

Gender-specific impacts of road accessibility on rural development

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ABSTRACT

This study examines the impact of road accessibility on socio-economic and infrastructure outcomes in rural areas, with a focus on gender-specific effects. Using data from Oaxaca, Mexico from the 2010 and 2020 censuses and the CONEVAL Accessibility Index, which combines geographic proximity and social factors, the research identifies significant correlations between improved road access and reductions in unemployment, particularly among women, as well as increases in educational attainment. Specifically, a 1.7 % decrease in unemployment and a 0.21-year increase in average schooling were observed per unit increase in accessibility. These findings highlight the critical role of road infrastructure in addressing gender-specific barriers to employment and education in rural contexts. By applying a novel methodological approach, this study contributes to development studies and transport geography scholarship, offering valuable insights for policymakers aiming to promote inclusive and sustainable development in underserved regions.

1. Introduction

Transportation infrastructure is a critical driver of economic development, particularly in rural areas where economic opportunities (Fagbemi et al., 2022), access to job markets (Mu and Van de Walle, 2011; Duranton and Turner, 2012; Foster et al., 2023), healthcare (Canning and Schultz, 2012), education (Zhao and Barakat, 2015; Aggarwal, 2018; Asher and Novosad, 2020; Zhu et al., 2023), and other essential services can be improved. Roads often serve as vital conduits that connect isolated communities to broader economic and social networks (Asher and Novosad, 2020).

In Mexico, rural communities, sometimes face substantial challenges due to geographic isolation and inadequate infrastructure. Oaxaca is one of the most marginalized states in the country, characterized by high poverty rates, low levels of education, and limited access to basic services such as electricity, water, and healthcare (INEGI, 2020). The lack of adequate transportation infrastructure exacerbates these issues, making it difficult for residents to access opportunities that could improve their socio-economic conditions. Despite the well-documented benefits of transportation infrastructure, there is a notable gap in the literature concerning the impact of road accessibility on rural communities in Mexico, particularly in Oaxaca. This study aims to address this

gap by examining the socio-economic and infrastructure-related outcomes associated with road accessibility in Oaxaca using data from the 2010 and 2020 censuses (INEGI, 2010, 2020) and the CONEVAL Accessibility Index (CONEVAL, 2018, 2021b). This index—developed by CONEVAL (*Consejo Nacional de Evaluación de la Política de Desarrollo Social*, National Council for the Evaluation of Social Development Policy)—measures road accessibility by considering both geographic proximity and social factors that affect people's access to paved roads.

Existing studies are rarely set in the context of a marginalized Mexican subnational entity and often overlook the gendered impacts of infrastructure development, despite evidence that suggests women benefit disproportionately from improved access to transportation networks (Ghani et al., 2014). The gendered impacts of improved road infrastructure are particularly pronounced in rural Oaxaca, where women face additional socio-economic barriers, including lower labor force participation rates and limited access to services (Maravalle and Pandiella, 2022). According to INEGI (2020), the female labor force participation rate in rural Oaxaca is less than half that of men, and women have half a year less of education on average than men. These disparities are linked to geographic isolation and lack of transportation options, which restrict women's ability to access employment and schooling. Improved road connectivity can alleviate these barriers by

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reducing travel times to schools and healthcare facilities and by enabling women to access employment opportunities in urban centers. Studies in other developing nations, such as rural India (Aggarwal, 2018) or Vietnam (Mu and Van de Walle, 2011), suggest that road improvements disproportionately benefit women by increasing access to education and formal employment. The lack of region-specific and gender-disaggregated data on the impact of road accessibility in the Mexican context hinders the development of targeted policies that could effectively address the unique challenges faced by some communities. This study addresses this critical research gap by providing an empirical analysis of the impact of road accessibility on unemployment, educational attainment, and infrastructure development in rural Oaxaca, with a focus on gender-specific outcomes.

The primary objective of this study is to quantify the impact of road accessibility on various socio-economic and infrastructure-related outcomes in rural Oaxaca. Specifically, the study examines how changes in the CONEVAL Accessibility Index between 2010 and 2020 are associated with changes in unemployment rates, educational attainment, and the availability of basic services such as electricity and internet access. Using an Ordinary Least Squares (OLS) regression model with a fixed-effects specification applied to panel data, we find generally positive effects associated with better road accessibility, with a decrease of 1.7 % per unit increase in the accessibility index score, and an increase in average years of schooling by up to 0.21 years per unit increase in accessibility.

These findings suggest that improved road accessibility is a crucial factor in enhancing socio-economic conditions and infrastructure development in rural areas and make this article an important contribution to transport geography scholarship. This study is among the first to use the CONEVAL Accessibility Index in academic research, providing a novel methodological approach to evaluating the impact of road infrastructure in a developing country context. By focusing on Oaxaca, this research contributes to Latin American scholarship by offering insights into how improved road access can drive socio-economic development in one of Mexico's most disadvantaged regions.

2. Literature review

2.1. Economic development and measuring accessibility

The concepts of remoteness, accessibility, and rurality are often used interchangeably but differ significantly. Rurality typically measures population density and proximity to urban areas (Bollman and Reimer, 2019). Rural areas can also be defined through their functional characteristics, such as economic reliance on primary industries, limited access to markets, and distinct patterns of social and cultural organization (Wiggins and Proctor, 2001). These dimensions offer a nuanced understanding of rurality, emphasizing the unique socio-economic functions that distinguish rural areas from urban spaces. Definitions vary globally: the U.S. and England use a threshold of 10,000 inhabitants (Ingram and Franco, 2014; Bibby and Brindley, 2013), while Canada defines rural areas as those with fewer than 1000 inhabitants (Statistics Canada, 2016). Accessibility has been defined as “the potential for opportunities for interaction” (Hansen, 1959); this explanation encompasses all the previously mentioned terms and allows for the particularization of accessibility in specific sectors such as health, economy, energy, or transportation. This is interesting, since research has shown that road accessibility is a critical determinant of socio-economic outcomes, particularly in rural contexts. Olsson (2009) find that road connection improves employment outcomes by allowing better job matching between localities, while Jacoby and Minten (2009) find that better roads in Nepal facilitate economic growth by lowering transportation costs. In a recent article, Gertler et al. (2024) demonstrate that improved road infrastructure in rural Indonesia reduced poverty and increase educational attainment using a fixed-effects regression model.

When discussing accessibility from a sectoral perspective, it is important to define the term “remote.” In the literature, this term is often conceptualized as peripheral to urban areas in terms of distance, but also in social, economic, and cultural terms (Roberts and Guenther, 2021). In economic terms, remoteness can be studied by measuring the distance between a locality and the nearest trade centers or, in other words, how far it is from potential commercial partners (Duran Duran Fernandez, 2008). In the health sector, it can be assessed based on the accessibility to health services and specialized care through geographic distance or the time required to reach these services (Wakeman and Humphreys, 2008). Access to energy is evaluated by whether there is access to modern cooking fuels (such as natural gas) and sufficient electricity to light the home (Modi et al., 2005). For the transportation sector, remoteness can be measured by evaluating accessibility to various services, including transportation services (Bhat et al., 2002), or in other words, the opportunities to access other community-used services. Sector-specific indices are instrumental in contextualizing accessibility's impact. Khandker et al. (2009), using an OLS fixed-effects model with various transport-related indicators, demonstrate how rural road improvements in Bangladesh increased economic opportunities by enhancing connectivity to urban centers. Zhao and Barakat (2015) further illustrated how transport infrastructure affected educational accessibility in rural China, emphasizing that such indices must account for localized barriers, including seasonal travel limitations and socio-economic vulnerabilities. Given these different definitions, measuring accessibility is highly context dependent. Accessibility indices each have their strengths and weaknesses, which should be considered to avoid biased conclusions (Stringer et al., 2023).

When choosing an accessibility index to measure economic development, one should account for changes in transportation and land use over time, as well as individual needs, opportunities (for employment, social interaction, or recreation for example) and abilities within the population (Geurs and Wee, 2013). Additionally, it is important to note that each measure provides a unique perspective on accessibility that cannot be captured by any other measure (Kwan, 1998; Thill and Kim, 2005; Neutens et al., 2010). That said, accessibility measures typically follow these recommendations as they generally consist of two components: the cost of transportation (determined by the spatial distribution of the population using transportation and opportunities) and the ratio of quantity and quality of opportunities. In other words, what can be derived from these measures is the relationship between the transportation network and the geographic distribution of activities (Páez et al., 2012), as well as whether the indicator is normative or positive.¹

¹ Páez et al. (2012) classify accessibility measures into two categories: normative, defined as how far people ought to travel or how far it is reasonable for people to travel, and positive, which are based on the actual experiences of individuals traversing space to engage in out-of-home activities. Table A1 in the Appendix shows some examples of positive and normative indices found in the literature. For example, in Europe, accessibility tends to be higher in Central Europe, particularly around Germany, and diminishes as one moves away from this core area. This normative observation reflects expected patterns based on geographical distribution and infrastructure (Baradaran and Ramjerdi, 2001). Factors like transportation costs and gravity-type measures, which are normative, often perform poorly in border regions due to low population density and limited infrastructure. In a different example, a positive measure can be seen in the study by Deboosere and El-Geneidy (2018), which developed an accessibility metric for low-income jobs for vulnerable individuals. Their findings, based on real data, show that while Toronto offers greater accessibility to regular jobs, Montreal provides better opportunities for vulnerable people, likely due to the concentration of vulnerable groups near city centers and major public transport corridors. Generally, normative measures provide standardized assessments based on expected patterns and infrastructure, positive measures offer insights based on actual experiences and data. Both perspectives are essential to fully understand accessibility and its impact on different populations.

