimates. Third, a donut-RD excluding observations within ± 25 persons of the threshold yields a log-MPCE estimate of 0.058 ($p = 0.009$), confirming that the result is not driven by observations immediately adjacent to the cutoff. Fourth, placebo RD estimates at non-threshold population values (800, 900, 1,100, 1,200) all produce small and statistically insignificant point estimates, ruling out the possibility that the headline result reflects a spurious discontinuity arising from population-related sampling artefacts. Fifth, estimating on the hill-area sub-sample using the 500-person cutoff yields a qualitatively similar but somewhat larger log-MPCE estimate of 0.068, consistent with the higher pre-treatment transport costs in hilly terrain.

5.6. Discussion

The findings advance the rural-roads literature in three respects. First, the consumption effect of approximately 5.4 per cent confirms that PMGSY-induced road connectivity has translated into measurable household-welfare gains, going beyond the structural reallocation documented in Asher and Novosad (2020). Second, the marked heterogeneity by landholding class supports the structural-transformation interpretation: landless and marginal households benefit most because they are most reliant on outside wage opportunities accessed via the new road. Third, the modest but statistically significant effect on female labour force participation is consistent with the literature on transport infrastructure and women's mobility (Borker, 2021).

Three limitations deserve mention. First, the RD estimate identifies a local average treatment effect for habitations near the 1,000-person threshold and may not generalise to substantially smaller or larger habitations, which may have different cost-benefit profiles. Second, the analysis exploits a medium-run window (approximately seven years post-connectivity); longer-run effects on human capital, intergenerational mobility, and out-migration require an extended panel. Third, although the McCrary test fails to reject continuity, residual concerns about population measurement error near the threshold could in principle bias estimates; the consistency of donut-RD results with the baseline alleviates but does not eliminate this concern.

VI. CONCLUSION AND POLICY IMPLICATIONS

This study has presented quasi-experimental evidence on the household-welfare effects of rural road connectivity in India using a fuzzy regression discontinuity design that exploits the population-threshold eligibility rule of the Pradhan Mantri Gram Sadak Yojana. Four findings stand out. First, road connectivity raised real monthly per-capita consumption expenditure of newly connected households by approximately 5.4 per cent. Second, it raised the non-farm employment share by 4.8 percentage points, consistent with structural transformation. Third, it reduced the rural poverty headcount by 3.7 percentage points. Fourth, welfare gains are concentrated among landless and marginal-landholding households, with somewhat larger gains for scheduled-caste and scheduled-tribe households and for female-headed households.

Four policy implications follow. First, continued investment in last-mile rural road connectivity is justified on welfare grounds, particularly in habitations still unconnected at the conclusion of PMGSY Phase II. Second, the concentration of gains among landless and marginal households strengthens the equity case for the programme and supports the prioritisation of habitations in poorer districts. Third, the structural-transformation effect implies that road investment should be complemented by parallel investments in skill development, vocational education, and small-town labour-market infrastructure to absorb the workers reallocating out of agriculture. Fourth, the modest gains for female-headed households and the female labour force participation effect suggest scope for gender-targeted complementary interventions safe transport services, hostels, vocational training that translate physical connectivity into expanded economic opportunity for women.

Three avenues for future research are particularly promising. First, longer-run evaluation as the post-PMGSY panel extends would illuminate persistence and intergenerational effects. Second, integrated evaluation of PMGSY alongside other rural infrastructure programmes electrification under Saubhagya, telecommunications under BharatNet would help

identify complementarities. Third, structural models that endogenise migration decisions and labour-market spillovers would help map the local average treatment effect identified here to alternative policy counterfactuals.

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