Road to the Future: Identifying Impacts of Roads on Education in Colombia *

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Abstract

This study examines the impact of Colombia's road concession program on educational outcomes in public schools. Using a staggered difference-in-differences approach, I find that road improvements lead to a significant increase of 0.169 standard deviations in math scores, with the full effect materializing after project completion. Reading scores also show a positive, though less pronounced, trend. These findings are robust to various checks, including alternative estimators and control groups. Additionally, I observe reduced child labor participation and increased higher education pursuit following road improvements. This highlights the importance of road infrastructure, suggesting policymakers should expedite road projects and explore alternative transportation solutions where roads are impractical, potentially leveraging public-private partnerships.

JEL Codes: O28, I21.

Keywords: Road Infrastructure, Education, Economic Development, Public-Private Partnerships (PPPs), Developing Countries, Human Capital

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1 Introduction

Access to quality education is a fundamental right, yet for millions of children in Colombia, the journey to school is fraught with challenges such as traversing miles of rugged terrain, crossing treacherous rivers on makeshift bridges, or braving perilous weather conditions (Consonante, 2022; Pulzo, 2022; Tiempo, 2023a, 2023b), all for the chance to learn. This is the reality for countless students in Colombia, where inadequate road infrastructure, particularly in rural areas, poses a significant barrier to educational attainment, hindering economic mobility and perpetuating inequality.

The inadequacy of road infrastructure is a particularly pressing issue in developing countries, where limited access often coincides with severe educational disparities. Evidence suggests a strong correlation between road accessibility and educational outcomes. For instance, comparing the rural access index (Ahmed et al., 2016) with PISA 2018 results (Organisation for Economic Co-operation and Development, 2019) reveals that countries with better road access tend to achieve higher scores in math and language. Specifically, a 15% increase in the rural accessibility index translates to an improvement of 22 points in language and 25 points in math on the PISA test—equivalent to more than a year of school learning (Organisation for Economic Co-operation and Development, 2021).

This study investigates the impact of Colombia's road concession program on education, focusing on student performance in math and reading literacy as measured by the SABER 11 standardized test. This program, designed to leverage private capital to improve the National Road Network (NRN) due to the state's limited resources, offers a unique opportunity to examine the effectiveness of Public-Private Partnerships (PPPs) in promoting educational outcomes. Given the ongoing debate surrounding the impact of road development on education, this study aims to answer the following research question: Does the implementation of PPP-driven road concessions in Colombia lead to improved educational outcomes, as measured by performance on the SABER 11 standardized test?

While adequate road infrastructure is widely recognized as crucial for economic growth and development (Allen & Arkolakis, 2022; Donaldson, 2019; Fajgelbaum, 2020), the impact of road development on education remains subject to debate. Some studies have shown that improved road networks can increase access to education, reduce travel time, and potentially increase attendance (Adukia, Asher, & Novosad, 2020; Asher & Novosad, 2020; Mukherjee, 2012), while others highlight potential downsides, such as increased economic activity drawing children into the labor force and reducing their time for education (Fafchamps & Wahba, 2006). This underscores the need for rigorous analysis to understand the complex interplay between roads and educational outcomes, particularly within the context of PPP-driven infrastructure projects like Colombia's road concession program.

PPPs in infrastructure development are increasingly common, but their impact on education remains understudied. Unlike publicly funded programs, PPPs may prioritize economically profitable routes, potentially bypassing areas with greater educational needs. Moreover, the quality, maintenance, and long-term sustainability of PPP infrastructure might differ from publicly funded projects, leading to varied effects on education over time. Colombia provides a particularly relevant context for this investigation. Despite recognizing education as a fundamental right and public service, the country faces persistent disparities in educational access and quality, especially in rural areas where 22% of the population lacks access to all-weather roads (Ahmed et al., 2016). Furthermore, previous research suggests that road development in Colombia has unequally impacted production and income distribution (Quintero & Sinisterra, WP2022), raising concerns that road concessions might exacerbate existing inequalities.

By focusing on this program, this study makes two key contributions to the literature. First, it specifically examines the impact of a PPP-driven road concession program on education, addressing a significant gap in existing research, as most studies have concentrated on publicly funded programs Adukia et al. (2020). Analyzing the effectiveness of PPPs in promoting educational outcomes is crucial, as these models are increasingly common in infrastructure development but may differ from publicly funded projects in their prioritization of routes, construction quality, and long-term impact on communities.

Second, this study employs a difference-in-differences (DiD) approach with staggered treatment to address the methodological challenge of evaluating infrastructure projects with continuous and evolving impacts. Unlike traditional DiD methods Callaway and Sant'Anna (2021);

Goodman-Bacon (2021); Roth, Sant'Anna, Bilinski, and Poe (2023), this study recognizes that road construction unfolds gradually, with impacts potentially arising even before the project is fully completed. This study leverages this gradual rollout to its advantage, examining how educational outcomes change at various stages of construction (10%, 50%, and 100% completion). This allows for a more refined causal assessment, capturing how the effects on education dynamically unfold as the road progresses through different stages of development.

This study provides compelling evidence that Colombia's road concession program has yielded positive and significant impacts on educational outcomes. Employing a dynamic difference-in-differences approach, we find that students attending schools near roads improved through the concession program experience an increase of 0.16 standard deviations in math scores and 0.11 standard deviations in reading literacy scores. This improvement is evident across various stages of road construction, demonstrating the program's dynamic and evolving influence on education. Moreover, my analysis reveals a 3% reduction in child labor participation and a 4.8% increase in the proportion of students pursuing higher education following road improvements. These findings underscore the transformative potential of road infrastructure, particularly through public-private partnerships, to enhance educational opportunities and promote human capital development in developing countries.

The findings of this study hold important implications for policymakers considering PPPs as a mechanism for promoting human capital development. The evidence suggests that well-designed road concession programs, particularly those that prioritize connectivity for under-served rural communities, can contribute to significant and lasting improvements in educational outcomes.

The remainder of this article is organized as follows. Section 2 presents the institutional context related to political regulations, roads, concession agreements, and education in Colombia. Section 3 describes the data used in this study. The empirical strategy, which allows for the estimation of causal inference, including the mechanism by which roads can affect education, is presented in Section 4. The results are discussed in Section 5, and the article concludes in Section 6. The tests and additional results are reported in the Appendix.

2 Education and Road Infrastructure in Colombia

Colombia recognizes education as a vital pillar of its social and economic development. However, long-standing challenges persist, particularly in ensuring equitable access to quality education in rural areas. Inadequate road infrastructure has been a major contributing factor, limiting opportunities and hindering social mobility.

Access to quality education is fundamental for social and economic development in Colombia. It is enshrined in the Colombian constitution as a fundamental right and public service. However, despite this recognition, stark disparities in educational access and outcomes persist, particularly between urban and rural areas. Inadequate infrastructure is a significant contributing factor to this persistent challenge.

In Colombia, a significant portion of the schools are isolated from the rest of the world due to the lack of access to paved roads. Based on my calculation of the minimum perpendicular Euclidean distance between schools and the nearest road, I find that 50% of the schools in the country are more than 1 kilometer from a road that provides vehicular access 24/7, with a staggering 24% located more than 5 kilometers from such a road (see, for example, the conditions in Figure 1). This isolation makes it difficult for students to reach school regularly and for schools to access essential resources and support.

Figure 1: Students from the rural area of El Toco in northern Cesar, Colombia. Source: Ávila (2018)

In addition to the challenges faced by schools, a significant proportion of the rural population also lacks adequate access to roads. 22% of the rural population lacks access to all-weather roads[1], as indicated by a Rural Access Index (RAI of 78%) (Ahmed et al., 2016). This means that over a fifth of the rural population lives more than a 20-25 minute walk from an all-season road, highlighting the significant barriers they face in accessing education and other essential services. While this figure is better than the RAI for Africa (66%), it still lags behind the United States (14%) and the average for Latin America and the Caribbean (41%), emphasizing the need for continued infrastructure improvements in Colombia.

The Colombian government has increasingly turned to public-private partnerships (PPPs) to address these infrastructure gaps and foster development, notably through road concession programs. Historically, Colombia's road network, particularly in rural and remote areas, has suffered from chronic underfunding, leading to inadequate maintenance, low pavement quality, and limited connectivity. These deficiencies hampered economic growth, social inclusion, and crucially, access to educational opportunities. Security concerns in certain regions further compounded the problem, making it difficult and risky to invest in and construct new roads. Recognizing the urgent need for improved infrastructure but facing limited state resources, PPPs offered a promising alternative. Law 80 of 1993 and Law 105 of 1993 laid the legal groundwork for road concessions, marking a turning point by enabling private sector participation in financing, building, operating, and maintaining vital road segments.

The Build-Operate-Maintain-Transfer (BOMT) model, where private companies are granted concessions for a specified period and collect tolls to recover costs, became the cornerstone of this program.

Since its inception in the 1990s, the road concession program has evolved through five distinct generations. The first generation, launched in the 1990s, focused on addressing critical bottlenecks and improving connectivity on major corridors, exemplified by projects like the Santa Marta-Riohacha-Paraguachón and Barranquilla-Cienaga highways. Building on these early successes, the second generation (late 1990s - 2000s) tackled larger and more complex projects, including the El Vino - Tobiagrande - Puerto Salgar - San Alberto highway and the expansion of the Cauca road network, even amidst economic challenges. The third generation, commencing

[1]RAI measures the proportion of the rural population living within two kilometers (typically a 20-25 minute walk) of an all-season road.

in the 2010s and central to this study, marked a shift towards developing integrated ”corridors of commerce” that prioritized trade, regional integration, and socio-economic development, illustrated by projects like the Briceño - Tunja – Sogamoso corridor and the Bogotá - Buenaventura corridor. This focus on regional development makes this generation particularly relevant for understanding the impact of road concessions on education. The fourth generation, formalized with Law 1508 of 2012 and launched in 2013, significantly expanded the program's scope, aiming to rehabilitate and construct approximately 5,200 km of roads, along with numerous tunnels, bridges, and viaducts, through 30 concession projects, signifying a deep commitment to large-scale infrastructure development through PPPs. Finally, the fifth generation, known as the ”Concesiones del Bicentenario” or ”5G program,” launched in 2021, further emphasizes multimodal transportation, incorporating roads, railways, waterways, and airports. The 5G program prioritizes sustainability and aims to generate significant economic impact while fostering community development (ANI, 2024).

A typical road concession project in Colombia unfolds through several key stages, as illustrated in Figure 2. Following the contract signing, an initial period of approximately six months, known as ”Stage Zero,” is dedicated to preparatory work before pre-construction begins, culminating in the signing of the initiation document. The subsequent Pre-Construction stage, typically lasting 18 to 24 months, encompasses crucial studies such as initial feasibility assessments, route selection, and environmental impact evaluations. Once these groundwork steps are completed, the Construction stage commences, encompassing all activities related to building the road and associated infrastructure. This phase generally requires an average of 10 years to complete. Finally, the Operation stage begins upon the road's completion, during which the concessionaire assumes responsibility for road maintenance and toll collection, often lasting 25 to 30 years (Sanchez (2022)).

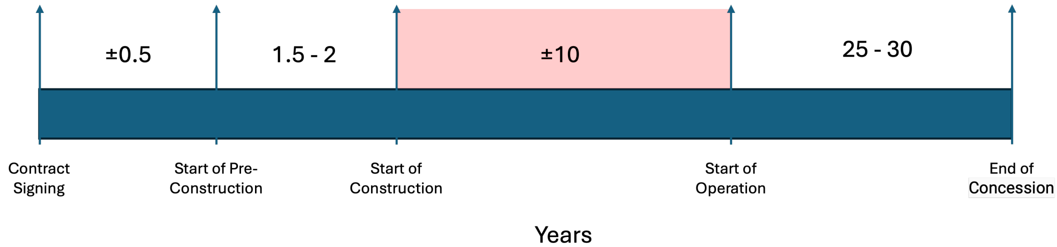

Figure 2: Stages of road concession project in Colombia

While the primary objective of road concessions is to enhance transportation and connect economically significant regions, they also hold the potential to significantly impact education. Improved road infrastructure can stimulate local economic activity, as documented by Jacoby (2000); Quintero and Sinisterra (WP2022), leading to increased employment opportunities and higher family incomes. This, in turn, enables families to invest more in their children's education, whether through reducing reliance on child labor as found by Fafchamps and Wahba (2006), or by providing better access to educational resources, as suggested by Pritchett and Filmer (1999). Moreover, reduced travel time and transportation costs thanks to improved roads can directly benefit education, especially in rural areas. This increased accessibility can lead to improved school attendance, reduced absenteeism, and broader access to educational resources and opportunities beyond the immediate school environment, as shown in studies by Adukia et al. (2020); Idei, Kato, and Morikawa (2020); Mukherjee (2012). Furthermore, by offering alternative employment opportunities for adults, improved road infrastructure can potentially reduce the demand for child labor, as observed in Fafchamps and Wahba (2006). This shift allows children to dedicate more time to their studies, potentially leading to improved academic performance and increased human capital accumulation, as discussed in Acemoglu (2010). This study leverages the unique context of Colombia's 3rd generation road concession program to empirically investigate these potential pathways from road improvements to educational outcomes, shedding light on the complex relationship between infrastructure development, economic opportunities, and human capital accumulation in a developing country setting.

3 Data

This study investigates the causal impact of improved road infrastructure on academic performance in Colombia. We leverage a rich dataset spanning 2006 to 2019, encompassing student-level academic records, school characteristics, and detailed information on road construction projects. My analysis centers on the role of improved road accessibility in enhancing educational outcomes, particularly in regions historically hindered by poor transportation infrastructure.

My primary data source is the Colombian Ministry of National Education's standardized testing system, SABER-es. This system provides a comprehensive assessment of student competencies across various educational stages. I utilize data from three specific exams: SABER 11 (standardized exam for Secondary Education), SABER PRO (for students completing undergraduate university studies), and SABER TYT (for students in technical and technological programs). These exams offer a multifaceted view of student achievement across a range of disciplines.

I focus on SABER 11 exam scores in Mathematics and Reading Literacy as my primary outcome variables. These subjects are widely recognized as fundamental indicators of cognitive skills, problem-solving abilities, and academic preparedness, holding significant weight in determining future educational and employment opportunities. To ensure the reliability and comparability of my analysis, data from virtual exams administered in 2020-2021 are excluded due to documented differences in exam structure, administration methods, and potential disruptions caused by the COVID-19 pandemic. Similarly, I exclude exams prior to 2005 as their format differed significantly from subsequent years, potentially introducing inconsistencies in score interpretations.

To establish a precise spatial relationship between students and road infrastructure projects, I utilize a comprehensive database of school addresses from the National Administrative Department of Statistics (DANE) (National Administrative Department of Statistics (DANE), 2023). Recognizing that geographical access to schools plays a crucial role in educational attainment, particularly in rural areas, we carefully map each school's location relative to road networks. For schools lacking geo-referenced coordinates (approximately 15,000), we implemented a custom script leveraging the Google Maps API to accurately determine their latitude and longitude.

My analysis focuses on students attending schools located within a 1500-meter radius of a road construction or improvement project. This distance, equivalent to a 15-20 minute walk. This distance is chosen based on the Rural Acces Index (Ahmed et al., 2016), but differs in that it measures the proportion of people who have access to an all-season road within an approximate walking distance of 2 km (km) or 30 minutes walking. In this study I focused on schools within a distance of 1.5 km considering i am using the a eucledian distance, ususally in colombia geograpgic condition the eucledian distance is the 75% of the real distance (see Figure 3).

My analysis focuses on students attending schools located within a 1500-meter radius of a road construction or improvement project. This distance, equivalent to a 15-20 minute walk, is chosen based on the Rural Access Index (Ahmed et al., 2016), which measures the proportion of people who have access to an all-season road within an approximate walking distance of 2 km (or 30 minutes). While the Rural Access Index uses a 2 km threshold, I focus on a 1.5 km radius for two primary reasons. First, I employ a Euclidean distance calculation, which, due to geographical conditions in Colombia, typically represents approximately 72% of the actual walking distance. This is supported by my estimation, which shows an average ratio of 0.72 between Euclidean and real distances. Additionally, the standard deviation ratio for distance is 0.11, indicating relatively low variability in this proportion. Second, by using a slightly shorter radius, I aim to capture a more immediate and localized impact of road improvements on school accessibility, minimizing the potential influence of other, more distant, transportation options. This is further justified by the average ratio of 0.70 for time, with a standard deviation ratio of 0.17, suggesting that the walking time calculated using Euclidean distance is reasonably consistent with the actual walking time. This proximity-based approach allows us to isolate the effects of improved road accessibility on student outcomes while controlling for other factors that might influence academic performance.

I utilize data on road construction progress from the INVIAS georeferenced vector database of roads in Colombia (Instituto Nacional de Vías (INVIAS), 2024). This detailed database provides critical information on the start and completion dates of road projects, enabling us to track the timing of road access for each school in our sample. By linking this temporal dimension to student-level academic data, we can employ a difference-in-differences approach to estimate the causal impact of road improvements on educational outcomes over time.

Road Infrastructure Data

I utilize data on road construction and their progress from the INVIAS georeferenced vector database of roads in Colombia and National Public Procurement Agency (Instituto Nacional de Vías (INVIAS) (2024), Table 12). This detailed database provides critical information on the start and completion dates of road projects, enabling me to track the timing of road access for each school in my sample. By linking this temporal dimension to student-level academic data, I can employ a difference-in-differences approach to estimate the causal impact of road improvements on educational outcomes over time.

My analysis focuses on national roads under concession contracts, as these projects typically involve substantial investments in upgrading and expanding existing road networks, leading to more significant potential impacts on accessibility. To characterize these road infrastructure projects and their influence on school accessibility. I pinpointed the commencement of construction for each project using the project start date, establishing a clear timeline for possible accessibility improvements. The Project Completion Date then allows me to pinpoint when a road project reached 100% completion, marking the full realization of its intended accessibility benefits. To account for the scale and reach of these improvements, I incorporate the Road Length (in kilometers), recognizing that longer projects may have a broader impact on surrounding areas and a larger number of schools. Finally, the Number of Lanes provides insight into the road's capacity and traffic flow, which could influence travel times and overall accessibility. Roads with more lanes generally accommodate higher traffic volumes, potentially reducing congestion and improving travel times for students.

