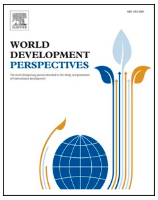
World Development Perspectives 37 (2025) 100666

Contents lists available at ScienceDirect

World Development Perspectives

journal homepage: www.sciencedirect.com/journal/world-development-perspectives



Research paper

Ice roads and income in remote indigenous communities of Canada

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ARTICLE INFO

Keywords:
Ice Roads
Infrastructure
Transportation
Income
Remote Communities
Climate Change
Northwest Territories
Canada

ABSTRACT

I estimate the effects of ice road length deviation on the level of income in the Northwest Territories communities. The harsh weather conditions and extreme climates in the NWT magnify the challenges associated with maintaining infrastructure, often undermining its long-term benefits. I find that the disruptions in ice roads, which serve as vital links for northern Canadian communities, exacerbate income inequality by placing a greater burden on low-income households while disproportionately favoring higher-income groups. Education is a critical factor in driving income growth and reducing inequality. Conversely, reliance on social assistance notably reduces income for higher-income families, while it provides a boost for those in need. Larger communities, however, experience more severe economic challenges, especially within lower-income groups.

1. Introduction

The geographic isolation of remote Indigenous communities in Canada's northern territories presents significant barriers to economic development and social well-being (Ahmed, Ahmed, et al., 2025; Dumas & Játiva, 2024; Donaldson, 2018; Gertler et al., 2024). The name "Northwest Territories" was originally given to the land acquired by Canada in 1870 from the Hudson's Bay Company and Great Britain, known as Rupert's Land and the North-Western Territory. In 1880, the Arctic islands north of the mainland were also ceded to Canada, expanding the territory (Wonders, 2011). Indigenous people, with fur trade posts being the only significant non-Indigenous settlements. Despite perceptions of the Arctic as a geopolitical backwater after the Cold War, minerals have become the most crucial economic driver in the NWT since the 1930s, surpassing all other industries except services (Stephenson et al., 2011). Yet, inadequate infrastructure limits their ability to fully benefit from these assets. A critical component of this infrastructure is the winter roads, also known as ice roads, which function as vital transportation routes during the coldest months of the year (Zapata et al., 2025). These seasonal roads are more than just pathways; they are lifelines that connect isolated communities to the broader all-season road network (Barrette et al., 2022), facilitating access to goods, services, and economic opportunities that would otherwise remain out of reach (Adjei, et al., 2025; Ford et al., 2021; Kuryk, 2003; Proskin et al., 2011). Despite the importance of ice roads, their impact on the economic outcomes of these communities remains underexplored in the literature, the existing literature on transportation infrastructure tends to focus on permanent road networks in temperate regions, leaving a gap in our understanding of how Arctic conditions and the unique challenges they present affect economic outcomes. As climate change continues to shrink the operational windows of these ice roads, the concerns for the communities that depend on them have never been higher (Dong et al., 2025; Koetse & Rietveld, 2009; Vogel & Bullock, 2021).

In this paper, I explore the potential effect of ice road deviations and analyze its underlying causes to provide insights into the types of policies that could be most effective in reducing regional disparities. I aim to fill this gap by empirically assessing the economic impact of ice roads on remote Indigenous communities in Canada's Northwest Territories (NWT). Focusing on income levels and economic activities, this study seeks to contribute to the broader literature on the connection of transportation infrastructure, economic development, and climate change. The findings are particularly relevant as the ongoing changes in the Arctic environment threaten the viability of ice roads and, consequently, the economic resilience of the communities that depend on them (Ahmed & Hall, 2025; Jochem et al., 2016; Vogel & Bullock, 2021).

To ensure the robustness of my findings, I adopt a methodological approach that emphasizes precision, following the insights of Tol (2021) and Kahn et al. (2021) and focus on deviations from long-term averages to avoid the pitfalls of trended variables in growth regressions. The paper employs a spatial autoregressive model and apply corrections for potential spatial correlations, including arbitrary clustering correction (ACR) of standard errors for panel data to account for both spatial and

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https://doi.org/10.1016/j.wdp.2025.100666
Received 5 November 2024; Received in revised form 30 January 2025; Accepted 4 February 2025

temporal correlations (Colella et al., 2023) and a semi-parametric thin-plate spline correction (Kelly et al., 2023). This approach allows for a more accurate assessment of the relationship between ice road conditions and economic outcomes.

The results reveal a clear relationship between ice road deviations and income. When ice roads extend beyond their average length, average family income increases, particularly among higher-income families. Education emerges as a crucial driver of income growth and a reducer of inequality, while reliance on social assistance is shown to significantly decrease income, in particular, for higher income families, while it improves the income for people in need. Larger communities, on the other hand, face more noticeable economic challenges, especially among lower-income households. These findings highlight the key role of infrastructure, education, social assistance, and population dynamics in shaping economic outcomes in Canada's northern regions.

The remainder of this article is organized as follows: Section 2 outlines the theoretical framework, Section 3 details the empirical methodology, Section 4 presents the data analysis, Section 5 discusses the results and robustness checks, and Section 6 concludes with policy implications and recommendations for future research.

2. Literature review

Transportation infrastructure is widely recognized as a key driver of economic development. Improved infrastructure enhances market access, reduces transportation costs, and promotes competition (Amber et al., 2023), thereby contributing to economic growth (Aschauer, 1990; Asher & Novosad, 2020; Banerjee et al., 2020; Gertler et al., 2024). This is particularly true in remote regions where isolation is a significant barrier to economic opportunities. In such areas, roads play a crucial role in increasing income and improving access to essential services (Dumas & Játiva, 2024; Donaldson, 2018). In Canada's northern territories, where geographic isolation and harsh climates pose substantial challenges and the cost of transportation is notoriously high, winter roads are vital (Ahmed, Poelzer, et al., 2025). These seasonal routes link small, remote communities to the all-season road network, enabling access to broader economic centers across the country (Barrette et al., 2022). However, the Northwest Territories (NWT) presents unique economic and infrastructural challenges that complicate the relationship between transportation infrastructure and economic development. The NWT, one of Canada's most economically unstable regions, faces numerous obstacles, including maturing diamond mines, labor shortages, and limited economic diversification (Economic Review for the Northwest Territories (NWT), 2023). High inflation and rising interest rates have further constrained the region's growth prospects, despite a recent rebound from the COVID-19 pandemic. Additionally, key macroeconomic indicators such as real GDP (as shown in Fig. 1), productivity, and new investments have declined compared to baseline levels from 2007, highlighting the fragility of the region's economy (Economic Review for the Northwest Territories (NWT), 2023).