Various indices have been developed to quantify rurality, accessibility, and remoteness, each employing different methodologies that typically measure the level of difficulty in accessing economic opportunities. Accessibility indices based on a very specific measure are not uncommon. Some examples include the average number of supermarkets per square kilometer (Apparicio et al., 2008), availability of at least one dentist within 10 miles of a town (Horner and Mascarenhas, 2007), number of grocery stores within an individual’s typical travel distance (Páez et al., 2010), or the number of jobs that can be reached within a certain time frame (Deboosere and El-Geneidy, 2018). More universal indices, such as road distance-based indicators (Government of Australia, I, et al., 2001) and population-based indices (Zhao and Guthridge, 2008), are also common. Other methods measure service availability (Alasia et al., 2017; Jo et al., 2021), estimate average travel costs accounting for seasonal variation (Stringer and Kim, 2023), use GIS techniques (Luo and Qi, 2009; Luo and Wang, 2003), or analyze satellite imagery of light pollution (Zangeneh et al., 2020).

Hamelin’s Polar Value (VAPO) index, created in 1968, was a pioneering effort in quantifying remoteness through a comprehensive ten-criteria scale (Hamelin, 1975). Modern indices like the Australian ARIA (Government of Australia, I, et al., 2001) and Canada’s Remoteness Index (RI) (Alasia et al., 2017) build on these foundations. The ARIA index is widely used for evaluating access to services and socio-economic outcomes in Australia, while RI incorporates travel cost to better capture socio-economic isolation. Despite their utility, existing indices have limitations and are not universally applicable. Typically, a clear objective or application should be defined when choosing the right index (Stringer et al., 2023).

Fixed-effects OLS regression has been a standard approach in quantifying the effect of roads on economic development (Khandker et al., 2009; Donaldson, 2018; Rokicki and Stępnia, 2018; Banerjee et al., 2020; Stringer and Joanis, 2022; Gertler et al., 2024), this study applies this methodology in a novel context by combining it with the CONEVAL Accessibility Index to examine gender-disaggregated impacts and educational outcomes. Such combinations have not been explored in the rural Mexican setting, providing new insights into how accessibility influences socio-economic outcomes. While studies like Banerjee et al. (2020), Khandker et al. (2009), Gertler et al. (2024) and Donaldson (2018) have analyzed transport accessibility in other parts of the Global South, the focus on rural Latin America, coupled with gender-disaggregated outcomes, marks a distinct contribution to development studies and transport geography.

2.2. The CONEVAL accessibility index

In Mexico, CONEVAL (*Consejo Nacional de Evaluación de la Política de Desarrollo Social*, National Council for the Evaluation of Social Development Policy) is an organization dedicated to studying accessibility using poverty indices. The index the organization created for measuring road accessibility is known as “Grado de accesibilidad a carretera pavimentada” or “Degree of accessibility to paved road”. In this article, we will refer to this index as the CONEVAL Accessibility Index. CONEVAL defines accessibility as “a complex concept that integrates two distinct dimensions: the geographical, which corresponds to the physical proximity between two points and considers elements related to orographic and natural features, and the social, which takes into account the characteristics of the people or services being accessed” (CONEVAL, 2021a).

According to the classification of accessibility indicators (Páez et al., 2012) in the previous subsection, CONEVAL’s definition of accessibility includes a structured, theoretical framework that integrates both geographical and social dimensions. It doesn’t focus on the actual experiences or behaviors of individuals but rather on the conceptual and standardized understanding of accessibility as influenced by physical and social factors. This approach aligns with normative measures, which are designed to assess accessibility based on predefined criteria or

standards, rather than empirical data on how people experience accessibility in practice. The indicator described in this section reflects this normative definition of accessibility.

As shown in Table 1, based on CONEVAL’s definition of accessibility (CONEVAL, 2021a), localities are classified into 5 categories. The percentage of the population falling into the “low” and “very low” categories is one of the metrics used to determine the level of poverty at the state and municipal levels.

These grades of accessibility are obtained using a Latent Class Analysis, which is a statistical procedure used to identify different groups within a sample that share certain characteristics (Weller et al., 2020). The analysis is conducted using values from three additional variables: distance to a paved road, availability of public transport and access to a service center. The points that can be attributed to each of these variables are shown in Table 2. CONEVAL attributes these points to each of these 3 variables and calculates the index score from 1 to 5 for each locality in Mexico.

This index is different than other indices mentioned in the previous subsection in that it does not just account for travel times or distances, but also accounts for the availability of public transport and the quality of the road in attributing points to the distance of the nearest paved road. Indices such as Canada’s Remoteness Index (Alasia et al., 2017) or Australia’s ARIA index (Government of Australia, I, et al., 2001) account for travel time/cost and distance respectively but have no integration of roadway quality or public transit factors. In the context of rural Mexico, where most people do not own cars, as seen in the descriptive statistics below, availability of public transit becomes very important. In this sense, the CONEVAL Accessibility Index is particularly interesting when evaluating accessibility in a developing country. While used in Mexico, this index is virtually unknown outside of the country, which makes this article a great conduit for its visibility to a larger audience.

2.3. Road development in Mexico and the state of Oaxaca

Investing in building roads has been shown in past literature to foster economic development. Investments in transportation infrastructure have been used as policy tools, especially during periods of economic decline, to stimulate the economy (Melo et al., 2013). These investments directly affect the construction sector, which in turn generates positive impacts on other sectors such as education, health, materials, transportation, and the economy overall (Brocker and Rietveld, 2009; Fagbemi et al., 2022).

These economic benefits can be attributed to several factors, including job creation from road infrastructure projects (Nying’iro, 2023), the connectivity of raw materials with markets and producers, and the promotion of socioeconomic interaction between groups and

Table 1
Grades of the CONEVAL Accessibility Index (CONEVAL, 2021a).

Degree of Accessibility	Score	Characteristics
Very Low	1	Small, isolated communities (53 people on average), 2–50 km away from paved roads with no access to basic services (water and electricity).
Low	2	1–10 km away from a paved road, no public transport, and more than 2 h to reach the municipal center; usually 1 h away from a community of 15,000 people or more.
Medium	3	Within 2–3 km of a paved road, mostly no access to public transport, and 1–2 h away from a community of 15,000 people or more.
High	4	One km or less away from a paved road, most have public transport, and it takes 60 min or less to reach the municipal center; usually 1 h away from a community of 15,000 people or more.
Very High	5	High population density, better accessibility to paved roads, public transport, and proximity to the municipal center.

Table 2
Variables and scores for CONEVAL Accessibility Index components (CONEVAL, 2021a).

Variable	Score	Description
Distance to paved road	3	≤ 1000 m
	2	> 1000 and < 2000 m
	1	≥ 2000 m
Availability of Public Transport	5	Localities with 2500 inhabitants or more, or that are the municipal center, or where travel time by public transport to the municipal center is less than 20 min.
	4	Travel time by public transport to the municipal center is between 20 min and 1 h.
	3	Travel time by public transport to the municipal center is more than 1 h but less than 1.5 h.
	2	Travel time by public transport to the municipal center is more than 1.5 h but less than 2 h, or availability and travel time are not specified.
	1	No public transport, or travel time by public transport to the municipal center is more than 2 h.
Travel time to a service center	5	Less than 1 h
	4	1 to 2 h
	3	2 to 3 h
	2	3 to 4 h
	1	More than 4 h

societies (Luo et al., 2021). Better healthcare services (Canning and Schultz, 2012), and education (Zhao and Barakat, 2015; Aggarwal, 2018; Asher and Novosad, 2020; Zhu et al., 2023) have also been demonstrated through better road access. There is a trend of socioeconomic development driven by road infrastructure. The integration of two or more regions—whether countries, states, or cities—with roads leads to enhanced trade and investment in various sectors is promoted, leading to a positive impact on the region’s overall economic development (Schindler and Kanai, 2019; Owusu-Manu et al., 2019; Ng et al., 2019). Therefore, it is crucial to consider the development of roads alongside social indicators to reinforce this positive economic impact.

For Mexico, road development has had positive effects on the gross regional output of manufacturing activities and retail trade (Ortega et al., 2019). From an industrial perspective, this implies a significant increase in the average product of labor in the manufacturing sector. Improved international accessibility leads to higher productivity, while poor road quality can hinder economic performance. As such, greater accessibility has been associated with the wider diffusion of technology, and better production in the country (Duran-Fernandez and Santos, 2014).

Mexican road development dates back to the Spanish Colonial period (1521–1810), during which roads were built to connect resource extraction areas with Veracruz, from where goods were sent to Spain. During the *Porfiriato*, or the period when Porfirio Díaz ruled Mexico from 1884 to 1911, significant economic resources were allocated to connect the country through railways, leaving no budget for a road network, resulting in no road development during this period (Bess, 2016b). The Mexican Revolution (1910–1920) led to the destruction of approximately 4000 km of roads leading to the capital, causing a setback in road connectivity (Bess, 2016b). In the following decade, leaders focused on developing thousands of kilometers of roads in collaboration with the private sector (Bess, 2016a). The 1940s promised significant industrial development, making road development a priority as it would improve accessibility in certain regions and open new markets (Bess, 2014).

The construction of the first highway (Mexico City–Acapulco) under President Miguel Alemán (1946–1952) was a milestone, as it became a model that set the standard for future highways that would connect the country. Foreign investment boosted road construction. During the 1960s, President López Mateos allocated a budget of 300 million pesos for building new roads (Bess, 2017). Under the presidency of Carlos Salinas de Gortari (1988–1994), 5800 km of roads were built, mainly

funded by private investment (Foote, 1997). Following this effort, no significant actions were taken until the administration of Felipe Calderón (2006–2012), during which more than 23,000 km of roads were built and repaired as part of a program to combat rural poverty. This was a clear example of how roads were used as a policy tool for economic development. The most recent important initiative was the National Infrastructure Program, which projected investments greater than those made in the previous 20 years (Pérez Cervantes and Hernández, 2015); the most ambitious goal of this program focused on the southern part of the country, which suffers from severe socioeconomic deficiencies.

