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TIEN MANH VU、山田浩之

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Keio University

CALAMVS GLADIO FORTIOR 1858

Institute for Economic Studies, Keio University
2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan
ies-office@adst.keio.ac.jp
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JEL Classification: O15, R11, R58, R42

キーワード: Improved rural roads, wealth, rice, education, pollution, Cambodia

【要旨】

We examine impacts of improved rural roads on villagers, using panel data of Cambodian villages (2006-2021). We find an association between the wealth of villagers and the improvement of rural roads. A higher minimum price for rice at farm gate may be one of the reasons for the increase in wealth. We also find impacts of improved rural roads on (reducing) illiteracy rates among villagers. However, we do not find any statistically significant impacts on school enrollment rate, structural change, or internal migration. Instead, improved rural roads lead to a higher share of families being subjected to environmental pollution.

TIEN MANH VU

中央大学 国際経営学部

東京都八王子市東中野742-1

mvu264@g.chuo-u.ac.jp

山田浩之

慶應義塾大学 経済学部

東京都港区三田2－15－45

hyamada@econ.keio.ac.jp

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Impacts of improved rural roads on the well-being of Cambodian villagers

TIEN MANH VU

Corresponding author. Faculty of Global Management, Chuo University
742-1 Higashinakano, Hachioji, Tokyo 192-0393, Japan
Email: mvu264@g.chuo-u.ac.jp
https://orcid.org/0000-0002-2251-0795

HIROYUKI YAMADA

Faculty of Economics, Keio University
2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan
E-mail: hyamada@econ.keio.ac.jp
https://orcid.org/0000-0003-3709-1914

Abstract: We examine impacts of improved rural roads on villagers, using panel data of Cambodian villages (2006–2021). We find an association between the wealth of villagers and the improvement of rural roads. A higher minimum price for rice at farm gate may be one of the reasons for the increase in wealth. We also find impacts of improved rural roads on (reducing) illiteracy rates among villagers. However, we do not find any statistically significant impacts on school enrollment rate, structural change, or internal migration. Instead, improved rural roads lead to a higher share of families being subjected to environmental pollution.

Keywords: Improved rural roads, wealth, rice, education, pollution, Cambodia

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1. Introduction

Rural roads connect large proportions of low-income areas in developing countries, but few studies have investigated the impacts of improvements to rural roads. If there is a positive externality, existing rural roads might be in an under-investment stage. Therefore, research on improved rural roads would generate insightful policy implications with the potential to enhance the well-being of local residents, especial low-income residents.

Herein, we examine the possible impacts of improved roads under the purview of the Cambodian Improved Rural Roads project overseen by the Asian Development Bank (ADB) on various well-being outcomes of villagers, including education, health, income, wealth, and migration. Specifically, we combine panel data of (annual) village-level censuses during 2006–2021 with detailed GPS maps of rural roads that were targeted for improvement as part of the project. Following the method of Callaway and Sant'Anna (2021), which relies on event-study and inverse probability weighting (doubly-robust) methods, we examine the possible impacts of the improved rural roads on villagers with variations in treatment timing and multiple time periods.

We find that the share of families who upgrade their houses with better materials after the completion of the improved roads increases. Villagers receive a higher price of rice at farm gate. In addition, we find that illiteracy rates among villagers aged 36–45 years decreased significantly in association with improved rural roads. However, we do not find any significant impacts on junior high or high school enrollment rates, structural changes, or internal migration. As a negative externality, we find that improved rural roads lead to increased environmental pollution.

Our research makes several important contributions to the literature. First, our results are from data having among the highest resolution over a long period of time (up to 15 years before the treatment and 8 years after) within the theme of (the impacts of) improved rural roads in developing countries. Second, our findings provide possible answers regarding the short- and medium-term impacts of improved rural roads. Third, our findings support the few studies that show a new negative externality of improved rural roads—environmental pollution.

The remainder of this paper is organized as follows. Section 2 provides the background literature of our study. Section 3 describes the data as well as the division of the treatment and control groups. Section 4 outlines the methodology. Section 5 reports the results and section 6 concludes the paper.

2. Related literature

Numerous studies have examined whether investments in roads in developing countries have causal effects on economic growth, opening up trade, reallocation of firms along the roads, structural changes, rural poverty reduction, higher school enrollment, and reducing crime as well as environmental externalities such as deforestation and biodiversity loss (Berg et al., 2017). However, the impacts may vary depending on the type of roads (highway, major roads, rural roads), type of investment (newly built, improved/repaired roads), and duration of observation (short-, medium-, and long-term effects). The literature reports conflicting findings, suggesting that this is a complex issue.

Specifically, the findings regarding newly constructed roads in rural areas are mixed. New roads help Indian villagers to access work in sectors other than agriculture but changes in agricultural outcomes, income, and assets are not significant (Asher & Novosad, 2020). New roads also lead to higher enrollment rates in middle school and higher test scores among students in response to higher returns of schooling from newly available markets (Adukia, Asher, & Novosad, 2020). Aggarwal (2018) finds that in India, rural households close to newly constructed roads have lower prices, greater variety of non-local goods, increased usage of agricultural technologies, and more teenagers leaving school to enter the workforce. In Ethiopia, newly constructed rural roads connecting agricultural villages help to increase agricultural income (Kebede, 2024), consumption, and wage employment, particularly for women and young people (Nakamura et al., 2020). Also in Ethiopia, combining roads with agricultural extension services is suggested to increase productivity by offering a better market and greater access to public services (Gebresilasse, 2023).

Although few studies have examined the impacts of improved rural roads, the findings of such research provide new perspectives. Shimamura et al. (2023a) find that in Morocco, improved rural roads have different associations with some impacts according to gender. Specifically, more females had higher secondary school attainment. However, the proportion of males with wage employment increases (Shimamura et al., 2023a). Improved rural roads in Vietnam have impacts on access to markets, leading to a change from agriculture to services (Mu & van de Walle, 2011). In Tanzania, households transition from agricultural to wage employment and pay lower prices for rice (consumption) as a result of lower transportation costs from improved major roads (Dumas & Jativa, 2024).

Transportation costs can also account for the impacts of improved roads in Cambodia. Using Demography and Health Surveys and a differences-in-differences (DID) approach, Anti and Zhang (2023) count the number of built roads within 15 km from the respondents' residence to estimate the impacts on women's employment and gender equity. Similarly, using survey data of 400 residents in 2016, Takada et al. (2021) evaluate the perception of respondents on the impacts of improved rural roads in Cambodia during 2010–2016. Takada et al. (2021) suggest that improved roads lead to an increase in the frequency of visiting local markets and time savings, which eventually leads to higher income growth.

However, there are some methodological issues concerning these previous studies. First, is the endogeneity of the selected roads. Newly constructed roads in rural areas have two endogenous issues: the direction of the roads and where they are located. In contrast, research on improvements to rural roads have only one of these issues: selection of the road(s) to be improved.

Solving endogeneity issues is not straightforward. The problem lies in the existence of counterfactuals. Some research uses unique methods such as (fuzzy) regression discontinuity (Asher & Novosad, 2020; Adukia et al., 2020), counterfactual roads based on cost conditions (Kebede, 2024), and distance to historical ports (Banerjee et al., 2020), which can be difficult to apply to other countries. Other studies use propensity score matching methods (in combination with DID) (Mu & de van Walle, 2011; Nakamura et al., 2020; Dumas and Jativa, 2024). However, propensity score matching methods are known to be subject to the selection of observables and the algorithm methods in use.

Meanwhile, the majority of studies (Takada et al., 2021; Aggarwal, 2018, 2021; Gebresilasse, 2023; Anti & Zhang, 2023) rely on a DID approach. However, recent research on this method (de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021; Callaway & Sant'Anna, 2021; Sun & Abraham, 2021) reveals many drawbacks of using simple DID (e.g., "negative" weighting of two-way fixed effects, different treatment timings). Roth (2022) and Rambachan and Roth (2023) show that conventional parallel trend tests in simple DID (event study) may lack statistical power and lead to wrong conclusions.

Second, most of the studies face a limitation in terms of the window of observation in association with the available data. The main question is when the possible impacts might appear. Takada et al. (2021) reports on outcomes 1 year after road construction. However, some possible impacts may appear over the medium term rather than the short term. Specifically, Mu and van de Walle (2011) and Asher and Novosad (2020) suggest 27 months and 4 years, respectively, for impacts to be realized. The "resolution" of the data, especially survey data, might raise concerns on the real impacts of improved roads. Low "resolution" also includes cases in which the distance between rural roads and objects (e.g., people in developing countries) is far (≥15 km) and when the (integrated data level) observations are large geographical areas (>150 km^2).

3. Panel data and division of treated and control groups

We construct panel data of Cambodian villages for an event study of 2006–2021, using two important sources of information. The first is the Commune Village Database (CVD) from the Cambodian National Institute of Statistics. The institute collects data for the CVD annually. The location of each village is identifiable (as map points), with approximate latitude and longitude.

The second source of information is global information system data on rural roads under the purview of ADB-supported projects. The ADB has provided loans for the Cambodian government to improve the country's existing rural road system in three phases. As of 2021, phase 1 (started in 2011, targeting 505.4 km of rural roads) and phase 2 (started in 2014, targeting 1,200 km of rural roads) have been completed.[1] However, none of the roads in phase 3 (started in 2023, targeting 360 km of rural roads) had been completed as of 2021, which is the most recent year in the available CVD data.

We obtain detailed information on the road locations and year of completion from the ADB rural roads improvement project office. Phase 1 covered seven provinces, mainly in the Tonle Sap Basin. Phase 2 covered ten provinces: Banteay Meanchey, Battambang, Kampong Cham, Kampong Chhnang, Kampong Speu, Kampong Thom, Pursat, Siem Reap, Takeo, and

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[1] The details of phases 1, 2, and 3 can be found on the ADB website (https://www.adb.org/projects/42334-013/main, https://www.adb.org/projects/42334-014/main, and https://www.adb.org/projects/42334-018/main). We cover all roads improved during 2011–2021 (i.e., phases 1 and 2).

Tbuong Khmum. Phase 3 covers five provinces: Kampong Cham, Kratie, Prey Veng, Svay Rieng, and Tboung Khmum. Although the roads targeted for improvement are rural roads in rural areas, the reasons these roads were selected are not documented. From the geographic locations of the roads, we find that about 2,787 (4,686) villages of Cambodia's (approximately) 14,000 villages are located within 2 km (4 km) of the roads to be improved in phases 1, 2, and 3. A map of the roads targeted by the project is shown in Figure 1.

[Insert Figure 1 here]

The distance between the centroid of the villages and the improved rural roads is a key factor for deciding the possible influences of improved roads. As suggested by findings in China by Banerjee, Duflo, and Qian (2020), the closer an area is to the transportation network, the higher the causal impacts of the roads on the area's income in the long term. Therefore, for each village, we calculate the nearest distance to each road targeted in phases 1, 2, and 3 to (the map point of) the village. Among rural roads with a fully identified date of completion, we limit the closest distance to 2 km to construct our sample,[2] giving us 16 years' worth of data on 1,569 for analysis. The descriptive statistics of the data are presented in Appendix 1.

We assign villages close to the roads that were improved in phase 1 and 2 as the treatment group and those near roads to be improved in phase 3 as the control group, under the assumption that roads targeted for improvement in phase 3 were selected in a similar way to those targeted in the first two phases. However, villages near the roads targeted for improvement in phase 3 did not receive any "treatment" during the observation window. If a village is close to roads targeted by more than one phase, with different completion timings, we use the earliest year of completion. Furthermore, because villages in the control group are

[2] We also construct the sample with 4 km and report the results in the Appendices.

close to the roads in phase 3 but not to those in phase 1 and 2, there should be no spillover effects from the treatment group to the control group.

We acknowledge that our assumption and selection may be subject to biasness. Our division between treatment and control groups may be the second-best choice. The best choice would be villages that are completely identical to villages in the treatment group but cannot be impacted by the road improvement. However, the best choice is not practical in the context of Cambodia. In addition, matching methods based on observable characteristics of the villages do not guarantee homogeneity of unobservables. Meanwhile, the selection of roads under the purview of ADB-supported projects is not arbitrary; they were selected because policymakers had specific targets/outcomes in mind for the given areas and villagers.

To quantify the biasness that we would need to address, we perform simple balance checks between the treatment and control groups, using information from 2006, about 8 years before any of the roads were improved (Appendix 2). The balance tests in Appendix 2 suggest that villages in the control group tend to have a better starting point in 2006 with a lower illiteracy rate, slightly higher wealth (better housing conditions), and a smaller population. Therefore, any evidence showing that the treatment group had better outcomes compared with the control group (because of the improved roads) would underestimate the real impacts of the improved roads.

4. Methods and econometric specification

Our identification strategy is based on a sophisticated event-study with different treatment timings. Recent advanced studies of DID methodology support our empirical implementation. Specifically, we apply the methods by Callaway and Sant'Anna (2021) for our final reports, and Sun and Abraham (2021) for robustness checks. The approach can be explained as follows.

First, standard DID can be used to estimate the average treatment effects (β) of improved roads on villages i

$$outcome_{it} = \beta \times treated_i \times post_{it} + \varpi_i + \gamma_t + \lambda \times X_{it} + \varepsilon_{it}, \quad (1)$$

where two-way fixed effects (TWFE) are ϖ_i (village fixed effects) and γ_t (time fixed effects), and X_{it} are the control variables. $treated_i$ equals 1 if village i is in the treatment group, and 0 otherwise. $post_{it}$ is 1 if the roads corresponding to the village are improved, and 0 otherwise. The canonical identification of the standard DID is that the parallel trend assumption must be satisfied (the pre-treatment trend of the outcome would be parallel between the treatment and control groups). Furthermore, the canonical DID assumes no spillover effects from the treatment group to the control group.