2.1. Transportation infrastructure and economic development

Transport-induced growth theory explains how advancements in transportation infrastructure drive economic development by reducing costs, improving market accessibility, and facilitating regional integration (Erik et al., 2021; Redding & Turner, 2015; Li et al., 2020). Historically, transportation infrastructure has significantly shaped economic activity and social connectivity across regions (Chanieabate et al., 2023; and Dercon et al., 2009; Gertler et al., 2024; Nakamura, et al., 2020; Zapata et al, 2025). In Ancient Rome, the vast network of Roman roads not only determined the locations of many modern roads but also served as a central driver of local economic activity (Dalgaard et al., 2022). Furthermore, transport investments can spur regional development by linking previously isolated or disadvantaged areas to economic hubs, reducing disparities and unlocking new opportunities for growth. However, the benefits of transport-induced growth are not evenly distributed, as wealthier or more developed regions often gain more, potentially exacerbating inequalities. For instance, Gertler et al., (2024) use comprehensive data on road quality from 1990 to 2007 in Indonesia to demonstrate that improved roads facilitate job creation, support transitions from informal to formal employment, and increase labor income. Their study also find that road quality can reduce the cost of living by lowering prices for perishable goods, though it may also raise housing prices due to increased demand. Also, Nakamura, et al., (2020) and Dercon et al., (2009) find that rural road programs in Ethiopia led to increased consumption, underscoring the broader economic benefits of infrastructure investments in rural areas. Similarly, Li et al. (2020) utilize extensive highway traffic data in China to establish a strong association between transportation network features and regional economic indicators, highlighting the role of transport infrastructure in economic development. In the same vein, Chanieabate et al. (2023) examine the relationship between transportation infrastructure and the rural–urban income gap in China. Their findings suggest that transportation infrastructure can effectively reduce income disparities and generate noticeable spatial spillover effects, improving economic equity

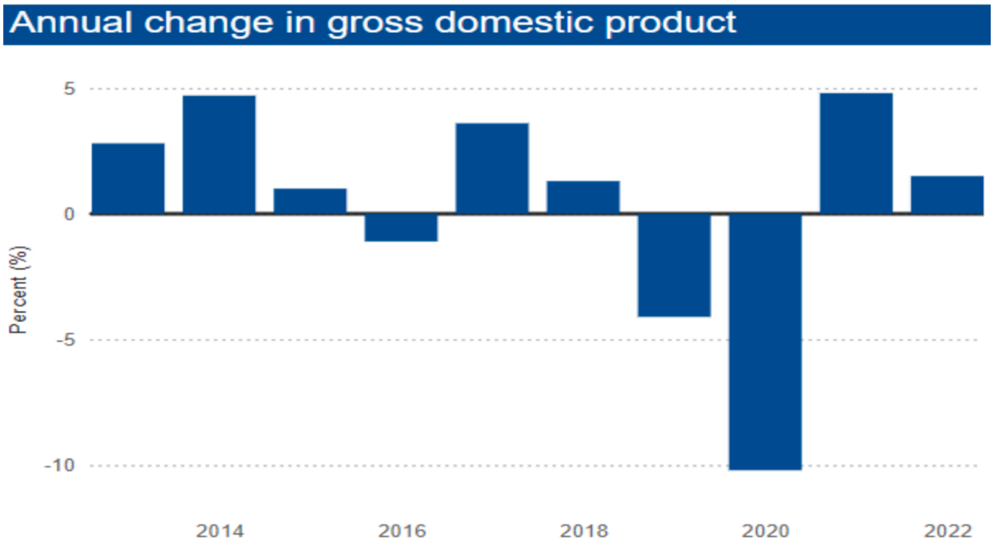

Fig. 1. GDP Growth Compares Changes in Economic Output over Time (GNWT, 2023).

across regions. However, the benefits of infrastructure improvements are not conclusive. For instance, Lu et al. (2022) highlight, regions with good transportation facilities tend to experience higher economic growth rates, but this growth can exacerbate structural issues such as income inequality. Banerjee and Somanathan (2007) find that high levels of infrastructure expenditure can widen income gaps, particularly between wealthier individuals and underprivileged populations. Similarly, Calderón and Chong (2004) note a negative relationship between infrastructure development and income equality, suggesting that infrastructure investments might disproportionately benefit wealthier regions. Li and DaCosta (2013) also argue that highway development in China was associated with greater income disparity across provinces.

2.2. Climate change and arctic economies

The harsh weather conditions and extreme climate in the NWT magnify the challenges associated with maintaining infrastructure, often undermining its long-term benefits (Timilsina et al., 2024). Climate change worsens these issues, as the rapidly shortening operational season of ice roads poses significant risks to the economic stability of these communities (Ford et al., 2021; Jochem et al., 2016; Zell, 2014; Ahmed, Zapata, et al., 2024). The declining reliability of winter roads threatens not only the economic viability of remote communities but also risks deepening socio-economic inequalities, particularly within indigenous populations who are already disproportionately affected by climate change (Vogel & Bullock, 2021).

Ultimately, winter roads are crucial for the socio-economic prosperity of remote Indigenous communities in the Arctic (Ahmed et al., 2024). In particular, ice roads are not only essential for connectivity but also serve as significant employers and vital sources of income for local residents (Berman & Schmidt, 2019). These seasonal roads, constructed annually on frozen lakes and rivers, are operational only during the coldest months and provide critical access to goods, services, and economic opportunities that would otherwise be inaccessible due to the harsh environment (Barrette et al., 2022). In many northern communities, winter roads are the sole overland transportation routes, connecting these remote areas to larger, more economically integrated regions of Canada. This connectivity is vital for industries such as mining, oil and gas, and hydroelectric power, which are major employers in these regions.

However, the increasing impact of climate change raises significant concerns about the future viability of winter roads. The Arctic is warming at twice the global average rate, leading to shorter and less predictable winters, which in turn reduce the operational season for these roads (Koetse & Rietveld, 2009; Voosen, 2021). As a result, communities that rely on these roads for their economic and social wellbeing face increased risks of isolation, food insecurity, and limited access to healthcare and education (Vogel & Bullock, 2021). Moreover, these challenges are paired by the fact that indigenous communities in the NWT are particularly vulnerable due to their traditional dependence on subsistence hunting and gathering (Ahmed, Ahmed, et al., 2025). Climate change threatens these activities through impacts such as thawing permafrost, rising sea levels, warming temperatures, melting sea ice, and ocean acidification, which disrupt the natural ecosystems that sustain these livelihoods (Larsen, 2015). Notably, the economic significance of winter roads extends beyond transportation; they also support recreational activities like ice fishing, which provide both a source of protein and economic revenue for local communities (Sharma et al., 2020). Finally, the annual construction and maintenance of winter roads, which provide employment opportunities for northern residents, are also threatened by these climatic changes, further impacting the local economy (Barrette et al., 2022).

Despite the critical importance of transportation infrastructure in the Arctic, there remains a notable gap in the literature regarding its specific impacts on Indigenous communities. While previous research has documented the economic benefits of infrastructure in developing regions (Dumas & Játiva, 2024; Gertler et al., 2024), the unique challenges posed by seasonal ice roads in the context of climate change have received limited attention. This study addresses these gaps by providing an empirical analysis of the economic impact of ice roads on remote Indigenous communities in the Northwest Territories (NWT) of Canada.