Southern Mexico is characterized by higher poverty and socioeconomic disparity (Dávila et al., 2002). Oaxaca is one of the poorest states of this region. In 2018, 66.4 % of the population in the region lived in poverty (CONEVAL, 2020). Oaxaca is one of the three states (along with Guerrero and Chiapas) with the least access to paved roads (CONEVAL, 2021b). The geographical location the state, along the Sierra Madre del Sur mountain range, with rugged terrain, makes many of their communities less accessible. Economic activities in Oaxaca are primarily concentrated in the Isthmus and Central Valleys regions. The state’s geographic dispersion presents significant challenges for infrastructure development and its terrain complicates infrastructure projects (Rojas-Ramírez and Molina-Vargas, 2018). For this reason, Oaxaca has one of the lowest levels of accessibility for its citizens. The government has made efforts to connect communities in Oaxaca through the Priority Rural Roads Program (Secretaría de Comunicaciones y Transportes, 2021). During the last decade, several thousand kilometers of roads have been built in the state. Fig. 1 shows localities in the state of Oaxaca by CONEVAL grade of accessibility in 2010, while Figure shows them in 2020. In these two figures, each locality is represented by a dot. The colour of the dot refers to an index score between 1 and 5, that of the CONEVAL grade of accessibility, as seen in each map’s legend. We can see that there is an important change in the number of localities with low or very low accessibility scores. This makes the state a prime candidate in analyzing the effect of this growth in accessibility. (See Fig. 2.)

To date, despite a huge push to encourage road construction in Oaxaca, no study examines whether these investments have improved living conditions or foster economic development in this state. While existing studies have extensively explored the concepts of remoteness, accessibility, and rurality, particularly in developed countries, there remains a significant research gap in the context of developing regions like Southern Mexico, where infrastructure challenges are more pronounced. Specifically, the impact of road accessibility on socioeconomic outcomes in Oaxaca—a region with unique geographic and economic characteristics—has not been adequately studied. This article addresses this gap by using the Accessibility Index to empirically analyze how road improvements in Oaxaca have influenced key socio-economic indicators such as unemployment, education, and infrastructure development between 2010 and 2020. The study contributes to the field by providing a novel methodology tailored to the context of a developing region, offering valuable insights for policymakers aiming to improve living standards in similarly disadvantaged areas.

3. Materials and methods

To conduct our study, we apply an Ordinary Least Squares regression model to census data from INEGI (*Instituto Nacional de Estadística, Geografía e Informática*), and accessibility index scores from CONEVAL (*Consejo Nacional de Evaluación de la Política de Desarrollo Social*), for 2010 and 2020, for localities in the State of Oaxaca. This section describes the data and the model that were used.

3.1. Census and accessibility data

To conduct our study, we use data from two sources. The first is census data obtained from INEGI’s, 2010 and 2020 Census of Population

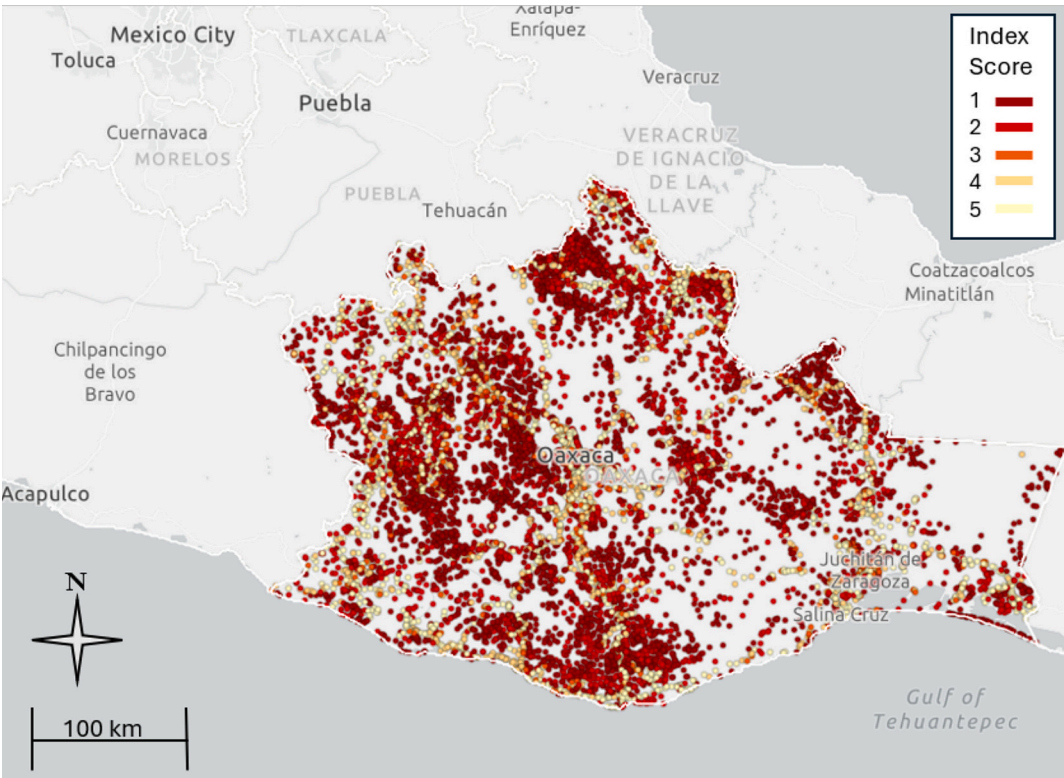


Fig. 1. Localities in the Mexican State of Oaxaca; by CONEVAL Grade of Accessibility index scores; 2010 (CONEVAL, 2024).

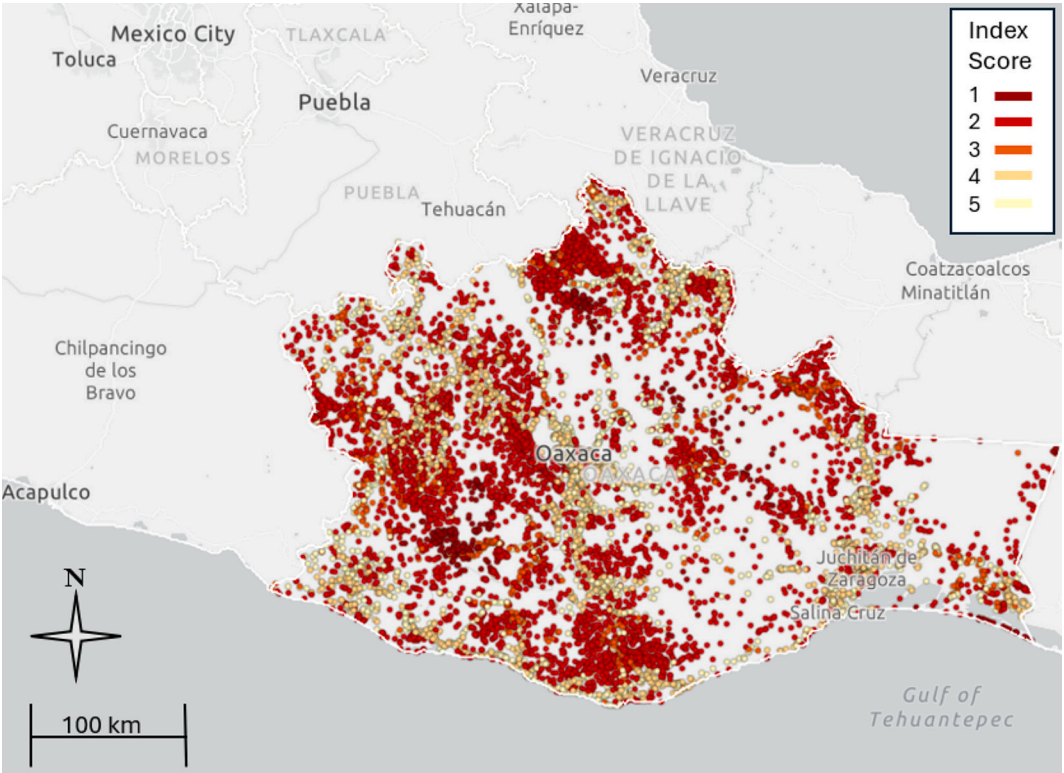


Fig. 2. Localities in the Mexican State of Oaxaca; by CONEVAL Grade of Accessibility index scores; 2020 (CONEVAL, 2024).

and Household (INEGI, 2010, 2020; available at: <https://www.inegi.org.mx/programas/ccpv/>). The variables used in our study for which data was collected in the census are described in Table 3.

The second is accessibility index score data obtained from the databases made available online by CONEVAL (2018, 2021b, available at: <https://www.coneval.org.mx/Medicion/Paginas/>

Table 3
Census variables for which data was collected.

Variable	Description
Dependent Variables	
Accessibility Score	Index score as defined by CONEVAL from 1 to 5 that describes the level of accessibility of a community.
Unemployment Rate	Population over the age of 12 that is not economically active divided by the total population.
Unemployment Rate (Male)	Male population over the age of 12 that is not economically active divided by the total male population over 12 years old.
Unemployment Rate (Female)	Female population over the age of 12 that is not economically active divided by the total female population over 12 years old.
Average Years of Schooling	Total completed years of schooling for the population over 15 years old in a locality divided by the total population.
Average Years of Schooling (Male)	Total completed years of schooling for the male population over 15 years old in a locality divided by the total male population over 15 years old.
Average Years of Schooling (Female)	Total completed years of schooling for the female population over 15 years old in a locality divided by the total female population over 15 years old.
Average Live Births	Total live births for the female population over 12 years old divided by the total female population over 12 years old.
Percentage of Dwellings with Electricity	Dwellings that have electricity divided by the total number of dwellings.
Percentage of Dwellings with Piped Water	Dwellings that have piped water divided by the total number of dwellings.
Percentage of Dwellings with Internet	Dwellings that have Internet divided by the total number of dwellings.
Population Variables	
Population	Total number of people that declare residence in a locality.
Percentage of Population Born Out of Locality	Population that is not born in the locality divided by the total population of the locality.
Percentage that Identifies as Indigenous	Dwellings that declare themselves to be indigenous divided by the total number of dwellings.
Consumption Variables	
Percentage of Dwellings with a TV	Dwellings that have a television divided by the total number of dwellings.
Percentage of Dwellings with a Refrigerator	Dwellings that have a refrigerator divided by the total number of dwellings.
Percentage of Dwellings with a Washer	Dwellings that have a washer divided by the total number of dwellings.
Percentage of Dwellings with a Car	Dwellings that have a car divided by the total number of dwellings.