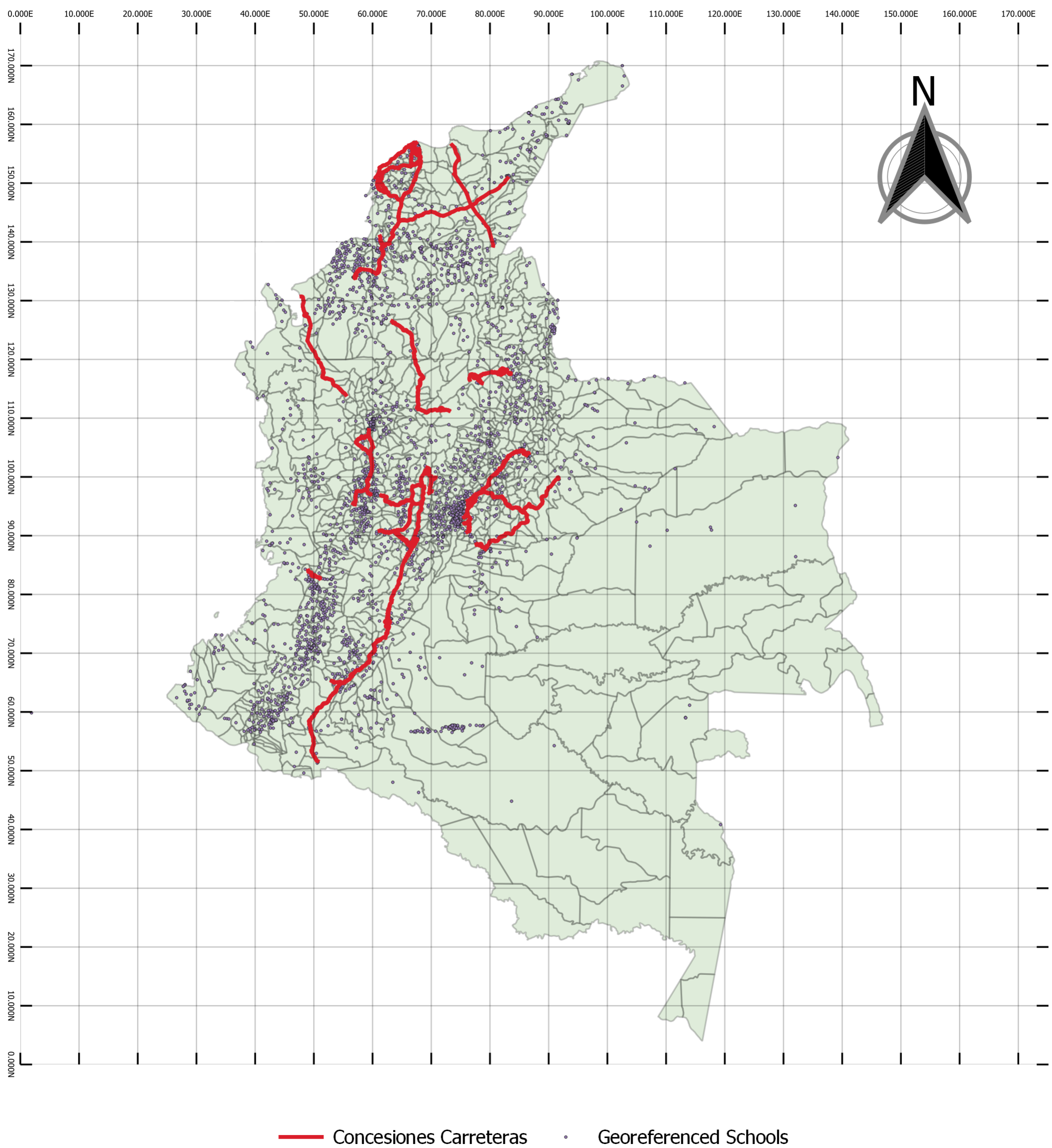

Figure 3: Roads under concession and schools georeferenced. Purple points illustrate the Georeferenced schools, and the red lines illustrate the roads under concession at the considered time.

Construction Progress and Gradual Impact:

I recognize that the impact of road infrastructure on school accessibility is not instantaneous or simply a matter of whether a road exists or not. The construction process itself can span several years, and accessibility benefits may accrue gradually as different phases of a project are completed. To mitigate potential temporal misalignment bias, we utilize data on construction progress milestones (10%, 50%, 100%) to create time-varying measures of road accessibility. This approach allows us to capture the evolving impact of road improvements throughout the construction period, providing a more accurate representation of the relationship between infrastructure development and educational results (See Table 1).

Table 1: Time Required for Road Construction Progress (Years)

Construction Phase	**0%-10%**	**10%-100%**	**0%-50%**	**50%-100%**	**0%-100%**
Mean	4.2	9.0	5.8	3.2	12.3
Median	4	8.5	5	3	12.5
Standard Deviation	1.9	3.1	3.0	2.5	6.4
Number of Road Projects	13	10	12	9	8

Note: This table shows the time (in years) taken for different phases of road construction progress. Each phase represents the duration from the starting point to the specified completion percentage. For example, "0%-50%" indicates the average time from project signing to reaching 50

Variable Construction

Standarized Math and Reading Literacy Score:

To assess student performance relative to a national benchmark, we standardize the raw SABER 11 scores for Mathematics and Reading Literacy using the national mean and standard deviation for each year. This approach offers several advantages, particularly in terms of policy implications. By comparing students' performance against a consistent national standard, we can identify regions or school districts that are lagging behind the national average, highlighting areas where targeted interventions or resource allocation might be most beneficial. This national perspective is crucial for policymakers seeking to address educational disparities and ensure equitable access to quality education across Colombia.

However, it is important to acknowledge that this national-level standardization might not fully disentangle the specific impact of road infrastructure from other factors that could influence both road access and school performance. For instance, schools in areas with better road infrastructure might also benefit from higher levels of government funding, greater access to qualified teachers, or a more supportive socioeconomic environment. These confounding factors could contribute to higher test scores independently of the road improvements themselves, making it challenging to isolate the causal effect of road infrastructure on academic outcomes using this standardization approach. I calculate the standardized score for each student using the following formula:

$$Standarized_{score_{i,s,t}} = \frac{Score_{i,s,t} - \mu_t}{\sigma_t} \tag{1}$$

Where $Standardized_{score_{i,s,t}}$ represents the standardized score for student i in school s in year t. $Score_{i,s,t}$ is the raw SABER 11 score obtained by student i in school s in year t, while μ_t is the mean (average) SABER 11 score for all students of the country in year t, and σ_t is the standard deviation of SABER 11 scores for all students in Colombia in year t.

To address the potential for confounding and isolate the causal effect of road infrastructure, I employ a staggered difference-in-differences (DiD) approach. This method leverages the variation in the timing of road project completion across different schools, allowing me to compare changes in academic outcomes for schools before and after they gain access to improved roads. By exploiting this temporal variation, I can control for time-varying confounders and reduce my reliance on a perfectly matched control group, strengthening the causal interpretation of my findings.

Child Labor Index:

To assess the prevalence of child labor within our sample, we construct a school-level Child Labor Index. This index leverages self-reported data from the SABER 11 survey, which includes questions about students' participation in the labor force. Specifically, we calculate the proportion of students in each school s and year t who report being engaged in any form of paid work. This ratio, ranging from 0 to 1, provides a measure of child labor intensity within each school. A higher value indicates a greater proportion of students engaged in work, potentially reflecting economic hardship or limited access to quality education within the school's catchment area.

Human Capital Accumulation Index:

To capture the long-term impact of road infrastructure on human capital development, we construct a Human Capital Accumulation Index. This index measures the proportion of students who successfully transition from secondary education to higher education. We link the student-level SABER 11 database with the SABER PRO database using unique student identifiers provided by ICFES. This linkage allows us to track students over time and determine whether they enrolled in and completed any university program within a specified timeframe (t+n years) after finishing secondary school.

The Human Capital Accumulation Index is calculated as the number of students from school s in year t who appear in the SABER PRO database within the specified timeframe, divided by the total number of students in school s in year t. This ratio, also ranging from 0 to 1, reflects the school's effectiveness in preparing students for higher education. A higher value suggests greater success in promoting human capital accumulation among its students, potentially indicating better educational quality, increased future earnings potential, and improved socioeconomic outcomes for those individuals.

Descriptive Statistics

Table 2 presents a comparative overview of key characteristics for schools located within 1500 meters of a road construction or improvement project (treatment group) before and after road completion. This analysis focuses on the years preceding and following the completion of the nearest road project for each school.

Table 2: School Characteristics and Student Outcomes: Treatment Group Before and After Road Completion

Variable	Treatment Group		Difference
	Pre-Road	**Post-Road**	
Outcome Variables:			
Standardized Math Score	-0.130 (0.900)	0.011 (0.906)	0.141
Standardized Reading Score	-0.171 (0.919)	-0.022 (0.899)	0.149
School Characteristics:			
School Size (Enrollment)	58.04 (54.50)	67.65 (47.64)	9.61
Average Distance to School (km)	0.634 (0.427)	0.502 (0.352)	-0.132
Student Demographics:			
INSE	0.451 (0.069)	0.475 (7.871)	0.024
Child Labor Index	0.129 (0.119)	0.381 (0.080)	0.252

Note: "Pre-Road" and "Post-Road" represent periods three years before and after road completion within a 1500-meter radius of schools. Math and reading scores are standardized using national means. School size is the average enrollment. INSE measures socioeconomic disadvantage (higher scores indicate greater disadvantage). Average distance is the mean student travel distance to school. The "Difference" column shows the difference in means (Post-Road minus Pre-Road). Values in parentheses are standard deviations.

Notably, before road construction, the average standardized math score for the treatment group was -0.130, indicating that students in these schools were performing below the national average. Following road completion, the average standardized math score rose to 0.011, suggesting that these students' performance converged towards the national mean. Similarly, while reading scores also showed a positive shift, moving from -0.171 to -0.022, they also moved closer to the national average. This pattern suggests that improved road access might be associated with academic improvement, potentially by facilitating access to better educational resources or reducing absenteeism.

Interestingly, the average school size increased by 8.612 students in the post-road period, while the Child Labor Index also increased substantially from 0.129 to 0.381. These shifts suggest potential changes in student composition and a possible increase in students' work participation following improved road access. A rigorous causal analysis will be necessary to disentangle the specific impact of road infrastructure from other confounding factors and explore the potential interplay between these observed trends.

4 Empirical Strategy and Mechanism

This chapter outlines the empirical strategy employed to estimate the causal impact of improved road infrastructure on educational outcomes in Colombia. I aim to address the fundamental challenge of isolating the effect of road access from other factors that might influence student performance. To achieve this, I utilize a staggered difference-in-differences (DiD) approach, exploiting the variation in the timing of road project completion across different schools.

4.1 Staggered DiD and Estimator Choice

The staggered DiD method (Sun and Abraham (2021) estimator), is particularly well-suited to this research question because it allows me to account for the gradual rollout of road construction projects, the potential for heterogeneous effects across schools and time, and the dynamic nature of the cost-benefit analysis underlying educational investment decisions.

I employ the Staggered DiD estimator proposed by Sun and Abraham (2021) because it is specifically designed to address the challenges of analyzing interventions with variation in treatment timing and potential violations of the strict parallel trends assumption. This estimator allows me to examine the dynamic treatment effects of road improvements on educational outcomes, recognizing that these effects may evolve over time as access to education improves and the cost-benefit calculus for families shifts. Importantly, this approach accommodates heterogeneity in treatment effects, both across schools and over time, allowing me to capture the nuanced ways in which road infrastructure influences the expected value of education. My analysis aims to disentangle these dynamic relationships and quantify how road improvements alter the perceived costs and benefits of education, leading to changes in investment decisions.

I employ the staggered DiD estimator proposed by Sun and Abraham (2021) because it allows for potential violations of the strict parallel trends assumption often found in traditional DiD models (Callaway & Sant'Anna, 2021; Goodman-Bacon, 2021; Roth et al., 2023). This is particularly relevant in my context because road construction projects are staggered over time and may have different pre-treatment trends depending on local factors like pre-existing road quality or socioeconomic conditions. The Sun and Abraham (2021) estimator relaxes the parallel trends assumption by allowing for (1) staggered treatment adoption, (2) treatment effect heterogeneity across units and time, and (3) potential violations of parallel trends in the short term, as long as pre-treatment trends converge in the long term. These relaxed assumptions are more plausible in my study given the complexity of the road construction process and its potential impacts on education.

Assumptions and Justification

To address potential violations of the parallel trends assumption, I carefully examine the pre-treatment trends for schools located near roads under concession compared to schools farther away. Figure 7 and Figure 8 illustrate the mean standardized math and reading scores for different treatment cohorts in the five years leading up to road construction. The trends appear largely parallel across cohorts, suggesting that schools near future road projects followed similar trajectories to other schools before the interventions. While some deviations from parallel trends are observed for cohorts treated in 2010 and 2011, these cohorts included a very small number of schools (between 3 and 10 for 2010 and between 1 and 3 for 2011), representing a small fraction of the total students observed in the pre-treatment period (fewer than 20 students in 2010 and fewer than 100 students in 2011), making their trends more susceptible to random fluctuations. The remaining cohorts, which constitute the majority of the sample and include a substantially larger number of students (over 700 students per cohort on average), exhibit consistent pre-treatment trends, providing initial support for the parallel trends assumption.

Anticipation effects are unlikely in this context because road projects are planned primarily to connect major commercial centers, and the location of schools is rarely considered in the decision-making process. The route selection is based on minimizing construction costs and maximizing transportation efficiency, with the final route often determined only after the concession contract is awarded. This commercially driven approach and the late finalization of the route make it difficult for schools to anticipate future road improvements.

To further mitigate concerns about anticipation effects, I investigate the timeline and planning process of road concession projects. In Colombia, these projects prioritize connecting major commercial centers. The route selection is primarily driven by minimizing construction costs and optimizing transportation efficiency between these economic hubs. The location of schools is rarely a significant factor in this planning process. While there is a lengthy period of feasibility studies and public bidding before construction begins (on average, 1.5 years between project announcement and construction start), the specific route and construction schedule are often finalized only after the concession contract is awarded. This, combined with the commercially driven route selection process, implies that the location of a school relative to a future road project is quasi-random (see Sanchez (2022)). Schools are unlikely to anticipate the precise timing and location of road improvements because these decisions are largely determined by economic considerations and finalized relatively late in the project development process.

While I focus on a homogenous set of road projects to enhance the plausibility of treatment effect homogeneity, I recognize the potential for remaining heterogeneity. Therefore, I conduct subgroup analyses based on distance to road and school type (public vs. private) to explore how the impact of road improvements might vary across different contexts. This approach allows me to identify potential heterogeneities and refine the understanding of the causal mechanisms at play.

4.2 Addressing Challenges: Continuous Treatment and Anticipation

Estimating the causal effect of road construction on education poses a unique challenge because the treatment (improved road access) is not a one-time event but a continuous process that unfolds over several years. Traditional DiD models, which assume discrete treatment times, are not well-suited to handle this continuous treatment dynamic. To address this issue, I propose analyzing the impact of road construction at three specific completion percentages: 10%, 50%, and 100% (See Figure 5). Analyzing the impact at different completion percentages allows me to capture how the perceived benefits of education change as road construction advances, potentially reflecting the emergence of new economic opportunities, reduced transportation costs, and improved access to educational resources.

Furthermore, by analyzing these distinct stages, I can leverage the flexibility of the Sun & Abraham (2021) estimator to strategically choose reference periods that skip the periods of ac-

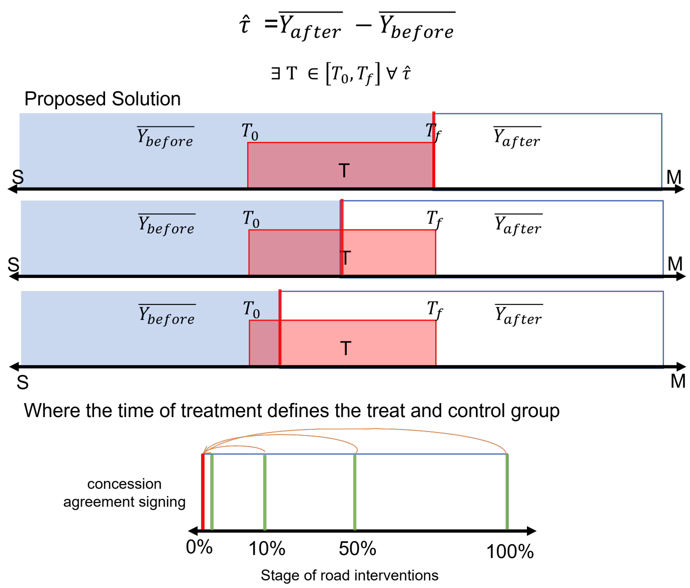

Figure 5: Addressing Continuous Treatment in Staggered DiD: Defining Treatment Groups Based on Road Completion Stages

tive construction. This is particularly important because the parallel trends assumption might be most vulnerable during these periods, as construction activities could introduce temporary disruptions or changes in school attendance patterns. By focusing on periods before construction begins (0% completion) and after certain milestones are reached (10%, 50%, 100%), I can mitigate concerns about parallel trends violations during the construction phase itself. This approach allows me to isolate the effects of improved accessibility once a certain level of road functionality is achieved, rather than conflating those effects with the potentially disruptive impacts of ongoing construction. To address potential violations of the parallel trends assumption during active construction periods, I strategically choose reference periods that focus on periods before construction begins and after specific milestones are reached. This helps to isolate the long-term effects of improved accessibility from the potentially disruptive short-term impacts of ongoing construction activities.

I estimate the following dynamic DiD model with school and time fixed effects:

$$Score_{c,t,j} = \sum^{-2} \varphi = -S\mu\varphi \cdot D_{c,\varphi} + \sum^{M} \varphi = 0\mu\varphi \cdot D_{c,\varphi} + \sigma_t + \gamma_c + \varepsilon_{c,t} \tag{2}$$

Where:

$Score_{c,t,j}$ represents the standardized test score (math or reading) for school c in year t for subject j. μ_φ captures the effect of road construction on education in relative period φ. $D_{c,\varphi}$ is a set of dummy variables indicating the distance of each period from the treatment period, defined by the stage of road construction (10σ_t represents time fixed effects to control for time-varying factors common to all schools. γ_c represents school fixed effects to control for unobserved school-specific factors. $\varepsilon_{c,t}$ is the error term, clustered at the school level to account for within-school correlation. The effect of road construction on education is captured by the coefficients μ_φ, which estimate the impact of road access at different time lags and leads relative to the chosen completion percentage. I consider a time window from -S to M to capture both pre-treatment and post-treatment effects.

4.3 Additional Outcomes and heterogeneities

To provide further evidence for the mechanisms linking road infrastructure to educational outcomes, I examine two additional outcomes: (1) Human Capital Accumulation, measured by students' enrollment and completion of higher education programs, (2) Child Labor, assessed using the Child Labor Index. Analyzing these outcomes will allow me to test whether road improvements lead to changes in long-term educational attainment, child labor participation, and the socioeconomic composition of schools, as predicted by my theoretical framework

Heterogeneities Analysis by Distance:

To further investigate the localized effects of road infrastructure and rule out potential spillover effects, I conduct subgroup analyses based on distance bands. I divide schools into groups based on their distance to the nearest road project, with each band representing a 500-meter increment (0-500 meters, 500-1000 meters, 1000-1500 meters, and so on, up to 4000 meters). I then estimate our dynamic DiD model separately for each distance band to examine how the magnitude and significance of the treatment effects vary with proximity to the road.

By conducting subgroup analyses based on distance bands, I can investigate whether the effects of road improvements are concentrated in schools closest to the new roads, suggesting a stronger influence of reduced transportation costs and enhanced access to educational resources. This analysis will help to rule out potential spillover effects and provide more precise estimates of the localized impact of road infrastructure.

4.4 Mechanisms: How Road Infrastructure Shapes Educational Investment

I posit that improved road infrastructure influences educational outcomes by altering the cost-benefit calculus that students and their families undertake when making decisions about education. This perspective aligns with the human capital model, as articulated by Becker (1993), which posits that individuals invest in education based on its anticipated returns. Road improvements, I argue, can shift this equation in several important ways, making education both more affordable and more valuable in the long run.

First, road infrastructure improvements directly reduce the costs associated with education. Lower transportation costs are particularly significant in rural areas where students often face long and arduous journeys to school, as vividly described in news reports like (Consonante, 2022; Pulzo, 2022; Tiempo, 2023a, 2023b). Improved roads reduce travel time, making it easier for students to attend school regularly, and they decrease transportation expenses, alleviating a financial burden on families. Better roads also improve the flow of educational resources to remote schools. Textbooks, teaching materials, laboratory equipment, and even qualified teachers can reach these schools more easily, enhancing the quality of education and reducing the indirect costs associated with attending poorly equipped schools (Khumalo & Mji, 2014; Zipporah M Mokaya, 2013). These changes make education more appealing and effective by lowering both the direct and indirect costs of participation.

Beyond reducing costs, road infrastructure improvements also indirectly influence educational outcomes by altering the perceived benefits of education. New roads often stimulate economic activity, creating new markets and job opportunities (Asher & Novosad, 2020; Jacoby, 2000; Quintero & Sinisterra, WP2022). These changes are particularly visible in rural areas, where the arrival of new businesses and industries clearly demonstrates the economic value of education and skills. Witnessing these opportunities firsthand can raise the perceived returns to education, motivating students to invest more in their schooling. Improved roads also break down the isolation of rural communities, connecting them to urban centers and a wider range of possibilities (Idei et al., 2020; Mukherjee, 2012). This increased exposure to new ideas, technologies, and career paths can broaden students' aspirations and increase their motivation to pursue higher education, driving human capital accumulation.

Importantly, road infrastructure can transform the educational landscape itself, creating a more dynamic and equitable system. Easier access to transportation allows students to travel further to attend better schools, expanding their educational opportunities and potentially leading to a more efficient allocation of students to schools based on their needs and abilities (Dustan & Ngo, 2018; Herskovic, 2020). Additionally, as road infrastructure stimulates economic development, it can create alternative employment opportunities for adults, potentially reducing the reliance on child labor (Fafchamps & Wahba, 2006). This allows children to dedicate more time to their studies, further promoting human capital accumulation and breaking the cycle of poverty.