3. Data and setting

The Northwest Territories (NWT) of Canada is divided into several key areas, namely, the Beaufort Delta, Sahtu, Dehcho, South Slave, Tłı̨chǫ, and Yellowknife. Within these regions, many communities are deeply reliant on a network of winter roads and ice crossings. Our dataset includes information on ice road seasons and socioeconomic indicators for 33 NWT communities, revealing a spectrum of accessibility, as illustrated in Fig. 2.

Conspicuously, some communities benefit from year-round road access, while others are completely isolated except for air transport. Many communities, however, rely entirely on winter roads for part of the year, as illustrated in Fig. 3. In the Beaufort Delta, for example, communities such as Aklavik and Tuktoyaktuk are heavily dependent on the Aklavik ice road and Tuktoyaktuk ice road, respectively. These routes are essential during the winter months when other transportation options are limited. Similarly, the Sahtu region relies on winter roads to connect its remote communities.

The Colville Lake winter road and Délı̨ne winter road are vital for maintaining access to Colville Lake and Deline, while the Wrigley to Tulita winter road and Tulita to Norman Wells winter road ensure continuous access between Tulita and Norman Wells. The Norman Wells to Fort Good Hope winter road further reinforces regional connectivity, serving as a crucial artery for economic and social stability in these isolated areas. Additionally, in the Dehcho region, the Ft. Simpson – Wrigley winter road (Highway #1) is essential for linking Fort Simpson to Wrigley during the winter months. The Nahanni Butte Winter Road provides critical access to Nahanni Butte, and the Liard River Crossing at Fort Simpson is vital for maintaining regional connectivity when waterways freeze. The South Slave region also depends heavily on winter infrastructure. The Mackenzie River Crossing at Fort Providence is key to ensuring access to Fort Providence during winter, while the Mackenzie River Crossing at Camsell Bend plays a pivotal role in sustaining regional economic activities and mobility. In the Tłı̨chǫ region, communities such as Wekweètì, Whatì, and Gamètì rely on the Wekweètì Winter Road, Whatì Winter Road, and Gamètì Winter Road, respectively, to remain connected throughout the winter. Even in the more centrally located Yellowknife area, winter roads such as the Dettah Ice Road are crucial, particularly for linking Dettah with Yellowknife. Finally, the Tibbitt-Contwoyto Winter Road, a privately managed route, is vital for the mining industry, enabling the transport of heavy equipment and supplies to remote northern mining sites. Nevertheless, in this study to ensure a homogeneous dataset for our analysis, I focus on publicly managed winter roads to circumvent public and private winter road management issues.

I obtained the winter road data from the Department of infrastructure (GNWT, 2023). The NWT Bureau of Statistics developed community reports that include data on various social indicators and other selected metrics tracked by the GNWT. Where available, data are provided for 33 communities, the NWT as a whole, smaller communities within the NWT, and Canada. These data sources include contributions from various GNWT departments as well as Statistics Canada. The NWT Bureau of Statistics offers community profiles for all NWT communities from 2013 to 2022. During my visit to the NWT Bureau of Statistics, i was fortunate to receive data extending back to 1990 for some variables and from 1994 for others. The opening and closing dates of these ice road segments in the NWT determine the length of the ice road season for each community connected to the frozen pathway network. This seasonality plays a crucial role in shaping the economic and social activities of these communities, underscoring the importance of

Fig. 2. Communities Maps ().
Source: NWT Bureau of Statistics

maintaining and adapting these critical transportation links in the face of environmental changes. Then, I analyzed winter road statistics over time and across various communities, with the findings presented in Figs. 4 and 5. Fig. 4 show the annual operations of winter roads, while Fig. 5 breaks down operations by community

Fig. 5 shows variability between communities and over time. This variability can be attributed to several factors, including meteorological conditions, topography, and surface conditions. Climatic influences, such as warmer winters and irregular freeze–thaw cycles, play a crucial role in determining the length of the winter road season (Ford et al., 2021; Petrov et al., 2015). Additionally, the rugged terrain and uneven distribution of technological advancements further contribute to differences in road usability across communities (Barrette, 2018; Perrin et al., 2015).

Although the main focus is income, I also consider community characteristics in our analysis, including education levels, population, unemployment rate and the dependency on social assistance. Table 1 shows the definitions of the variables in our analysis.

The descriptive statistics provided in the Table 2 offer a detailed examination of the variability in winter road operation days and key socioeconomic indicators across communities in the Northwest Territories (NWT). Winter road operation days exhibit a substantial range, from 0 to 365 days, with a mean of approximately 154 days. This wide variation underscores the differing levels of accessibility across regions, driven by both seasonal conditions and geographical factors. Income distribution within these communities also shows significant disparities. The percentage of families earning less than $30,000 annually averages 31.3 %, indicating a notable presence of low-income households. In contrast, the percentage of families with incomes exceeding $75,000 stands at an average of 34.45 %, highlighting the explicit income inequality that characterizes certain areas of the NWT. The average family income is approximately $74,880, but this figure masks considerable variation between communities. Education varies widely, with the percentage of individuals holding at least a high school diploma averaging 45.73 %. This variability points to significant differences in educational outcomes across the region. Population data reveal a marked range, from small communities with as few as 35 residents to larger centers with populations exceeding 21,000, while social assistance beneficiary rate average is 0.09, but can reach as high as 0.49 in some communities. Finally, the unemployment rate averages 21.05 %, with some communities experiencing rates as high as 50 %.

The correlation analysis highlights the relationships between winter road access and income in the Northwest Territories (NWT). Table 3 shows that communities with better winter road access tend to have higher income levels, better educational attainment, and larger populations, suggesting that improved infrastructure supports stronger economic outcomes. Conversely, communities with higher rates of low income, unemployment, and social assistance dependency are typically those with poorer road access, lower education levels, and smaller populations. See (Table 4).

4. Estimation strategy and methods

To date, very little economic data, about ice roads and income in remote communities. Generally, when analyzing the impacts of climate conditions on income using regression models, it is essential to address potential biases arising from population self-selection. Communities often choose their residential locations based on a combination of climate conditions, geographical features, and economic opportunities, introducing endogeneity and complicating result interpretation. First, self-selection bias occurs because populations tend to settle in areas that align with their climate preferences and related economic opportunities. For example, Dell et al., (2012) point out that communities in tropical regions often settle in areas conducive to agriculture, leading to economies heavily reliant on climate-sensitive crop yields. As a result, climate conditions in these areas are influenced by the socioeconomic activities of the populations residing there, rather than being entirely independent. Second, simultaneity complicates the relationship between climate conditions and socioeconomic outcomes. Burke et al., (2015) highlight that wealthier regions may adapt more effectively to