However, because each road was constructed and completed on different timelines, equation (1) is subject to at least four problems. The first is that some treated villages were part of the control group in years when the treated villages had not yet received the treatment (de Chaisemartin & D'Haultfœuille, 2020; Goodman-Bacon, 2021). Meanwhile, the desired estimation is the difference between treated units and control units that will never receive any treatments. The second problem is when the treatment effect is not homogenous (i.e., changes over time). The estimands from the standard DID (or TWFE) can be contaminated when earlier treated observations serve as the basis for later treated observations (the trend of treated effects in earlier treated observations enter to the estimand with a negative-sign weight component) (de Chaisemartin & D'Haultfœuille, 2020). The bias would be worse if the remaining observations of the untreated group were few or nonexistent in the last window of time (Goodman-Bacon, 2021). The parallel trend cannot be properly tested for the same reason, which is the third problem. The fourth problem lies in fact that the (calendar) timing of treatment may be associated with different magnitudes of impact. For example, if the village receives the treatment 2 calendar years earlier, the impacts would have been higher than if it received the treatment in the present year.

To solve the second problem, a panel event-study might help to separate the treatment effects into each period after the event (intervention), using the following equation (Miller, 2023),

$$outcome_{it} = \left(\sum_{j\in\{-15,\dots,0,\dots,8\}} \alpha_j \times D_{i,t-j}\right) + \gamma_i + \varphi_t + \mu \times X_{it} + \epsilon_{it}, \tag{2}$$

in which γ_i and φ_t are panel fixed effects and X_{it} are the control variables.[3] The term $\alpha_j \times D_{i,t-j}$ is for each j event period (measured in year unit). $D_{i,t-j}$ indicates the event time. The coefficients after the event occurred, α_j if $j \geq 0$. A year before the event is often used as the baseline. To claim the causal effects from the event, the parallel trend condition should be met. Specifically, and ideally, all α_j before the event ($j < -2$) should be the same as the baseline (α_{-1}).[4] However, the standard event study cannot solve the previous two problems in the TWFE. In addition, the parallel trend is difficult to test because of the differences in treatment timings.

Fortunately, recent literature (de Chaisemartin & D'Haultfœuille, 2020; Goodman-Bacon, 2021; Callaway & Sant'Anna, 2021; Sun & Abraham, 2021) generously provides many solutions to the above issues. We apply the approach of Callaway and Sant'Anna (2021)[5] on using an event-study because the settings are closest to the context of the problem settings, allowing for variation in treatment timings and multiple time periods as well as for flexible

[3] From the data, the maximum of treatment period is 8 and pre-treatment one is 15. Our graphical results report only 7 periods of pre-treatment from the numeric estimations.
[4] Recent studies such as Rambachan and Roth (2023) suggest researchers can do more even when the ideal parallel assumption is not met. If the post-trend can be predicted from the pre-trend, researchers may still come to a conclusion on the impacts (Rambachan and Roth, 2023).
[5] We also use Sun and Abraham (2021) for robustness checks.

covariates.[6] Specifically, Callaway and Sant'Anna (2021) propose an estimation procedure based on the outcome regression and inverse probability weighting (doubly-robust) methods. The procedure disaggregates causal parameter–identified group-time average treatment effects by comparing treated observations with never-treated observations, and treated observations with "not-yet-treated" observations. Then, the procedure aggregates group-time average treatment effects. Using a bootstrap procedure, inference procedures simultaneously account for balances such as those across times and estimands. Thus, the estimations from Callaway and Sant'Anna (2021) can show treatment effects that change with the length of exposure to the treatment, variations in average treatment effects across treatment groups, and the evolution of cumulative average treatment effects over the calendar year.

We apply the estimation procedure from Callaway and Sant'Anna (2021) to equation (2) with three different outcome groups. The first group covers wealth, income, structural change, and internal migration, including share of families having a house with a zinc/fibro roof (or a TV set), the minimum farm-gate price of rice per kilogram, share of families using chemical fertilizer in previous year, share of families who irrigated their paddy field, share of (fe)males 18 years of age or older, (Chamkar) rice farmer, share of (fe)males above 18 years of age whose main occupation is long crop growing, share of (fe)males above 18 years of age whose main occupation is wage employment in agriculture/construction, and share of (fe)males above 18 years of age whose main occupation is migrating to work in the country. The second group covers educational attainment, including illiteracy rates in the village by age cohort (18–24, 25–35, and 36–45 years) and by gender (males and females), and school enrollment rate

[6] For example, the staggered treatment adoption assumption of Callaway and Sant'Anna (2021) is exactly true in our context. Once the villages are subjected to the treatment, the roads exert the treatment effect over time. Also, their approach ensures that time-varying control variables are not affected by the intervention. In our context, the control variable is the village population.

per age cohort (12–14 and 15–17 years) for junior and high school and by gender. The third group covers pollution (share of families who are affected by environmental pollution) and sanitation (share of families who regularly boil water for drinking). We use village population as a control covariate because village population might account for the spatial agglomeration perspective.

The parallel trend assumption is important for the claim of causal effects. Specifically, the trend before the event would be parallel between the treatment and control groups (H0: All α_j with $j < 0$ should be all zero). Callaway and Sant'Anna (2021)'s procedure assumes conditional parallel trends based on never-treated and later-treated observations. However, recent studies have raised some concerns about the validity of the test even though all coefficients of the pre-trend are (jointly) statistically insignificant. The first is the lower power of conventional tests (Freyaldenhoven, Hansen & Shapiro, 2019; Kahn-Lang & Lang, 2020; Roth, 2022). For example, each coefficient of the pre-trend cannot be rejected for being different non-zero values with the same p-values that are observed in similar tests where the conclusion is that H0 cannot be rejected (H0: having a value of 0). Therefore, the pre-trend may exist in either linear or non-linear form, which continues and even vibrates after the event and causes biasness in the estimated coefficients of interest. In addition, the draws of the data for the tests are a selected sample, which induces additional statistical issues (Roth, 2022).

Fortunately, Roth (2022) and Rambachan and Roth (2023) also provide some procedures to detect the pre-trend and test its sensitivity. The key point of the procedure is to find the probability of encountering the issues and to determine how sensitive it is, by accepting the violation of the pre-trend assumptions in different scenarios and using helpful information from the pre-event coefficients. We apply these procedures for each reported outcome.

5. Results

5.1 Wealth, income, structural change, and internal migration

We find that improved roads are associated with more families having houses with a zinc or fibro roof in the village, as seen in Figure 2 (2.1). This is an indicator of more wealth. Villagers would have become richer in association with improved roads. Similarly, we find the share of families having a TV (Figure 2.3) also increases in association with improved roads.

[Insert Figure 2 here]

We checked the sensitivity of the pre-trend assumption shown in Appendix 8, using procedures from Roth (2022) and Rambachan & Roth (2023). Regarding the share of families having a house with a zinc or fibro roof shown in Appendix 8 (8.1), the test using procedures from Roth (2022) indicates a 50% probability that we would find a positive upward trend with a slope of 0.0008. The test result, illustrated in the graph on the lefthand side, uses the smoothness restriction of Rambachan & Roth (2023).[7] The critical value for the bound M is approximately 0.001. If the extrapolation of the pre-trend does not change more than 0.001 percentage points across consecutive periods, we can reject the null effect. Therefore, we are confident that the effects on the share are more likely to exist even when there is a linear pre-trend and a nonlinear pre-trend (up to $M \approx 0.001$). Meanwhile, the right-hand side of the graph, which illustrates the results from using the procedure of Roth (2022), shows the estimated coefficients during the treatment time position far above the expectation after pre-testing, suggesting that the effects of improved roads are significant regardless of the pre-trend and the expectation after pre-testing. A similar interpretation can be applied to the share of families having houses with a zinc or fibro roof with TV set.

[7] The graphs corresponding to Rambachan and Roth (2023) show the confidence interval of a bound M, which is the slope of the difference in trend changes from pre-treatment to treatment. When M=0, the difference in trends is linear. A large M is associated with greater non-linearity of the post-event trend compared with the pre-event trend. However, as M becomes larger, the impacts fade away.

We seek evidence for a possible mechanism. We note that the roads already existed before the treatment and that road construction was carried out for the purpose of improving the quality of these roads. There are two hypotheses for increasing wealth in association with improved roads. One is that the cost of building or renovating a house decreases because of lower transportation costs. Another is that the annual income of the villages increases because of structural changes, enabling villagers to build or renovate houses such that the overall condition of houses in the village improves. A potential reason for structural changes due to improved roads might be that villagers can access (labor) markets that are farther away at lower costs. Villagers can earn a higher income than that from agriculture and thus begin to transition away from agricultural production.

Unfortunately, we do not have any information on transportation costs and housing construction costs to test the first hypothesis directly. However, several outcomes related to the price of rice at farm gate, share of workers by industry, and internal migration in the data can be used to test the other hypotheses. For example, one hypothesis is that the probability of selling rice outside the villages would have been limited by high transportation costs likely due to poor road conditions. Therefore, the minimum price of rice at farm gate would be depressed by intermediate traders. However, owing to the improved roads, farmers can access a variety of markets and negotiate for a higher price because transportation costs have been reduced. Another hypothesis is that structural change in the village leads to higher income, that is, more income owing to increased wage employment. In addition, having better roads may help underemployed workers reach better job markets outside their villages. As they migrate to work elsewhere (enabled by lower travel costs), they would earn a higher income and use part of their earnings to upgrade their housing conditions. We test the hypotheses with the available outcomes in the data, as shown in Figures 2 (2.4, 2.5, 2.6) and 3.

[Insert Figure 3 here]

We find evidence to support one of these hypotheses. The minimum price of rice at farm gate would have been increased in association with the improved roads, as shown in Figure 2 (2.4). The higher price potential incentivizes rice production (more workers, more chemical fertilizer, and more paddies irrigated). However, as shown in Figure 2 (2.5 and 2.6) and Figure 3 (3.1 and 3.2), the effects on rice production are statistically insignificant. In addition, the analyses in Appendix 8 (8.4, 8.5, and 8.6) suggest that the statistical results might be sensitive to the pre-trend assumption.

However, we do not find evidence to support the other hypotheses. We do not find that improved roads lead to structural change or more (internal) migration, as shown in Figure 3. There is no significant change in the share of people with wage employment (Figure 3.5 and 3.6), agriculture (long crop growing; Figure 3.3 and 3.4), and internal migration (Figure 3.7 and 3.8). Additional pre-trend sensitivity analyses refute any possible effects. Also, unlike Shimamura et al. (2023a), our findings suggest no statistically significant differences by gender.

5.2 Education

We find that improved roads have significant effects on illiteracy rates. As shown in Figure 4, we find the illiteracy rate among people aged 36–45 years decreases after roads are improved. In Appendix 10 (10.5 and 10.6), the test using procedures from Roth (2022) indicates a 50% probability that we would find a positive upward trend with a slope of 0.0006 (0.0007). In the sensitivity analysis using the smoothness restriction of Rambachan and Roth (2023), the critical value for the bound M in the case of males (Appendix 10.6) is about 0.002. If the extrapolation of the pre-trend does not change more than 0.002 percentage points across consecutive periods, we can reject the null effect. Therefore, we are also confident that the effects on the illiteracy rate are more likely to exist even when there is a linear pre-trend and a nonlinear pre-trend (up to $M \approx 0.002$). However, we come to no clear conclusion on the statistically significant average effects on the illiteracy rates of people aged 18–24 and 25–35 years in Figure 4 (4.1, 4.2, 4.3 and 4.4).

[Insert Figure 4 and 5 here]

However, we do not find evidence for the effects on school enrollment rates among people aged 12–14 (junior high school) and 15–17 (high school) years, as shown in Figure 5. The pre-trend assumptions are violated. Further sensitivity analyses, as shown in Appendix 11, do not give any evidence to support rejecting the null effects.

5.3 Pollution and sanitation

The results shown in Figure 6 (6.1) suggest that after the roads are improved, a higher share of families in the village are subjected to environmental pollution. Although it does not appear immediately, the share of families subjected to environmental pollution increases and becomes statistically significant from the third year after the event. Although the pre-trend assumption is not held, as shown in Appendix 12, sensitive analyses of the pre-trend suggest that the effects would be sustained in the existence of the pre-trend.

[Insert Figure 6 here]

Meanwhile, we do not find statistically significant effects on the share of families who regularly boil water for drinking, as shown in Figure 6 (6.2).

5.4 Robustness checks

First, we apply the methods suggested by Sun and Abraham (2021). The estimation results can be found in Appendices 3–7. The interpretation of the results remains similar.

Second, we alter the distance that would constitute the influence scope of the improved roads to 4 km. Although the effects on the share of families having a house with a zinc/fibro roof (or a TV) tend to be magnified, as shown in Appendix 12 (12.1), the previously found effects with the setting of 2 km are no longer statistically significant in the setting of 4 km (see

Appendices 13–17). These results agree with Shimamura et al. (2023b). The possible impacts of improved rural roads may be limited to within a few (≤5) kilometers of the site.

6. Conclusions

We use panel data of Cambodian villages during 2006–2021 to investigate the possible impacts of improved rural roads on nearby villagers. We find that improved rural roads help to increase the wealth of villagers, perhaps via higher income (higher price of rice) channel and reduce illiteracy among villagers. However, we do not find any increase in school enrollment rates, structural changes, or internal migration. In addition, we find that improved rural roads increase environmental pollution. Finally, the impacts of improved roads in Cambodia may be limited to within a short distance (2 km).

Our study shows that rural road improvement might have welfare-enhancing impacts as well as welfare-damaging impacts (in our context, environmental pollution). Hence, policymakers should take into account both the pros and cons of such projects. Conducting a cost-benefit analysis would be preferable. However, due to data limitations, this will be a target of future research.