[Grado_accesibilidad_carretera.aspx](#)), calculated from data from 2010 and 2020. We combine the two sets of data by using the unique locality codes used by both INEGI and CONEVAL. While 2020 is the most recent census year available, we acknowledge that more recent local dynamics may not be captured in our analysis. Future research could complement these findings with field studies or alternative data sources to validate post-2020 trends. The sample of localities we use is based on the following selection rules regarding a locality:

- It is geographically located in the State of Oaxaca
- It has a population in 2020 between 1 and 2500, based on INEGI's definition of what a rural community is (Zamudio Sánchez et al., 2008).
- It has complete data for all the variables described in Table V for both 2010 and 2020.

After applying these rules, we are left with a sample of 7168 rural localities with data over two periods, and thus 14,336 observations in total. Table 4 in the following section shows the descriptive statistics of the variables for which data was collected for these observations.

Table 4
Descriptive statistics.*

Variables	Year	Mean	Std. Dev.	Coef. Var.	Min	Max
Dependent Variables						
Accessibility Score	2010	2.41	1.53	0.64	1	5
	2020	3.03	1.32	0.43	1	5
Unemployment Rate	2010	57.4 %	13.1 %	0.23	0.0 %	100.0 %
	2020	49.5 %	18.7 %	0.38	0.0 %	100.0 %
Unemployment Rate (Male)	2010	30.0 %	17.4 %	0.58	0.0 %	100.0 %
	2020	28.8 %	18.5 %	0.64	0.0 %	100.0 %
Unemployment Rate (Female)	2010	82.8 %	16.3 %	0.20	0.0 %	100.0 %
	2020	68.7 %	24.3 %	0.35	0.0 %	100.0 %
Average Years of Schooling	2010	5.07	1.58	0.31	0.00	18.23
	2020	6.20	1.71	0.27	0.00	17.45
Average Years of Schooling (Male)	2010	5.40	1.68	0.31	0.00	19.50
	2020	6.44	1.78	0.28	0.00	18.40
Average Years of Schooling (Female)	2010	4.76	1.67	0.35	0.00	17.14
	2020	5.98	1.81	0.30	0.00	17.00
Average Live Births	2010	3.20	0.82	0.26	0.00	10.00
	2020	2.98	0.79	0.26	0.00	15.00
Percentage of Dwellings with Electricity	2010	82.8 %	26.6 %	0.32	0.0 %	100.0 %
	2020	93.3 %	14.1 %	0.15	0.0 %	100.0 %
Percentage of Dwellings with Piped Water	2010	47.4 %	40.4 %	0.85	0.0 %	100.0 %
	2020	81.3 %	30.1 %	0.37	0.0 %	100.0 %
Percentage of Dwellings with Internet	2010	0.7 %	3.9 %	5.46	0.0 %	90.9 %
	2020	11.3 %	15.6 %	1.37	0.0 %	100.0 %
Population Variables						
Population	2010	265.8	362.4	1.36	4	2704
	2020	280.9	386.0	1.37	4	2499
Percentage of Population Born Out of Locality	2010	4.3 %	8.6 %	2.01	0.0 %	100.0 %
	2020	5.1 %	8.8 %	1.71	0.0 %	90.9 %
Percentage that Identifies as Indigenous	2010	53.9 %	43.0 %	0.80	0.0 %	100.0 %
	2020	53.4 %	41.9 %	0.79	0.0 %	100.0 %
Consumption Variables						
Percentage of Dwellings with a TV	2010	52.2 %	27.9 %	0.53	0.0 %	100.0 %
	2020	57.0 %	23.9 %	0.42	0.0 %	100.0 %
Percentage of Dwellings with a Refrigerator	2010	34.8 %	28.1 %	0.81	0.0 %	100.0 %
	2020	49.6 %	28.6 %	0.58	0.0 %	100.0 %
Percentage of Dwellings with a Washer	2010	17.0 %	20.2 %	1.19	0.0 %	100.0 %
	2020	28.6 %	24.4 %	0.85	0.0 %	100.0 %
Percentage of Dwellings with a Car	2010	12.0 %	14.4 %	1.20	0.0 %	100.0 %
	2020	16.1 %	16.0 %	0.99	0.0 %	100.0 %

* N (2010) = 7168; N (2020) = 7168.

3.2. Regression model

Informed by one of the authors' previous research (Stringer and Joanis, 2022), we apply a two-way fixed effects specification to an OLS regression model to quantify the effect of changes in CONEVAL accessibility index scores on locality-level outcomes. We focus on outcomes measures pertaining to unemployment, birth rates, schooling, and infrastructure uptake. Two-way fixed effects models are widely used as an econometric research method for causal inference with panel data (De Chaisemartin and d'Haultfoeuille, 2020; Verdier, 2020; Imai and Kim, 2021; Schmidheiny and Siegloch, 2023). The two-way fixed effects model was chosen for its ability to isolate the effect of accessibility on socio-economic and infrastructure-related outcomes while controlling for unobserved locality-specific and time-specific factors that could confound results. This approach is particularly well-suited for panel data with two time periods, as it ensures that the effects of omitted variables that are constant across time or locality do not bias the estimates (Angrist and Pischke, 2009). Alternative non-linear models, such as logit or probit, were considered; however, they were not implemented because the majority of our dependent variables are continuous, and OLS provides straightforward interpretation for such outcomes. The model we use was tailored to panel data with two periods (2010 and 2020) as the locality level. Our model is as follows:

$$Y_{lt} = \beta_0 + \beta_1 \bullet A_{lt} + \beta_2 \bullet P_{lt} + \beta_3 \bullet C_{lt} + \gamma_t + \delta_l + \varepsilon_{lt}$$

where Y_{lt} is the dependent variable (Unemployment Rate, Unemployment Rate (Male), Unemployment Rate (Female), Average Years of Schooling, Average Years of Schooling (Male), Average Years of Schooling (Female), Average Live Births, Percentage of Dwellings with Electricity, Percentage of Dwellings with Piped Water, Percentage of Dwellings with Internet) measured in locality l at census year t , A_{lt} is the CONEVAL accessibility index score from 1 to 5, P_{lt} is a vector of three additional population-based covariates (Total Population, Percentage of the population born outside of the locality, Percentage of the population that identifies as indigenous), C_{lt} is a vector of four additional consumption-based covariates (Percentage of dwellings with a television, Percentage of dwellings with a refrigerator, Percentage of dwellings with a washer, Percentage of dwellings with a car), γ_t is the fixed effect for each year t , δ_l is the fixed effect for each municipality l , and ε_{lt} is a municipality-year-specific error term.

To assess potential multicollinearity among independent variables, we calculated variance inflation factors (VIFs) for all covariates in the preferred model. The results showed that VIF values were far below the commonly accepted threshold of 10, indicating that multicollinearity is not a concern (Hair, 2009). We also calculated the Pearson coefficients of correlation between the independent variables in each regression specification and only found moderate levels of correlation (0.5 to 0.75) between consumption variables. This finding is unsurprising, as these variables are all indicators of household wealth and socio-economic status, which are conceptually related. We chose to keep these variables, since they together form a vector of covariates that can serve as a rough proxy for measuring the standard of living. Removing one of these variables could lead to omitted variable bias and potentially skew the interpretation of results.

The year fixed effects allow to control for trends in time that are common to all municipalities. The locality fixed effects control for time-invariant factors within a specific locality. Population covariates are included in the model to control for changes in the localities' demographics, namely population growth, migration patterns and changes in indigeneity. Consumption, or standard of living, covariates are included in the model to attempt to control for changes in economic development and disposable income. The logic here is that people in localities that earn more and that have more buying power will likely purchase consumer goods such as home appliances or a vehicle. An estimation with the above model is performed for each dependant

variable, with results displayed in the following section. All analyses were conducted with Stata using fixed-effects panel data functions (version 18).

Additionally, robustness tests are carried out by calculating outcome values using various alternative specifications. These involve three different combinations after omitting year fixed effects and municipality fixed effects, and the two sets of covariates. However, our preferred specification remains the comprehensive model (as detailed in (4) in the Results tables). This preferred model utilizes a robust standard error method called the Driscoll-Kraay method to ensure the error terms are not affected by cross-sectional dependence. Given that we employ panel data from localities that are geographically similar, spatial dependence might be present in the standard error terms of a two-way fixed effects regression model that does not use robust standard errors. The method developed by Driscoll and Kraay (1998) specifically addresses this cross-sectional dependence. Not accounting for such dependence can introduce biases in the standard error estimates. Therefore, we favor this method over other robust standard error methods.

To test the robustness of our model, we use four different specifications and obtain four sets of results for each of the dependent variables for which the model was used. Specification (1) is simply a model with the dependent variable and only the accessibility index score as an independent variable. Specification (2) is the same as (1) but adds time-fixed and locality-fixed effects controls. Specification (3) also adds a vector of population covariates. Finally, Specification (4) also adds a vector of consumption covariates. Tables 6 and 7 in the following section show the results for each of these specifications for socio-economic dependent variables and infrastructure-related dependent variables in the following two subsections. Finally, we acknowledge that the linear nature of the model imposes limitations in capturing potential non-linear relationships between accessibility and outcomes. While approaches such as Generalized Additive Models (GAMs) or machine learning-based causal inference could uncover non-linear dynamics, these were not employed due to the focus on interpretability and policy relevance. By prioritizing simplicity and robustness, this study provides clear and actionable insights while leaving more complex modeling approaches as a promising avenue for future research.

4. Results and discussion

4.1. Descriptive statistics

Table 4 shows the descriptive statistics for the variables for which we collected data for the 7168 localities included in our sample. The statistics are divided by year, for 2010 and 2020. The first aspect to note is that data varies between the two periods. On average, accessibility scores, years of schooling, infrastructure uptake (electricity, piped water, Internet) and consumer goods ownership (television, refrigerator, washer, car) all increase, while unemployment and average live births decrease. All these changes are generally indicative of positive economic development, as better adhesion to services, education, healthcare and goods signal better economic outcomes. Population also increases throughout the sample. The fact that the data shows time trends also justifies the use of time-fixed effects controls in our model.