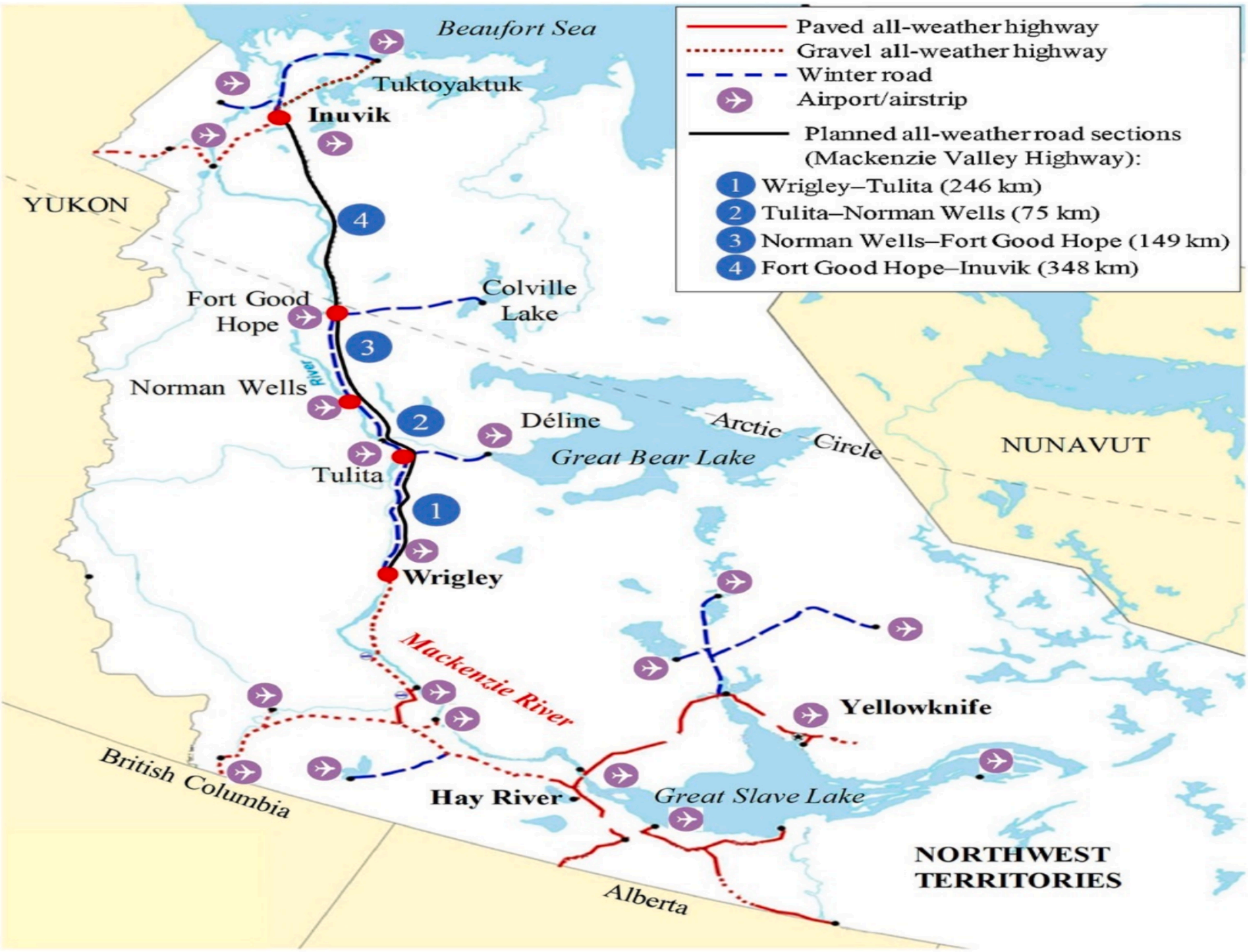

Fig. 3. Ice Roads NWT transportation network (.
Adapted from Li and Kim, 2020)

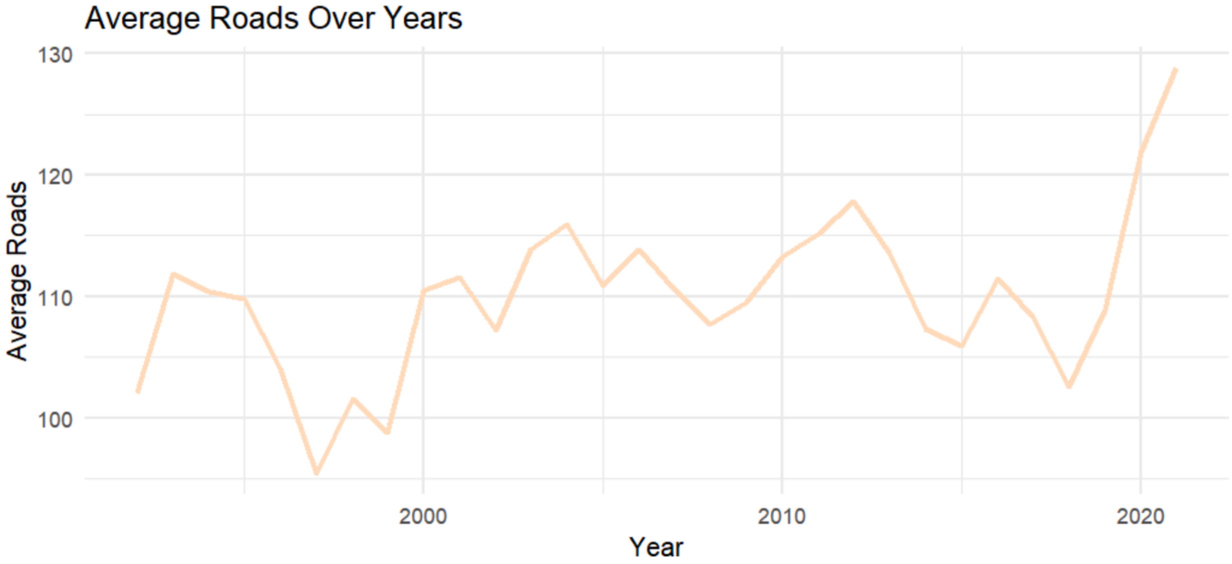

Fig. 4. Ice Roads Length Average over Years.