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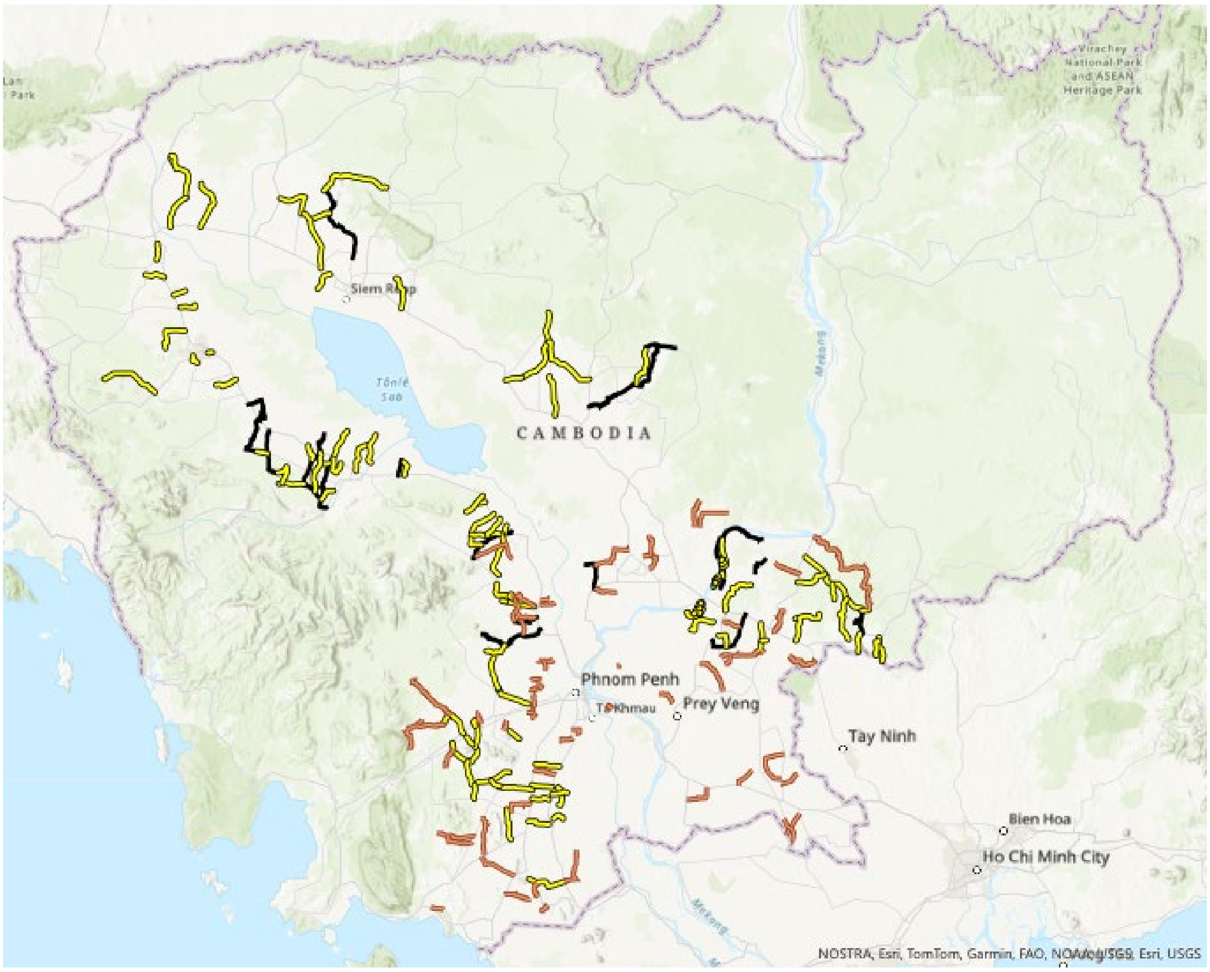
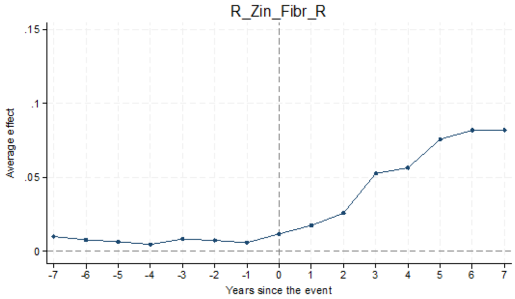
Figure 1 Improved roads under ADB supported road projects

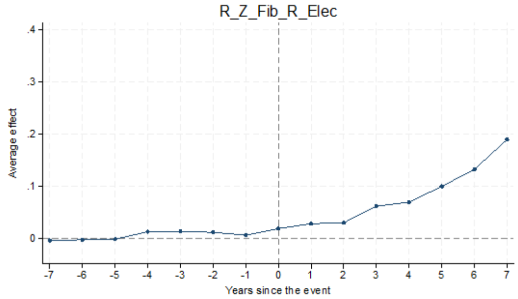


Notes: Black curves: Rural roads under phase 1. Yellow curves: Rural roads under Phase 2. Red curves: Rural roads under Phase 3.

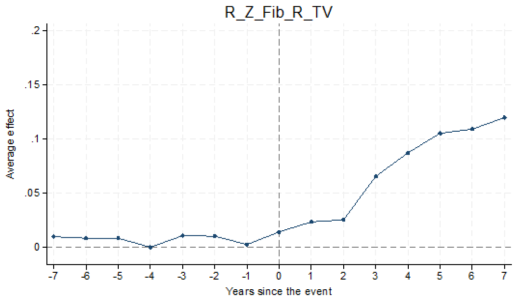
Figure 2 Wealth and income



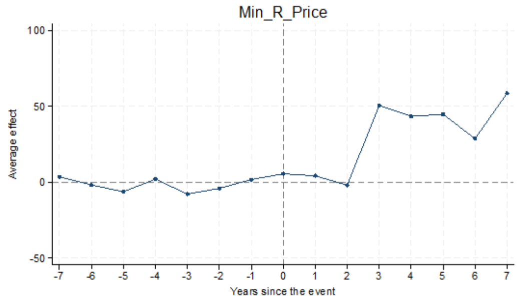
2.1 Share of families having houses with zinc/fibro roof
P-value (pretrend test): 1.000
ATT on Treated: 0.0329 (0.0085)***



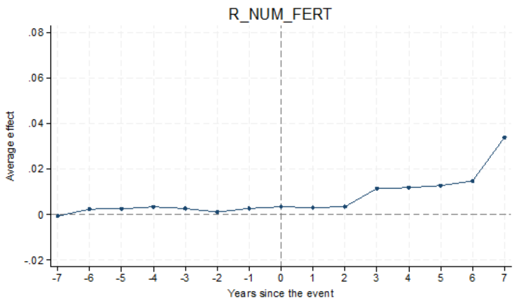
2.2 Share of families having houses with zinc/fibro roof & electricity
P-value (pretrend test): 0.0000
ATT on Treated: 0.047 (0.031)



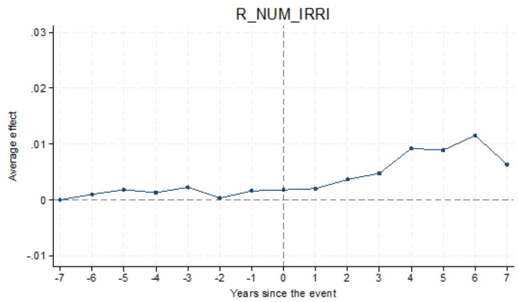
2.3 Share of families having houses with zinc/fibro roof & TV
P-value (pretrend test): 0.9999.
ATT on Treated: 0.042 (0.011)***



2.4 Minimum farm gate price of rice
P-value (pretrend test): 0.9992
ATT on Treated: 15.638 (9.078)*



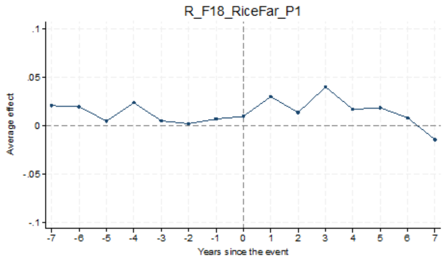
2.5 Share of families using chemical fertilizer in previous year
P-value (pretrend test): 0.9970
ATT on Treated: 0.0067 (0.0062)



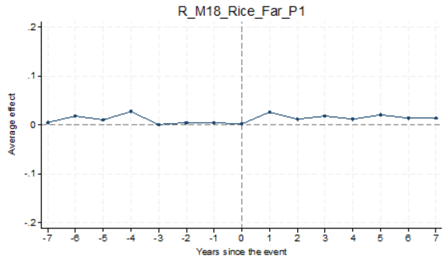
2.6 Share of families who irrigated paddy field
P-value (pretrend test): 1.000
ATT on Treated: 0.0042 (0.0032)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

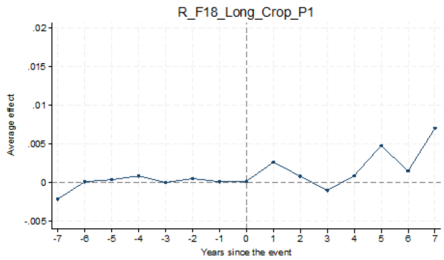
Figure 3 Structural change and internal migration



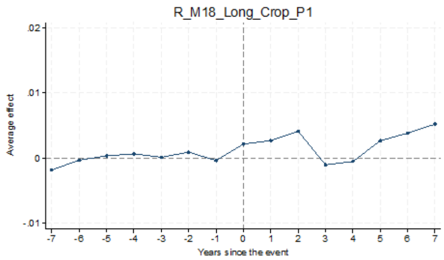
3.1 Share of females over 18 years old whose main occupation as rice farmers
P-value (pretrend test): 0.5152
ATT on Treated: 0.0169 (0.014)



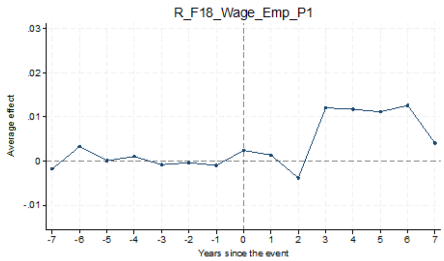
3.2 Share of males over 18 years old whose main occupation as rice farmers
P-value (pretrend test): 0.0000
ATT on Treated: 0.0131 (0.018)



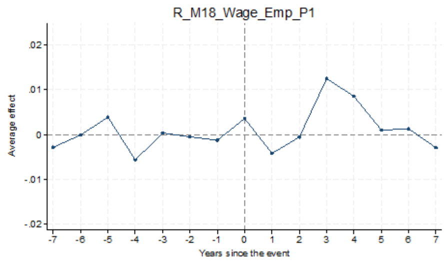
3.3 Share of females aged 18 and over whose main occupation as long crop growing
P-value (pretrend test): 0.000
ATT on Treated: 0.0015 (0.0009)*



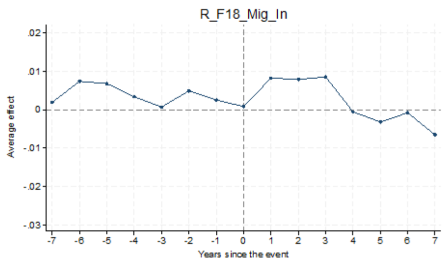
3.4 Share of males aged 18 and over whose main occupation as long crop growing
P-value (pretrend test): 0.000
ATT on Treated: 0.00252 (0.0011)**



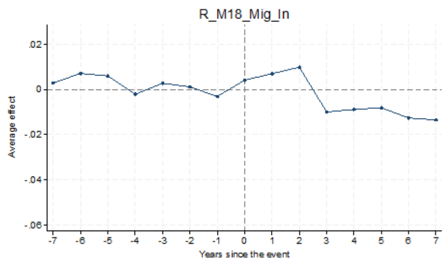
3.5 Share of females aged 18 and over with wage employment
P-value (pretrend test): 0.000
ATT on Treated: 0.0038 (0.0033)



3.6 Share of males aged 18 and over with wage employment
P-value (pretrend test): 0.6833
ATT on Treated: 0.0013 (0.0029)



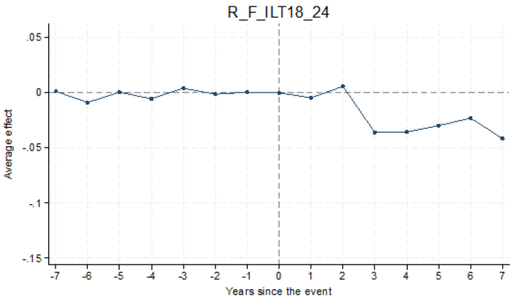
3.7 Share of females aged 18 and over whose main occupation as migrating to work in the country
P-value (pretrend test): 0.000
ATT on Treated: 0.0033 (0.0036)



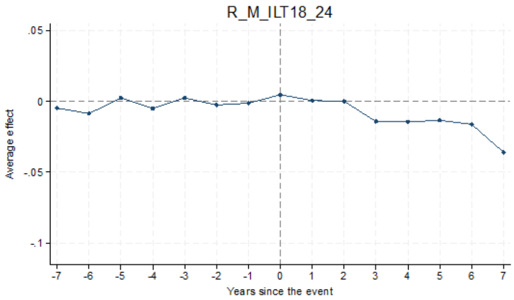
3.8 Share of males aged 18 and over whose main occupation as migrating to work in the country
P-value (pretrend test): 0.000
ATT on Treated: 0.0012 (0.0062)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

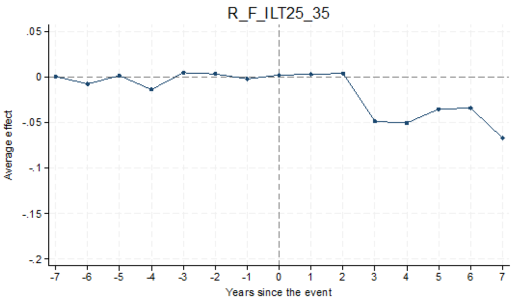
Figure 4 Illiteracy rate



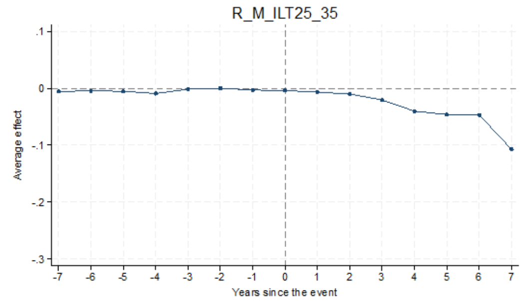
4.1 Share of illiterate females aged 18-24
P-value (pretrend test): 0.000
ATT on Treated: −0.01 (0.008)