Public-private partnerships (PPPs) play a significant role in these dynamics by mobilizing private sector resources, expertise, and efficiency to complement public investments in road infrastructure. Through PPPs, the burden of financing and maintaining road projects is shared between the public and private sectors, potentially accelerating the development of critical infrastructure in underserved areas. The involvement of private entities can introduce innovative construction and maintenance techniques, enhance project management, and ensure that roads are built to high standards, thereby maximizing their positive impact on education.

My analysis emphasizes that the decision to invest in education is a complex one, guided by a cost-benefit analysis conducted under inherent uncertainty about future returns. I adopt the framework established by Becker (1993), who emphasizes that individuals invest in education based on its expected value, weighing potential benefits against their likelihood of being realized. However, I go a step further, arguing that road infrastructure plays a crucial role in shaping these expectations.

Central to my argument is the concept of conditional expectation. When families consider investing in their child's education, they don't simply look at the average benefits that education might provide. They form expectations based on the specific circumstances and opportunities available, taking into account factors that can influence their child's likely success. Academic performance acts as a crucial predictor of this future success. Numerous studies have demonstrated a strong positive correlation between academic achievement and higher earnings (e.g., Clotfelter, Ladd, & Vigdor, 2007; Ozier, 2018). Moreover, individuals with higher levels of education tend to enjoy greater job satisfaction, experience better health outcomes, and engage more actively in their communities (Barrett, Treves, Shmis, Ambasz, & Ustinova, 2018; Evans & Popova, 2016).

Road infrastructure, by influencing academic performance, indirectly shapes these expected benefits. Studies on the impact of road construction in developing countries, such as those by Mukherjee (2012) and Adukia et al. (2020), have found that improved road access leads to increased school enrollment and improved test scores, particularly in regions with higher returns to education. These findings highlight the causal chain: road infrastructure investments lead to enhanced educational opportunities, which in turn drive improved academic performance and ultimately greater individual and societal benefits.

This complex relationship is captured in the following equation:

$$\text{Invest if} \quad \sum_{t=0}^{n} \frac{E[B_t|A(I)]}{(1+r)^t} > I + \sum_{t=0}^{n} \frac{C_t(I)}{(1+r)^t} \tag{3}$$

This equation highlights the key elements of the cost-benefit analysis that influences educational investment decisions. The expected benefits ($E[B_t|A(I)]$) represent the potential rewards of education, such as higher future earnings, increased job satisfaction, and improved health outcomes. These benefits are conditional on the anticipated level of academic performance (A), which is influenced by road infrastructure investment (I). Road improvements can enhance academic performance by improving access to better-quality schools, creating a more conducive learning environment, reducing absenteeism, and increasing student motivation. The discount factor $(1+r)^t$) captures the fact that future benefits are valued less than present benefits. The initial road investment (I) represents the upfront cost of improving infrastructure, while the cost of education ($C_t(I)$) must be considered in each period, acknowledging that road improvements can reduce these costs by lowering transportation expenses.

My research emphasizes that road infrastructure investments can profoundly impact educational choices, not just by directly reducing costs but also by fundamentally shaping the expected value of education itself. By improving academic performance, road infrastructure indirectly enhances the likelihood of realizing greater benefits from education, making it a more compelling investment for individuals and families. My empirical analysis aims to quantify these dynamics, offering evidence for the crucial role of road infrastructure in promoting human capital development and fostering a brighter future for all.

5 Results

This section presents the empirical findings from my analysis of the impact of Colombia's road concession program on educational outcomes. To provide a robust benchmark for interpreting the magnitude of our estimated effects, I draw upon previous studies that have established typical effect sizes for educational interventions. Table 3 presents a summary of effect sizes categorized as small, moderate, and large, based on two comprehensive reviews of randomized controlled trials (RCTs) in education: Kraft (2020) and Evans and Yuan (2022).

Table 3: Benchmark Effect Sizes for Educational Interventions from RCTs (in Standard Deviations)

	Overall		**Math**	**Reading**	**Enrollment**
Effect Size	**Evans (2022)**	**Kraft (2020)**	**Evans (2022)**	**Evans (2022)**	**Evans (2022)**
Small	0.08	0.04	0.05	0.03	0.03
Moderate	0.10	0.10	0.07	0.14	0.06
Large	0.45	0.47	0.31	0.50	0.38
Number of Studies		96	199	269	33

Note: This table presents typical effect sizes, categorized as small, moderate, and large, based on reviews of randomized controlled trials (RCTs) in education. The effect sizes are reported in standard deviations (SD). The source of each effect size is indicated in the column headings.

Kraft (2020) analyzed 747 RCTs, while Evans and Yuan (2022) considered a larger sample of 96 studies. Both reviews found a median impact on overall educational outcomes of approximately 0.1 SD. When focusing specifically on learning outcomes, such as math and reading achievement, Evans and Yuan (2022) reports similar median effect sizes (0.07 SD for math and

0.14 SD for reading). The table also highlights the variation in effect sizes across studies, with the 25th and 75th percentiles for overall effects ranging from 0.04 SD to 0.1 SD in Kraft (2020) and 0.08 SD to 0.47 SD in Evans and Yuan (2022). Effects exceeding 0.45 SD are generally considered large.

I will use these benchmarks as a guide for assessing the practical significance of our findings, considering both the magnitude and the direction of the estimated effects.

I begin by examining the effects of road concessions on standardized math and reading literacy scores, followed by an exploration of heterogeneity in treatment effects by distance. I then present the results for our additional outcome variables, providing a more comprehensive assessment of the program's impact.

5.1 Impact of Road Concessions on Standardized Test Scores

5.1.1 Impact of Road Construction on Math Scores

My analysis reveals a dynamic and evolving relationship between road construction progress and standardized math scores. This relationship unfolds over time, from the initial anticipation of a new road to the eventual realization of its full benefits. To capture these dynamics, I present the estimated total average treatment effects on the treated (ATT) for math scores at different stages of road construction completion (Table 4), derived using the Sun & Abraham (2021) estimator.

Table 4: Impact of Road Construction Progress on Standardized Math Scores

	Completion			
Stage	0%	10%	50%	100%
ATT Estimate	-0.1114 (0.0497)*	-0.0251 (0.0506)	0.0341 (0.0307)	0.1687 (0.0322)**
Within R^2	0.1023	0.1142	0.1092	0.1278
RMSE	0.8633	0.859	0.8583	0.8517
Observations	118143	97020	89949	70535
Fixed Effects	School ID , year			
S.E. Clustered by:	School ID, Road ID			

Note: This table presents the average treatment effect on the treated (ATT) estimates for standardized math scores at different stages of road construction completion, using the Sun & Abraham (2021) estimator. The treatment group consists of schools located within 1500 meters of a road project. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Before construction even begins, a surprising pattern emerges. Schools near planned road projects (0% completion stage) experience a statistically significant decline in math scores (ATT estimate of -0.11). This suggests that anticipation of the upcoming construction, with its potential for noise, disruption, and community anxieties, has a negative impact on the learning environment. This finding aligns with research demonstrating the adverse effects of noise pollution on student concentration and learning (Tomek & Urhahne, 2022; Yasar Avsar, 2004).

As construction gets underway (10% and 50% completion stages), this negative effect fades, and the impact on math scores shifts towards a positive, though statistically insignificant, direction. It's possible that during these active phases of construction, the potential benefits of improved access and reduced transportation costs are counterbalanced by the ongoing disruptions and uncertainties associated with a changing physical environment.

The full positive effect of road construction on math scores becomes evident once projects are finished and the roads are fully functional (100% completion stage). At this stage, I observe a statistically significant and positive ATT estimate of 0.1687, indicating that students in schools near completed road projects experience an increase in standardized math scores equivalent to roughly one-sixth of a standard deviation. This magnitude aligns with moderate effect sizes reported in meta-analyses of educational interventions (Evans & Yuan, 2022; Kraft, 2020), suggesting a substantively meaningful impact.

To further explore these dynamic effects, I present event study plots depicting how the estimated impact on math scores evolves over time, relative to the year each school is first treated, based on the detailed ATT estimations presented in Table 13 (Figures 9 to 12 in the Appendix).

My analysis of standardized math scores across different stages of road construction reveals a compelling narrative of anticipation, transition, and the eventual realization of benefits, consistent with Table 13. Even before construction begins (0% completion), a statistically significant negative effect emerges. Students in schools near planned road projects experience a decline in math scores, particularly in the year leading up to construction (year -1), suggesting a negative anticipation effect. This pattern aligns with my initial hypothesis that the prospect of road construction, with its potential for disruption and uncertainty, can create a less conducive learning environment.

However, as construction progresses (10% and 50% completion), this negative effect dissipates, and a transitional phase emerges. The estimated impacts on math scores during these active phases of construction are mixed and generally statistically insignificant, suggesting a period of flux where potential benefits, such as improved access to resources and reduced commuting times, might be counterbalanced by ongoing disruptions from noise, dust, and changes to the school's surroundings. It's only once road construction is complete (100% completion) that the full positive effects of improved road infrastructure become evident. A clear upward trend in math scores starts around year 1 after completion and grows more pronounced over time. This aligns with the anticipated long-term benefits of enhanced access to quality education, reduced transportation costs, and increased student motivation potentially fueled by new economic opportunities.

While the positive and statistically significant effects observed after road completion (100% stage) are encouraging, it's crucial to acknowledge the statistically significant coefficients in the pre-treatment period, as evidenced in Table 13. This pattern suggests a potential violation of the parallel trends assumption, raising concerns about the causal interpretation of the estimated treatment effects. Several factors could contribute to this divergence in pre-treatment trends. As I hypothesized earlier, the most significant impacts of road construction on education might be concentrated in the later stages of the project. While the road might be technically "complete" at the 100% mark, many of the associated benefits, such as increased economic activity and improved school quality, might only fully materialize after the road has been operational for some time. This means that schools in the treatment group, even before the road is officially finished, could be experiencing advantages not shared by the control group, leading to the observed pre-treatment differences.

While the positive and statistically significant effects observed after road completion (100% stage) are encouraging, it's crucial to acknowledge the statistically significant coefficients in the pre-treatment period, as evidenced in Table 13 and Figure 12. This pattern suggests a potential violation of the parallel trends assumption, raising concerns about the causal interpretation of the estimated treatment effects.

Several factors could contribute to this divergence in pre-treatment trends. As I hypothesized earlier, the most significant impacts of road construction on education might be concentrated in the later stages of the project. While the road might be technically "complete" at the 100% mark, many of the associated benefits, such as increased economic activity and improved school quality, might only fully materialize after the road has been operational for some time. This means that schools in the treatment group, even before the road is officially finished, could be experiencing advantages not shared by the control group, leading to the observed pre-treatment differences.

Furthermore, it's important to note that the roads are often accessible to traffic well before the official completion date. In many cases, the road might be usable at around 70% completion, allowing for reduced transportation costs and improved access to resources even during the final phases of construction. This could explain why the treatment group appears to diverge from the control group in the pre-treatment period. Schools near these almost-finished roads are already reaping some of the benefits, while schools near roads that are still in earlier stages of construction are not.

These findings underscore the dynamic and evolving nature of the relationship between road infrastructure and educational outcomes. The initial negative anticipation effects give way to a more nuanced picture during construction, ultimately leading to substantial and long-lasting benefits once roads are fully operational. This pattern underscores the importance of considering both short-term and long-term impacts when evaluating infrastructure projects. While temporary disruptions during construction are inevitable, the long-term gains in math achievement highlight the significant value of investing in road infrastructure to promote human capital development, especially in rural areas where access to quality education is often limited.

5.1.2 Impact of Road Construction on Reading Scores

My analysis of standardized reading literacy scores reveals a nuanced pattern, distinct from the trends observed for math. While there is a slight negative effect on reading scores before construction begins (0% completion stage, as seen in Table 5 with an ATT estimate of -0.0398), this effect is not statistically significant. This suggests that anticipation effects, such as noise and disruption from upcoming construction, might have a less pronounced impact on reading literacy compared to math. One possible explanation is that reading skills are less susceptible to the immediate disruptions of a changing physical environment, or that students can adapt their reading habits more easily than their math study habits. However, as observed with math scores, the effects during the active construction phases (10% and 50% completion) are generally small and statistically insignificant.

Table 5: Impact of Road Construction Progress on Standardized Reading Scores

	Completion			
Stage	0%	10%	50%	100%
ATT Estimate	-0.0398 (0.0315)	0.0128 (0.0285)	0.007 (0.0121)	0.1123 (0.0308)*
Within R^2	0.103	0.1091	0.1093	0.1229
RMSE	0.8724	0.8703	0.8696	0.8686
Observations	118143	97020	89949	70535
Fixed Effects	School ID , year			
S.E. Clustered by:	School ID, Road ID			

Note: This table presents the total average treatment effect on the treated (ATT) estimates for standardized reading scores at different stages of road construction completion, using the Sun & Abraham (2021) estimator. The treatment group consists of schools located within 1500 meters of a road project. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

In contrast to these ambiguous effects during construction, the 100% completion stage reveals a clear positive impact on reading literacy. This positive effect becomes statistically significant approximately a year after road completion, with reading scores showing an increase of 0.1123 standard deviations and reaching a moderate effect of 0.24 standard deviations five years after road completion (Table 14).

Examining the event study plots in Figures 13 to 16 provides further insight into these dynamics. The anticipation effect, while negative, is statistically insignificant for reading literacy, unlike the pattern observed for math. The figures for the 10% and 50% completion stages reinforce the finding that the effects during active construction are minimal and statistically indistinguishable. However, the figure for the 100% completion stage reveals a clear and positive trend in reading scores starting around year 1 after road completion, which aligns with the statistically significant ATT estimate at the 100% completion stage. These findings suggest that the full benefits of improved road infrastructure for reading literacy, such as increased access to better schools and resources, reduced commuting time, and potentially greater motivation driven by economic opportunities, take time to materialize.

These findings suggest that while the disruptions of the construction process can temporarily obscure the benefits of improved road infrastructure, the long-term effects on reading literacy are positive and meaningful. This underscores the importance of considering both short-term and long-term impacts when evaluating infrastructure projects, recognizing that the full benefits for educational outcomes may not be immediately apparent.

5.2 Heterogeneity Analysis by Distance

To further examine the localized effects of road infrastructure improvements and rule out potential spillover effects, I conduct a heterogeneity analysis by distance. I group schools into bands based on their proximity to the nearest road project, with each band representing a 500-meter increment (e.g., 0-500 meters, 500-1000 meters, and so on, up to 2500 meters). For each distance band and stage of road completion, I estimate the total average treatment effect on the treated (ATT), using the Sun & Abraham (2021) estimator. The results of this analysis are presented in Figures 5 and 6 for standardized math and reading scores, respectively.

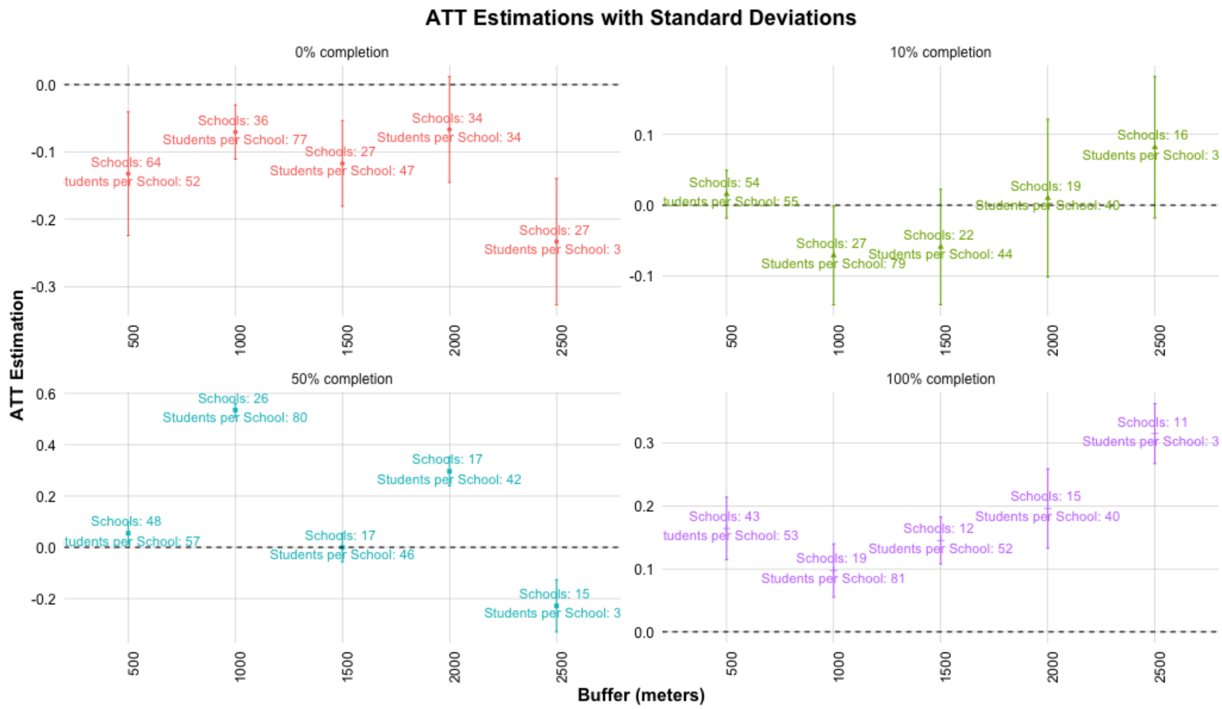

Figure 5: ATT Estimations with Standard Deviations for Math Scores across Distance Bands and Construction Stages. Error bars represent 95% confidence intervals for the total ATT. Each data point reflects the estimated ATT at different distances, considering the number of schools and the average number of students per school.

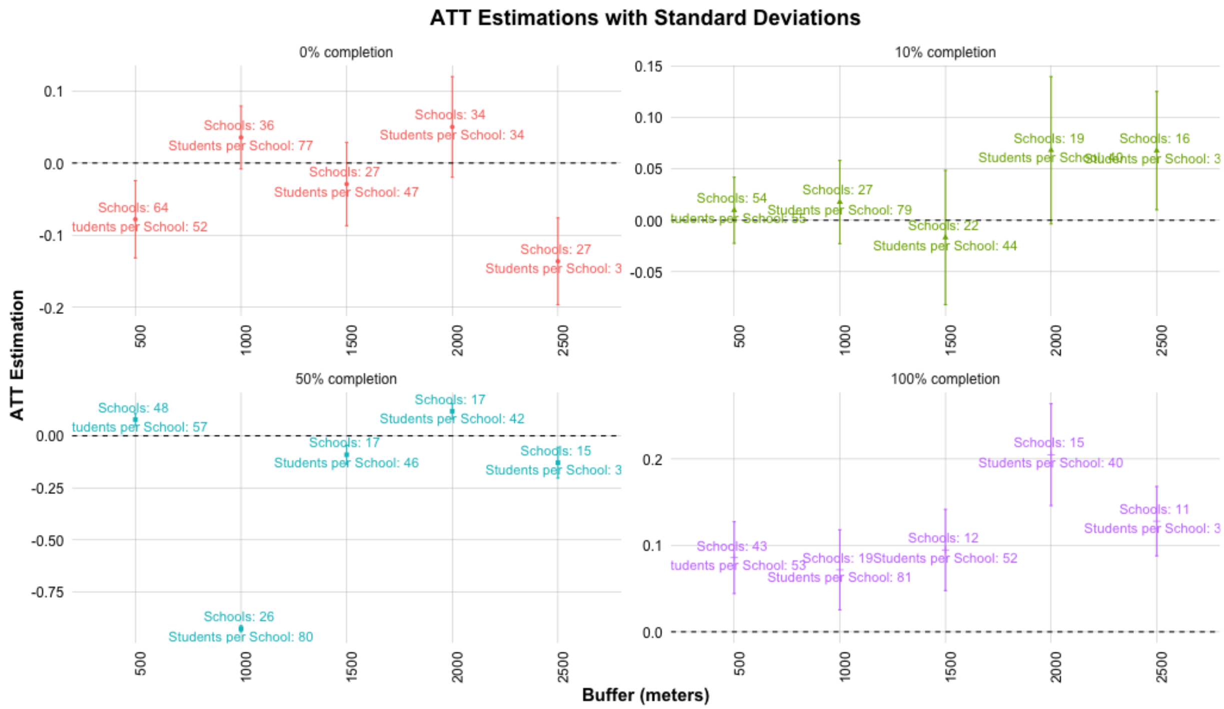

Figure 6: ATT estimations with standard deviations for reading literacy scores across distance bands and construction stages. Error bars represent 95% confidence intervals for the total ATT. Each data point reflects the estimated ATT at different distances, considering the number of schools and the average number of students per school.