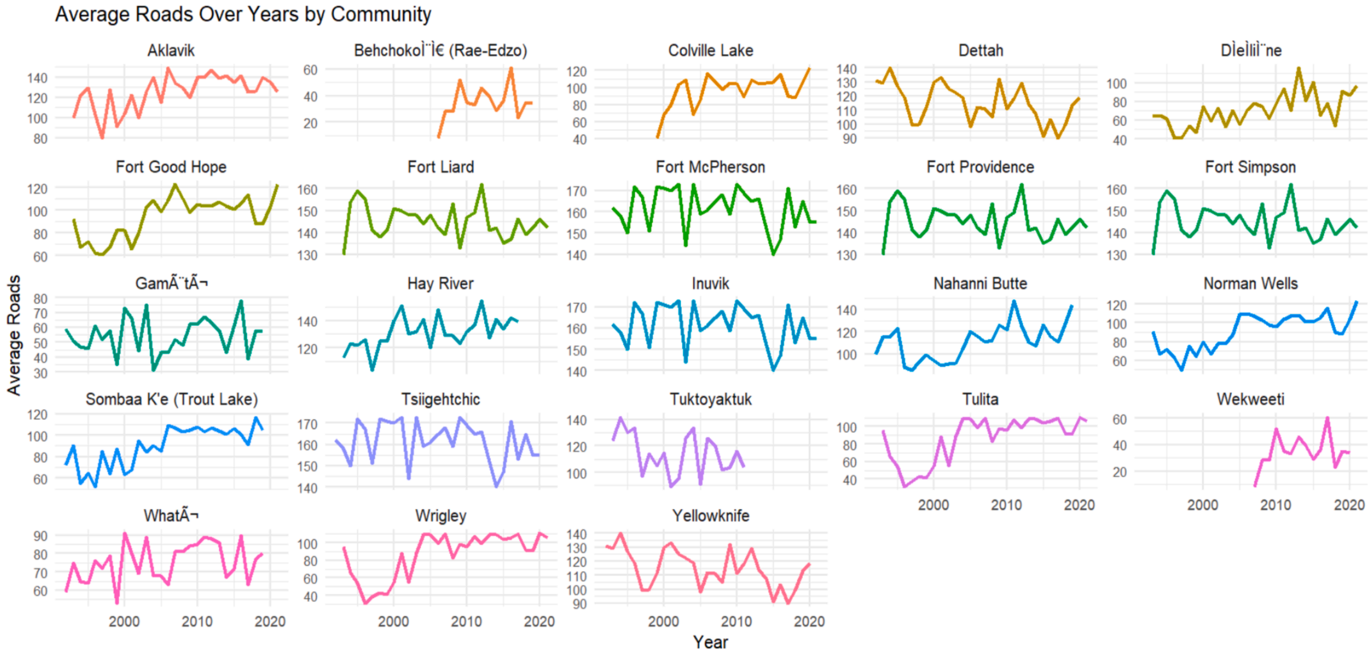

Fig. 5. Ice Road Variability between Communities and over Time.

climate variability through better infrastructure or more efficient technologies, which can mitigate some adverse impacts of climate change. This adaptation reinforces the existing economic structure, making it challenging to identify the direct effects of climate conditions without accounting for these endogenous factors. Third, omitted variable bias arises when unobserved factors, such as cultural attitudes towards risk or community governance structures, influence both a community's ability to adapt to climate conditions and its socioeconomic outcomes. As Hsiang (2016) notes, these biases can distort regression results, making it difficult to distinguish correlation from causation, leading to potentially misleading conclusions. See (Table 5).

In order to fill this gap, and to address these endogeneity issues, several studies (Dell et al., 2012; Hsiang, 2016; Burke et al., 2015; Deschênes and Greenstone, 2007; Tol, 2021; Kahn et al., 2021; Cachonet al., 2012) recommend using deviations from historical climate averages as explanatory variables. These deviations represent random fluctuations in climate conditions that occur independently of the socioeconomic characteristics of a location, providing an exogenous measure of climate impact. For example, a sudden and unexpected increase in rainfall in a typically arid region is considered a random event, unaffected by local population decisions. Using deviations from historical temperature norms provides a clearer and more accurate estimate of the economic impact of climate variability (Dell et al., 2012). Similarly, Tol (2021) and Kahn et al, (2021) argue that focusing on these deviations helps avoid biases associated with trended variables and self-selection, yielding more robust and policy-relevant insights. In the context of ice roads, deviations from the historical average operation length, such as an unexpectedly shorter or longer season, can serve as an exogenous variable that captures the true impact of climate variability on community outcomes. This randomness in ice road operation length helps isolate the effects of climate variability, free from the confounding influence of self-selection or simultaneous feedback loops. Thus, I will use deviations of the ice roads length as an explanatory variable as it is critical for identifying the causal impact of climate variability on socioeconomic outcomes. To quantify the deviation in the operational duration of ice roads, we employ the following expression: See (Table 6).

$$\Delta_{it} = S_{it} - \overline{S_{it}} \tag{1}$$

Where:

$\overline{S_{it}}$: denotes the historical mean duration, in days, that the ice road has been accessible for community *i* in year *t*.

S_{it}. signifies the actual observed duration, in days, that the ice road was operational for community *i* in year *t*.

Δ_{it}: captures the deviation, representing the differential between the actual season length and the long-term average season length for community *i* in year *t*.

The baseline OLS specification is:

$$\mathrm{Y_{it}} = \alpha + \beta_1 \mathrm{Dev\_Roads_{it}} + \beta_2 \mathrm{Edu_{it}} + \beta_3 \mathrm{Pop_{it}} + \beta_4 \mathrm{SA_{it}} + \beta_5 \mathrm{Unemp_{it}} + \mathrm{e_{it}} \tag{2}$$

Where:

Y_{it} is the income variable weather the log of the family average income, or low-income percentage, or high-income percentage at time t and for community i . Dev_Roads_{it} represents the impact of road accessibility for each community i at time t. Edu_{it} indicates the percentage of people in each community *i* has completed a high school diploma or equivalency certificate or more at time *t*. Pop_{it} represents the log of the population size or demographic factors associated with community i at time t. SA_{it} This rate is calculated by dividing the total number of social assistance beneficiaries—those who receive financial aid for essential needs such as food, shelter, clothing, and other daily necessities—by the total population of the community. $Unemp_{it}$ represent the unemployment rate at time t and for community i as a percentage. e_{it} is the error term, representing unobserved factors or random variation influencing Y_{it}. See (Table 7).

5. Results

Our analysis demonstrates that operational disruptions in ice roads—a lifeline for northern Canadian communities—intensify income inequality, systematically disadvantaging low-income households while disproportionately benefiting high-income groups. These findings, robust across spatial and temporal specifications, socioeconomic controls, and methodological refinements, emphasize the regressive economic consequences of climate-vulnerable infrastructure in Arctic regions.

Initial OLS models reveal that a one-unit increase in ice road deviation raises average household income by 1 %, yet this overarching

Table 1
Definitions of the Variable in the Analysis.