We can also note important differences in the coefficients of variation, which is equal to the standard deviation of a sample divided by the mean. For most variables, including accessibility index scores, schooling, infrastructure uptake and consumer goods uptake, as conditions improve, the coefficients of variation decrease. This means that there is an overall standardization of conditions for these factors. Curiously, for unemployment, as unemployment rates go down, coefficients of variation increase. This could mean that there is an increased polarization of people to job matching over time, with the disparity between localities becoming more obvious between 2010 and 2020. In any case, there is important variation between localities in the sample, which warrants the use of locality-fixed effect controls to account for time-

invariant characteristics specific to each locality. We also see important differences between localities when it comes to population and consumption variables between 2010 and 2020, which would justify their use as controls in our model.

4.2. Socio-economic outcomes

Table 5 presents regression results evaluating the impact of road construction on various socio-economic outcomes in Oaxaca, using the accessibility index scaled from 1 to 5. The table includes multiple specifications of the regression models, allowing for comparison of results across different dependent variables and model adjustments.

The coefficients for the unemployment rate indicate a decrease across all specifications, suggesting that improved road access is associated with a reduction in unemployment. For instance, in Specification (1), the coefficient is -0.246 , indicating that a one-unit increase in the accessibility index is associated with a 25 % decrease in the unemployment rate. As more covariates are added, the coefficients become substantially smaller (less negative), with Specification (4) showing a coefficient of -0.0172 , or a 1.7 % decrease instead. This indicates that additional factors partially explain the observed changes in unemployment. For both male and female unemployment rates, the coefficients are negative across all specifications. Female unemployment shows a more substantial decrease compared to male unemployment. In Specification (1), the coefficient for female unemployment is -0.0404 , whereas for male unemployment, it is -0.00981 . In Specification (4), the coefficients are -0.0257 for women and -0.00789 for men, indicating a consistent but slightly reduced impact after accounting for additional covariates. These findings suggest that improved road access

Table 5
Regression results for socio-economic dependent variables.*

Dependent Variable	(1)	(2)	(3)	(4)
Unemployment Rate				
Coefficient	-0.246	-0.0318	-0.0300	-0.0172
Std. Err.	0.000868	0.00189	0.0019	0.00201
R-squared (Overall)	4.7 %	4.7 %	1.1 %	4.1 %
Unemployment Rate (Male)				
Coefficient	-0.00981	-0.00905	-0.00864	-0.00789
Std. Err.	0.000976	0.00197	0.00199	0.00214
R-squared (Overall)	0.6 %	0.6 %	1.4 %	0.9 %
Unemployment Rate (Female)				
Coefficient	-0.0404	-0.0531	-0.0499	-0.0257
Std. Err.	0.00112	0.00255	0.00258	0.00267
R-squared (Overall)	7.3 %	7.3 %	2.5 %	6.9 %
Average Years of Schooling				
Coefficient	0.494	0.449	0.414	0.207
Std. Err.	0.00940	0.0109	0.0111	0.0111
R-squared (Overall)	17.2 %	17.2 %	17.9 %	33.3 %
Average Years of Schooling (Male)				
Coefficient	0.459	0.405	0.372	0.178
Std. Err.	0.00990	0.119	0.0121	0.0123
R-squared (Overall)	13.8 %	13.8 %	13.7 %	25.2 %
Average Years of Schooling (Female)				
Coefficient	0.531	0.490	0.454	0.234
Std. Err.	0.00986	0.123	0.0125	0.0123
R-squared (Overall)	17.7 %	17.7 %	19.5 %	35.7 %
Average Live Births				
Coefficient	-0.155	-0.0873	-0.0795	-0.0424
Std. Err.	0.00426	0.00641	0.00648	0.00719
R-squared (Overall)	7.9 %	7.9 %	6.1 %	8.2 %
Year and locality fixed effects	No	Yes	Yes	Yes
Population covariates	No	No	Yes	Yes
Consumption covariates	No	No	No	Yes

* All results shown in this table are statistically significant (p -value < 0.05).

benefits women's employment opportunities more significantly, up to a decrease of 2.6 % per increase of one point in accessibility index score, or a decrease of 10.4 % in unemployment for a locality that goes from least accessible to most accessible. The consistent negative coefficients across all specifications indicate that better road access reduces unemployment rates. The reduction in unemployment rates, more substantial among women, highlights the potential of road infrastructure projects to improve labor market conditions for this group.

The decrease in unemployment, particularly among women, may be attributed to improved access to labor markets. As road infrastructure improves, remote communities become more integrated with urban centers, providing greater employment opportunities (Mu and Van de Walle, 2011; Foster et al., 2023). This is consistent with findings by Duranton and Turner (2012), who showed that transportation infrastructure is strongly correlated with employment growth in connected regions. Ghani et al. (2014) found that road improvements in India had a more pronounced effect on female labor force participation, possibly due to enhanced safety and convenience in traveling longer distances for work. Women are more likely to experience constraints on mobility due to household responsibilities, cultural expectations, and safety concerns. Improved road access may disproportionately alleviate these barriers, making it easier for women to access employment opportunities in urban centers or other regions. Furthermore, it is possible that female employment often increases when transportation infrastructure reduces commuting time, as this provides women with more opportunities to balance work and domestic responsibilities. All in all, this finding suggests that targeted road development could be a valuable policy tool for enhancing employment opportunities, particularly in marginalized communities where women face greater employment challenges.

The positive coefficients for average years of schooling across all specifications suggest that better road access is associated with increased educational attainment. For example, in Specification (1), the coefficient is 0.494, indicating that a four-unit increase in accessibility, or from lowest accessibility to highest accessibility using the CONEVAL scale, correlates with an almost 2-year increase in average schooling. This effect remains robust, albeit smaller, even after accounting for additional covariates, with Specification (4) showing a coefficient of 0.207. Improved roads likely enhance students' ability to attend school regularly and access educational resources, leading to higher educational attainment. Years of schooling also seem to relate to accessibility differently between men and women, with women experiencing more benefits from better accessibility than men according to the results in Table Y.

The positive correlation between road accessibility and average years of schooling can be explained by the reduced travel time and increased ease of access to educational institutions. Students in more accessible areas can attend school more regularly, leading to better educational outcomes (Asher and Novosad, 2020). This finding aligns with Zhao and Barakat (2015), who observed that improved transportation infrastructure in rural China significantly reduced dropout rates and increased the average years of schooling. In many rural communities, girls may face higher opportunity costs for attending school, such as household chores or caregiving responsibilities. Road accessibility could help mitigate these challenges by decreasing travel time and improving the safety of commutes, thereby encouraging families to prioritize girls' education. Improved infrastructure may reduce these barriers by facilitating quicker travel and access to schools and educational resources. This seems to suggest, much like with unemployment, that road accessibility could be a valuable tool to improve women's outcomes in more remote communities.

The coefficients for average live births show a decrease across all specifications, indicating that improved road access is associated with a reduction in live births. For example, in Specification (1), the coefficient is -0.155 , suggesting that a one-unit increase in the accessibility index is associated with a 0.155 decrease in the average number of live births. In Specification (4), the coefficient slightly decreases substantially to

–0.0424, showing that additional factors included in the later specifications explain some of the initial observed impacts.

The reduction in live births associated with better road access could be linked to improved access to healthcare facilities, including family planning and maternal health services (Canning and Schultz, 2012). While improved road access appears to correlate with reduced birth rates, this relationship may also be influenced by other uncontrolled factors. For instance, greater accessibility could increase exposure to education and awareness programs on family planning, which are critical for lowering fertility rates (Canning and Schultz, 2012). Social influences, such as changing attitudes toward family size and increased female labor force participation, may also play a role. Moreover, enhanced access to healthcare services, particularly maternal and reproductive health, is likely a key driver of the observed reductions in live births. Future studies could explore these mediating factors to better understand the pathways through which road infrastructure impacts fertility rates. This highlights the critical role of infrastructure in enabling access to essential health services, which has broader implications for population dynamics, and once again a disproportionate impact on women.

The progression from Specification (1) to (4) demonstrates how the inclusion of additional covariates affects the estimated impact of road access. Generally, the coefficients' magnitudes decrease, indicating that some of the initial observed impacts are explained by other factors included in the later specifications. The conclusion we can draw is that the effects of road access are significant in terms of the socio-economic outcomes presented in Table Y. However, given the low r-squared values in many of the specifications, we can assume that these effects are not the most important factors in assessing these outcomes and should be taken with caution. Despite controlling for population and consumption-based covariates, some uncontrolled factors, such as regional variations in social norms or local investments in education and healthcare, may still influence the observed outcomes. For example, localities with greater accessibility may also attract more public or private investments, compounding the effects of road infrastructure. It's possible that factors influencing socio-economic outcomes, such as regional policies, international or national labor market dynamics or community-level educational initiatives, remain uncontrolled. The observed gender differences may reflect broader socio-cultural dynamics that are not fully captured in the model.

4.3. Infrastructure-related outcomes

Table 6 presents regression results evaluating the impact of road construction on infrastructure-related outcomes in Oaxaca, using the

Table 6
Regression results for infrastructure-related dependent variables.*

Dependent Variable	(1)	(2)	(3)	(4)
Percentage of Dwellings with Electricity				
Coefficient	0.0294	0.0457	0.0441	0.0180
Std. Err.	0.00126	0.00208	0.00213	0.00192
R-squared (Overall)	3.8 %	3.8 %	6.4 %	28.7 %
Percentage of Dwellings with Piped Water				
Coefficient	0.0479	0.131	0.126	0.0697
Std. Err.	0.00217	0.00400	0.00406	0.00419
R-squared (Overall)	3.2 %	3.2 %	4.7 %	10.3 %
Percentage of Dwellings with Internet				
Coefficient	0.0223	0.0402	0.0370	0.0158
Std. Err.	0.000731	0.00149	0.00152	0.00156
R-squared (Overall)	6.8 %	6.8 %	4.8 %	14.4 %
Year and locality fixed effects	No	Yes	Yes	Yes
Population covariates	No	No	Yes	Yes
Consumption covariates	No	No	No	Yes

* All results shown in this table are statistically significant (p-value <0.05).

accessibility index scaled from 1 to 5. Like in the previous subsection, the table includes multiple specifications of the regression models, allowing for comparison of results across different dependent variables and model adjustments.