Analyzing the impact of road construction on standardized math scores across different distances reveals intriguing patterns. Before construction begins (0% completion), I find a statistically significant negative effect on math scores for schools within 2500 meters of the planned road project. This effect is most pronounced for schools in the 2500-meter band (-0.2332 standard deviations with 27 schools and an average of 35 students per school), suggesting that anticipation effects, such as noise disruption or community anxieties, might be amplified at a slight distance from the immediate construction zone. As construction gets underway (10% completion), these negative anticipation effects generally diminish. A slight negative effect persists within 1500 meters, but it lacks statistical significance. Interestingly, a positive, though statistically insignificant, effect emerges for schools in the 2500-meter band (0.0819 standard deviations, 16 schools, and an average of 32 students per school), potentially signaling that early benefits of improved accessibility are starting to outweigh the initial disruptions for these schools.

The 50% completion stage paints a more complex picture. Schools in the 1000-meter band experience a large and statistically significant positive effect (0.5352 standard deviations, 26 schools, average 80 students per school). This suggests that the benefits of improved road infrastructure, such as easier access to better-resourced schools, are starting to outweigh any remaining disruptions for schools relatively close to the project. However, a contrasting negative and significant effect appears in the 2500-meter band (-0.2282 standard deviations, 15 schools, average 32 students per school), indicating that disruptions or other unobserved factors could still be negatively impacting schools at this distance.

The picture becomes clearer once road construction is complete (100% completion). A consistent pattern of positive and statistically significant effects on math scores emerges across all distance bands. The largest effect is observed for schools in the 2500-meter band (0.3148 standard deviations, 11 schools, average 33 students per school), followed by the 2000-meter band (0.1959 standard deviations, 15 schools, average 40 students per school). These findings support the hypothesis that the full benefits of improved road infrastructure, including enhanced access to quality schools, reduced transportation costs, and increased economic opportunities, extend beyond the immediate vicinity of the road, impacting schools up to 2500 meters away.

Turning to the impact on reading literacy scores (Figure 6), I find no statistically significant effects across any distance band during the pre-construction period (0% completion). This suggests that anticipation effects, which negatively impacted math scores, might be less influential for reading literacy. This difference could reflect the nature of reading as a more individualized and internalized activity, potentially less vulnerable to external disruptions like noise. The trend observed during the active construction phases (10% and 50% completion) mirrors the pattern for math scores: the effects on reading literacy are generally small and statistically insignificant, regardless of distance to the project. This further suggests that disruptions associated with construction might temporarily outweigh any potential benefits of improved road access.

However, at the 100% completion stage, a statistically significant positive effect on reading literacy emerges for schools in the 500-meter (0.0858 standard deviations, 43 schools, average 53 students per school) and 1000-meter bands (0.0717 standard deviations, 19 schools, average 81 students per school), indicating that proximity to the completed road positively influences reading literacy. However, these effects are smaller in magnitude compared to those on math scores. This difference might indicate that the mechanisms through which road improvements benefit educational outcomes, such as enhanced access to resources or increased motivation, are somewhat weaker for reading literacy compared to math.

In conclusion, this heterogeneity analysis reveals the complex and localized nature of how road construction impacts educational outcomes. While the benefits ultimately extend beyond the immediate vicinity of the road, the strength and direction of the effects are influenced by both distance and the stage of construction. The findings suggest an interplay of several factors, including anticipation effects, construction disruptions, and the time it takes for the full benefits of improved access and economic opportunities to materialize. The observed differences between math and reading literacy scores warrant further investigation to unravel the subject-specific nuances of these impacts.

5.3 Impact on Additional Educational Outcomes

5.3.1 Human Capital Accumulation

Table 6 presents the estimated total average effects of treatment on treated (ATT) for the Human Capital Accumulation Index, which represents the proportion of students who successfully transition from secondary education to higher education. I use the Sun & Abraham (2021) estimator to assess how the impact of road construction on human capital accumulation evolves across different stages of project completion.

Table 6: Impact of Road Concessions on Human Capital Accumulation Index

	Completion			
Stage	0%	10%	50%	100%
ATT Estimate	-0.0048 (0.0141)	-0.06 (0.0308).	0.0004 (0.022)	0.0482 (0.0013)*
Adjusted R^2	0.7071	0.7088	0.7118	0.7723
Within R^2	0.7066	0.708	0.711	0.7713
RMSE	0.0861	0.0871	0.0865	0.0792
Observations	1901	1045	1029	681
Fixed Effects	School ID , year			
S.E. Clustered by:	School ID, Road ID			

Note: This table presents the average treatment effect on the treated (ATT) estimates for the Human Capital Accumulation Index at different stages of road construction completion, using the Sun & Abraham (2021) estimator. The treatment group consists of schools located within 1500 meters of a road project. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The total ATT estimates reveal an intriguing and nuanced relationship between road construction and human capital accumulation. Contrary to initial expectations, the most pronounced and statistically significant effect emerges at the completion stage 100%, where the ATT indicates that for every 100 students, we see an average of 5 more students making the transition to higher education (4.82 percentage points). This suggests that, on average, the completion of road construction projects is associated with an increase in the proportion of students transitioning to higher education. To gain a deeper understanding of this dynamic, Figures 21 to 24 present the estimated ATTs for each relative time period across the different stages of road construction.

This finding provides evidence that the anticipated benefits of road infrastructure, such as improved access to higher-quality schools, reduced transportation costs, and the emergence of new economic opportunities, may play a crucial role in encouraging students to invest in higher education. However, it is essential to acknowledge that these positive effects take time to materialize, manifesting most clearly once road projects are fully completed and the associated benefits become more tangible and readily accessible.

While the overall effect of road completion on human capital accumulation is positive, the dynamic patterns observed in the event study plots, along with the relatively small sample size at the 100% completion stage (681 observations), highlight the need for further investigation.

5.3.2 Impact on Child Labor

Table 7 presents the estimated average treatment effects on the treated (ATT) for the Child Labor Index, capturing the proportion of students in each school who report being engaged in paid work. These estimates are derived using the Sun & Abraham (2021) estimator, allowing me to assess the dynamic impact of road construction progress on child labor across different stages of project completion. To further explore the dynamic relationship between road construction and child labor, I present a series of event study plots (Figures 17 to 20) that depict the estimated ATT coefficients for the Child Labor Index at each relative time period, for different stages of road completion.

Table 7: Impact of Road Concessions on Child Labor Index

	Completion			
Stage	0%	10%	50%	100%
ATT Estimate	0.0104 (0.0155)	-0.008 (0.0218)	0.0873 (0.0161)***	-0.0321 (0.0102)*
Adjusted R^2	0.7616	0.7738	0.7927	0.7855
Within R^2	0.7612	0.7734	0.7922	0.7849
RMSE	0.1009	0.0941	0.0876	0.0853
Observations	1901	1539	1360	1105
Fixed Effects	School ID , year			
S.E. Clustered by:	School ID, Road ID			

Note: This table presents the average treatment effect on the treated (ATT) estimates for the Child Labor Index at different stages of road construction completion, using the Sun & Abraham (2021) estimator. The treatment group consists of schools located within 1500 meters of a road project. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The results reveal a complex relationship between road construction and child labor. Before construction begins (0% completion), there is no statistically significant effect on the Child Labor Index. This suggests that the mere anticipation of road improvements does not immediately alter child labor patterns. However, as construction progresses to the 50% completion stage, I observe a statistically significant and positive effect (ATT estimate of 0.0873). This indicates that during the active construction phase, the proportion of students engaged in paid work actually increases. This finding could reflect several factors. The construction process itself might create temporary employment opportunities for adolescents, or families might experience increased economic hardship during this period due to disruptions in local markets or employment.

However, once road construction is completed (100% completion), the effect on the Child Labor Index reverses. I find a statistically significant negative effect at this stage (ATT estimate of -0.0321), indicating that the completion of road projects is associated with a decrease in child labor participation. This suggests that the long-term benefits of improved road infrastructure, such as increased access to quality education, reduced transportation costs, and the emergence of new economic opportunities, may ultimately create conditions that discourage child labor.

These findings underscore the dynamic and sometimes counterintuitive relationship between infrastructure development and child labor. While the initial construction phase might lead to a temporary increase in child labor, the long-term effects appear to be beneficial, potentially aligning with the mechanism I described earlier, whereby road improvements stimulate economic development and create alternative employment opportunities for adults, reducing the reliance on child labor.

5.4 Robustness Checks

5.4.1 Attrition: Analyzing Changes in Student Enrollment

To assess potential attrition bias, I investigate changes in student enrollment patterns before and after road construction. Attrition bias could arise if students systematically leave or join schools in the treatment group compared to the control group, potentially influencing the estimated treatment effects on educational outcomes. To quantify these changes, I construct an Enrollment Impact Index (EII) using the following formula:

$$\text{Enrollment Impact Index (EII)} = \frac{(E_{t+n} - E_t)}{E_t}$$

Where E_{t+n} represents the total enrollment in the school at time $t+n$ (after treatment) and E_t represents the total enrollment in the school at baseline time t.

A positive EII indicates an increase in enrollment, while a negative EII indicates a decrease.

Table 8 presents the estimated ATT for the EII across different stages of road construction.

Table 8: Enrollment Impact Index (EII): Total Average Treatment Effects by Construction Stage

	Completion			
Stage	0%	10%	50%	100%
ATT Estimate	0.0069 (0.0473)	0.0499 (0.0433)	0.0971 (0.0441).	0.0059 (0.0224)
Adjusted R^2	0.3669	0.4468	0.5972	0.5648
Within R^2	0.3651	0.4445	0.5951	0.561
RMSE	0.2676	0.2668	0.1691	0.1998
Observations	1058	733	571	348
Fixed Effects	School ID , year			
S.E. Clustered by:	School ID, Road ID			

Note: This table presents the total average treatment effect on the treated (ATT) estimates for standardized reading scores at different stages of road construction completion, using the Sun & Abraham (2021) estimator. The EII measures the percentage change in enrollment from the pre-treatment period to the post-treatment period. The treatment group consists of schools located within 1500 meters of a road project. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

My analysis of the EII reveals that there is no consistent pattern of significant changes in student enrollment across different stages of road completion. While there is a marginally significant positive ATT estimate at the 50% completion stage, suggesting a potential increase in enrollment during the active construction phase, this effect is not sustained once the roads are fully operational. The lack of significant effects at the 0% and 100% completion stages suggests that, overall, road construction does not lead to systematic changes in student enrollment patterns that could bias my treatment effect estimates for educational outcomes.

These findings provide evidence that my estimated impacts on math and reading scores, as well as the Child Labor Index and Human Capital Accumulation Index, are not driven by attrition bias. The stability of enrollment patterns across the treatment and control groups strengthens my confidence in the causal interpretation of the observed effects.

5.4.2 Robustness Check: Callaway and Sant'Anna (2021) Estimator

To assess the robustness of my findings, I employ the Callaway and Sant'Anna (2021) estimator as an alternative to the Sun and Abraham (2021) estimator. While the Callaway and Sant'Anna

(2021) estimator does not allow for the aggregation of construction periods, it offers greater flexibility with the parallel trends assumption by focusing solely on the last period before treatment for assessing pre-treatment trends. This potentially provides a more accurate assessment of parallel trends, offering an alternative estimation strategy for comparison.

Table 9 presents the estimated treatment effects on standardized math and reading scores using the Callaway and Sant'Anna (2021) estimator.

Table 9: Impact of Road Construction Progress on Standardized Test Scores: Callaway and Sant'Anna (2021) Estimator

	Completion			
Stage	0%	10%	50%	100%
Math Score	-0.017 (0.0224)	0.1341 (0.0251)**	-0.1384 (0.1021)	0.1358 (0.0278)**
Reading Score	-0.0769 (0.0236)***	0.1176 (0.0252)***	-0.0301 (0.1002)	0.0311 (0.0291)
Observations	118143	97020	89949	70535
Fixed Effects	School ID, year			
S.E. Clustered by:	School ID, Road ID			

Note: This table presents the average treatment effect on the treated (ATT) estimates for standardized math and reading scores at different stages of road construction completion, using the Callaway and Sant'Anna (2021) estimator. The treatment group consists of schools located within 1500 meters of a road project. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

My analysis reveals a mixed picture. Consistent with the Sun and Abraham (2021) results, the Callaway and Sant'Anna (2021) estimator finds a positive and significant effect of road completion (100% stage) on math scores. However, it does not detect a significant effect on reading scores at this stage, contrasting with the Sun and Abraham (2021) analysis. Moreover, the Callaway and Sant'Anna (2021) estimator identifies significant positive effects at the 10% completion stage for both math and reading, a pattern absent in the previous analysis.

These discrepancies may stem from the distinct ways each estimator handles parallel trends and treatment effect heterogeneity. The stricter parallel trends assumption of the Callaway and Sant'Anna (2021) estimator, coupled with its inability to aggregate construction periods, could explain the differing results. The Sun and Abraham (2021) estimator, allowing for short-term deviations from parallel trends and capturing cumulative effects, might be more sensitive to long-term impacts, particularly for reading scores.

Despite these variations, the consistent positive effect on math scores across both estimators strengthens my confidence in this key finding. The mixed results for reading scores highlight the need for further research to clarify the long-term impact of road infrastructure on reading literacy.

5.4.3 Robustness Check: Distance-Based Control Group

To further assess the sensitivity of my results to the choice of control group and explore the potential for spillover effects identified in my heterogeneity analysis, I re-estimate my model using schools located more than 3000 meters away from the road project as an alternative "never treated" group. This approach helps address concerns about unobserved factors that might be driving pre-treatment differences between schools near and far from road construction. Table 10 presents the estimated treatment effects on standardized math and reading scores using this alternative control group.

Table 10: Impact of Road Construction Progress on Standardized Test Scores (Alternative Controls)

	Completion			
Stage	0%	10%	50%	100%
Math Score	-0.0788 (0.0445).	0.0152 (0.05)	0.0351 (0.0263)	0.1165 (0.0442)*
Reading Score	-0.0435 (0.0323)	0.0125 (0.0275)	-0.0147 (0.0121)	0.0612 (0.0298).
Observations	118143	97020	89949	70535
Fixed Effects	School ID, year			
S.E. Clustered by:	School ID, Road ID			

Note: This table presents the average treatment effect on the treated (ATT) estimates for standardized math and reading scores at different stages of road construction completion, using the Sun and Abraham (2021) estimator. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The results reveal that the positive and significant effect of road completion on math scores persists, albeit with a slightly smaller magnitude (0.1165 standard deviations). This suggests that the impact on math achievement is robust to different control group choices and that the positive effects observed up to 2500 meters in the heterogeneity analysis are unlikely due to spillovers from the treatment group. However, the effect on reading scores is no longer statistically significant, indicating potential sensitivity to unobserved factors correlated with distance. This finding aligns with the heterogeneity analysis, where the positive impacts on reading scores were concentrated within a shorter distance band (500-1000 meters). This pattern could reflect a more localized impact of road improvements on reading literacy, potentially due to factors like access to libraries or community literacy programs that are more prevalent closer to the road.

Overall, this robustness check, in conjunction with the heterogeneity analysis, reinforces the importance of considering distance when evaluating the impact of road infrastructure on education. While math scores appear to benefit consistently, even with a distant control group, the sensitivity of the reading score results suggests a more nuanced relationship, where proximity to the road might play a more significant role.

Okay, here's the completed and improved subsubsection for the robustness check using alternative distance thresholds:

5.4.4 Robustness Check: Alternative Distance Thresholds

To ensure my findings are not sensitive to the specific choice of the 1500-meter radius for defining the treatment group, I re-estimate my model using alternative distance thresholds of 500 meters, 1000 meters, and 2000 meters. This analysis examines how the estimated effects of road construction change when varying the proximity criteria for classifying schools as treated. Table 11 summarizes the results of this robustness check, presenting the ATT estimates for math and reading scores at different stages of road completion using these alternative thresholds.

Table 11: Impact of Road Construction Progress on Standardized Test Scores (Alternative Distance Thresholds)

		Completion			
Outcome	Distance (m)	0%	10%	50%	100%
Math Score	500	-0.1323 (0.0918)	0.0155 (0.0339)	0.055 (0.0424)	0.1643 (0.0497)*
Math Score	1000	-0.1108 (0.0487)*	-0.0179 (0.0462)	0.0582 (0.0296).	0.1446 (0.0241)**
Math Score	1500	-0.1114 (0.0497)*	-0.0251 (0.0506)	0.0341 (0.0307)	0.1687 (0.0322)**
Math Score	2000	-0.1017 (0.0524).	-0.0202 (0.0587)	0.0696 (0.0315).	0.1456 (0.035)**
Reading Score	500	-0.078 (0.0536)	0.0097 (0.0321)	0.0782 (0.0289)*	0.0858 (0.0416).
Reading Score	1000	-0.0417 (0.0299)	0.0181 (0.0216)	0.0797 (0.0112)***	0.0883 (0.0258)*
Reading Score	1500	-0.0398 (0.0315)	0.0128 (0.0285)	0.007 (0.0121)	0.1123 (0.0308)*
Reading Score	2000	-0.0307 (0.0352)	0.0184 (0.031)	0.0223 (0.0133)	0.0976 (0.0356)*

Note: This table presents the ATT estimates for standardized math and reading scores at different stages of road construction completion using the Sun and Abraham (2021) estimator and alternative distance thresholds for defining the treatment group. Standard errors (in parentheses) are clustered at the school and road ID level.
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

My findings demonstrate a high degree of consistency across the different distance thresholds. The positive and significant effect of road completion (100% stage) on both math and reading scores remains evident regardless of the radius used. This suggests that the positive impacts of improved road access on educational outcomes extend beyond a narrowly defined treatment area. Interestingly, the significance of the effect on math scores at the 0% completion stage (the anticipation effect) diminishes as the distance threshold increases. This suggests that the negative anticipation effect might be more localized and concentrated closer to the road project.

This robustness check strengthens my confidence in the generalizability of my findings and suggests that the estimated effects are not driven by an arbitrary choice of distance threshold. The consistent positive impact of road construction on both math and reading scores, regardless of the specific proximity criteria, reinforces the conclusion that improved road infrastructure plays a meaningful role in enhancing educational outcomes in Colombia.

6 Conclusions

This study provides compelling evidence that Colombia's road concession program, a Public-Private Partnership initiative designed to improve the national road network, has yielded positive and significant impacts on educational outcomes in public schools. By employing a staggered difference-in-differences approach that accounts for the gradual rollout of road construction projects, I find that road improvements lead to a notable increase in student performance on the SABER 11 standardized test, particularly in mathematics.

My analysis reveals that the positive effect on math scores becomes most pronounced once road projects are completed, suggesting that the full benefits of improved access, reduced transportation costs, and increased economic opportunities take time to materialize. While the impact on reading literacy is also positive, it is less pronounced and shows greater sensitivity to the choice of control group. This highlights the need for further investigation into the specific mechanisms driving the effects on different subjects and the potential for heterogeneity in those impacts.

Furthermore, my analysis reveals a significant decrease in child labor participation following road completion, suggesting that improved economic opportunities for adults, facilitated by better road connectivity, reduce the reliance on child labor. This, in turn, allows children to dedicate more time to their education, potentially contributing to the observed improvements in academic performance. Additionally, I find an increase in the proportion of students pursuing higher education after road improvements, indicating that road infrastructure can have a lasting impact on human capital accumulation.

My findings remain robust across several rigorous robustness checks, including alternative estimators Callaway and Sant'Anna (2021), different control groups, and varying distance thresholds for defining the treatment group. This strengthens my confidence in the causal interpretation of the results and highlights the generalizability of the positive effects observed.