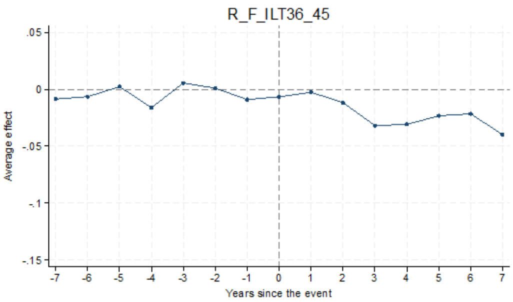
4.2 Share of illiterate males aged 18-24
P-value (pretrend test): 0.0000
ATT on Treated: −0.0036 (0.0078)



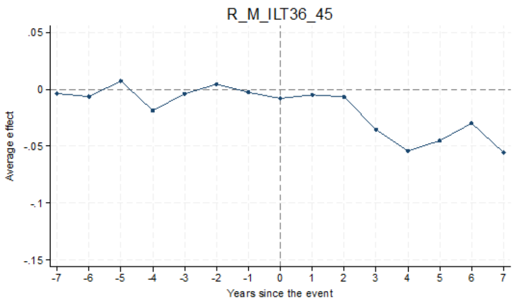
4.3 Share of illiterate females aged 25-35
P-value (pretrend test): 0.002
ATT on Treated: −0.012 (0.01)



4.4 Share of illiterate males aged 25-35
P-value (pretrend test): 1.000
ATT on Treated: −0.019 (0.014)



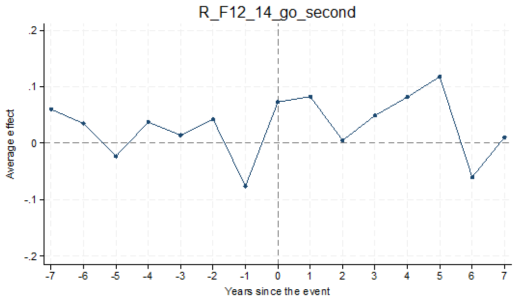
4.5 Share of illiterate females aged 36-45
P-value (pretrend test): 0.9831
ATT on Treated: −0.013 (0.0075)*



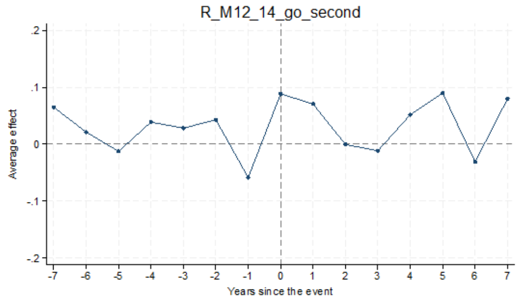
4.6 Share of illiterate males aged 36-45
P-value (pretrend test): 0.000
ATT on Treated: −0.018 (0.01)*

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

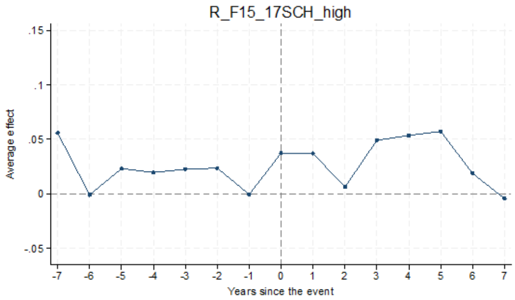
Figure 5 School enrolment rate



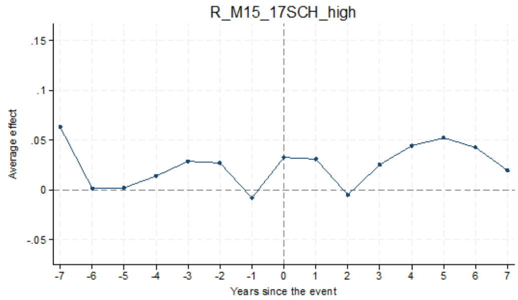
5.1 School enrolment rate in junior high school (females aged 12-14)
P-value (pretrend test): 0.0000
ATT on Treated: 0.055 (0.0294)*



5.2 School enrolment rate in junior high school (males aged 12-14)
P-value (pretrend test): 0.000
ATT on Treated: 0.0527 (0.03)*



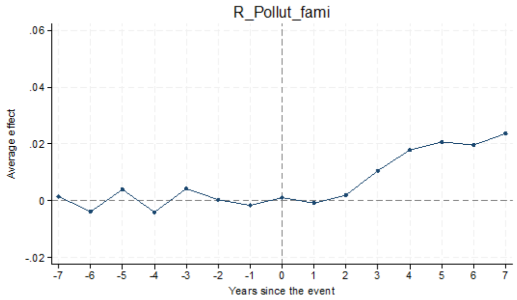
5.3 School enrolment rate in high school (females aged 15-17)
P-value (pretrend test): 0.1687
ATT on Treated: −0.0025 (0.0157)



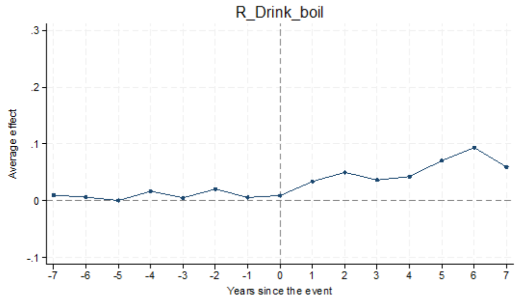
5.4 School enrolment rate in high school (males aged 15-17)
P-value (pretrend test): 0.0000
ATT on Treated: 0.028 (0.020)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

Figure 6 Sanity and pollution



6.1 Share of families who are affected by environment pollution
P-value (pretrend test): 0.000
ATT on Treated: 0.059 (0.031)*



6.2 Share of families who regularly boil water for drinking
P-value (pretrend test): 0.8035
ATT on Treated: 0.0383 (0.027)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

Online Appendix 1: Descriptive statistics

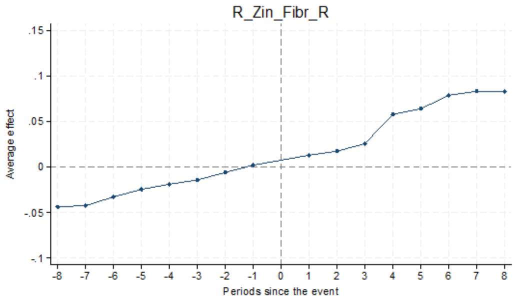
Variable	Obs.	Mean	Std. dev.	Min	Max
Year	25,104	2013.5	4.609864	2006	2021
Population	25,104	902.46	633.2282	69	8378
Distance to to-be-improved roads	25,104	0.813	0.634	0.00	1.99
Treated group	25,104	0.725	0.446	0	1
Treated group * treated	25,104	0.123	0.329	0	1
Minimum farm gate price of rice per kilogram	24,732	769.36	169.820	300	2000
Share of families					
Having house with zinc/fibro roof	25,104	0.439	0.217	0	1
Having house with zinc/fibro roof and electricity	25,104	0.213	0.254	0	1
Having house with zinc/fibro roof and TV	25,104	0.320	0.223	0	0.99
Using chemical fertilizer in previous year	25,104	0.143	0.075	0	0.71
Effected by environmental pollution	25,104	0.011	0.088	0	1
Regularly boiling water for drinking	25,104	0.348	0.298	0	1
Who irrigated paddy field	25,104	0.034	0.062	0	0.56
*Share of people among their gender and cohort (aged ≥ 18) whose main occupation as**					
(Chamkar) Rice farmers (Females)	15,690	0.508	0.274	0	1
(Chamkar) Rice farmers (Males)	15,690	0.575	0.253	0	1
Long crop growing (Females)	15,690	0.009	0.042	0	0.79
Long crop growing (Males)	15,690	0.012	0.048	0	0.93
Wage employment in agriculture/construction (Females)	15,690	0.025	0.054	0	0.91
Wage employment in agriculture/construction (Males)	15,690	0.063	0.084	0	1
Migrating to work in the country (Females)	14,121	0.076	0.101	0	0.96
Migrating to work in the country (Males)	14,121	0.087	0.114	0	0.95
Illiterate rate					
Female aged 18-24	23,534	0.045	0.113	0	1
Male aged 18-24	23,535	0.045	0.112	0	1
Female aged 25-35	23,531	0.072	0.138	0	1
Male aged 25-35	23,533	0.069	0.137	0	1
Female aged 36-45	23,532	0.116	0.176	0	1
Male aged 36-45	23,533	0.112	0.174	0	1
*School enrolment rate**					
Female aged 12-14 to jr. high school	15,687	0.402	0.310	0	1
Male aged 12-14 to jr. high school	15,688	0.405	0.314	0	1
Female aged 15-17 to high school	15,686	0.242	0.255	0	1
Male aged 15-17 to high school	15,682	0.251	0.259	0	1

Note: * The data only have such information from 2011.

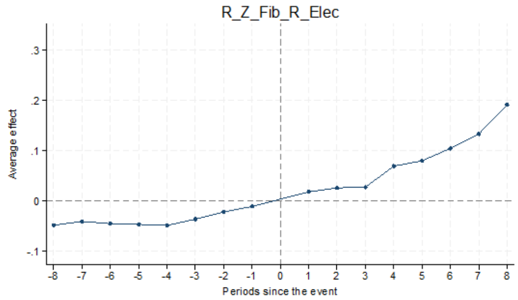
Online Appendix 2: Balance checks between the treated and control groups in 2006

Variables	Control (C)		Treated (Tr)		Diff.	H0: Diff.=0
	Mean	Obs.	Mean	Obs.	(C−Tr)	Pr(|T| > |t|)
Population	705	431	861	1138	−156***	0.000
Distance to health center (km)	4.3	431	3.9	1138	0.356	0.146
Share of families having houses with						
Zinc/fibro roof	0.392	431	0.328	1138	0.065***	0.000
Zinc/fibro roof and electricity	0.172	431	0.024	1138	−0.007	0.178
Zinc/fibro roof and having TV	0.271	431	0.179	1138	0.091***	0.000
Minimum farm gate price of rice per kilogram	474.13	431	442.24	1138	31.89***	0.000
Share of families						
Using chemical fertilizer in previous year	0.141	431	0.139	1138	0.003	0.447
Who irrigated paddy field	0.045	431	0.027	1138	0.018***	0.000
Effected by environmental pollution	0.008	431	0.002	1138	−0.0008	0.811
Regularly boiling water for drinking	0.475	431	0.316	1138	0.159***	0.000
Share of illiterate						
Female aged 18-24	0.065	431	0.098	1138	−0.033***	0.000
Male aged 18-24	0.058	431	0.098	1138	−0.04***	0.000
Female aged 25-35	0.116	431	0.154	1138	−0.039***	0.000
Male aged 25-35	0.100	431	0.134	1138	−0.033***	0.000
Female aged 36-45	0.177	431	0.209	1138	−0.033***	0.007
Male aged 36-45	0.157	431	0.183	1138	−0.026**	0.018

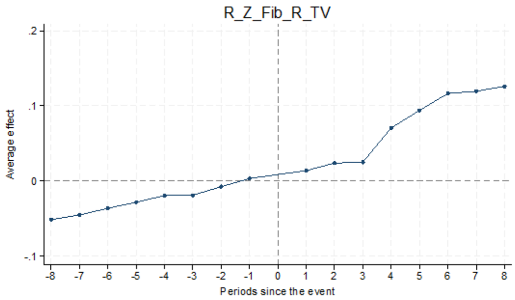
Online Appendix 3: Repeated Figure 2's specification using Sun and Abraham (2021)



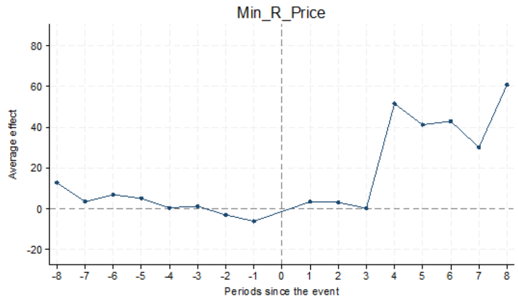
3.1 Share of families having houses with zinc/fibro roof



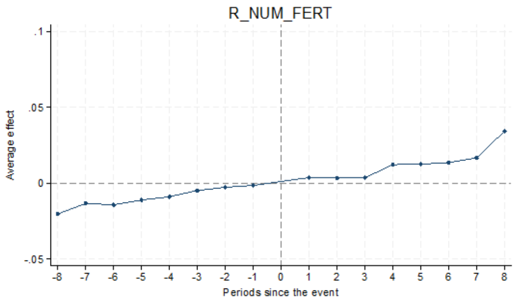
3.2 Share of families having houses with zinc/fibro roof & electricity



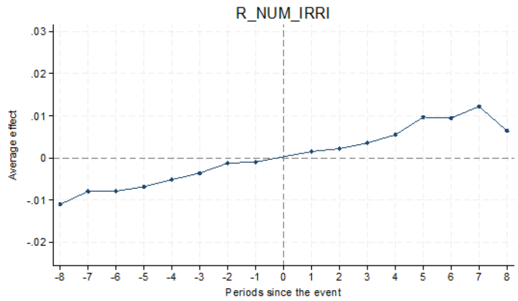
3.3 Share of families having houses with zinc/fibro roof & TV



3.4 Minimum farm gate price of rice



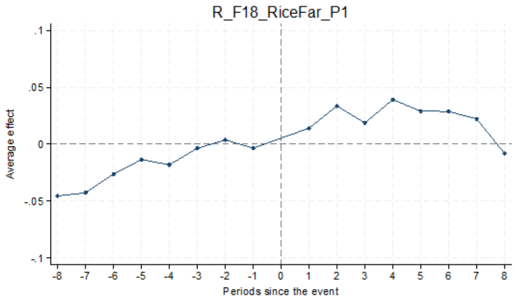
3.5 Share of families using chemincal fertilizer in previous year



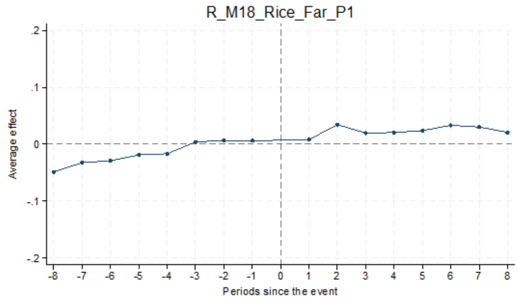
3.6 Share of family who irrigated paddy field

Note: The settings on the event are similar to our equation (2).