Variable	Definition	**Source**
Ice Road Deviation	The deviation variable, quantifies the difference between the actual observed duration of the ice road's accessibility for a given community i in year t, and the historical mean duration (the long-term average) of the ice road's accessibility for the same community and year.	Department of Infrastructure (GNWT, 2023)
Average Family Income	The log of the after-tax income which is the total of market income and government transfers, less income tax. Market income consists of employment income and private pensions, as well as income from investments and other market sources. Government transfers include benefits such as old age security, the guaranteed income supplement, the Canada pension plan and the Quebec pension plan, employment insurance, social assistance, the goods and services tax or harmonized sales tax credit, provincial tax credits, and child benefits.	The NWT Bureau of Statistics
High Income	Percentage of families with income less than $30,000.	The NWT Bureau of Statistics
Low Income	Percentage of families with income greater than $75,000.	The NWT Bureau of Statistics
Unemployment Rate	The unemployment rate expressed as a percentage of the labour force in that group.	The NWT Bureau of Statistics
Education	The percentage of people who has completed a high school diploma or equivalent certificate.	The NWT Bureau of Statistics
Population	Log of the number of people in each community.	The NWT Bureau of Statistics
Social Assistance Beneficiary Rate	It is a measure that quantifies the proportion of the community's population receiving social assistance payments during the reference period. This rate is calculated by dividing the total number of social assistance beneficiaries—those who receive financial aid for essential needs such as food, shelter, clothing, and other daily necessities—by the total population of the community. Eligible social assistance recipients include individuals and households experiencing financial hardship, and the support may extend to specific groups such as the elderly, persons with disabilities, single-parent families, and those facing barriers to employment.	The NWT Bureau of Statistics and the rate has been calculated by the author

Table 2
Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Roads	963	153.96	124.95	0	365
Low Income	587	31.29	15.56	0	77.78
Average Family Income	576	74880.29	32002.18	27973.33	205131.58
High Income	573	34.45	20.71	0	83.33
Education	431	45.73	17.3	0	88.69
Population	889	1306.54	3392.81	35	21,720
Social Assistance Beneficiary Rate	866	0.09	0.07	0	0.49
Unemployment Rate	429	21.05	10.75	0	50

impact hides sharp disparities in distribution. Low-income households (earning < 30,000annually) experiencea0.23–0.25 percentage point decline, while high − income households (>75,000) gain 0.22–0.25 percentage points.

Fixed effects models, which account for unobserved community and year heterogeneity, corroborate these results with improved precision. The stability of coefficients across specifications suggests that ice road disruptions amplify existing inequalities, likely by destabilizing subsistence economies reliant on seasonal access while advantaging capital-intensive sectors with adaptive capacity (Barrette et al., 2022; Pearce et al., 2010).

Introducing controls for education, population, and social assistance uncovers critical drivers of inequality. Education elevates average and high-income households 0.02 and 0.92, respectively, but suppresses low-income shares −0.71, reflecting skill-biased labor markets where formal education marginalizes traditional livelihoods (Natcher & Hickey, 2002). Specifically, education exerts a negative effect on low-income families, which may be explained by the fact that many low-income families in these regions rely on traditional activities for their livelihood. These activities often require skills and knowledge that are passed down through generations and may not necessarily align with formal education systems. Increased educational attainment can act as a barrier to accessing these traditional resources, thereby hindering income improvement for these families (Natcher & Hickey, 2002; Berman, 2014). Conversely, education has a positive impact on average and high-income families, suggesting that greater educational attainment is linked to higher income levels within these groups. This finding aligns with extensive literature that underlines the role of education in enhancing human capital, leading to better employment opportunities and higher earnings (Becker, 1993; Card, 1999). For average and high-income families, education typically facilitates access to more lucrative job markets and professional networks, which in turn contribute to increased income levels.

Additionally, social assistance exhibits a paradoxical duality: while associated with collapsing average and high-income shares 1.67 and 81.59, it surges among low-income households 80.89, show up its role as both a safety net and poverty trap. As the number of social assistance beneficiaries rises, income levels among economically disadvantaged individuals increase. This finding is consistent with the literature that highlights the role of social assistance in providing critical financial support to vulnerable populations, helping them meet basic needs and potentially improving their economic situation over time (Moffitt, 2003). However, for families with high or average income, social assistance demonstrates a negative effect, reflecting an inverse relationship between the number of beneficiaries and income levels in these groups. Social assistance programs are typically targeted toward those with lower incomes, and higher-income families may experience a relative reduction in resources or benefits when social assistance increases (Bitler et al., 2017).

Population growth further compounds deprivation, correlating with lower average income −0.80 and elevated low-income shares 45.83, signaling concentrated vulnerability in expanding communities, particularly among lower-income households.

In this study, I confront the challenges associated with spatial data in regression analysis, which frequently yield inflated t-statistics. These challenges stem from noticeable directional trends in the variables under consideration and the tendency for nearby data points to exhibit similarities, potentially leading to effective sample sizes that are smaller than anticipated (Milsom, 2024). Given these complexities, the literature has not converged on a singular approach to addressing spatial correlation. In general, in spatial analysis, each observation can

Table 3
Pairwise correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Roads	1.00							
(2) Low Income	−0.22*	1.00						
(3) Average Family Income	0.13*	−0.82*	1.00					
(4) High Income	0.23*	−0.85*	0.93*	1.00				
(5) Education	0.13*	−0.64*	0.74*	0.80*	1.00			
(6) Population	−0.03	−0.37*	0.45*	0.48*	0.49*	1.00		
(7) Social Assistance Beneficiary Rate	−0.24*	0.54*	−0.54*	−0.63*	−0.31*	−0.14*	1.00	
(8) Unemployment Rate	−0.06	0.48*	−0.51*	−0.58*	−0.55*	−0.33*	0.31*	1.00

* shows significance at $p < 0.01$.

Table 4
Base OLS and Fixed effect regression for the effect of Ice Road Length Deviation on Income.

Variables	**Panel A (OLS)**			**Panel B (Fixed effect)**		
	Average	**Low**	**High**	**Average**	**Low**	**High**
Ice Roads Length Deviation	0.01***	−0.23***	0.22***	0.01***	−0.25***	0.25***
	(0.00)	(0.05)	(0.07)	(0.00)	(0.04)	(0.04)
Constant	11.15***	31.28***	34.46***	11.15***	31.27***	34.47***
	(0.02)	(0.65)	(0.88)	(0.01)	(0.51)	(0.53)
Observations	549	560	546	549	560	546
R-squared	0.05	0.04	0.02	0.08	0.07	0.06
Community FE	No	No	No	YES	YES	YES
Year FE	No	No	No	YES	YES	YES
Number of Code				23	23	22

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5
Fixed effect regression for the effect of Ice Road Length Deviation on Income with Control Variables.

	(1)	(2)	(3)
Variables	**Average Income**	**Low Income**	**High Income**
Ice Roads Length Deviation	0.004***	−0.17***	0.14***
	(0.001)	(0.05)	(0.05)
Edu	0.02***	−0.71***	0.92***
	(0.00)	(0.12)	(0.13)
Population	−0.80***	45.83***	−19.97
	(0.30)	(12.49)	(13.25)
Social Assistance Beneficiary Rate	−1.67***	80.89***	−81.59***
	(0.31)	(11.84)	(12.47)
Unempl	0.001	0.06	−0.21
	(0.001)	(0.13)	(0.14)
Constant	15.46***	−252.62***	137.47
	(2.06)	(84.77)	(90.03)
Observations	206	209	206
R-squared	0.43	0.40	0.41
Number of Code	23	23	22
Community FE	YES	YES	YES
Year FE	YES	YES	YES

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

potentially correlate with any other, with the strength of correlation influenced by both temporal and spatial distance. Similar to time series, correlating two spatial variables can yield misleading relationships due to spatial autocorrelation, akin to the nonsensical relationships observed in correlated time series (Conley and Kelly, 2025).