These findings hold important implications for policymakers considering PPPs as a mechanism for promoting human capital development. My study demonstrates that well-designed road concession programs can contribute to significant and lasting improvements in educational outcomes, particularly in areas historically hindered by poor transportation infrastructure. However, careful consideration should be given to the potential for subject-specific differences in impacts, the importance of addressing potential anticipation effects during the construction phase, and the need to monitor the long-term sustainability of the benefits.

The findings of this study offer valuable insights for policymakers seeking to leverage infrastructure development for educational progress. Prioritizing road improvements in educationally underserved areas, particularly through well-structured public-private partnerships, can yield significant and lasting benefits for student learning, reduce child labor, and promote higher education aspirations. However, policymakers must adopt a long-term perspective, acknowledging the dynamic nature of these impacts and mitigating potential disruptions during the construction phase. Moreover, integrating road infrastructure development with broader education policies that address subject-specific needs, teacher quality, and resource allocation will maximize the transformative potential of these investments. Finally, a commitment to sustainable road construction practices is crucial to ensure that the educational gains achieved are maintained for future generations.

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A Appendix

A.1 Data and Descriptive Statistics

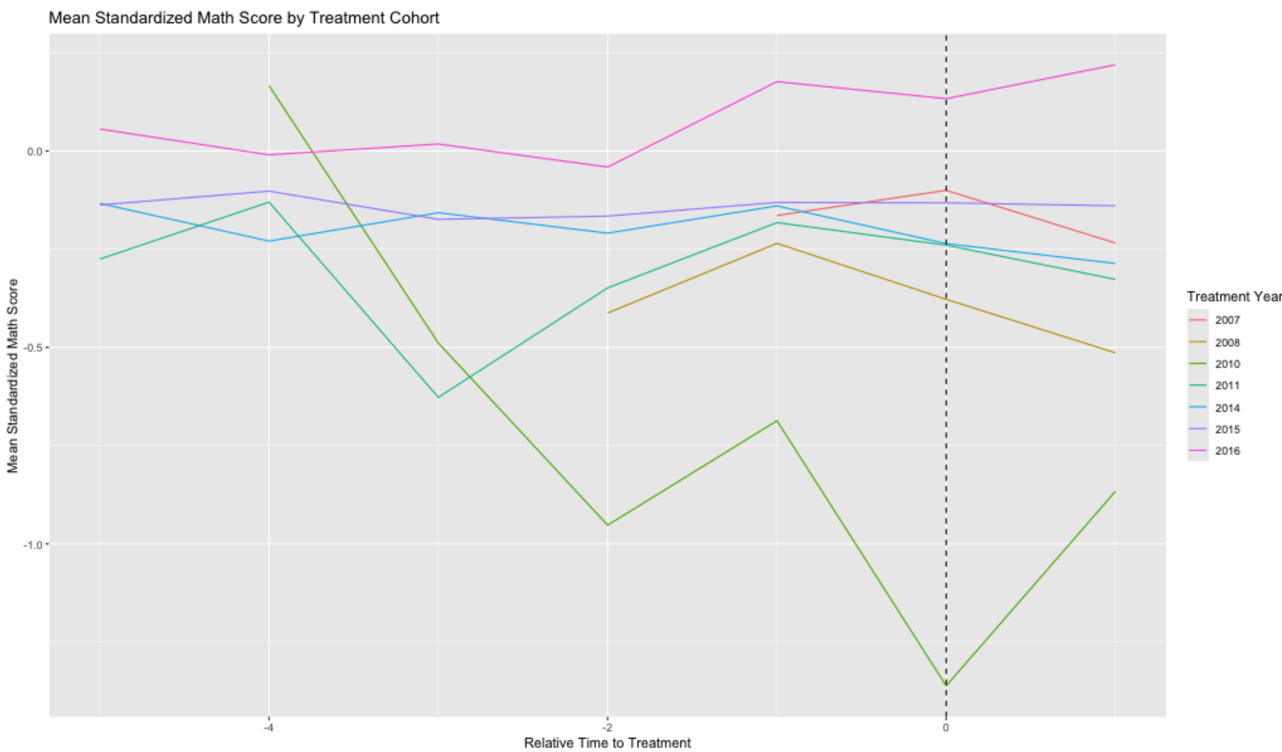


Figure 7: Mean Standardized Math Scores for Schools Near Road Projects, by Treatment Cohort (Pre-Treatment Period)

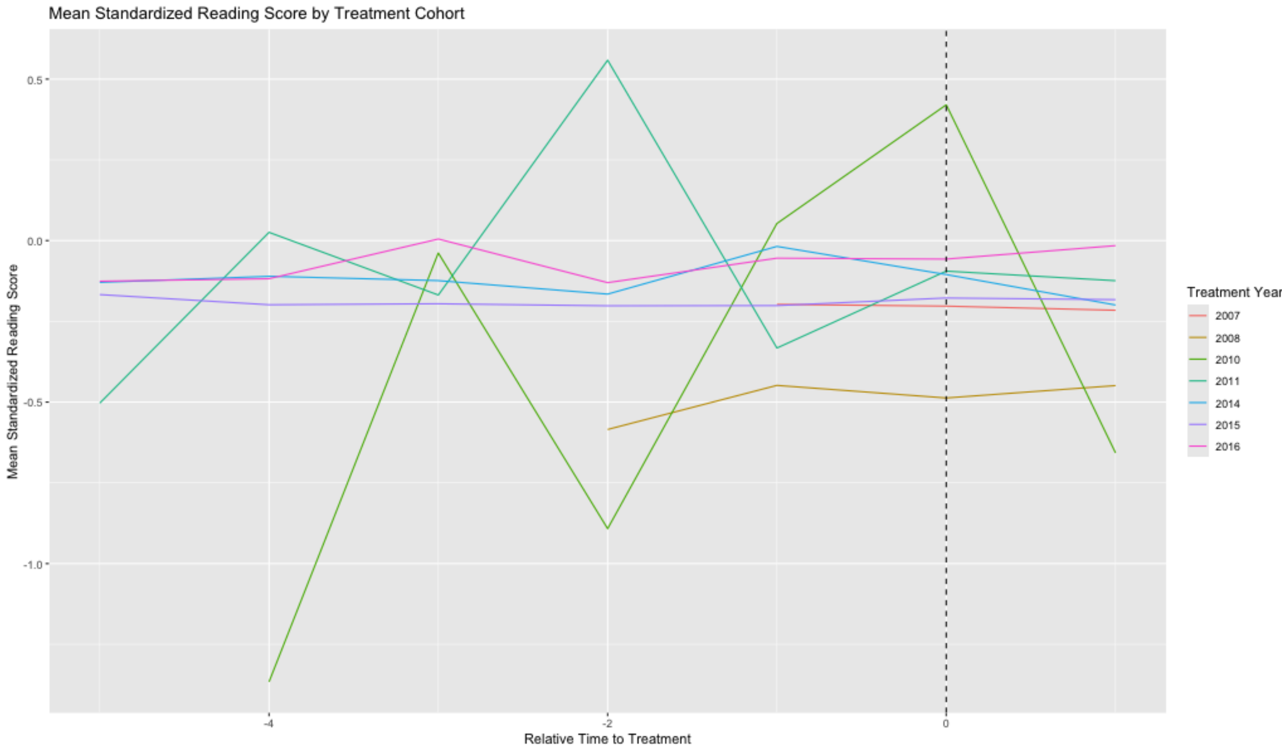


Figure 8: Mean Standardized Reading Scores for Schools Near Road Projects, by Treatment Cohort (Pre-Treatment Period)

Table 12: Concession Projects and their Details

Project	**Concessionaire**	**Contract Number**	**Intervenor**	**SECOP/ANI Link**
Bogotá - Siberia - La Punta - El Vino - Villeta	CONCESION SABANA DE OCCIDENTE S.A.	447-1994	SOCIEDAD CONCESION SABANA DE OCCIDENTE S.A.	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=16-12-4627222`
Bogota - Villavicencio	CONCESIONARIA VIAL DE LOS ANDES SAS COVIANDES S A S	444-1994	CONSORCIO INTERCONCESIONES	`https://www.contratos.gov.co/consultas/detalleProcesoPTE.do?numCompromiso=716&subEntidad=24-13-00`
Cartagena Barranquilla	CONSORCIO VIA AL MAR	503-1994	Consorcio Vía al Mar	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=15-1-133681`
Desarrollo Vial del Norte de Bogotá - DEVINORTE	UNION TEMPORAL DEVINORTE	664-1994	Consorcio ICITY	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=13-12-2075308`
Fontibon Facatativá Los Alpes	CONCESIONES CCFC S.A.	937-1995	CONSORCIO R&Q SERVINC	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=15-1-132180`
Desarrollo Vial del Oriente de Medellin - DEVIMED	DEVIMED S.A.	275-1996	CONSORCIO INTERCARRETEROS (Alcance básico) CONSORCIO HMV-SESAC (Adicional N° 14)	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=14-4-3070110`
Malla Vial del Valle y Cauca	UNION TEMPORAL MALLA VIAL DEL VALLE DEL CAUCA Y CAUCA	005-1999	CONSORCIO INTERCOL SP	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=14-1-116960`
Briceño -Tunja - Sogamoso	CSS CONSTRUCTORES S.A	377-2002	CONSORCIO CONCESIONES COLOMBIA	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=16-1-156465`
Bosa - Granada - Girardot	AUTOPISTA BOGOTA- GIRARDOT S.A.	040-2004		`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=16-1-156632`
Zona Metropolitana de Bucaramanga	AUTOPISTAS DE SANTANDER S.A	002-2006		`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=14-1-117218`
Cordoba - Sucre	AUTOPISTAS DE LA SABANA S.A.	002-2007	CONSORCIO EL PINO	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=06-1-3368`
Area Metropolitana de Cúcuta	CONCESIONARIA SAN SIMÓN S.A.	006-2007	Consorcio VELNEC-GNG	`https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=06-1-6047`

Continued on next page

Table 12 – continued from previous page

Project	Concessionaire	Contract Number	Intervenor	SECOP/ANI Link
Ruta Caribe	AUTOPISTAS DEL SOL S.A.	008-2007	CONSORCIO EPSILON VIAL	https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=06-1-5381
Girardot - Ibague - Cajamarca	CONCESIONARIA SAN RAFAEL S.A.	007-2007	CONSORCIO INTERCONCESIONES	https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=13-1-103191
Ruta del Sol sector - 1	CONSORCIO VIAL HELIOS	002-2010	Consorcio Zañartu MAB Velnec	https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=09-1-41316
Ruta del Sol sector - 2	CONCESIONARIO RUTA DEL SOL S.A	001-2010	CONSORCIO PROYECCIÓN VIAL PUERTO SALGAR	https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=09-1-41316
Ruta del Sol sector - 3	CONCESIONARIA YUMA S.A.	007-2010	CONSORCIO EL SOL	https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=10-
Transversal de las Américas - 1	CONSORCIO VÍAS DE LAS AMÉRICAS S.A.	008-2010		https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=09-1-49664
Transversal de las Américas - 2	TRANSVERSAL DE LAS AMÉRICAS S.A.S	009-2010		https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=09-1-49664
Vía Honda - Puerto Salgar - Villeta	RUTA DEL SOL - SECTOR 2 S.A.S.	003-2010		https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=09-1-49664
Ruta del sol sector - 3 (Yuma)	CONCESIONARIA YUMA S.A.S	007-2010	CONSORCIO PROYECCIÓN VIAL PUERTO SALGAR	https://www.contratos.gov.co/consultas/detalleProceso.do?numConstancia=09-1-49664

Note: This table provides details of various road concession projects in Colombia. It includes information about the project name, concessionaire, contract number, interventor (auditor), and a link to the SECOP or Portal ANI for further details.

A.2 Results

The results of the mathematics and reading score for all the different stages of construction are found in table 13 and 14, these estimation are based on Sun and Abraham (2021) estimation.

A.2.1 Math Results

Table 13: Dynamic DiD Estimation for Mathematics Scores

Relative Time Period	0% Completion	10% Completion	50% Completion	100% Completion
-15		-0.0925 (0.0971)	0.0323 (0.0241)	0.4326 (0.0784)
-14		-0.1043 (0.1121)	-0.2145 (0.1622)	0.4160 (0.0600)
-13		0.1505 (0.1475)	-0.1337 (0.2088)	0.3099 (0.0353)
-12		0.0562 (0.1751)	0.1806 (0.1230)	0.1667 (0.0239)
-11		0.1620 (0.1108)	0.1182 (0.1479)	0.00 (0.00)
-10	-0.0709 (0.0941)	0.1063 (0.1127)	0.0487 (0.0433)	0.00 (0.00)
-9	0.1342 (0.1326)	0.0725 (0.0563)	-0.2133 (0.0332)	0.00 (0.00)
-8	0.0849 (0.1310)	0.0324 (0.0621)	-0.0994 (0.0486)	0.00 (0.00)
-7	0.1097 (0.1004)	0.0322 (0.0814)	0.0460 (0.0308)	0.00 (0.00)
-6	0.1183 (0.0893)	0.0326 (0.0672)	0.00 (0.00)	0.00 (0.00)
-5	0.0964 (0.0548)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
-4	0.0478 (0.0604)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
-3	0.0092 (0.0743)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
-2	-0.0009 (0.0649)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1250 (0.0177)
2	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1390 (0.0391)
3	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1325 (0.0234)
4	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1574 (0.0481)
5	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.2401 (0.0327)
7	0.00 (0.00)	0.00 (0.00)	-0.0204 (0.0345)	
8	0.00 (0.00)	0.0352 (0.0631)	0.0755 (0.0320)	
9	0.00 (0.00)	-0.0663 (0.0540)	0.0549 (0.0330)	
10	0.00 (0.00)	-0.0467 (0.0493)		
11	-0.0788 (0.0721)			
12	-0.1099 (0.0507)			
13	-0.1258 (0.0379)			
14	-0.1383 (0.0441)			

Note: This table presents the average treatment effect on the treated (ATT) estimates for standardized math scores at key time periods relative to road construction completion, using the Sun & Abraham (2021) estimator. The treatment group consists of schools located within 1500 meters of a road project. Standard errors are in parentheses. The red "0.00 (0.00)" entries indicate reference periods that are excluded from the estimation to avoid collinearity and identify the treatment effects. The "never treated" cohorts, which only have negative RPs, act as the baseline reference group. The "always treated" cohorts have been removed from the analysis (represented by empty cells in the table).
Significance codes: *** p ¡ 0.001, ** p ¡ 0.01, * p ¡ 0.05, . p ¡ 0.1

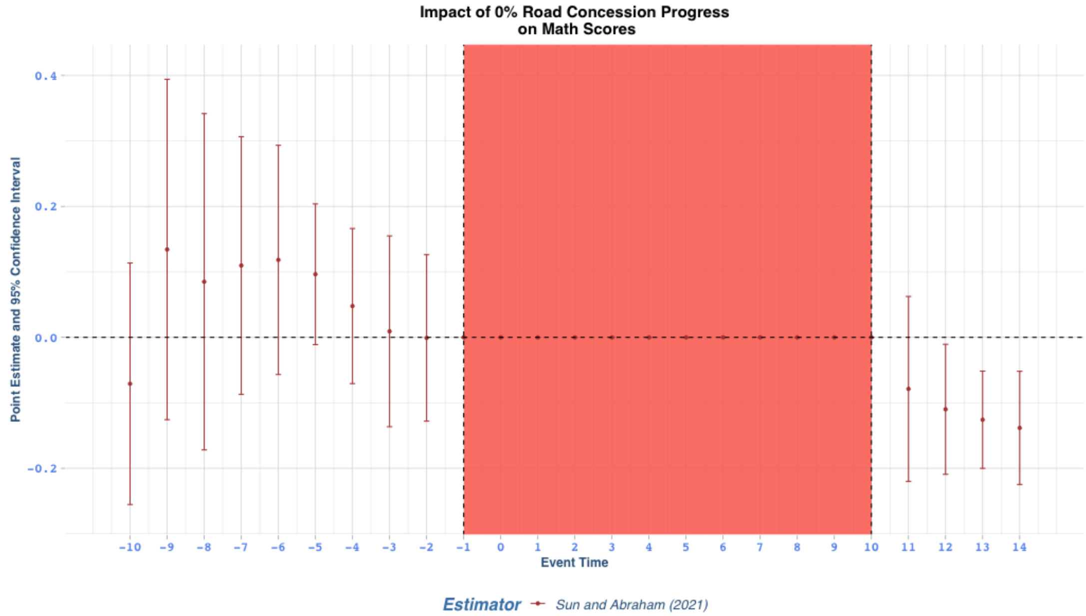


Figure 9: Impact of Road Construction on Standardized Math Scores (0% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

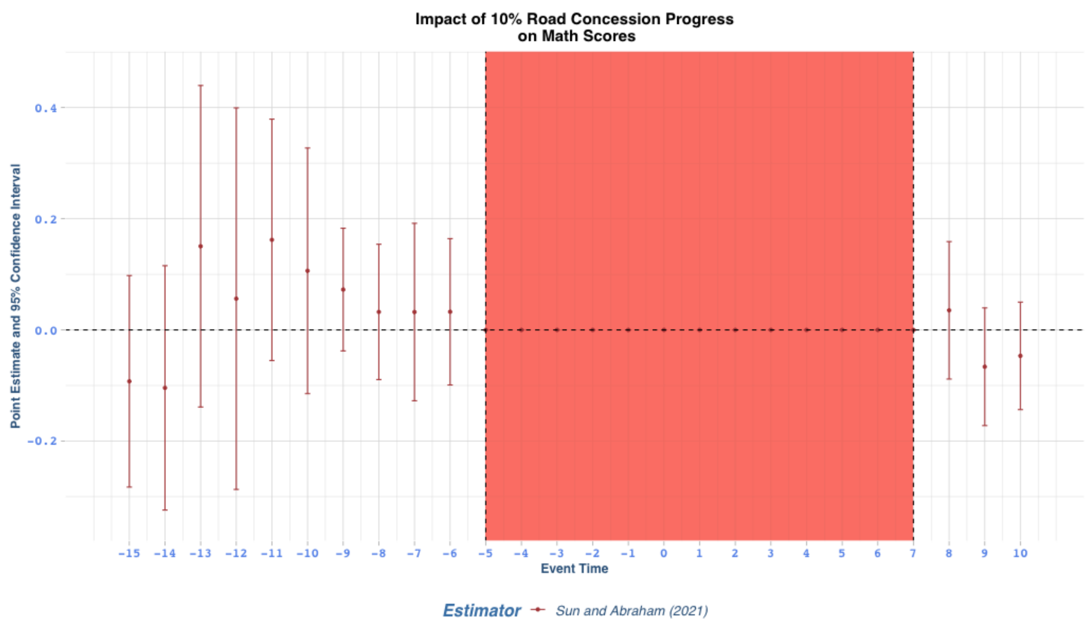


Figure 10: Impact of Road Construction on Standardized Math Scores (10% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

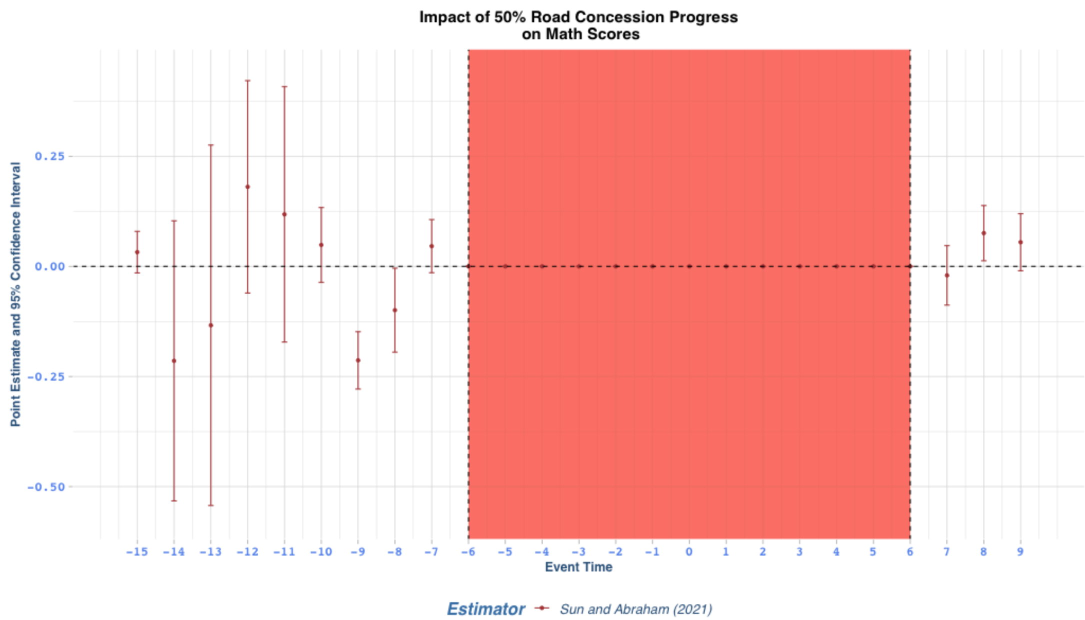


Figure 11: Impact of Road Construction on Standardized Math Scores (50% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