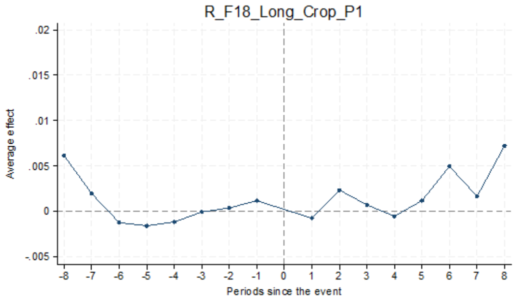
Online Appendix 4: Repeated Figure 3's specification using Sun and Abraham (2021)



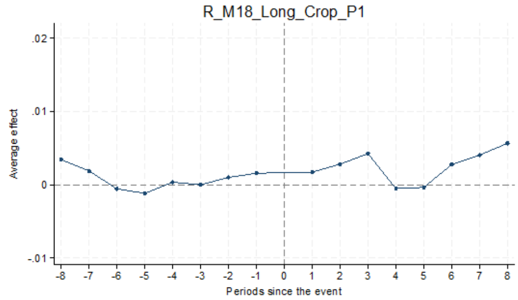
4.1 Share of females over 18 years old whose main occupation as rice farmers



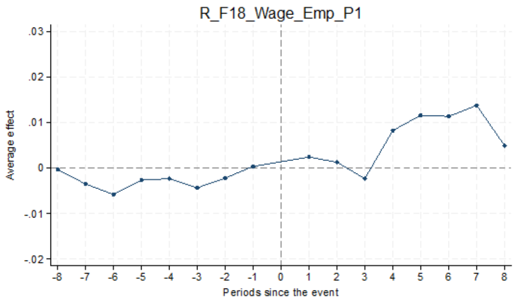
4.2 Share of males over 18 years old whose main occupation as rice farmers



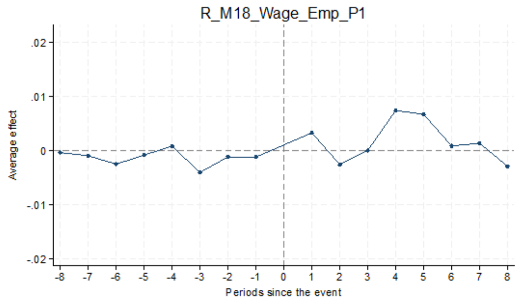
4.3 Share of females aged 18 and over whose main occupation as long crop growing



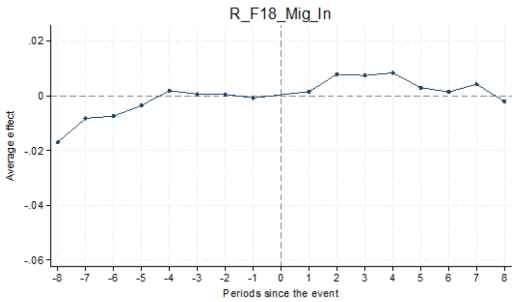
4.4 Share of males aged 18 and over whose main occupation as long crop growing



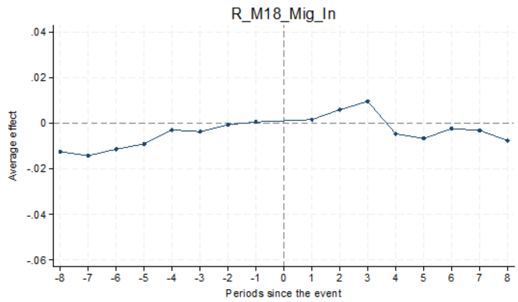
4.5 Share of females aged 18 and over with wage employment



4.6 Share of males aged 18 and over with wage employment



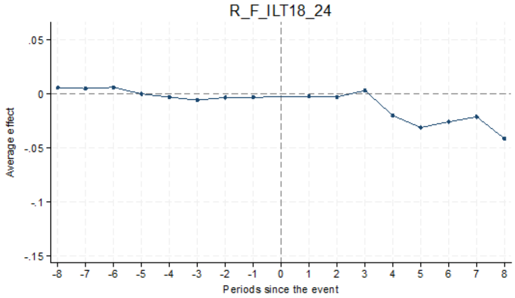
4.7 Share of females aged 18 and over whose main occupation as migrating to work in the country



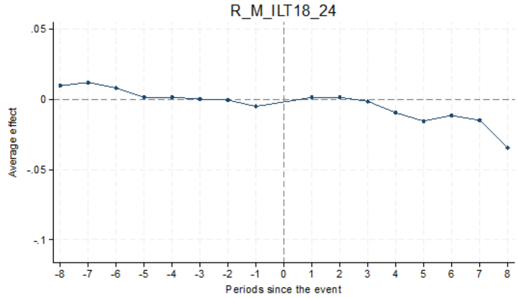
4.8 Share of males aged 18 and over whose main occupation as migrating to work in the country

Note: The settings on the event are similar to our equation (2).

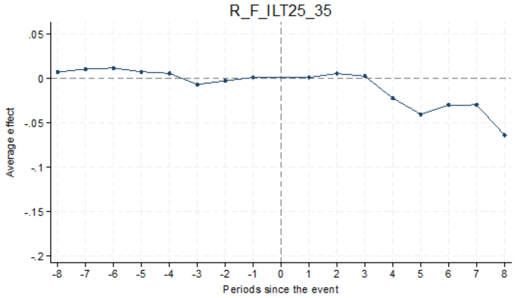
Online Appendix 5: Repeated Figure 4’s specification using Sun and Abraham (2021)



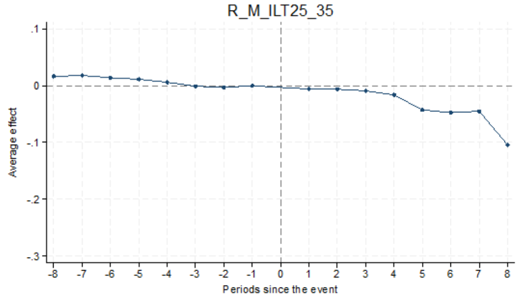
5.1 Share of illiterate females aged 18-24



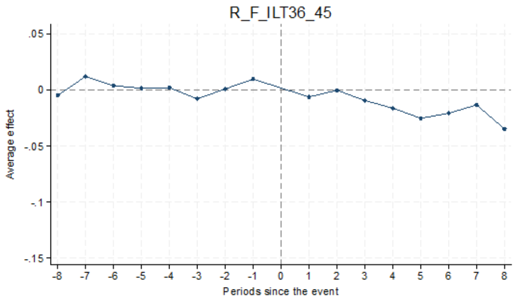
5.2 Share of illiterate males aged 18-24



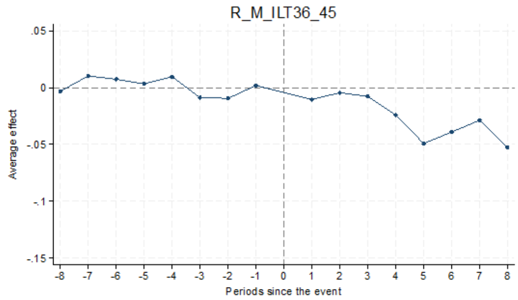
5.3 Share of illiterate females aged 25-35



5.4 Share of illiterate males aged 25-35



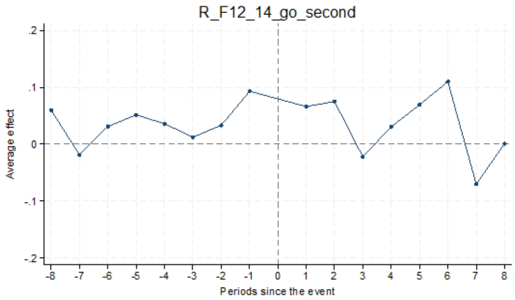
5.5 Share of illiterate females aged 36-45



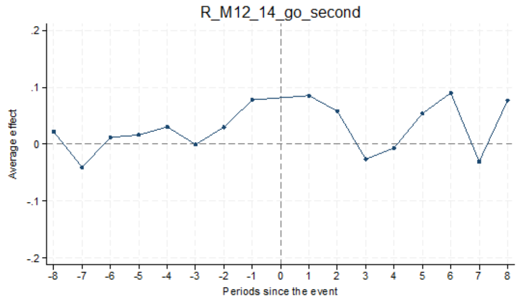
5.6 Share of illiterate males aged 36-45

Note: The settings on the event are similar to our equation (2).

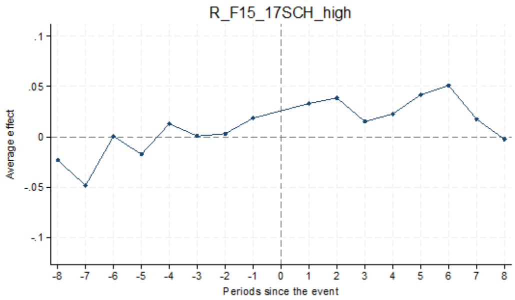
Online Appendix 6: Repeated Figure 5's specification using Sun and Abraham (2021)



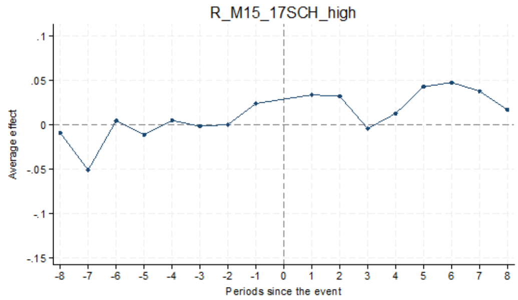
6.1 School enrolment rate in junior high school (females aged 12-14)



6.2 School enrolment rate in junior high school (males aged 12-14)



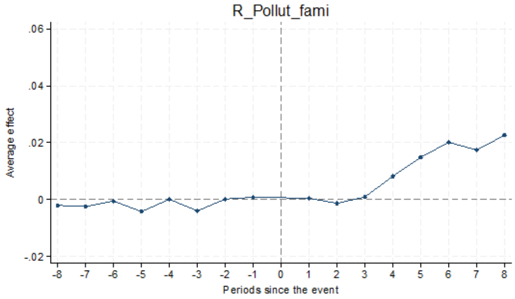
6.3 School enrolment rate in high school (females aged 15-17)



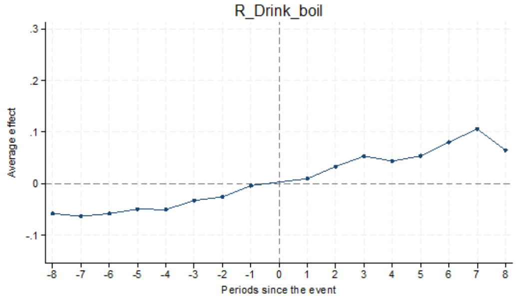
6.4 School enrolment rate in high school (males aged 15-17)

Note: The settings on the event are similar to our equation (2).

Online Appendix 7: Repeated Figure 6's specification using Sun and Abraham (2021)



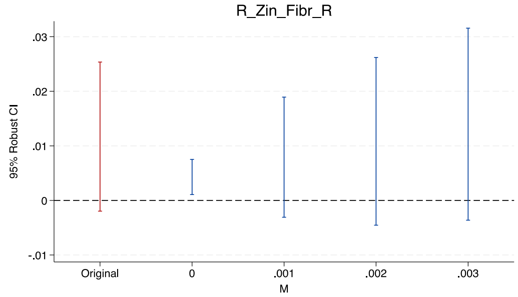
7.1 Share of families who are affected by environment pollution



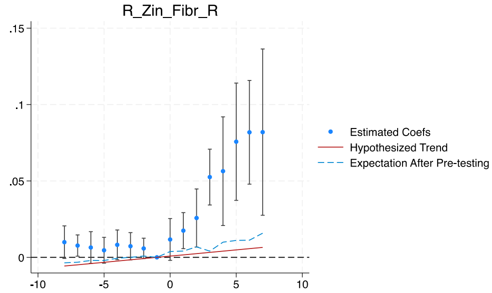
7.2 Share of families who regularly boil water for drinking

Online Appendix 8: Sensitive analyses on the pre-trend assumption (Figure 2)

8.1 Share of families having house with zinc or fibro roof

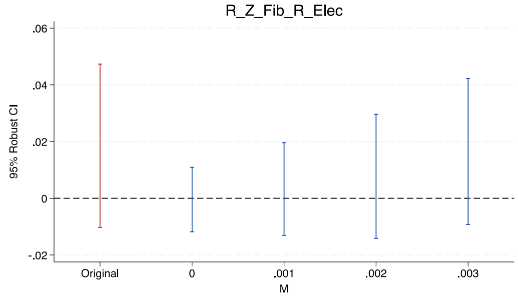


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

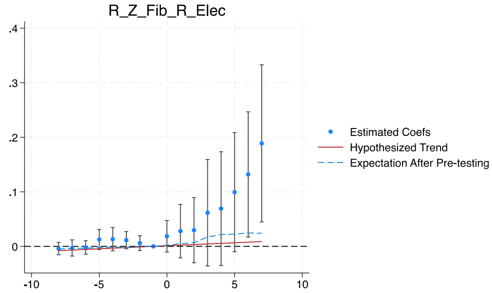


Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.0008 (50% power).

8.2 Share of families having house with zinc or fibro roof with electricity

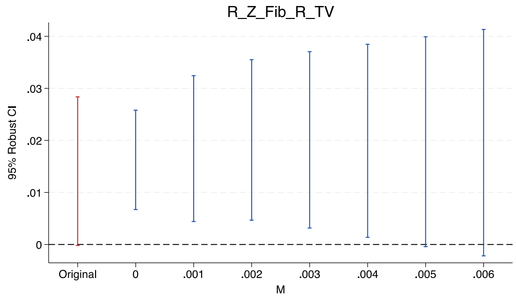


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

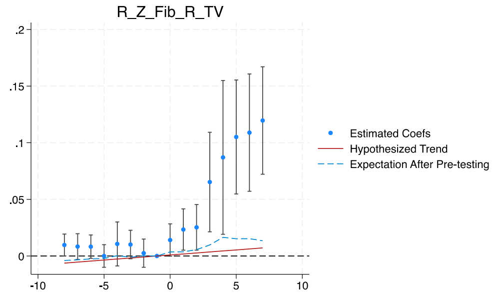


Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.0011 (50% power).