Overall, better accessibility is correlated with better uptake of electricity infrastructure, piped water and Internet. The coefficients for the percentage of dwellings with electricity and for the percentage of dwellings with Internet indicate a notable decrease across the specifications, much like with socio-economic outcomes, reflecting a varying impact of model covariates on the association between infrastructure and electricity access. For instance, in Specification (1), the coefficient is 0.0294 for electricity and 0.0223 for Internet, suggesting that a one-unit increase in the accessibility index score correlates with a 2.94 % increase in the percentage of dwellings with electricity and 2.23 % increase in the percentage of dwellings with Internet. As more covariates are included, this effect diminishes, with Specification (4) showing a coefficient of 0.0180 and 0.0158 for electricity and Internet respectively.

In the case of piped water, we see an increase between Specifications (1) and (2), which could mean that accounting for fixed effects may highlight an increase in the magnitude of the impact of accessibility on piped water uptake. However, between Specifications (3) and (4), we see an important decrease in magnitude, much like with electricity and Internet. This could highlight the fact that standard of living and consumption of goods is highly correlated with infrastructure uptake. More detailed consumption covariates in Specification (4) might reflect underlying trends in energy demand, water demand and consumption patterns that influence how infrastructure improvements affect electricity or water access. Further, local economic growth or governmental energy or water delivery policies might be driving improvements in electricity access independently of the infrastructure measure.

The increase in the percentage of dwellings with electricity, piped water, and Internet access suggests that road improvements facilitate infrastructure development. Foster et al. (2023) argue that transportation infrastructure is crucial for economic development. It tends to lower the cost-of-service delivery in remote areas, making infrastructure investments more feasible. The positive effects on infrastructure are moderated by other regional and socio-economic factors, such as local economic growth and government policies. This implies that while road improvements are necessary, they are not sufficient on their own to guarantee widespread infrastructure uptake; complementary policies are required to maximize the benefits of such investments.

4.4. Analyzing covariates

The results presented earlier do not show the effect of covariates on the dependent variables that are estimated with the regression model. Table 7 shows the coefficients for the covariates in predicting the ten dependent variables for which the model's Specification (4) was run.

Population is negatively correlated with unemployment rate and birth rate, but positively correlated with infrastructure uptake and average years of schooling. This clearly suggests that larger centers are more prone to better socio-economic conditions. While not surprising, it completely justifies the validity of the use of population count as a covariate in our model.

Migration seems to have a generally positive impact on socio-economic variables. For instance, the percentage of population born outside of the locality exhibits a negative relationship with the unemployment rate, and even more so when only considering female unemployment. We also see that higher percentages of population born outside of the locality is positively correlated with higher educational attainment. This suggests that a higher proportion of residents born outside the locality is associated with lower unemployment rates and better education, possibly indicating the positive impact of external migration on local job markets and development opportunities. These intersect with better accessibility: it's possible that building roads to reach localities could contribute to this migration.

Table 7

Covariate results for regression specification (4) for each dependent variable.

Dependent Variable		Independent Variable						
		Population	% Population Born Out of Locality	% Identify Indigenous	% Dwellings with TV	% Dwellings with Refrigerator	% Dwellings with Washer	% Dwellings with Car
Unemployment Rate	Coeff.	-0.0000895	-0.150	-0.0506	0.0284	-0.0877	-0.178	-0.0338
	Std. Err.	0.0000238	0.0484	0.0231	0.0133	0.0171	0.0192	0.0248
Unemployment Rate (Male)	Coeff.	0.0000112	-0.0842	-0.00113	0.00441	0.0309	-0.0413	-0.0567
	Std. Err.	0.0000242	0.0541	0.0253	0.0150	0.0183	0.0197	0.0250
Unemployment Rate (Female)	Coeff.	-0.000179	-0.234	-0.0802	0.0521	-0.211	-0.288	-0.174
	Std. Err.	0.000029	0.0732	0.0331	0.0177	0.0236	0.0276	0.0362
Avg. Years Schooling	Coeff.	0.00189	2.195	-0.690	-0.121	2.042	1.683	1.027
	Std. Err.	0.000190	0.373	0.173	0.0747	0.102	0.122	0.168
Avg. Years Sch. (Male)	Coeff.	0.00174	2.155	-0.586	-0.0670	1.941	1.500	1.028
	Std. Err.	0.000178	0.419	0.201	0.0863	0.117	0.137	0.197
Avg. Years of Sch. (Female)	Coeff.	0.00199	2.153	-0.801	-0.158	2.155	1.839	1.007
	Std. Err.	0.000211	0.463	0.191	0.0895	0.121	0.142	0.193
Average Live Births	Coeff.	-0.000592	-0.326	0.312	0.0271	-0.435	-0.249	-0.0785
	Std. Err.	0.0000726	0.261	0.125	0.0565	0.0707	0.0819	0.113
% Dwellings Electricity	Coeff.	0.0000823	-0.00663	-0.0208	0.396	0.316	-0.0299	-0.0192
	Std. Err.	0.00002	0.0531	0.0271	0.169	0.0185	0.178	0.0245
% Dwellings Piped Water	Coeff.	0.000223	0.197	0.0546	0.0789	0.563	0.460	0.0580
	Std. Err.	0.0000464	0.0990	0.0490	0.0271	0.0346	0.0395	0.0503
% Dwellings with Internet	Coeff.	0.000250	0.0702	-0.0224	-0.101	0.176	0.243	0.159
	Std. Err.	0.0000254	0.0448	0.019	0.00883	0.0142	0.0174	0.0223

*Results in black are statistically significant (p-value <0.05); results in red are not statistically significant.

Indigeneity seems to also has an effect, although mixed, on the dependent socio-economic variables. The percentage of households who identify as indigenous is negatively correlated with unemployment, meaning that the more a locality identifies as indigenous, the less unemployment there is. Conversely, indigeneity is also negatively correlated with educational attainment and positively correlated with the birth rate. This could suggest that there are certain structural or cultural aspects of more indigenous localities that catalyze higher job uptake but inhibit family planning or later school attendance. It is important to note that these results should be taken with extreme caution given that a limited sample size and very specific regression model with a different research objective are used.

The independent variables related to consumer goods have mixed effects on the dependent variables in the table in that many interactions are statistically insignificant. However, overall, uptake of consumer goods is correlated with less unemployment, more schooling, a lower birth rate and higher levels of infrastructure penetration. We also see that for unemployment and schooling, these effects are higher for women than for men. This is not surprising, since women typically benefit from time savings with appliances in the home.

5. Conclusion

This study explores the impact of road accessibility on various socio-economic and infrastructure-related outcomes in rural localities in Oaxaca, Mexico, using data from 2010 and 2020 and the CONEVAL Accessibility Index values (CONEVAL, 2018, 2021b). Not only is it one of the first studies to use this index in academic research, to examine gendered effects, or to study the effect of accessibility in the State of Oaxaca all at once, but it contributes greatly to the field of transport geography scholarship by laying out a straightforward methodology to evaluate the change in outcomes due to better transportation accessibility over time.

Key findings include a significant reduction in unemployment rates associated with improved road access, with overall unemployment decreasing by 1.7 % per unit increase in the accessibility index score. Similarly, average years of schooling increased by up to 0.21 years for every unit increase in accessibility. Infrastructure improvements were observed, with up to a 1.8 % increase in dwellings with electricity and up to a 1.6 % increase in dwellings with Internet access per unit increase in the accessibility index. We can conclude that improved road

accessibility may play an important role in enhancing socio-economic conditions and infrastructure development in rural areas. The reduction in unemployment, especially among women, suggests that better road infrastructure facilitates greater access to labor markets and employment opportunities. The positive correlation between road access and infrastructure uptake, particularly in terms of electricity and Internet access, underscores the role of transportation networks in driving broader economic development and improving living standards in remote communities.

The findings have significant implications for policy and practice. The reduction in unemployment and increase in educational attainment suggest that targeted investments in road infrastructure could be an effective tool for promoting gender equality and improving socio-economic outcomes in marginalized areas. The positive impact on infrastructure access highlights the need for complementary policies that focus on reducing barriers to essential services in rural areas. Policymakers should consider the broader benefits of road development projects, particularly in improving access to education, employment, and basic infrastructure, which are crucial for sustainable development.

While this study provides valuable insights, it has several limitations. The analysis is based on observational data, which may be subject to confounding factors that were not fully accounted for, such as government policies or economic conditions specific to certain periods. Limitations in the available data present challenges. For instance, the study utilizes a composite accessibility index with discrete categories rather than continuous metrics, potentially limiting the precision of accessibility measurements. The dataset also lacks detailed temporal information on infrastructure quality or socio-economic conditions, which may impact the robustness of findings. The use of a fixed-effects model, while controlling for time-invariant factors, may not fully capture the dynamic nature of socio-economic changes. Finally, as our analysis relies on 2020 census data, further research could incorporate qualitative fieldwork or updated datasets to verify whether these trends have persisted in the years following our study.

Moreover, there are potential challenges with data reliability and consistency, as rural data collection can sometimes suffer from under-reporting or inaccuracies due to limited resources and logistical barriers. This can result in incomplete or skewed data that may not fully represent on-the-ground realities. The study focuses on a specific, underdeveloped, region in Mexico, which may limit the generalizability of the findings to other states, countries or regions. However, its

methodology—particularly the use of the CONEVAL Accessibility Index—provides a valuable framework for evaluating road accessibility in other countries. This composite indicator could be adapted to include region-specific measures, such as proximity to critical services or the availability of public transport, enabling researchers to replicate and refine the methodology in diverse international contexts. Such adaptability underscores the broader utility of this approach for addressing rural development challenges in varying socio-economic environments. Another issue is the lack of data on informal economic activities, which play a significant role in rural economies but are often absent from formal datasets. Data limitations related to sample size or data quality may also influence the extent to which these findings apply to other areas, emphasizing the need for more granular and comprehensive data in future studies. However, care will have to be applied to variables chosen, as changing definitions or metrics for key indicators, such as accessibility and employment, over time may affect data comparability across years, potentially complicating longitudinal analyses.