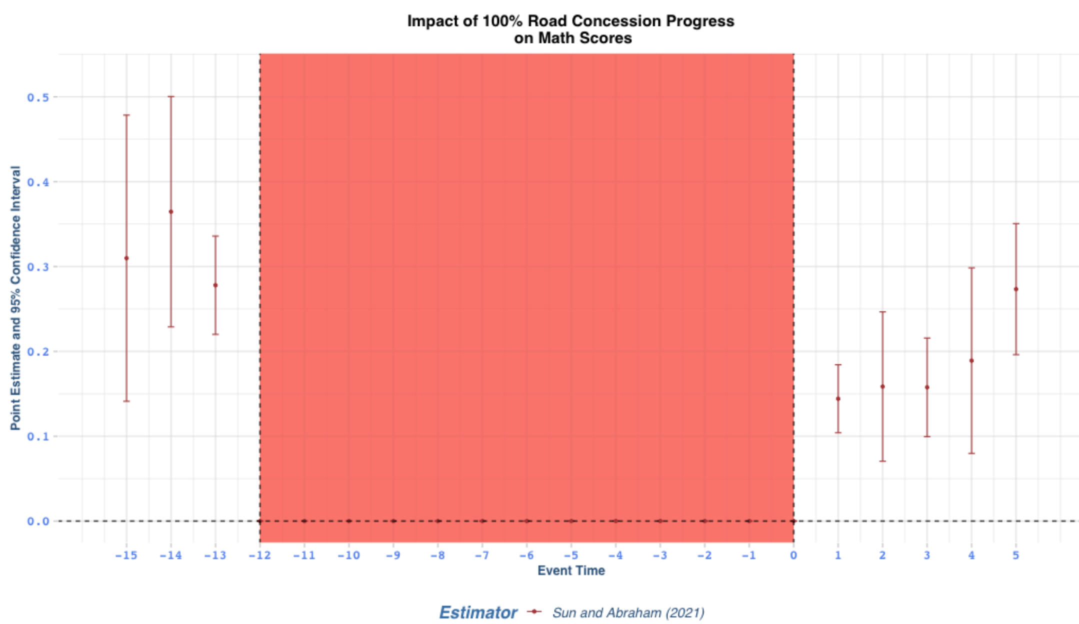


Figure 12: Impact of Road Construction on Standardized Math Scores (100% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

A.2.2 Reading Results

Table 14: Dynamic DiD Estimation for Reading Scores

Relative Time Period	0% Completion	10% Completion	50% Completion	100% Completion
-15		-0.0925 (0.0971)	0.0323 (0.0241)	0.4326 (0.0784)
-14		-0.1043 (0.1121)	-0.2145 (0.1622)	0.4160 (0.0600)
-13		0.1505 (0.1475)	-0.1337 (0.2088)	0.3099 (0.0353)
-12		0.0562 (0.1751)	0.1806 (0.1230)	0.1667 (0.0239)
-11		0.1620 (0.1108)	0.1182 (0.1479)	0.00 (0.00)
-10	-0.0709 (0.0941)	0.1063 (0.1127)	0.0487 (0.0433)	0.00 (0.00)
-9	0.1342 (0.1326)	0.0725 (0.0563)	-0.2133 (0.0332)	0.00 (0.00)
-8	0.0849 (0.1310)	0.0324 (0.0621)	-0.0994 (0.0486)	0.00 (0.00)
-7	0.1097 (0.1004)	0.0322 (0.0814)	0.0460 (0.0308)	0.00 (0.00)
-6	0.1183 (0.0893)	0.0326 (0.0672)	0.00 (0.00)	0.00 (0.00)
-5	0.0964 (0.0548)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
-4	0.0478 (0.0604)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
-3	0.0092 (0.0743)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
-2	-0.0009 (0.0649)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1250 (0.0177)
2	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1390 (0.0391)
3	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1325 (0.0234)
4	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.1574 (0.0481)
5	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.2401 (0.0327)
7	0.00 (0.00)	0.00 (0.00)	-0.0204 (0.0345)	
8	0.00 (0.00)	0.0352 (0.0631)	0.0755 (0.0320)	
9	0.00 (0.00)	-0.0663 (0.0540)	0.0549 (0.0330)	
10	0.00 (0.00)	-0.0467 (0.0493)		
11	-0.0788 (0.0721)			
12	-0.1099 (0.0507)			
13	-0.1258 (0.0379)			
14	-0.1383 (0.0441)			

Note: This table presents the average treatment effect on the treated (ATT) estimates for standardized math scores at key time periods relative to road construction completion, using the Sun & Abraham (2021) estimator. The treatment group consists of schools located within 1500 meters of a road project. Standard errors are in parentheses. The red "0.00 (0.00)" entries indicate reference periods that are excluded from the estimation to avoid collinearity and identify the treatment effects. The "never treated" cohorts, which only have negative RPs, act as the baseline reference group. The "always treated" cohorts have been removed from the analysis (represented by empty cells in the table).
Significance codes: *** p ¡ 0.001, ** p ¡ 0.01, * p ¡ 0.05, . p ¡ 0.1

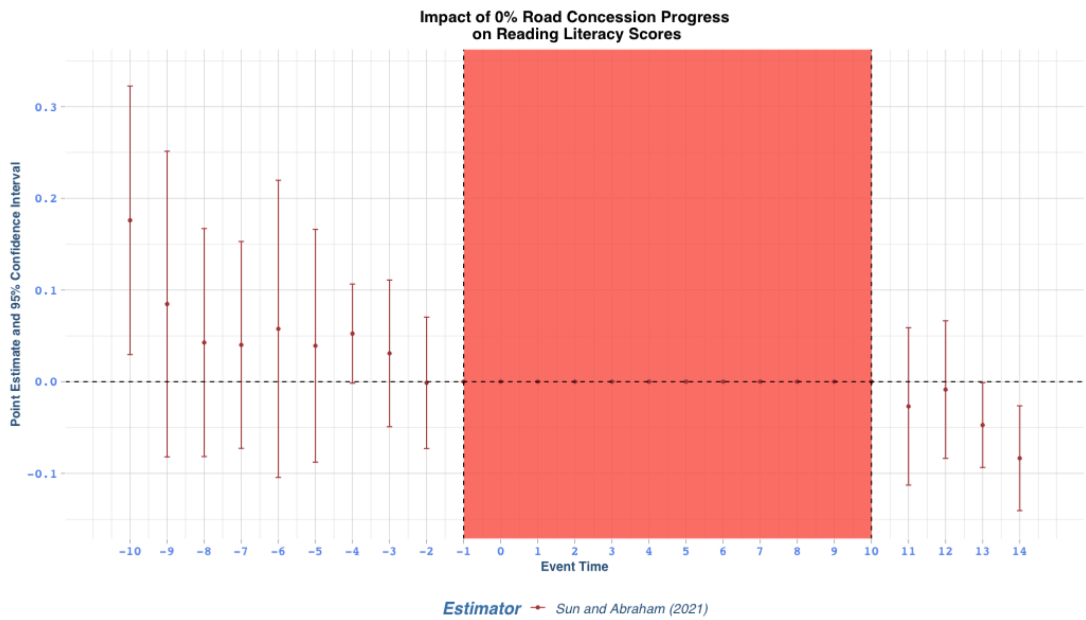


Figure 13: Impact of Road Construction on Standardized Reading Literacy Scores (0% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

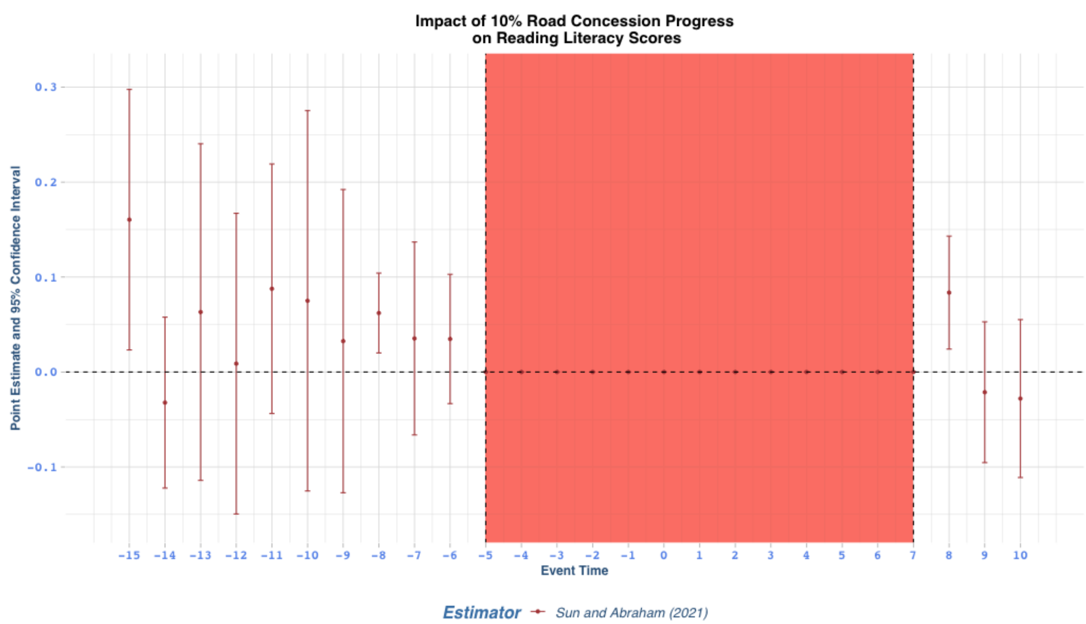


Figure 14: Impact of Road Construction on Standardized Reading Literacy Scores (10% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

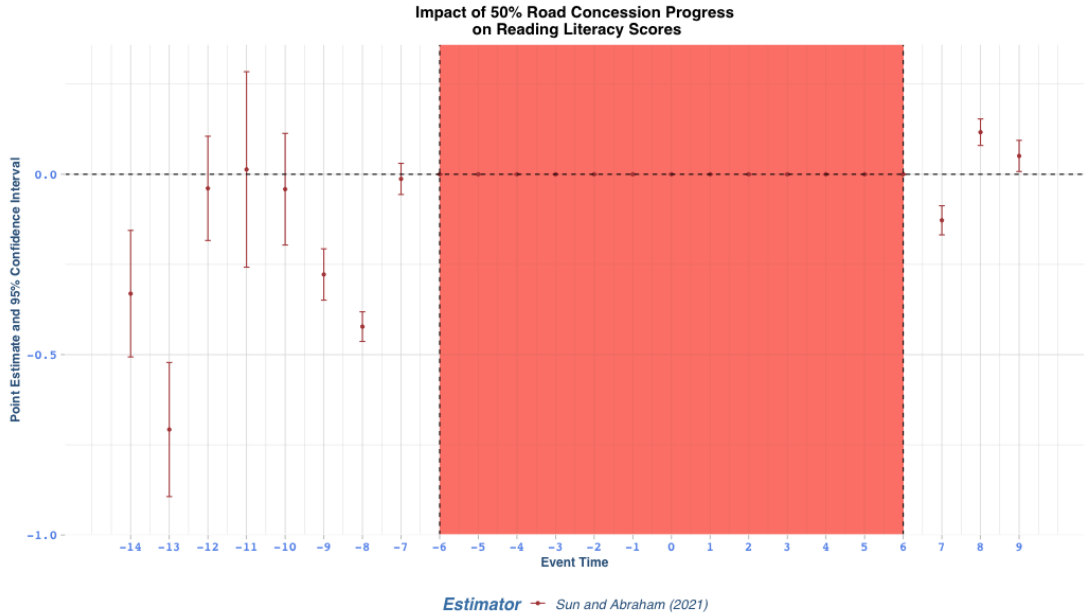


Figure 15: Impact of Road Construction on Standardized Reading Literacy Scores (50% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

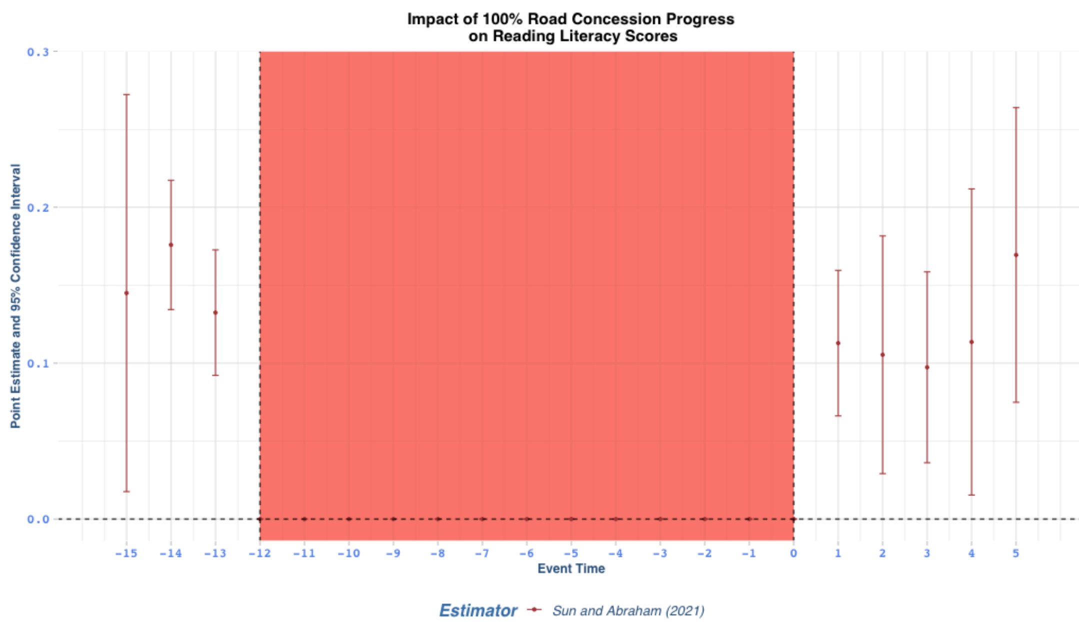


Figure 16: Impact of Road Construction on Standardized Reading Literacy Scores (100% Completion). The shaded area indicates the reference periods excluded from the estimation to avoid collinearity and identify the treatment effect, as these periods are considered part of the road construction process.

A.2.3 Child Labor Index

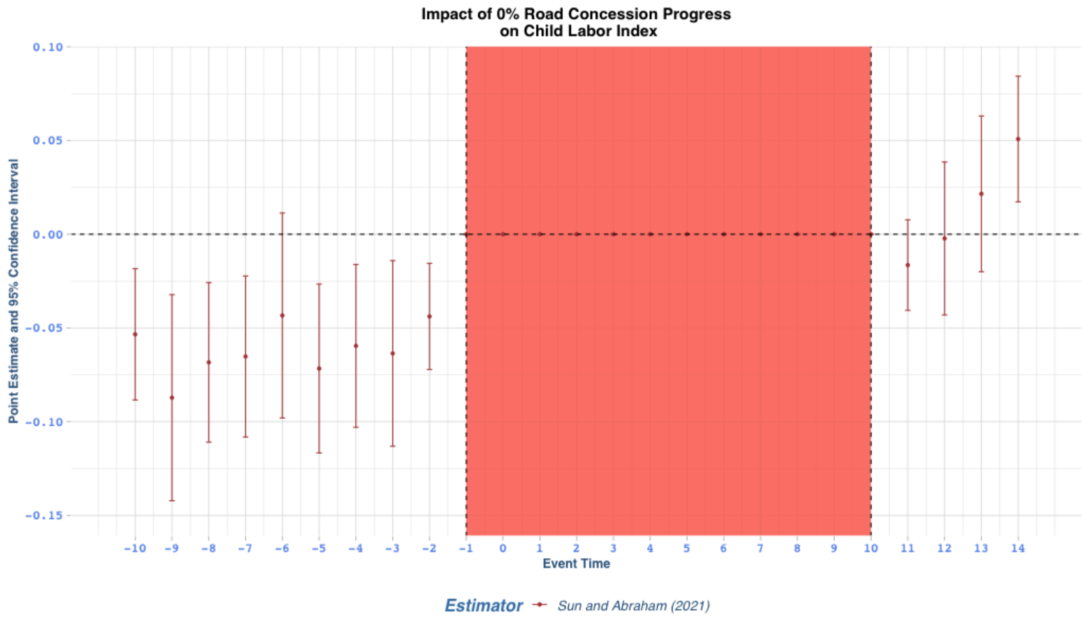


Figure 17: Impact of Road Construction on Child Labor Index (0% Completion). This figure shows the estimated average treatment effect on the treated (ATT) for the Child Labor Index in each year relative to the start of road projects. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

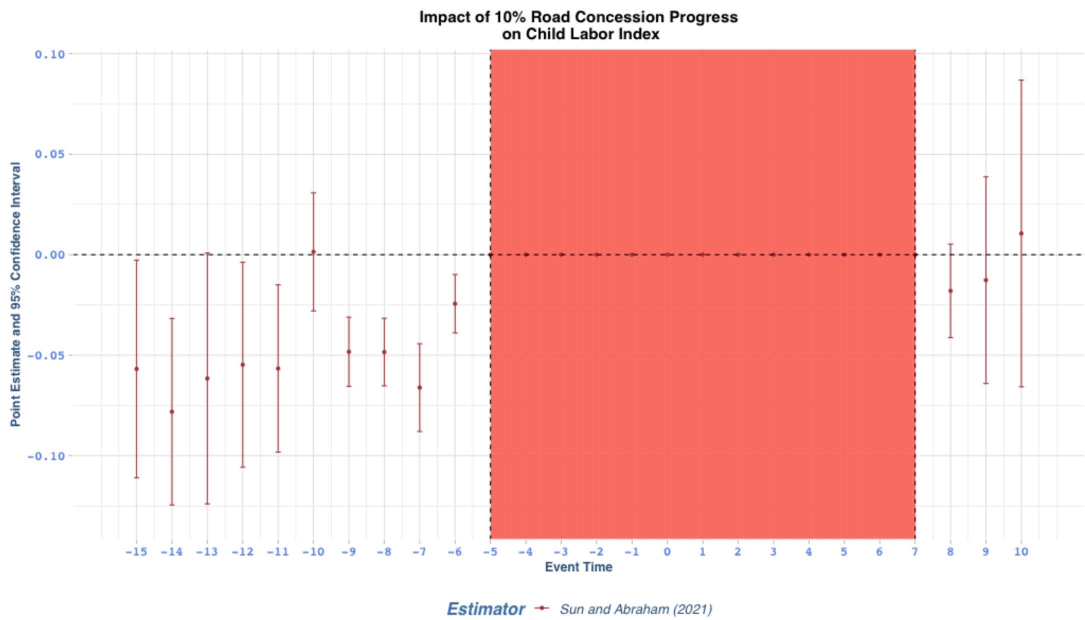


Figure 18: Impact of Road Construction on Child Labor Index (10% Completion). This figure shows the estimated ATT for the Child Labor Index in each year relative to the year when the road project reaches 10% completion. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