8.3 Share of families having house with zinc or fibro roof with TV set



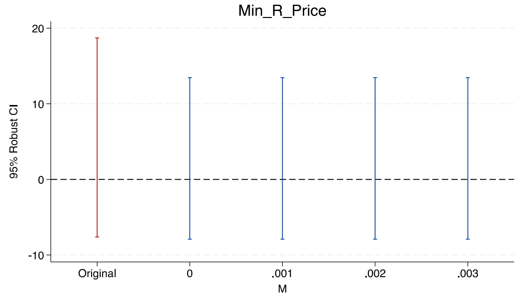
Sensitive analyses of pretrend (Rambachan & Roth, 2023)

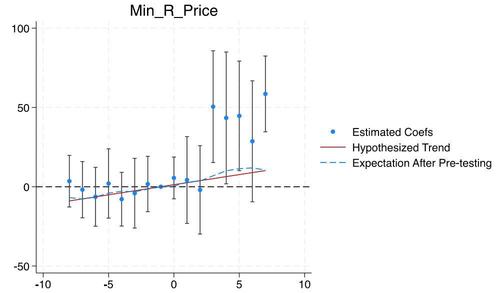


Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.0009 (50% power).

Online Appendix 8: (Cont.)

8.4 Minimum farm gate price of rice

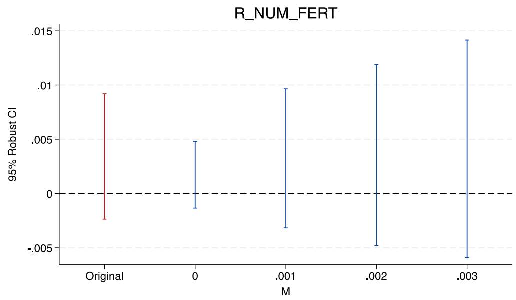


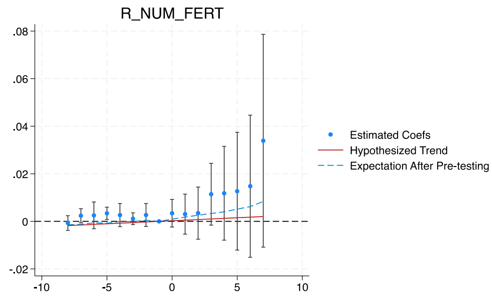


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 1.276 (50% power).

8.5 Share of families using chemical fertilizer in previous year

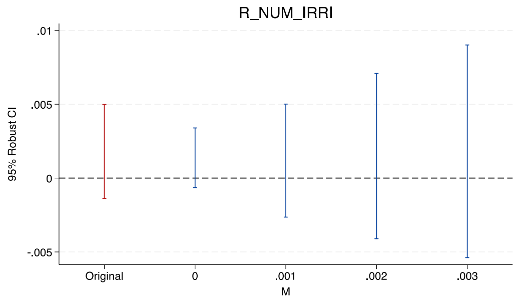


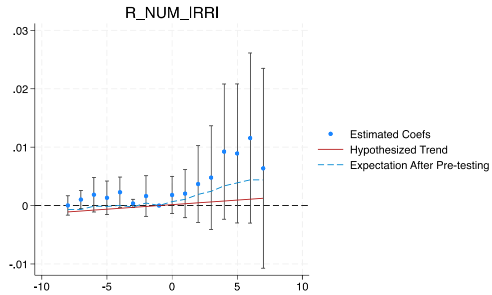


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.00025 (50% power).

8.6 Share of families who irrigated paddy field



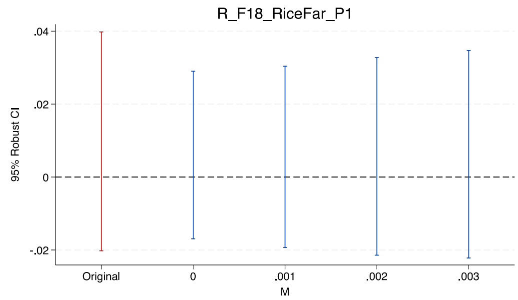


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

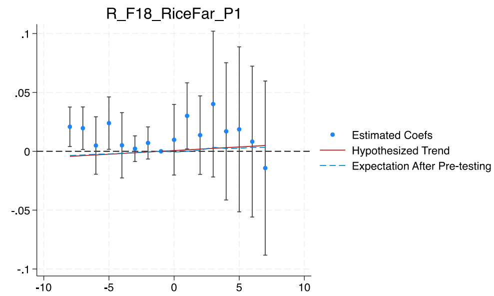
Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.00015 (50% power).

Online Appendix 9: Sensitive analyses on the pre-trend assumption (Figure 3)

9.1 Share of females over 18 years old whose main occupation as rice farmers

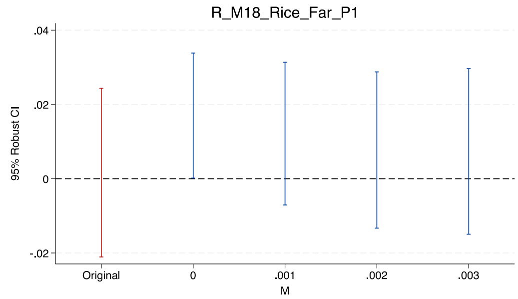


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

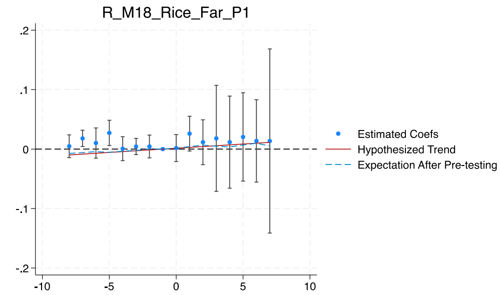


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0006 (30% power).

Share of males over 18 years old whose main occupation as rice farmers

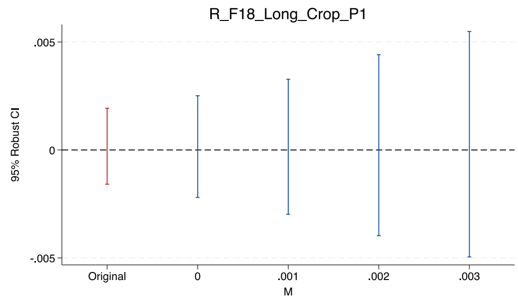


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

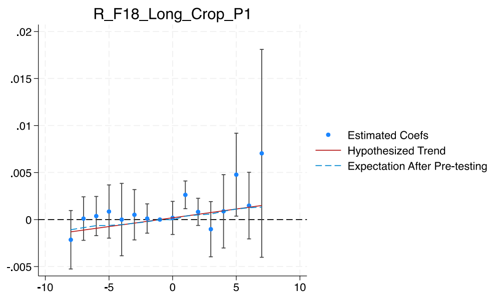


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0014 (50% power).

9.2 Share of females aged 18 and over in long crop

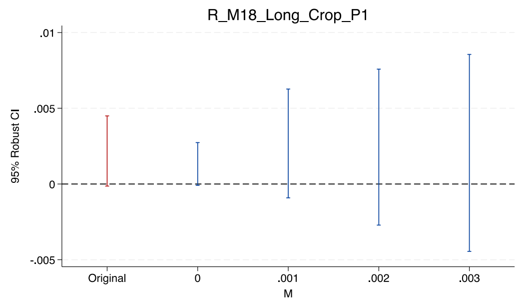


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

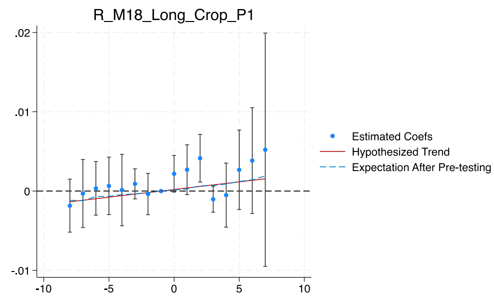


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.00019 (50% power).

9.3 Share of males aged 18 and over in long crop



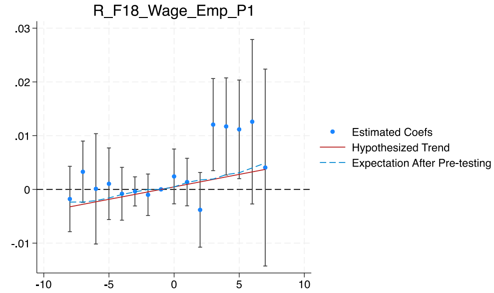
Sensitive analyses of pretrend (Rambachan & Roth, 2023)



Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.00019 (40% power).

Online Appendix 9 (Cont.)

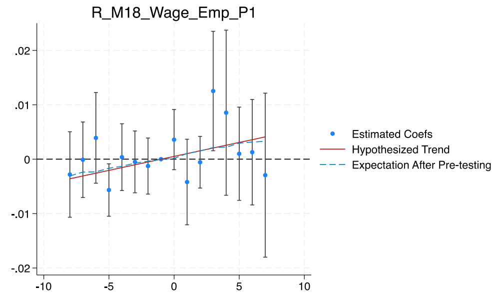
9.4 Share of females aged 18 and over with wage employment



Sensitive analyses of pretrend (Rambachan & Roth, 2023)

Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0005 (50% power).

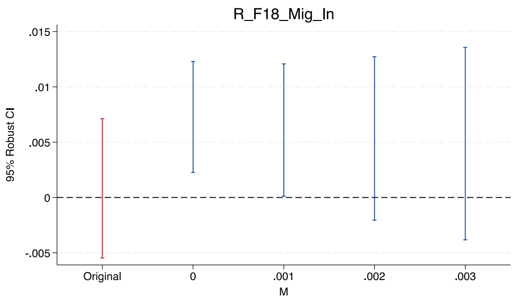
9.5 Share of males aged 18 and over with wage employment

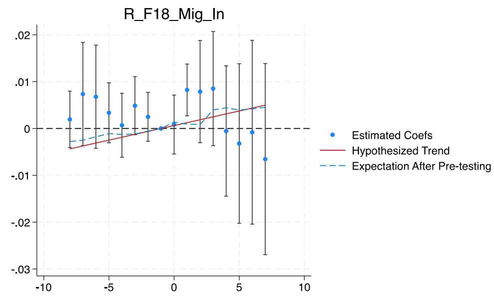


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0005 (50% power).

9.6 Share of females aged 18 and over whose main occupation as migrating to work in the country

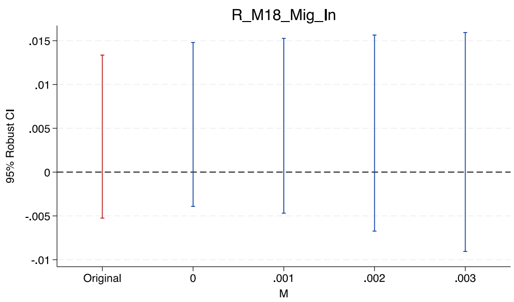


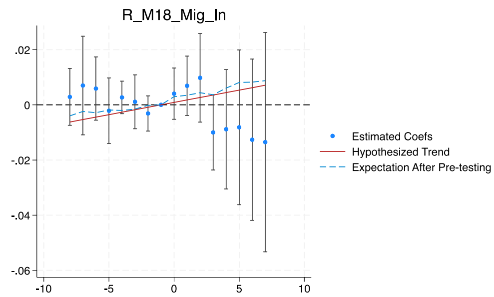


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0006 (50% power).

9.7 Share of males aged 18 and over whose main occupation as migrating to work in the country



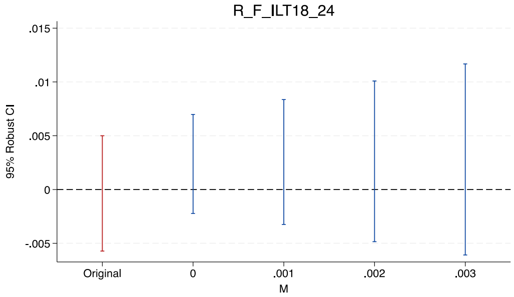


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

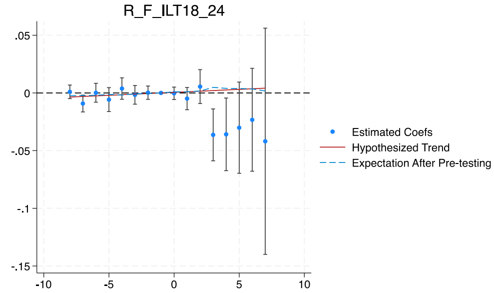
Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0009 (50% power).

Online Appendix 10: Sensitive analyses on the pre-trend assumption (Figure 4)

10.1 Share of illiterate females aged 18-24

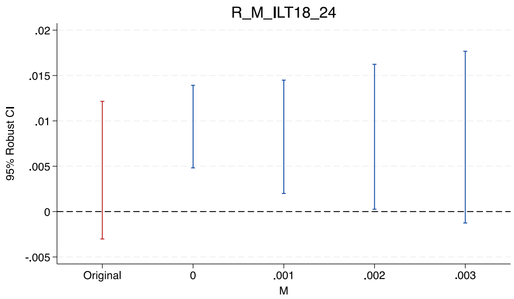


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

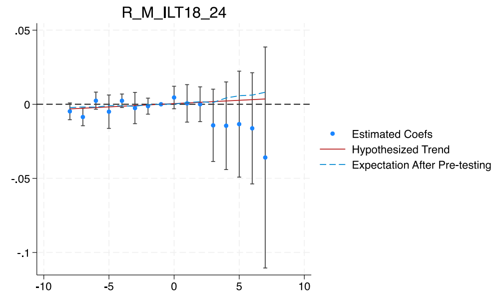


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0005 (50% power).