Future research could address these limitations by using experimental or quasi-experimental designs to better establish causality between road infrastructure and socio-economic outcomes. Longitudinal studies could explore the long-term impacts of road development on rural communities, including the potential for infrastructure to catalyze broader economic transformations. Comparative studies across different regions or countries would also be valuable in understanding the varying impacts of road infrastructure in diverse contexts. Future studies could try to obtain more granular data, particularly continuous metrics for accessibility and detailed data on changes in infrastructure and socio-economic conditions over time, at a locality-specific level.

Appendix A. Appendix

Table A1
Examples of accessibility measurements, classified according to Páez et al.'s (2012) framework.

Description	Type	Source
A comprehensive ten-criteria scale for quantifying remoteness.	Normative	Hamelin, 1975
Observes accessibility as defined by infrastructure and population density	Normative	Baradaran and Ramjerdi, 2001
Evaluates access to services and socio-economic outcomes based on remoteness.	Normative	Government of Australia, I, et al., 2001
Calculates the average cost of trips using an exponential distance decay function.	Positive	Horner and Mascarenhas, 2007
Assesses whether there is at least one dentist within a 10-mile radius of a town.	Positive	Horner and Mascarenhas, 2007
Measures the population within a 10 km buffer from a hospital.	Normative	Cervigni et al., 2008
Counts the number of fruit and vegetable stores within a 2 km network-based buffer.	Normative	Ball et al., 2009
Uses Geographic Information Systems to analyze road spatial data for accessibility.	Normative	Luo and Qi, 2009
Uses the spatial distribution of towns and rail stations with the travel time to nearest opportunity measured.	Normative	Vandenbulcke et al., 2009
Counts the number of grocery stores accessible within a typical travel distance.	Positive	Páez et al., 2010
Incorporates travel cost to measure socio-economic isolation.	Normative	Alasia et al., 2017
Measures accessibility to jobs for low-income individuals.	Positive	Deboosere and El-Geneidy, 2018
Analyzes satellite imagery to assess light pollution as a proxy for remoteness.	Normative	Zangeneh et al., 2020
Incorporates seasonal changes in travel costs and modes of travel.	Normative	Stringer and Kim, 2023

Data availability

Data will be made available on request.

References

Aggarwal, S., 2018. Do rural roads create pathways out of poverty? Evidence from India. *J. Dev. Econ.* 133, 375–395. <https://doi.org/10.1016/j.jdevco.2018.01.005>.
Alasia, A., Bédard, F., Bélanger, J., Guimond, E., Penney, C., 2017. *Measuring Remoteness and Accessibility: A Set of Indices for Canadian Communities*. Statistics Canada Ottawa.
Angrist, J.D., Pischke, J.S., 2009. *Mostly Harmless Econometrics: An empiricist's Companion*. Princeton University Press.

Enhanced data collection at regular intervals would allow researchers to capture the dynamic aspects of rural development more accurately. Larger sample sizes and richer datasets on infrastructure quality could improve the robustness and generalizability of findings across different regions and contexts.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to improve the English language quality. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

CRediT authorship contribution statement

Thomas Stringer: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Esteban Ricardo García Clavel:** Writing – original draft, Investigation. **Manuel Burelo:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Apparicio, P., Abdelmajid, M., Riva, M., Shearmur, R., 2008. Comparing alternative approaches to measuring the geographical accessibility of urban health services: distance types and aggregation-error issues. *Int. J. Health Geogr.* 7, 1–14.
Asher, S., Novosad, P., 2020. Rural roads and local economic development. *Am. Econ. Rev.* 110 (3), 797–823. <https://doi.org/10.1257/aer.20180250>.
Ball, K., Timperio, A., Crawford, D., 2009. Neighbourhood socioeconomic inequalities in food access and affordability. *Health Place* 15 (2), 578–585.
Banerjee, A., Duflo, E., Qian, N., 2020. On the road: access to transportation infrastructure and economic growth in China. *J. Dev. Econ.* 145, 102442.
Baradaran, S., Ramjerdi, F., 2001. Performance of accessibility measures in Europe. *J. Transp. Stat.* 4 (2/3), 31–48.
Bess, M., 2014. Routes of conflict : building roads and shaping the nation of Mexico, 1941-1952. *J. Transp. Hist.* 35 (1), 78–96.
Bess, M., 2016a. 'Neither motorists nor pedestrians obey the rules : transit Law, public safety, and the policing of northern Mexico's roads, 1920s-1950s. *J. Transp. Hist.* 37 (2), 155–174.