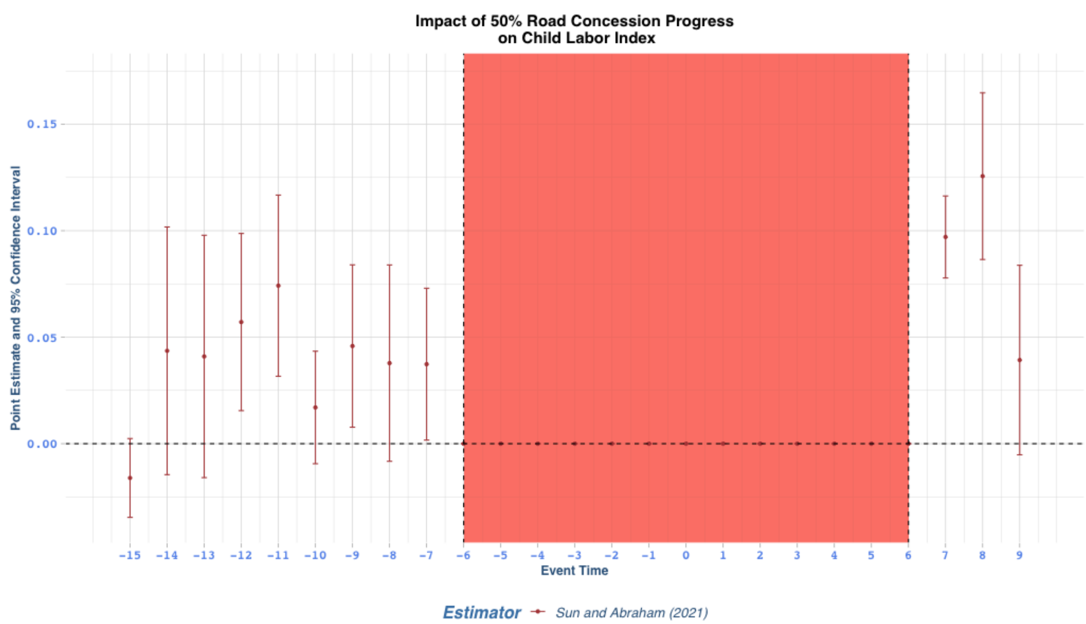


Figure 19: Impact of Road Construction on Child Labor Index (50% Completion). This figure shows the estimated ATT for the Child Labor Index in each year relative to the year when the road project reaches 50% completion. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

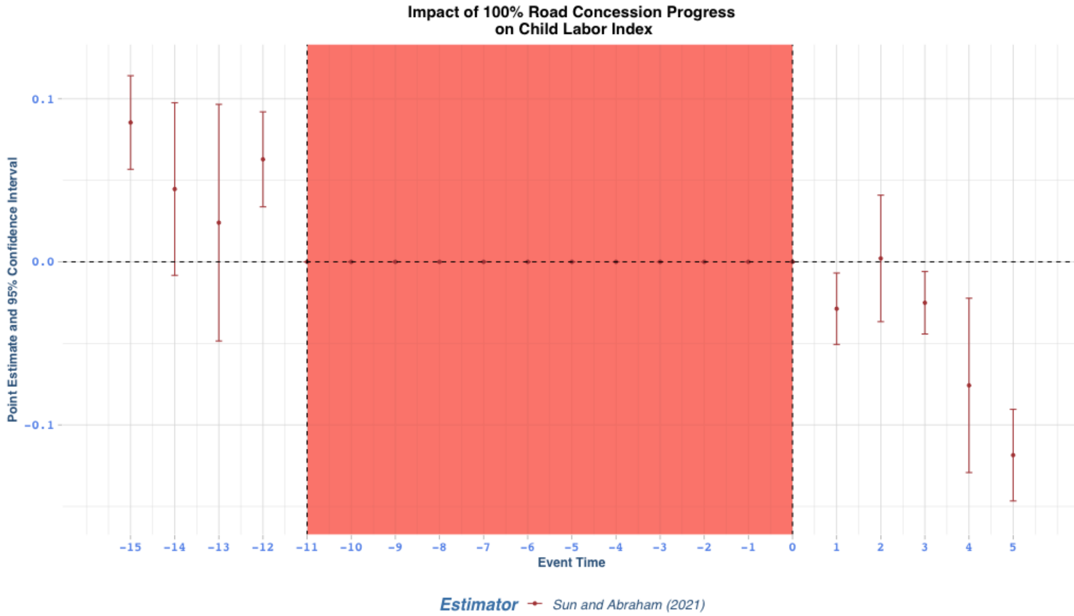


Figure 20: Impact of Road Construction on Child Labor Index (100% Completion). This figure shows the estimated ATT for the Child Labor Index in each year relative to the year when the road project is fully completed. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

A.2.4 Human Capital Accumulation Index

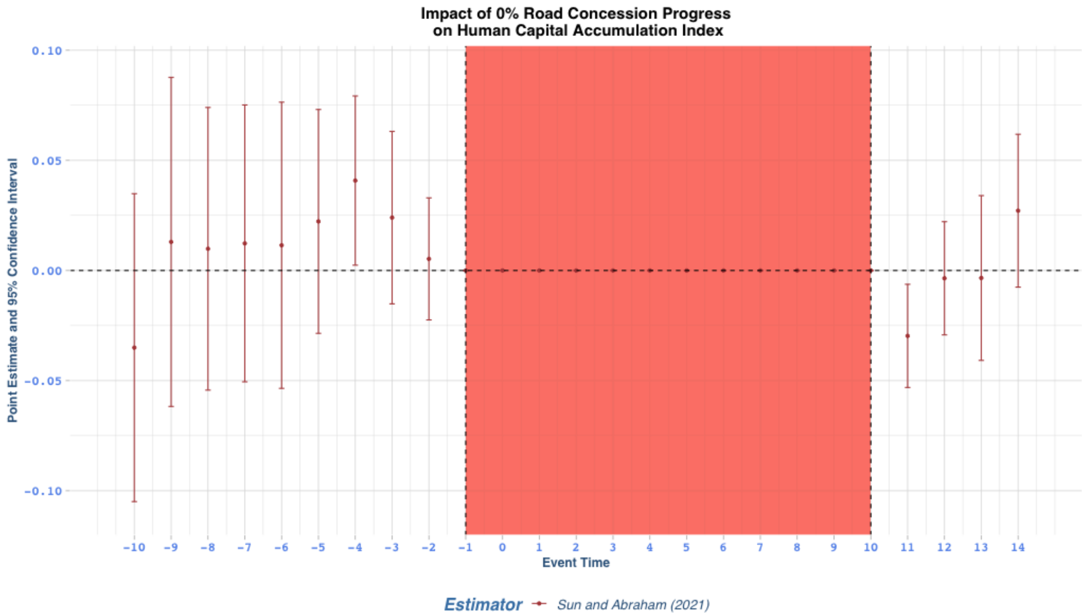


Figure 21: Impact of Road Construction on Human Capital Accumulation Index (0% Completion). This figure shows the estimated ATT for the Index in each year relative to the start of road projects. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

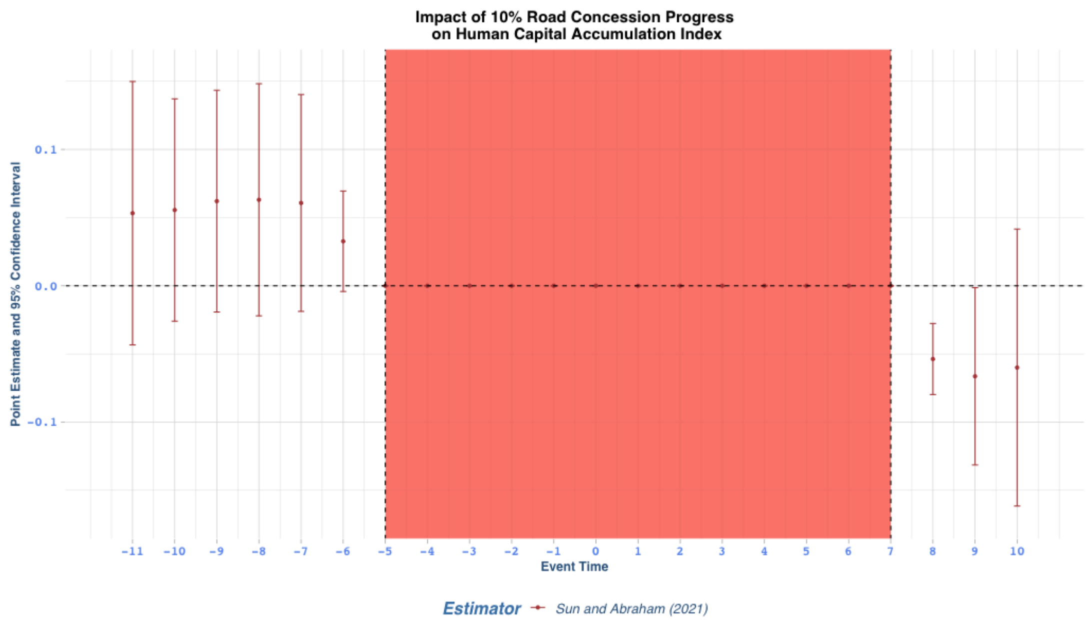


Figure 22: Impact of Road Construction on Human Capital Accumulation Index (10% Completion). This figure shows the estimated ATT for the Index in each year relative to the year when the road project reaches 10% completion. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

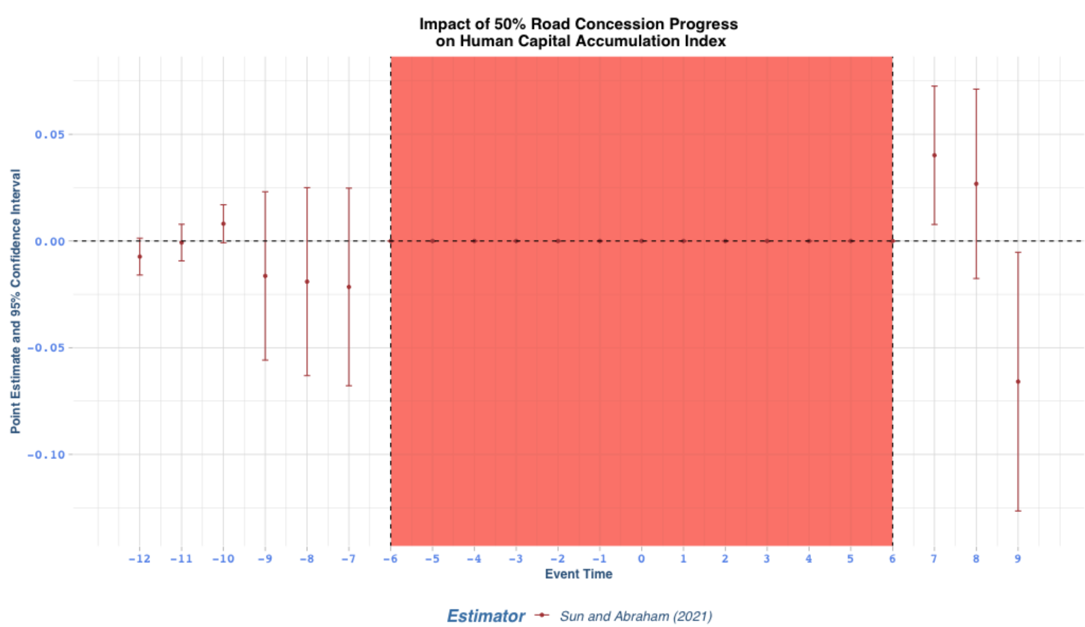


Figure 23: Impact of Road Construction on Human Capital Accumulation Index (50% Completion). This figure shows the estimated ATT for the Index in each year relative to the year when the road project reaches 50% completion. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

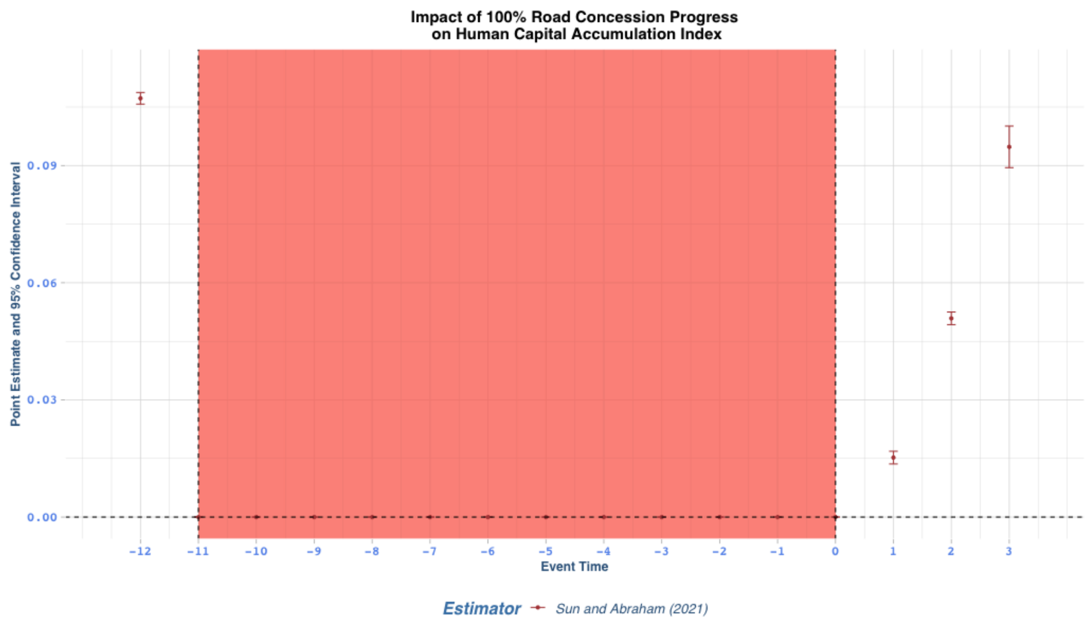


Figure 24: Impact of Road Construction on Human Capital Accumulation Index (100% Completion). This figure shows the estimated ATT for the Index in each year relative to the year when the road project is fully completed. The shaded area indicates the reference periods excluded from the estimation. Error bars represent 95% confidence intervals.

The results of the Reading literacy score for all the different stages of construction are found in table A.2.4.2, these estimation are based on Sun and Abraham (2021) estimation.

Table A.2.2 Reading literacy score for all the different stages of construction

Dependent Variable:	Reading literacy		
Model by level of construction :	10 % advance	50 % advance	100 % advance
Variables			
year = -8	-0.3852**	-0.0521	-0.0552
	(0.1915)	(0.0651)	(0.0608)
year = -7	0.2824***	-0.0701	-0.1408**
	(0.1017)	(0.0594)	(0.0635)
year = -6	-0.0934	-0.0622	0.0795
	(0.0919)	(0.0596)	(0.0693)
year = -5	0.0283	-0.0131	0.0293
	(0.0702)	(0.0571)	(0.0630)
year = -4	-0.0446	0.0176	0.0857
	(0.0714)	(0.0523)	(0.0590)
year = -3	-0.0094	0.1078**	0.0621
	(0.0666)	(0.0540)	(0.0558)
year = -2	-0.0173	0.0580	0.1121*
	(0.0568)	(0.0465)	(0.0584)
year = 0	0.0381	0.0459	0.1219**
	(0.0562)	(0.0453)	(0.0551)
year = 1	0.1691***	0.1074**	0.0841
	(0.0611)	(0.0452)	(0.0526)
year = 2	0.1027*	0.1474***	0.0630
	(0.0587)	(0.0506)	(0.0735)
year = 3	0.0888	0.1097**	-0.0247
	(0.0610)	(0.0519)	(0.0718)
year = 4	0.0917	0.0335	
	(0.0666)	(0.0718)	
year = 5	0.1497**	-0.1309	
	(0.0615)	(0.1534)	
year = 6	0.1640**	-0.1449	
	(0.0666)	(0.1471)	
year = 7	0.1752***	-0.0966	
	(0.0643)	(0.1423)	
year = 8	0.2455**		
	(0.0982)		
Fixed-effects			
id_name	Yes	Yes	Yes
year	Yes	Yes	Yes
Fit statistics			
Observations	5,882	5,882	5,843
R^2	0.74701	0.74888	0.74911
Within R^2	0.01748	0.01502	0.00854

Clustered (id_name) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

The table indicates the mean estimation effect and in parenthesis the standar desviation on reading scores. The columns clasify the results by the percetanje of completeness. The rows clasify the results acording to the year relative to the intervention. The last rows present the fit statistics.

The results of the Reading literacy score for all the different stages of construction are found in table A.2.4.3, these estimates are based on Sun and Abraham, 2021 estimation.

Table A.2.3 Fraction of students who participate in labor force for all the different stages of construction

Dependent Variable:	Fraction of students who participate in labor force		
Model by level of construction :	10 % advance	50 % advance	100 % advance
Variables			
year = -8	0.3341*	0.0429	0.1899*
	(0.1894)	(0.0866)	(0.0966)
year = -7	0.1566	0.3807***	-0.0574
	(0.3387)	(0.0985)	(0.0787)
year = -6	0.0765	0.0685	0.0028
	(0.1561)	(0.0815)	(0.0843)
year = -5	-0.0458	0.0578	0.1307
	(0.1150)	(0.0788)	(0.0986)
year = -4	0.0415	0.0709	0.0286
	(0.0910)	(0.0756)	(0.0820)
year = -3	0.2354***	0.0228	0.0773
	(0.0819)	(0.0653)	(0.0846)
year = -2	0.0879	-0.0199	0.0933
	(0.0945)	(0.0528)	(0.0941)
year = 0	-0.0100	0.0872	-0.0015
	(0.0670)	(0.0661)	(0.0812)
year = 1	-0.0506	0.0482	-0.1120
	(0.0687)	(0.0779)	(0.0829)
year = 2	-0.0279	-0.1970***	-0.0700
	(0.0790)	(0.0759)	(0.1469)
year = 3	-0.0699	-0.2323***	0.0070
	(0.0825)	(0.0784)	(0.1439)
year = 4	0.0377	0.0151	
	(0.0947)	(0.1105)	
year = 5	-0.0143	0.1681	
	(0.0922)	(0.2386)	
year = 6	-0.3295***	-0.3180	
	(0.0876)	(0.2464)	
year = 7	-0.2900***	0.1621	
	(0.0868)	(0.2181)	
year = 8	-0.2143**		
	(0.1088)		
Fixed-effects			
id_name	Yes	Yes	Yes
year	Yes	Yes	Yes
Fit statistics			
Observations	5,882	5,882	5,843
R^2	0.47454	0.47006	0.46806
Within R^2	0.03010	0.02145	0.00789

Clustered (id_name) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

The table indicates the mean estimation effect and in parenthesis the standar desviation on labor force. The columns clasify the results by the percetanje of completeness. The rows clasify the results acording to the year relative to the intervention. The last rows present the fit statistics.

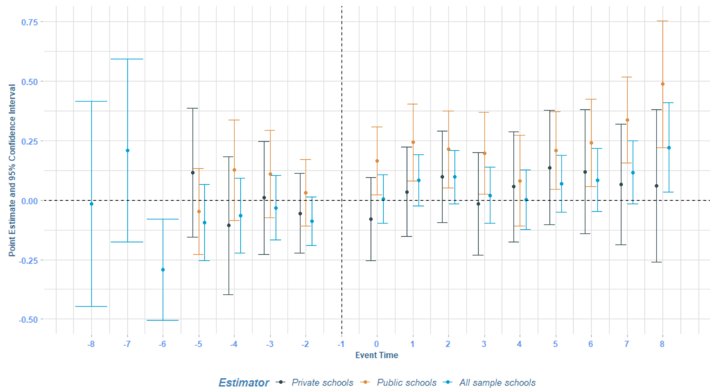
Table A.2.4 Fraction of students that finished some university level for all the different stages of construction

Dependent Variable:	Fraction of students that finished some university level	
Model by level of construction :	10 % advance	50 % advance
Variables		
year = -3	0.0016	-0.1275
	(0.0499)	(0.1112)
year = -2	0.0525	0.0038
	(0.0521)	(0.1437)
year = 0	0.0946^{*}	-0.2892
	(0.0523)	(0.1876)
year = 1	0.1415^{***}	0.1260
	(0.0534)	(0.1359)
year = 2	0.1342^{**}	
	(0.0633)	
Fixed-effects		
id_name	Yes	Yes
year	Yes	Yes
Fit statistics		
Observations	3,101	3,101
R^2	0.67737	0.66500
Within R^2	0.00350	0.00206

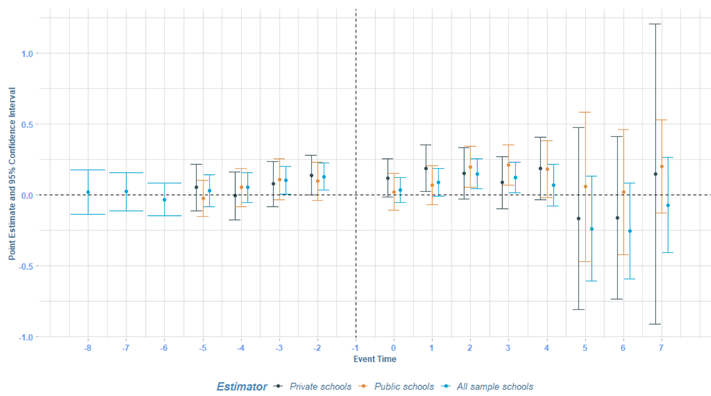
Clustered (id_name) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

The table indicates the mean estimation effect and in parenthesis the standar desviation on the fraction of students that finished some univeristy level. The columns clasify the results by the percetanje of completeness. The rows clasify the results according to the year relative to the intervention. The last rows present the fit statistics.