I adopt Colella et al., (2023), the results of which are presented in table 6 and 7. Colella et al., (2023) introduce *acreg*, a novel command in Stata designed to address standard errors with arbitrary clustering, as proposed in their earlier work (Colella et al., 2019). This method supplements existing techniques like spatial clustering (Conley, 1999; Bester, Conley, and Hansen, 2011). The strength of these correlations tends to weaken as the distance between communities increases (Conley, 1999). Given the panel nature of the dataset and the geographic distribution of communities across the Northwest Territories, this approach allows me to correct for spatial and temporal correlations simultaneously (Colella et al., 2019), while also ensuring consistency with heteroskedasticity and autocorrelation (HAC) as per Newey and West (1987).With spatial data, *acreg* constructs a matrix S based on the geographical distance between spatial units such as regions, cities, or countries.[1]The entries in the S matrix range from 0 to 1, representing the strength of correlation between two units, inversely proportional to their distance. The diagonal of S consists of ones, reflecting self-links within the dataset. The estimator of Colella et al., (2023) reduces the null-rejection rates by taking into account the spatial correlation across observations within the same cluster. In this model, there are n observations at each time instance t ,following the linear model described below.

$$y = X_i\beta + \epsilon \tag{3}$$

The variable y represents the dependent variable, while *X* denotes a matrix of *k* linearly independent components. Each individual appears *i* multiple times across various periods *t*.

The Ordinary Least Squares (OLS) estimator for this model can be expressed as follows:

$$\widehat{b_{OLS}} = (X'X)^{-1}X'y \tag{4}$$

The theoretical Variance-Covariance (VCV) matrix of the Ordinary Least Squares (OLS) estimates is:

$$\widehat{b_{OLS}} = (X'X)^{-1}X'\Omega(X'X)^{-1} \tag{5}$$

Drawing from White's (1980) foundational work and inspired by the multiway cluster-robust estimator framework introduced by Cameron et al. (2011), Colella et al., (2023) provided the following sandwich estimator for the variance–covariance matrix based on the estimated

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[1] Community locations (latitude and longitude) were collected from Census geography in Statistics Canada.

Table 6
Arbitrary Clustering Correction (ACR) Of Standard Errors for Panel Data to Account for both Spatial and Temporal Correlations results for 10 and 100 km Distance.

Variables	**Average**		**Low**		**High**	
Distance	**10**	**100**	**10**	**100**	**10**	**100**
Ice Roads Length Deviation	0.01***	0.01***	−0.16**	−0.16**	0.15**	0.15*
	(0.001)	(0.005)	(0.07)	(0.07)	(0.08)	(0.08)
Education	0.02***	0.02***	−0.32***	−0.32***	0.72***	0.72***
	(0.00)	(0.00)	(0.09)	(0.10)	(0.11)	(0.11)
Population	−0.01	−0.01	−2.02	−2.02	1.12	1.12
	(0.05)	(0.05)	(1.45)	(1.45)	(2.07)	(2.12)
Social Assistance Beneficiary Rate	−1.25***	−1.25***	61.88***	61.88***	−74.80***	−74.80***
	(0.39)	(0.40)	(15.57)	(15.92)	(14.60)	(14.84)
Unemployment	0.004	0.00	−0.05	−0.05	0.08	0.08
	(0.003)	(0.00)	(0.15)	(0.15)	(0.13)	(0.13)
Constant	10.49***	10.49***	55.30***	55.30***	−1.88	−1.88
	(0.30)	(0.32)	(9.56)	(9.63)	(13.02)	(13.45)
Observations	206	206	209	209	206	206
R-squared	0.58	0.58	0.51	0.51	0.69	0.69

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 7
Arbitrary Clustering Correction (ACR) Of Standard Errors for Panel Data to Account for both Spatial and Temporal Correlations results for 10 and 100 km Distance, after controlling for fixed effect.

Variables	**Average**		**Low**		**High**	
Distance	**10**	**100**	**10**	**100**	**10**	**100**
Ice Roads Length Deviation	0.004***	0.004***	−0.17***	−0.17***	0.14***	0.14**
	(0.001)	(0.001)	(0.06)	(0.06)	(0.06)	(0.06)
Edu	0.02***	0.02***	−0.71***	−0.71***	0.92***	0.92***
	(0.00)	(0.00)	(0.10)	(0.10)	(0.11)	(0.11)
Popu	−0.80**	−0.80**	45.83***	45.83***	−19.97	−19.97
	(0.32)	(0.32)	(12.38)	(11.95)	(12.87)	(13.06)
Social Assistance Beneficiary Rate	−1.67***	−1.67***	80.89***	80.89***	−81.59***	−81.59***
	(0.20)	(0.19)	(8.61)	(8.77)	(10.02)	(10.04)
Unemployment	0.00	0.00	0.06	0.06	−0.21	−0.21
	(0.00)	(0.00)	(0.12)	(0.12)	(0.14)	(0.14)
Constant	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
	(0.02)	(0.02)	(0.61)	(0.64)	(0.77)	(0.80)
Observations	206	206	209	209	206	206
R-squared	0.43	0.43	0.40	0.40	0.41	0.41
Community FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

residuals $e \equiv y - Xb_{OLS}$:

$$\widehat{VCV}(b_{OLS}) = (X'X)^{-1}X'\{S \times (ee')\}X(X'X)^{-1} \tag{6}$$

The essence of this estimator lies in the “meat” of the sandwich, which is represented by the matrix S. This matrix captures the interdependence among the error terms of each observation.

$$X'\{S \times (\epsilon\epsilon')\}X = \sum_{i=1}^{n}\sum_{t=1}^{T}\sum_{j=1}^{n}\sum_{s=1}^{T} x_{it}e_{it}e_{js}x'_{js}s_{itjs} \tag{7}$$

In this arbitrary cluster setting, units are permitted to exhibit correlations with one another in any conceivable manner, devoid of any predetermined structure (Milsom, 2024). Specifically, the $itjs-th$ components of the matrix S can assume values ranging from zero to one, or any other number in between, reflecting the degree of dependence between the error of observation i and the error of observation j. As mentioned above, the framework’s adaptability enables the accommodation of not only cross-sectional and time dependencies but also their interactions.

In table 6 and 7, I apply Colella et al.,’s (2023) across 10 km and 100 km distances. Ice road deviations retain significance (average income: 0.01–0.004; low-income: −0.16 to −0.17; high-income: 0.14–0.15), though population and unemployment lose explanatory power. Education and social assistance remain robust, emphasizing geography’s role in moderating labor market dynamics. Model consistency (R2: 0.40–0.69; stable AIC scores) confirms results are not artifacts of spatial–temporal correlation.