10.2 Share of illiterate males aged 18-24

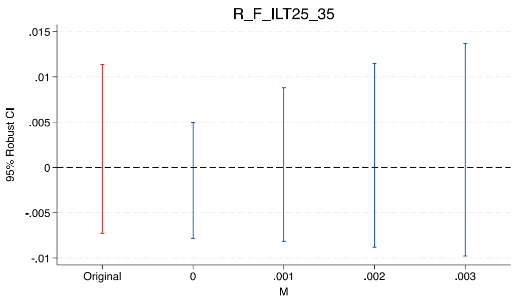


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

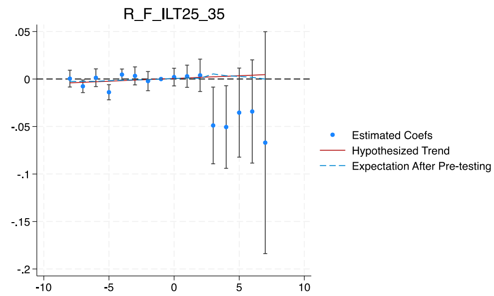


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0004 (50% power).

10.3 Share of illiterate females aged 25-35

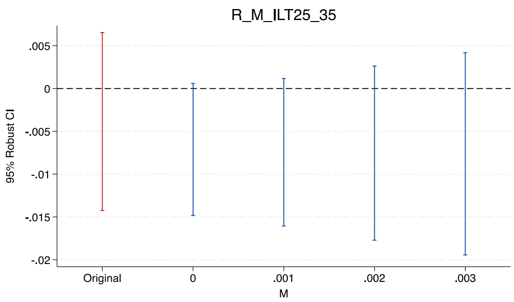


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

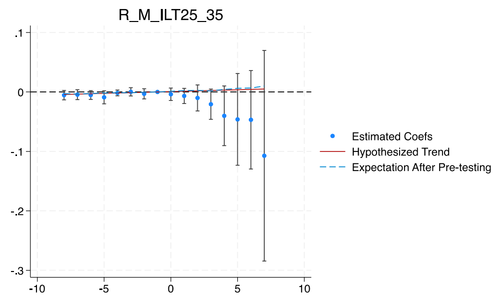


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0006 (50% power).

10.4 Share of illiterate males aged 25-35



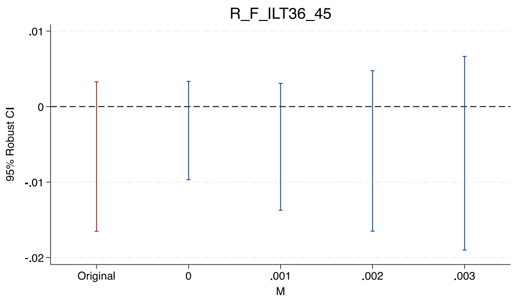
Sensitive analyses of pretrend (Rambachan & Roth, 2023)



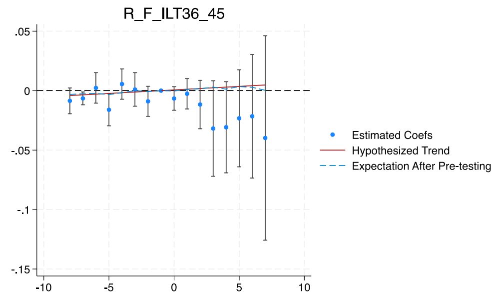
Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0006 (50% power).

Online Appendix 10 (Cont.)

10.5 Share of illiterate females aged 36-45

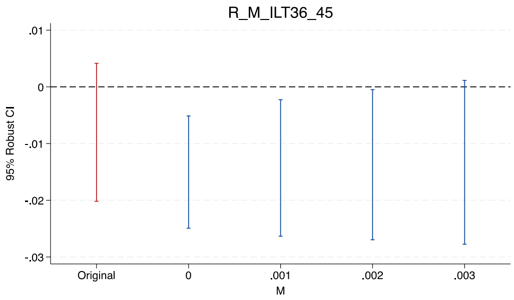


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

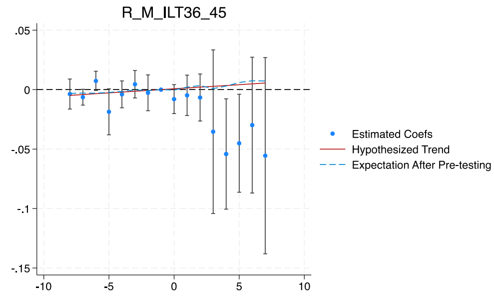


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0006 (50% power).

10.6 Share of illiterate males aged 36-45



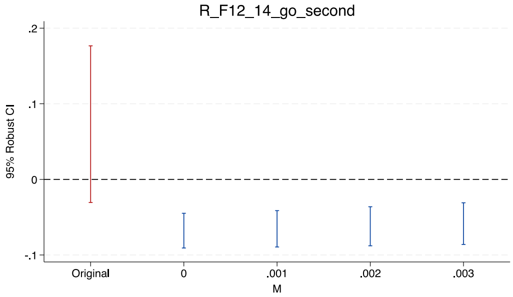
Sensitive analyses of pretrend (Rambachan & Roth, 2023)



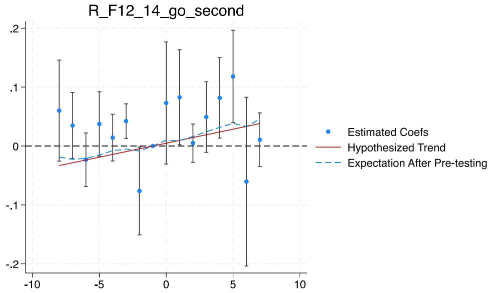
Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0007 (50% power).

Online Appendix 11: Sensitive analyses on the pre-trend assumption (Figure 5)

11.1 School enrolment rate in junior high school (females aged 12-14)

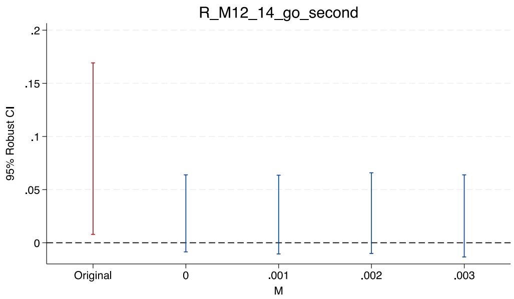


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

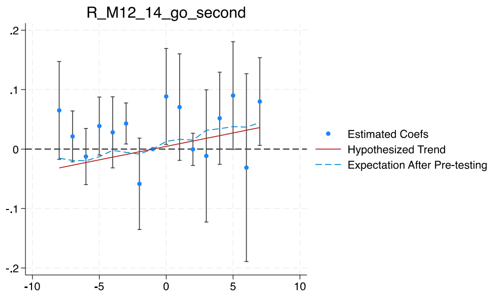


Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.005 (50% power).

11.2 School enrolment rate in junior high school (males aged 12-14)

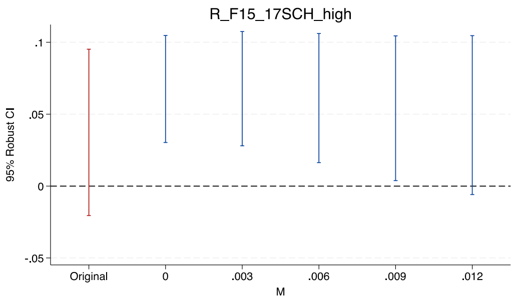


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

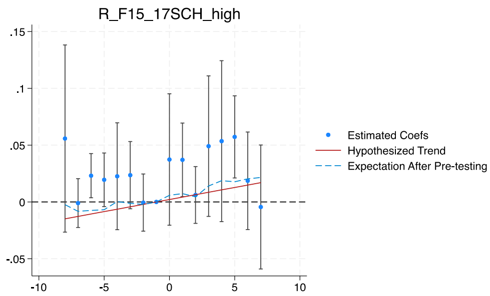


Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.0045 (50% power).

11.3 School enrolment rate in high school (females aged 15-17)

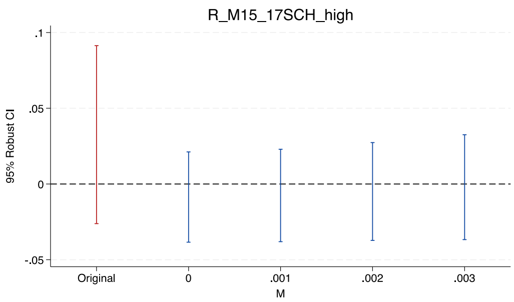


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

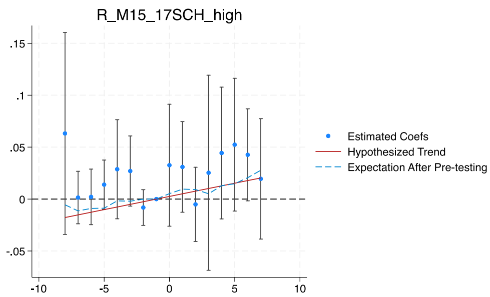


Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.002 (50% power).

11.4 School enrolment rate in high school (males aged 15-17)



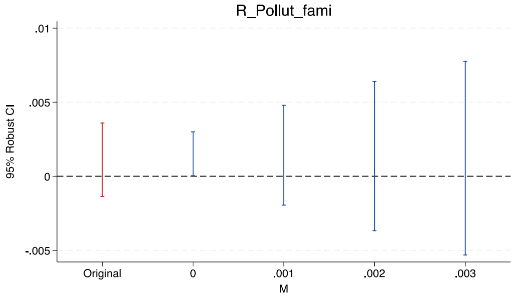
Sensitive analyses of pretrend (Rambachan & Roth, 2023)



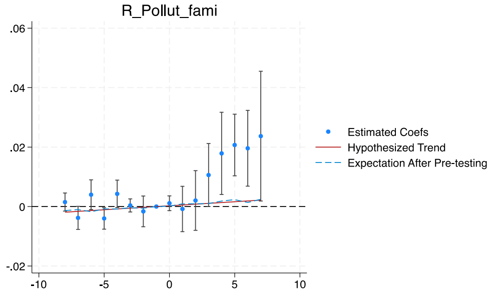
Sensitive analyses of pretrend (Roth, 2022)
Slope pretrend: 0.0025 (50% power).

Online Appendix 12: Sensitive analyses on the pre-trend assumption (Figure 6)

12.1 Share of families who are affected by environment pollution

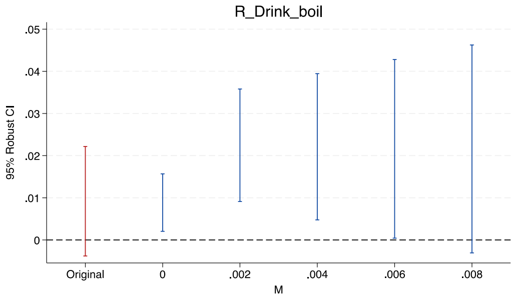


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

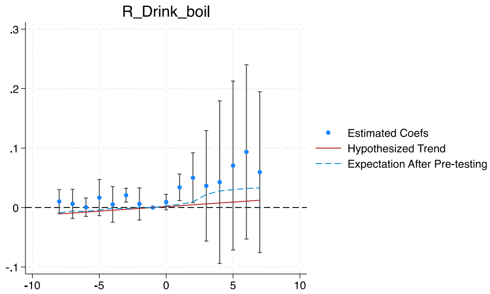


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0003 (50% power).

12.2 Share of families who regularly boil water for drinking

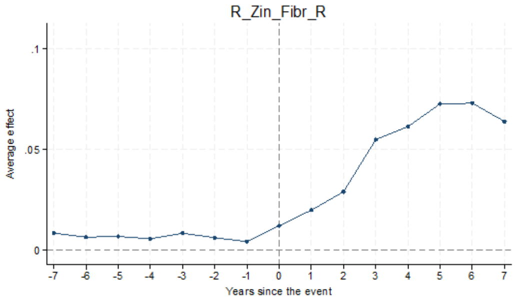


Sensitive analyses of pretrend (Rambachan & Roth, 2023)

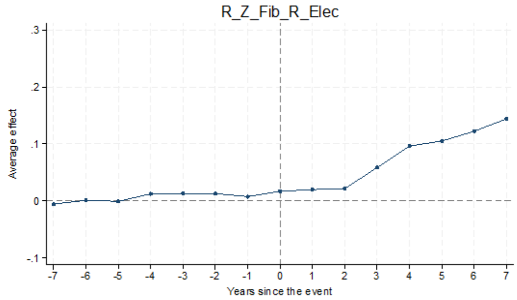


Sensitive analyses of pretrend (Roth, 2022) Slope pretrend: 0.0015 (50% power).

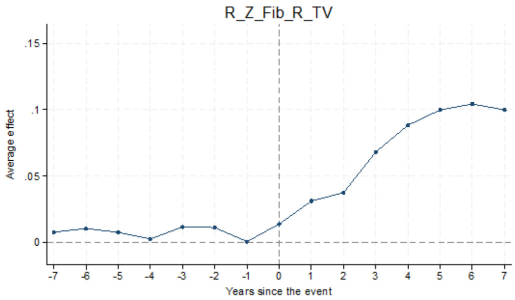
Online Appendix 13: Repeating estimations in Figure 2 with 4km as the potential influence scope of the improved rural roads.