- Bess, M., 2016b. Revolutionary paths : motor roads, economic development, and National Sovereignty in 1920s and 1930s Mexico. *Mexican Studies / Estudios Mexicanos* 32 (1), 5682.
- Bess, M., 2017. Routes of Compromise: Building Roads and Shaping the Nation of Mexico, 1917–1952. University of Nebraska Press, p. 246.
- Bhat, Chandra, Handy, Susan, Kockelman, Kara, Mahmassani, Hani, Weston, Lisa, Gopal, Anand, Srour, Issam, 2002. Development of an Urban Accessibility Index. Project 0-4938: Project Summary Report 4938-S. Center for Transportation Research. The University of Texas at Austin.
- Bibby, P., Brindley, P., 2013. Urban and Rural Area Definitions for Policy Purposes in England and Wales: Methodology.
- Bollman, R.D., Reimer, B., 2019. What is rural? What is rural policy? What is rural development policy? In: *The Routledge Handbook of Comparative Rural Policy*. Routledge, pp. 9–26.
- Brocker, J., Rietveld, P., 2009. Infrastructure and regional development. In: Capello, R., Nijkamp, P. (Eds.), *Handbook of Regional Growth and Development Theories*. Edward Elgar, pp. 152–181.
- Canning, D., Schultz, T.P., 2012. The economic consequences of reproductive health and family planning. *Lancet* 380 (9837), 165–171. [https://doi.org/10.1016/S0140-6736\(12\)60827-7](https://doi.org/10.1016/S0140-6736(12)60827-7).
- Cervigni, F., Suzuki, Y., Ishii, T., Hata, A., 2008. Spatial accessibility to pediatric services. *J. Community Health* 33, 444–448.
- CONeVAL, 2018. Grado de accesibilidad a carretera pavimentada (GACP) 2010: Anexo estadístico. URL: https://www.coneval.org.mx/Medicion/Paginas/Grado_accesibilidad_carretera_historico.aspx.
- CONeVAL, 2020. Informe de Pobreza y Evaluación 2020 Oaxaca. URL: https://www.coneval.org.mx/coordinacion/entidades/Documents/Informes_de_pobreza_y_evaluacion_2020_Documentos/Informe_Oaxaca_2020.pdf.
- CONeVAL, 2021a. Grado de accesibilidad a carretera pavimentada - Documento metodológico. URL: https://www.coneval.org.mx/Medicion/MP/Documents/Accessibilidad_carretera/2020/Documento_metodologico_GACP_2020.pdf.
- CONeVAL, 2021b. Grado de accesibilidad a carretera pavimentada (GACP) 2020: Anexo estadístico. URL: https://www.coneval.org.mx/Medicion/Paginas/Grado_accesibilidad_carretera.aspx.
- CONeVAL, 2024. Visor geoespacial del Grado de accesibilidad a carretera pavimentada. URL: <https://coneval.maps.arcgis.com/apps/dashboards/be91cfd62462445eeae1120baba650fb>.
- Dávila, E., Kessel, G., Levy, S., 2002. El sur también existe: un ensayo sobre desarrollo regional de México. *Economía Mexicana. Nueva Época* 11 (2), 205–260.
- De Chaisemartin, C., d'Haultfoeuille, X., 2020. Two-way fixed effects estimators with heterogeneous treatment effects. *Am. Econ. Rev.* 110 (9), 2964–2996.
- Deboosere, R., El-Geneidy, A., 2018. Evaluating equity and accessibility to jobs by public transport across Canada. *J. Transp. Geogr.* 73, 54–63. <https://doi.org/10.1016/j.jtrangeo.2018.10.006>.
- Donaldson, D., 2018. Railroads of the raj: estimating the impact of transportation infrastructure. *Am. Econ. Rev.* 108 (4–5), 899–934.
- Driscoll, J.C., Kraay, A.C., 1998. Consistent covariance matrix estimation with spatially dependent panel data. *Rev. Econ. Stat.* 80 (4), 549–560.
- Duran Fernandez, Roberto, 2008. Gravity, distance, and traffic flows in Mexico. In: *Transport Studies Unit. Working Paper N° 1030*. Oxford University Centre for the Environment.
- Duran-Fernandez, R., Santos, G., 2014. Road infrastructure spillovers on the manufacturing sector in Mexico. *Res. Transp. Econ.* 46, 17–29. <https://doi.org/10.1016/j.retrec.2014.09.002>.
- Duranton, G., Turner, M.A., 2012. Urban growth and transportation. *Rev. Econ. Stud.* 79 (4), 1407–1440. <https://doi.org/10.1093/restud/rds010>.
- Fagbemi, F., Osinubi, T.T., Adeosun, O.A., 2022. Enhancing sustainable infrastructure development: a boon to poverty reduction in Nigeria. *World Developm. Sustain.* 1, 100006. <https://doi.org/10.1016/j.wds.2022.100006>.
- Footo, W., 1997. Mexico's Troubled Toll Roads. ICWA Letters. February 3.
- Foster, V., Gorgulu, N., Straub, S., Vagliasindi, M., 2023. The Impact of Infrastructure on Development Outcomes. World Bank, Washington, DC.
- Gertler, P.J., Gonzalez-Navarro, M., Graener, T., Rothenberg, A.D., 2024. Road maintenance and local economic development: evidence from Indonesia's highways. *J. Urban Econ.* 143, 103687.
- Geurs, K.T., Wee, B.V., 2013. Accessibility: Perspectives, Measures and Applications.
- Ghani, E., Kerr, W.R., O'Connell, S.D., 2014. Political reservations and women's entrepreneurship in India. *J. Dev. Econ.* 108, 138–153. <https://doi.org/10.1016/j.jdevco.2014.01.010>.
- Government of Australia, I, R. B. D. of H, A. C., 2001. Measuring Remoteness: Accessibility/Remoteness Index of Australia (ARIA) Revised Edition, Occasional Papers: New Series Number 14.
- Hair, J., 2009. Multivariate Data Analysis. Exploratory Factor Analysis.
- Hamelin, L.-E., 1975. Nordicité canadienne, Montréal, Editions Hurtubise inc., coll. Les Cahiers Du Québec.
- Hansen, W.G., 1959. How accessibility shapes land use. *J. Am. Inst. Plann.* 25, 73–76.
- Horner, M.W., Mascarenhas, A.K., 2007. Analyzing location-based accessibility to dental services: an Ohio case study. *J. Public Health Dent.* 67 (2), 113–118.
- Imai, K., Kim, I.S., 2021. On the use of two-way fixed effects regression models for causal inference with panel data. *Polit. Anal.* 29 (3), 405–415.
- INEGI, 2010. Censo de Población y Vivienda 2010. Subsistema de Información Demográfica y Social. URL: <https://www.inegi.org.mx/programas/ccpv/2010/>.
- INEGI, 2020. Censo de Población y Vivienda 2020. Subsistema de Información Demográfica y Social. URL: <https://www.inegi.org.mx/programas/ccpv/2020/>.
- Ingram, D.D., Franco, S.J., 2014. 2013 NCHS Urban-Rural Classification Scheme for Counties.
- Jacoby, H.G., Minten, B., 2009. On measuring the benefits of lower transport costs. *J. Dev. Econ.* 89 (1), 28–38.
- Jo, E., Lane, C., McArthur, K., Xu, F., 2021. A distance-based approach to rurality and remoteness in health: concept, methodology and correlates of a patient-centred health services spatial accessibility index. *New Zealand Med. J. (Online)* 134 (1545), 91–105.
- Khandker, S.R., Bakht, Z., Koolwal, G.B., 2009. The poverty impact of rural roads: Evidence from Bangladesh. *Econ. Develop. Cultural Change* 57 (4), 685–722.
- Kwan, M.-P., 1998. Space-time and integral measures of individual accessibility: a comparative analysis using a point-based framework. *Geogr. Anal.* 30, 191–216.
- Luo, W., Qi, Y., 2009. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health Place* 15 (4), 1100–1107.
- Luo, W., Wang, F., 2003. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environ. Plan. B Plan. Design* 30 (6), 865–884.
- Luo, P., Song, Y., Wu, P., 2021. Spatial disparities in trade-offs: economic and environmental impacts of road infrastructure on continental level. *GISci. Remote Sens.* 58 (5), 756–775. <https://doi.org/10.1080/15481603.2021.1947624>.
- Maravalle, A., Pandiella, A.G., 2022. Expanding Access to Finance to Boost Growth and Reduce Inequalities in Mexico.
- Melo, P.C., Graham, D.J., Brage-Ardao, R., 2013. The productivity of transport infrastructure investment: a meta-analysis of empirical evidence. *Reg. Sci. Urban Econ.* 43, 695–706. <https://doi.org/10.1016/j.regsciurbeco.2013.05.00223>.
- Modi, V., McDade, S., Lallemand, D., Saghir, J., 2005. Energy Services for the Millennium Development Goals.
- Mu, R., Van de Walle, D., 2011. Rural roads and local market development in Vietnam. *J. Dev. Stud.* 47 (5), 709–734. <https://doi.org/10.1080/00220388.2010.509785>.
- Neutens, T., Schwanen, T., Witlox, F., de Maeyer, P., 2010. Equity of urban service delivery: a comparison of different accessibility measures. *Environ. Plan. A* 42 (7), 1613–1635.
- Ng, C.P., Law, T.H., Jakarni, F.M., Kulanthayan, S., 2019. Road infrastructure development and economic growth. In: *IOP Conference Series Materials Science and Engineering*, 512, 012045. <https://doi.org/10.1088/1757-899x/512/1/012045>.
- Nying'iro, G.O., 2023. Impact of County Road Infrastructure Investment on Employment. Doctoral dissertation. University of Nairobi.
- Olsson, J., 2009. Improved road accessibility and indirect development effects: evidence from rural Philippines. *J. Transp. Geogr.* 17 (6), 476–483.
- Ortega, I.E.Z., Ángeles-Castro, G., Carrillo-Murillo, D.G., 2019. Infraestructura carretera y crecimiento económico en México. *Problemas Del Desarrollo Revista Latinoamericana. De Economía* 50 (198). <https://doi.org/10.22201/iiec.20078951e.2019.198.66383>.
- Owusu-Manu, D.G., Jehuri, A.B., Edwards, D.J., Boateng, F., Asumadu, G., 2019. The impact of infrastructure development on economic growth in sub-Saharan Africa with special focus on Ghana. *J. Financ. Manag. Prop. Constr.* 24 (3), 253–273.
- Páez, A., Gertes Mercado, R., Farber, S., Morency, C., Roorda, M., 2010. Relative accessibility deprivation indicators for urban settings: definitions and application to food deserts in Montreal. *Urban Stud.* 47 (7), 1415–1438.
- Páez, A., Scott, D.M., Morency, C., 2012. Measuring accessibility: positive and normative implementations of various accessibility indicators. *J. Transp. Geogr.* 25, 141–153. <https://doi.org/10.1016/j.jtrangeo.2012.03.016>.
- Pérez Cervantes, F., Hernández, A. Sandoval, 2015. Estimating the Short-Run Effect on Market-Access of the Construction of Better Transportation Infrastructure in Mexico. Banco de México Working Papers. N.2015–15.
- Roberts, P., Guenther, J., 2021. Framing rural and remote: Key issues, debates, definitions, and positions in constructing rural and remote disadvantage. In: Roberts, P., Fuqua, M. (Eds.), *Ruraling Education Research: Connections between Rurality and the Disciplines of Educational Research*. Springer Singapore, pp. 13–27. https://doi.org/10.1007/978-981-16-0131-6_2.
- Rojas-Ramírez, L.E., Molina-Vargas, A., 2018. Public Infrastructure and its importance for Economic Growth: The Case of Oaxaca (Mexico). *Redalyc.Org*. <https://www.redalyc.org/articulo.oa?id=329056089001>.
- Rokicki, B., Stepniak, M., 2018. Major transport infrastructure investment and regional economic development—an accessibility-based approach. *J. Transp. Geogr.* 72, 36–49.
- Schindler, S., Kanai, J.M., 2019. Getting the territory right: infrastructure-led development and the re-emergence of spatial planning strategies. *Reg. Stud.* 55 (1), 40–51. <https://doi.org/10.1080/00343404.2019.1661984>.
- Schmidheiny, K., Sieglösch, S., 2023. On event studies and distributed-lags in two-way fixed effects models: identification, equivalence, and generalization. *J. Appl. Econ.* 38 (5), 695–713.
- Secretaría de Comunicaciones y Transportes, 2021. Avanza Programa Prioritario de Caminos Rurales en el estado de Oaxaca. URL: <https://www.gob.mx/sct/articulos/avanza-programa-prioritario-de-caminos-rurales-en-el-estado-de-oaxaca>.
- Statistics Canada, 2016. Population Centre (POPCTR). Dictionary, Census of Population, 2016.
- Stringer, T., Joanis, M., 2022. The impact of road connection on employment and education in northern Canada. *Can. J. Reg. Sci.* 45 (3), 150–162.
- Stringer, T., Kim, A.M., 2023. Transportation Access Index for Remote Communities that Considers Modal Seasonality. Findings.
- Stringer, T., Cheng, H.S., Kim, A.M., 2023. A comparison of remoteness indices. *Polar Geogr.* 46 (2–3), 95–119.
- Thill, J.C., Kim, M., 2005. Trip making, induced travel demand, and accessibility. *J. Geogr. Syst.* 2005 (7), 229–248.
- Vandenbulcke, G., Steenberghen, T., Thomas, I., 2009. Mapping accessibility in Belgium: a tool for land-use and transport planning? *J. Transp. Geogr.* 17 (1), 39–53.

- Verdier, V., 2020. Estimation and inference for linear models with two-way fixed effects and sparsely matched data. *Rev. Econ. Stat.* 102 (1), 1–16.
- Wakeman, John, Humphreys, John, 2008. Rural and Remote Health — Definitions, Policy and Priorities.
- Weller, B.E., Bowen, N.K., Faubert, S.J., 2020. Latent class analysis: a guide to best practice. *J. Black Psychol.* 46 (4), 287–311.
- Wiggins, S., Proctor, S., 2001. How special are rural areas? The economic implications of location for rural development. *Dev. Policy Rev.* 19 (4), 427–436.
- Zamudio Sánchez, F.J., Corona Ambriz, A., López Becerril, I.D., 2008. Un índice de ruralidad para México. *Espiral (Guadalajara)* 14 (42), 179–214.
- Zangeneh, P., Hamledari, H., McCabe, B., 2020. Quantifying remoteness for risk and resilience assessment using nighttime satellite imagery. *J. Comput. Civ. Eng.* 34 (5), 04020026.
- Zhao, D., Barakat, B., 2015. The increasingly long road to school in rural China: the impacts of education network consolidation on broadly defined schooling distance in Xinfeng County of rural China. *Asia Pac. Educ. Rev.* 16, 413–431.
- Zhao, Y., Guthridge, S., 2008. Rethinking remoteness: a simple and objective approach. *Geogr. Res.* 46 (4), 413–420.
- Zhu, Y., Zinda, J.A., Liu, Q., Wang, Y., Fu, B., Li, M., 2023. Accessibility of primary schools in rural areas and the impact of topography: a case study in Nanjiang County, China. *Land* 12 (6), 1134.