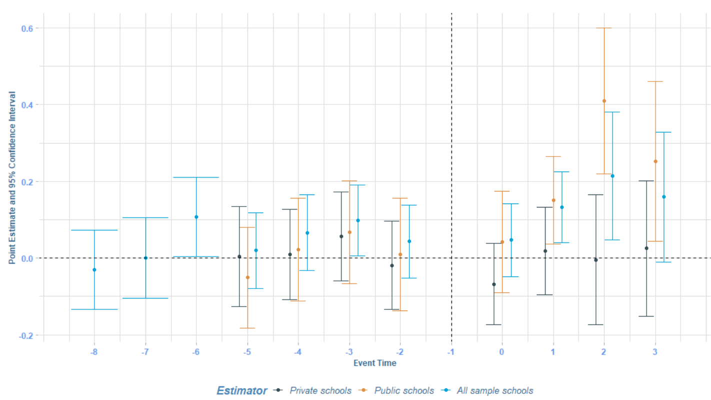
A.3 Otros resultados



(a) 10 % advance of construction

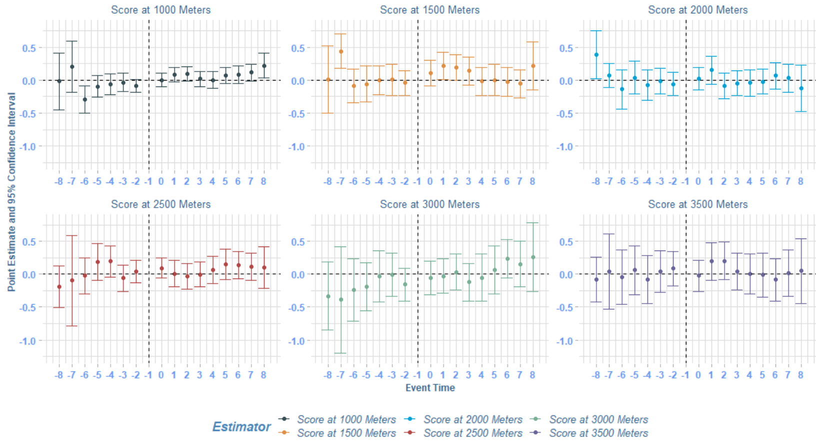


(b) 50 % advance of construction

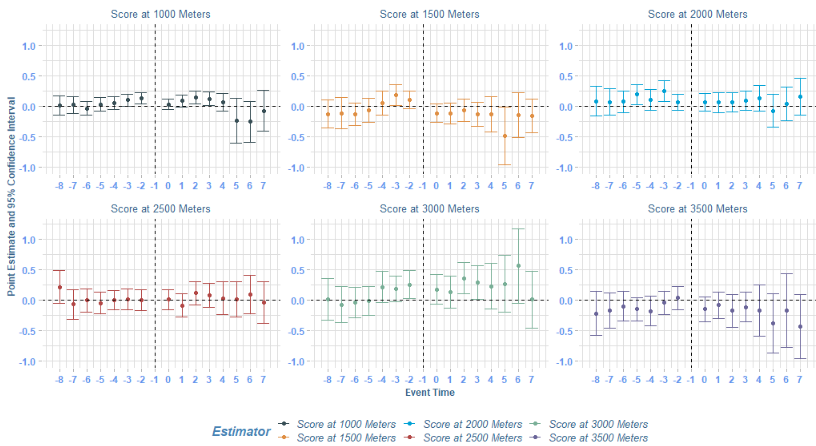


(c) 100 % advance of construction

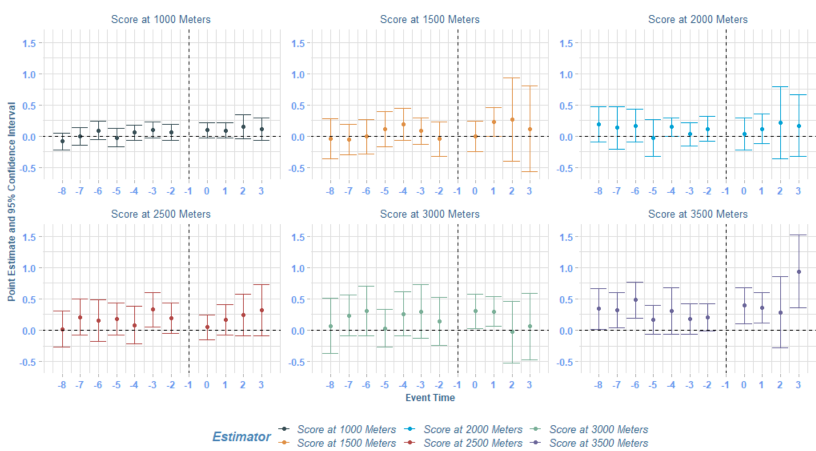
Figure A.3.1: Estimation of heterogeneities (Sun and Abraham (2021) estimator) in mathematics results according to the nature of the school



(a) 10 % advance of construction

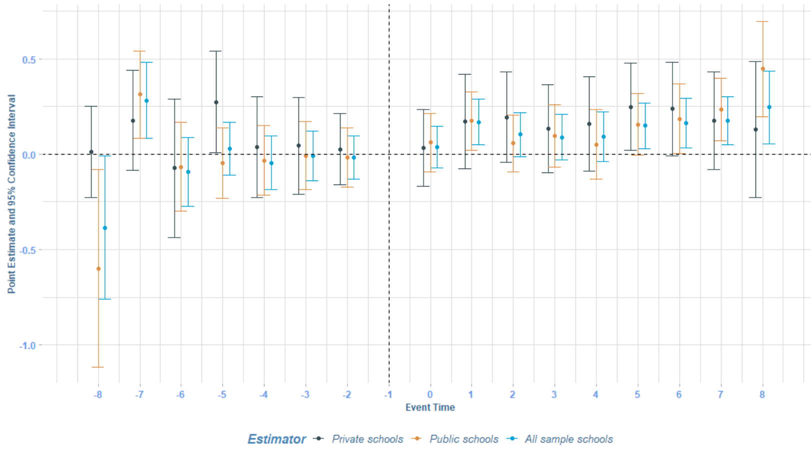


(b) 50 % advance of construction

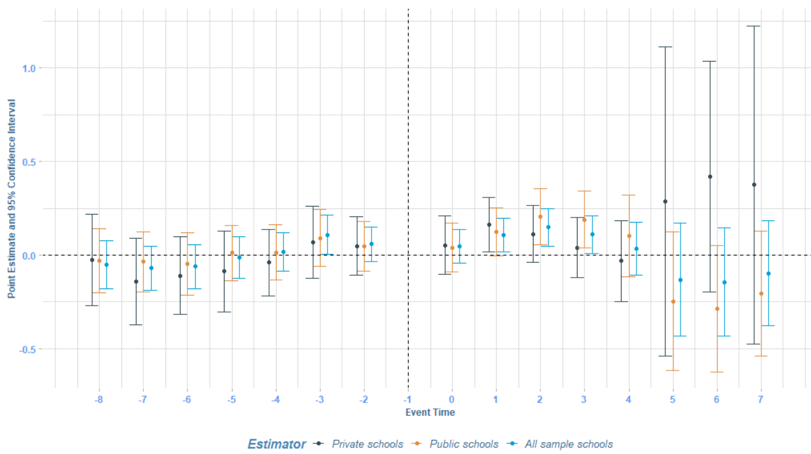


(c) 100 % advance of construction

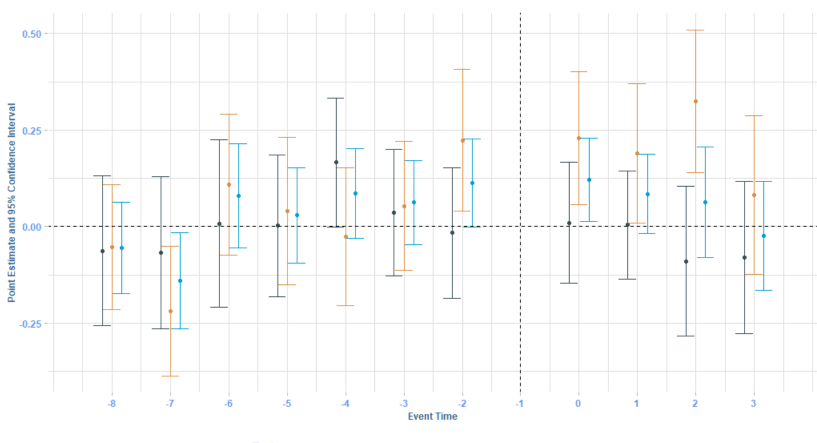
Figure A.3.2: Impact of road construction on math score by distance of school from road in Math Result



(a) 10 % advance of construction

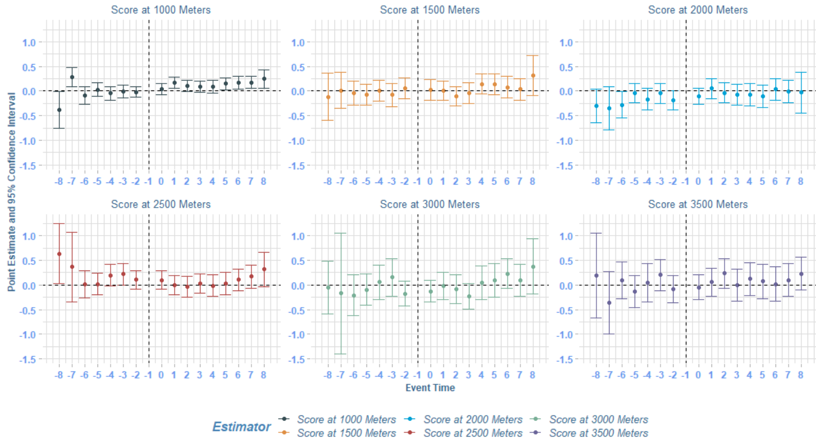


(b) 50 % advance of construction

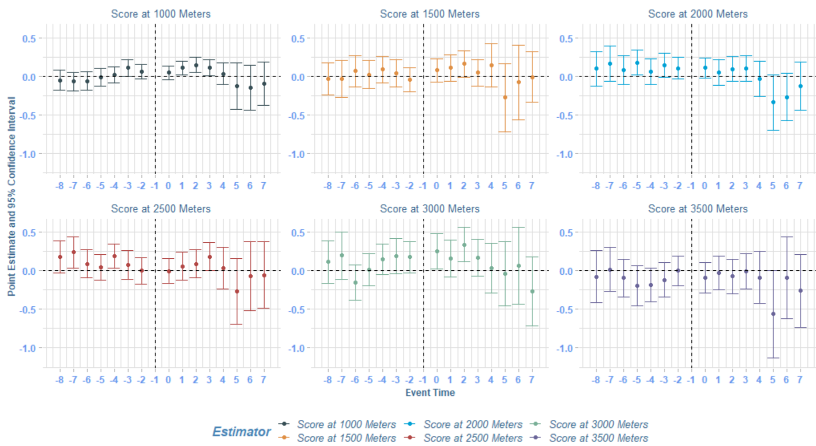


(c) 100 % advance of construction

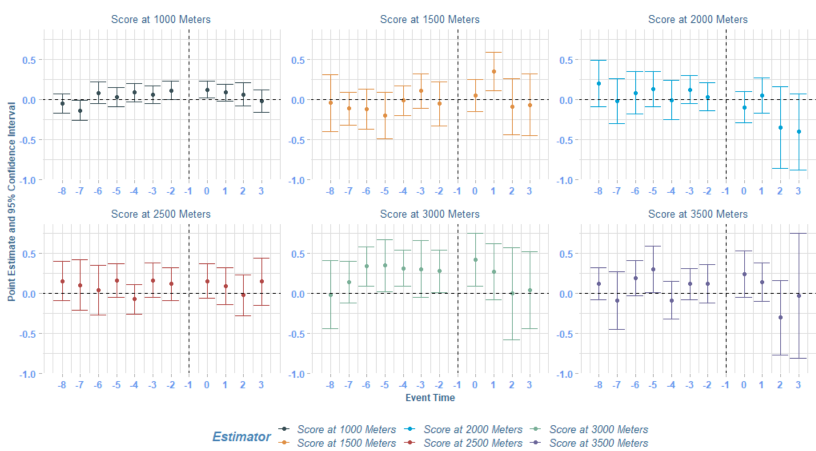
Figure A.3.3: Heterogeneities in reading literacy score of students by nature of the school



(a) 10 % advance of construction

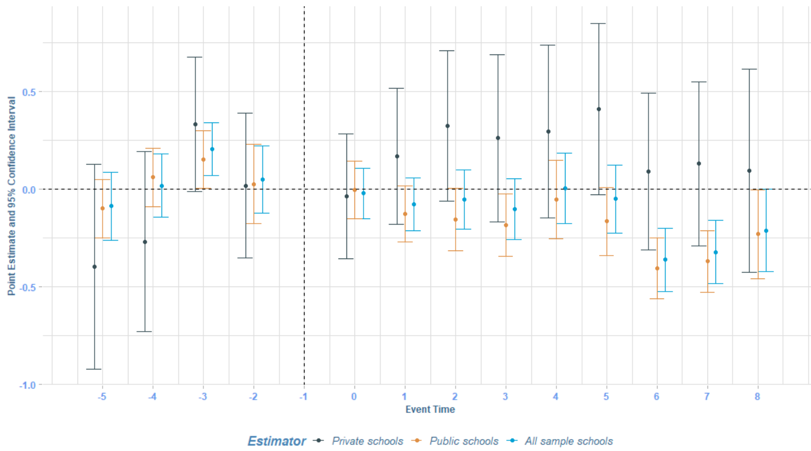


(b) 50 % advance of construction

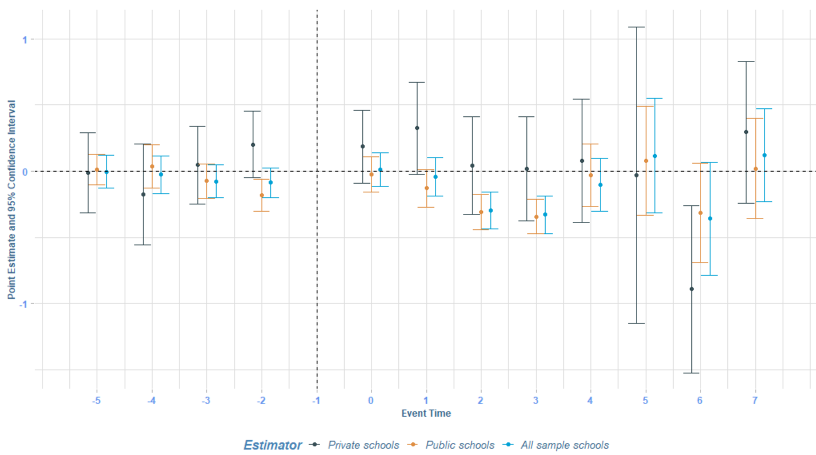


(c) 100 % advance of construction

Figure A.3.4: Impact of road construction on reading literacy score by distance of school from road

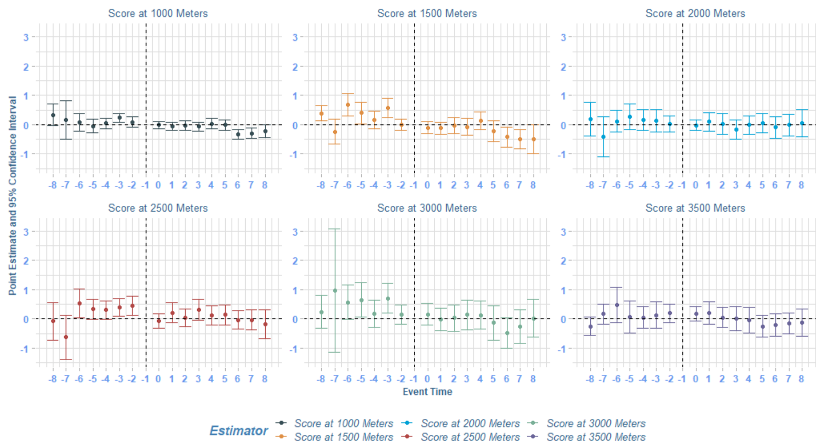


(a) 10 % advance of construction

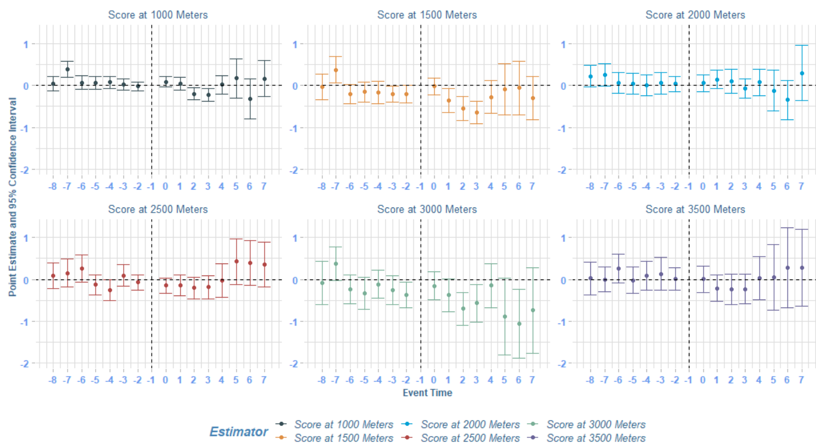


(b) 50 % advance of construction

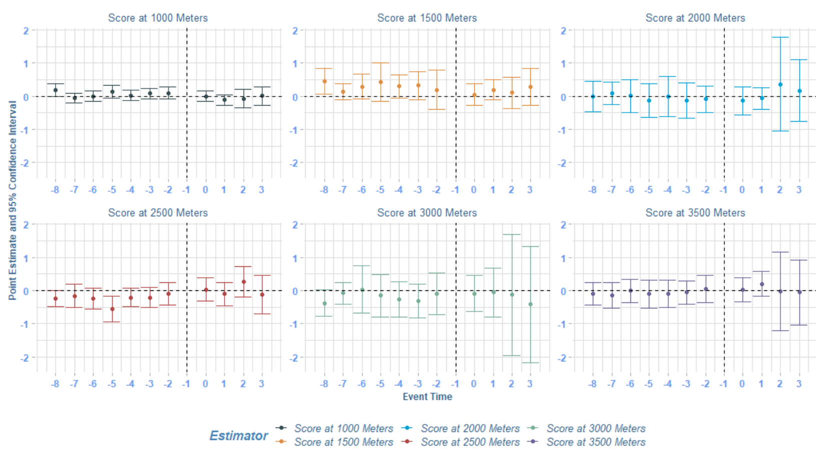
Figure A.3.5: Heterogeneities of fraction of students in labor force by nature of the school



(a) 10 % advance of construction



(b) 50 % advance of construction



(c) 100 % advance of construction

Figure A.3.6: Impact of road construction on school share of labor force participation by distance of school from road.