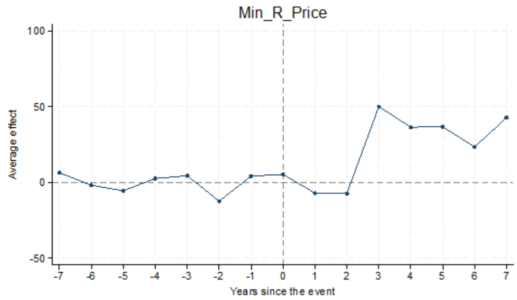
13.1 Share of families having houses with zinc/fibro roof
P-value (pretrend test): 0.000
ATT on Treated: 0.0335 (0.0085)***



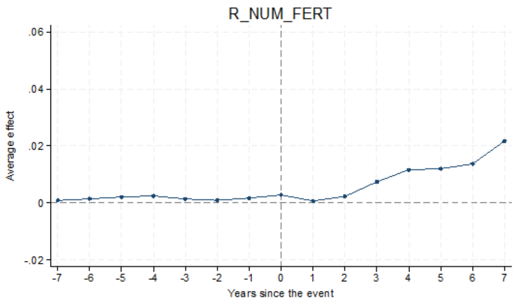
13.2 Share of families having houses with zinc/fibro roof & electricity
P-value (pretrend test): 0.0000
ATT on Treated: 0.0437 (0.0268)



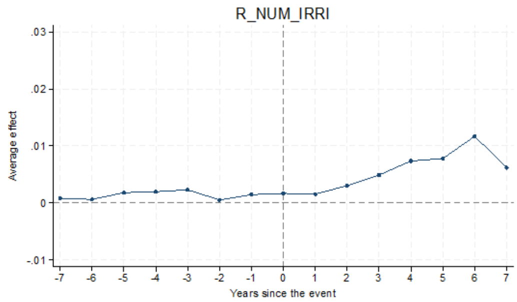
13.3 Share of families having houses with zinc/fibro roof & TV
P-value (pretrend test): 0.0436.
ATT on Treated: 0.046 (0.012)***



13.4 Minimum farm gate price of rice
P-value (pretrend test): 0.000.
ATT on Treated: 10.15 (7.3)



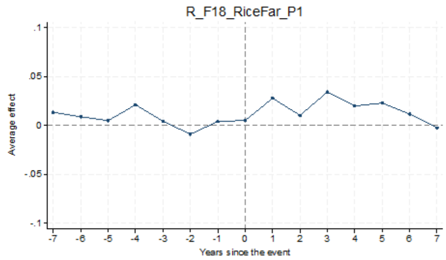
13.5 Share of families using chemical fertilizer in previous year
P-value (pretrend test): 0.0000
ATT on Treated: 0.005 (0.005)



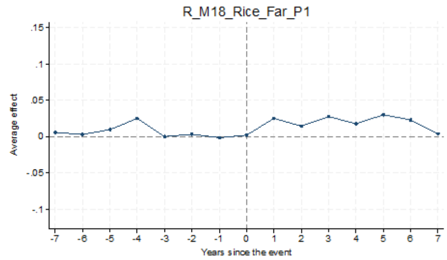
13.6 Share of families who irrigated paddy field
P-value (pretrend test): 0.000
ATT on Treated: 0.0038 (0.003)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

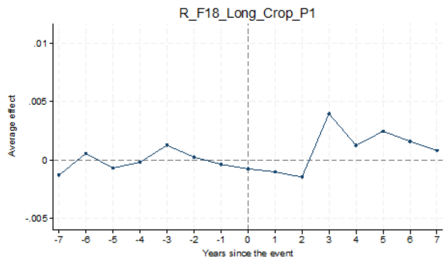
Online Appendix 14: Repeating estimations in Figure 3 with 4km as the potential influence scope of the improved rural roads.



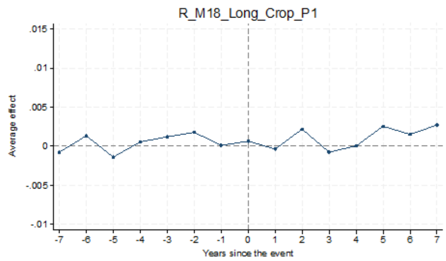
14.1 Share of females over 18 years old whose main occupation as rice farmers
P-value (pretrend test): 0.000
ATT on Treated: 0.015 (0.009)



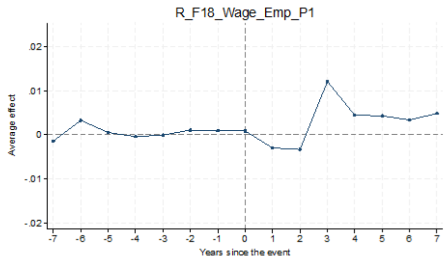
14.2 Share of males over 18 years old whose main occupation as rice farmers
P-value (pretrend test): 0.0000
ATT on Treated: 0.015 (0.014)



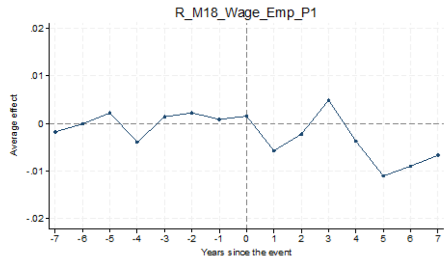
14.3 Share of females aged 18 and over whose main occupation as long crop growing
P-value (pretrend test): 0.000
ATT on Treated: −0.00008 (0.0007)



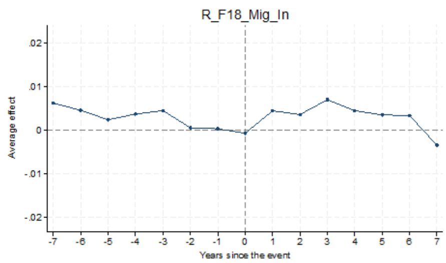
14.4 Share of males aged 18 and over whose main occupation as long crop growing
P-value (pretrend test): 0.000
ATT on Treated: 0.0008 (0.0007)



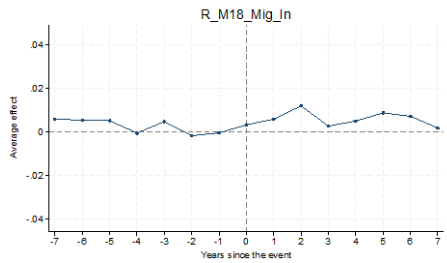
14.5 Share of females aged 18 and over with wage employment
P-value (pretrend test): 0.000
ATT on Treated: 0.00065 (0.0025)



14.6 Share of males aged 18 and over with wage employment
P-value (pretrend test): 0.000
ATT on Treated: −0.003 (0.002)



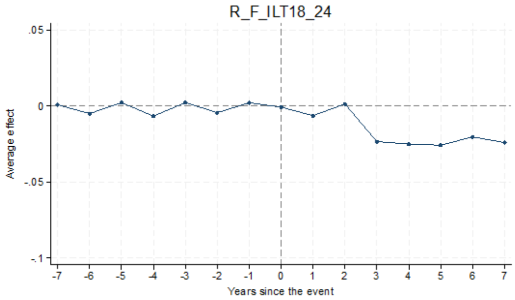
14.7 Share of females aged 18 and over whose main occupation as migrating to work in the country
P-value (pretrend test): 0.000
ATT on Treated: 0.0025 (0.0035)



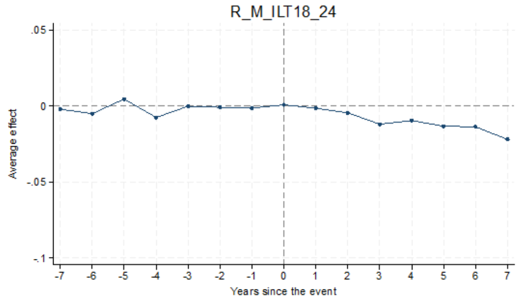
14.8 Share of males aged 18 and over whose main occupation as migrating to work in the country
P-value (pretrend test): 0.000
ATT on Treated: 0.006 (0.0066)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

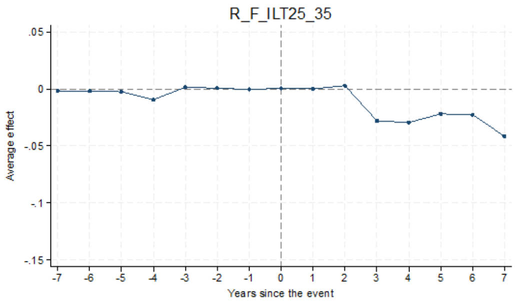
Online Appendix 15: Repeating estimations in Figure 4 with 4km as the potential influence scope of the improved rural roads.



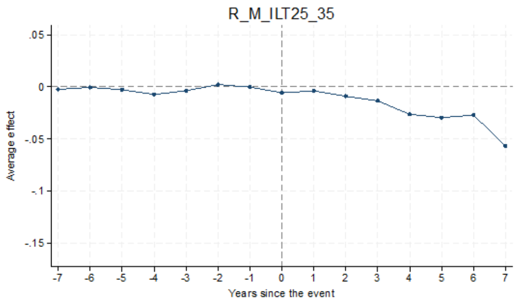
15.1 Share of illiterate females aged 18-24
P-value (pretrend test): 0.000
ATT on Treated: −0.0087 (0.0055)



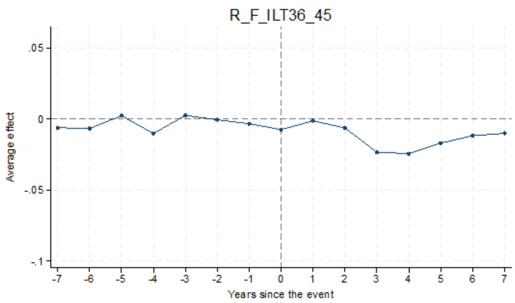
15.2 Share of illiterate males aged 18-24
P-value (pretrend test): 0.0000
ATT on Treated: −0.0049 (0.0054)



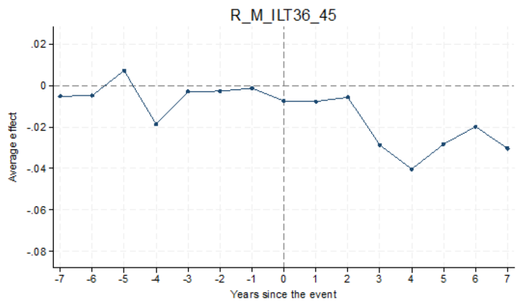
15.3 Share of illiterate females aged 25-35
P-value (pretrend test): 1.000
ATT on Treated: −0.0075 (0.0074)



15.4 Share of illiterate males aged 25-35
P-value (pretrend test): 0.000
ATT on Treated: −0.013 (0.009)



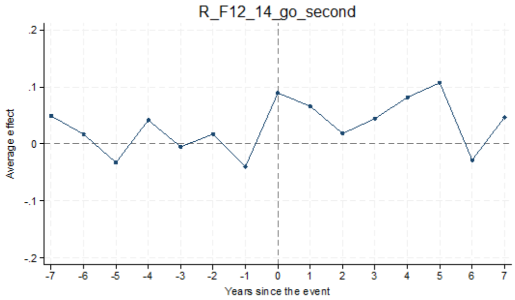
15.5 Share of illiterate females aged 36-45
P-value (pretrend test): 1.000
ATT on Treated: −0.009 (0.0067)



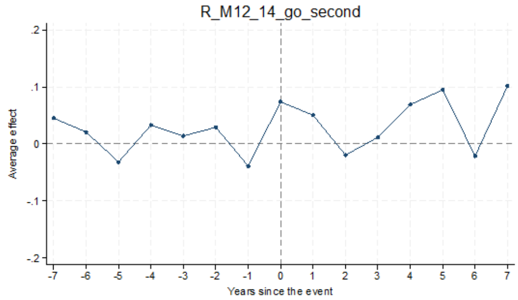
15.6 Share of illiterate males aged 36-45
P-value (pretrend test): 0.000
ATT on Treated: −0.014 (0.007)*

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from 0.

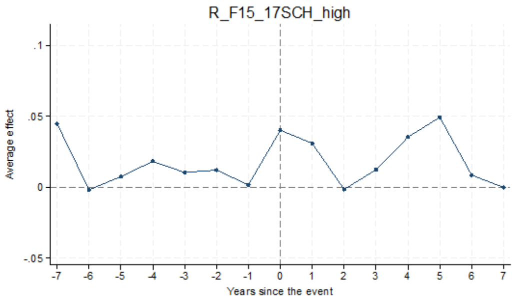
Online Appendix 16: Repeating estimations in Figure 5 with 4km as the potential influence scope of the improved rural roads.



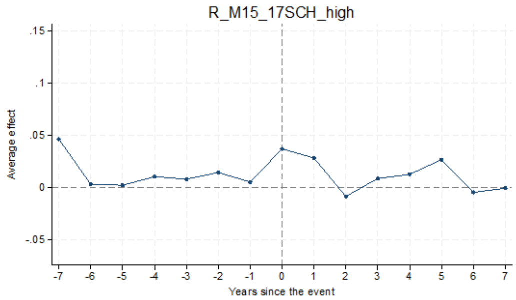
16.1 School enrolment rate in junior high school (females aged 12-14)
P-value (pretrend test): 0.0000
ATT on Treated: −0.039 (0.029)



16.2 School enrolment rate in junior high school (males aged 12-14)
P-value (pretrend test): 0.000
ATT on Treated: 0.045 (0.032)



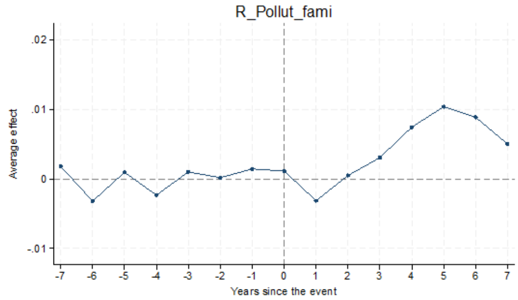
16.3 School enrolment rate in high school (females aged 15-17)
P-value (pretrend test): 0.0000
ATT on Treated: −0.003 (0.022)



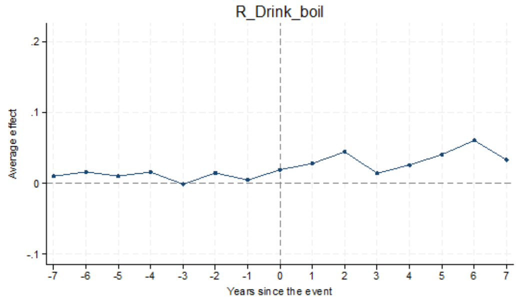
16.4 School enrolment rate in high school (males aged 15-17)
P-value (pretrend test): 0.0000
ATT on Treated: 0.019 (0.019)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.

Online Appendix 17: Repeating estimations in Figure 6 with 4km as the potential influence scope of the improved rural roads.



17.1 Share of families who are affected by environment pollution
P-value (pretrend test): 0.000
ATT on Treated: 0.019 (0.025)



7.2 Share of families who regularly boil water for drinking
P-value (pretrend test): 0.000
ATT on Treated: 0.031 (0.03)

Notes: Due to the default settings on the event of software package for Callaway and Sant'Anna (2021), the base year is not shown in the graph. The intervention starts from j=0.