6. Robustness check

For robustness check, I use Kelly et al., (2023) spatial regression approach that suggest a straightforward tactic using semiparametric regression with a spatial smoothing term. This method, rooted in Engle, et al., (1986) work, adapts linear regressions to fit unknown time trends. Though not widely used in economics, these models, known as Generalized Additive Models, are gaining traction in statistics and machine learning for their interpretability and I used R to run the model. Kelly et al., (2023) propose adding a two-dimensional spline in longitude and latitude, allowing us to deal with spatial issues effectively. Hence, I can control spatial dependencies directly by fitting a non-parametric spline, the method encompassing both trends and local correlation, not merely as a matter of standard errors but as a matter of specification in the following format:

$$y_i = x_i\beta + \eta_i \tag{8}$$

In general, any spatial regression tends to overlook numerous factors, each of which exhibits a directional trend and local correlation.

Therefore, adopting a less restrictive specification is advisable.

$$y_i = g(s_i) + x_i\beta + \varepsilon_i \tag{9}$$

The function g represents an unknown function of $s_i = (s_1, s_2)$, which denotes the longitude and latitude of the observations. This function captures the influence of the unobserved, spatially correlated explanatory variables. Employing a semiparametric approach allows the spatial structure of the regression to be treated as a nuisance variable during the estimation of the coefficients of interest, denoted by β.

$$\min_f \left\{ \sum_i (y_i - f(s_i))^2 + \lambda \int \left(\frac{\partial^2 f(s)}{\partial s_1^2}\right)^2 + 2\left(\frac{\partial^2 f(s)}{\partial s_1 \partial s_2}\right)^2 + \left(\frac{\partial^2 f(s)}{\partial s_2^2}\right)^2 ds \right\} \tag{10}$$

Initially, let's assume that $y_i = g(s_i) + \varepsilon_i$. Thin-plate spline smoothing value g by identifying the function $\widehat{f}$ that minimizes $\|y - f(s)\|^2 + \lambda J(f)$ where $J(f)$ penalizes overfitting, as indicated by changes in slope. The parameter λ controls the balance between fitting the data and the smoothness of f. In particular, the thin-plate spline $\widehat{f}$ is the explanation to the restricted minimization problem. The adjustment made results in changes to both coefficient estimates and standard errors. However, despite these adjustments, the primary point estimate continues to hold economic and statistical significance at the 10 % level (with a p-value of 0.079.

Tables 8, 9, 10, 11 address spatial autocorrelation that allows for the spatial structure of the regression to be treated as a nuisance variable, enabling standard inference on the remaining parameters. By directly controlling for spatial dependencies, this method influences both the coefficient estimates and the standard errors. The results show the road deviation coefficient and standard deviation estimates mirroring earlier, while some coefficient estimate is reduced or increased slightly. Despite these adjustments, the resulting point estimate for Average income remains both economically and statistically significant. Rising R^2 and declining AIC scores confirm spatial smoothing enhances precision without overfitting, rejecting spatial omitted variable bias.

To ensure the robustness of our results against time effects, I restrict the sample to 2019, eliminating potential confounding from COVID-19′s economic shocks. The effects of ice road disruptions remain consistent (average: 0.005; low-income: −0.155; high-income: 0.145), with improved model fit reinforcing the stability of these findings despite pandemic-related volatility. See (Table 12).

7. Discussion

Extended ice road seasons likely boost incomes by enhancing market access, increasing labor mobility, and reducing transportation costs for goods (Hayley & Proskin, 2008; Hinzmanet et al., 2005; Hong et al., 2011). The government has made substantial investments in ice road infrastructure, with programs like the Community Access Program (CAP) providing financial contributions to communities for constructing and maintaining access roads, trails, docks, and wharves. Despite its relatively modest annual budget of $1.5 million for both summer and winter projects, CAP plays a crucial role in supporting the infrastructure that improves the economic life of these remote communities (list of the

Table 8
The effect of Road Division on Income using semiparametric regression with a spatial smoothing term Kelly et al., (2023).

	Average	Low	High
Road Division	0.007***	−0.245***	0.226***
	(0.001)	(0.047)	(0.066)
Num.Obs.	549	560	546
R2	0.137	0.170	0.182
AIC	484.6	4573.0	4765.6

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 9
The effect of Road Division on Income using semiparametric regression with a spatial smoothing term Kelly et al., (2023).

	Average	Low	High
Road Division	0.006***	−0.216***	0.215***
	(0.001)	(0.057)	(0.061)
Education	0.019***	−0.612***	1.012***
	(0.001)	(0.048)	(0.051)
Num.Obs.	226	230	226
R2	0.591	0.482	0.689
AIC	39.9	1775.2	1755.2

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 10
The effect of Road Division on Income using semiparametric regression with a spatial smoothing term Kelly et al., (2023).

	Average	Low	High
Road Division	0.005***	−0.185***	0.146*
	(0.001)	(0.055)	(0.058)
Beneficiaries	−1.335***	58.547***	−82.292***
	(0.295)	(11.833)	(12.179)
Education	0.015***	−0.437***	0.825***
	(0.001)	(0.054)	(0.057)
Num.Obs.	206	209	206
R2	0.629	0.523	0.742
AIC	0.0	1576.1	1556.3

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 11
The effect of Road Division on Income and Control Variables using semiparametric regression with a spatial smoothing term Kelly et al., (2023).

	Average	Low	High
Road Division	0.005***	−0.177**	0.143*
	(0.001)	(0.056)	(0.059)
Unemployment Rate	0.003	−0.029	−0.028
	(0.003)	(0.112)	(0.118)
Population	−0.006	−2.197*	0.311
	(0.028)	(1.112)	(1.215)
Beneficiaries	−1.360***	58.400***	−81.781***
	(0.296)	(11.845)	(12.311)
Education	0.017***	−0.355***	0.802***
	(0.002)	(0.080)	(0.083)
Num.Obs.	206	209	206
R2	0.627	0.526	0.739
AIC	2.4	1576.5	1560.0

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 12
Effect of Road Division on Income to 2019 (Before COVID19).

	Average	Low	High
Road Division	0.005***	−0.155**	0.145*
	(0.001)	(0.056)	(0.058)
Unemployment Rate	0.003	−0.008	−0.015
	(0.003)	(0.118)	(0.123)
Population	0.002	−1.929	0.634
	(0.029)	(1.172)	(1.269)
Beneficiaries	−1.540***	67.355***	−85.135***
	(0.300)	(12.132)	(12.540)
Education	0.015***	−0.335***	0.745***
	(0.002)	(0.083)	(0.086)
Num.Obs.	185	188	185
R2	0.640	0.550	0.747
AIC	−9.9	1411.9	1393.9

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001.

projects and the funds for 2023 in Table A1 in the appendix). This research represents the first empirical investigation into the economic impact of ice road deviations on remote Indigenous communities in Canada's Northwest Territories (NWT). The study highlights the significant role that ice roads play in these communities, particularly regarding income levels, reliance on social assistance, and educational outcomes.

The study finds a positive connection between ice road deviations and higher income. Higher-income communities often have more diversified economic structures, enabling them to adapt to changes in transportation infrastructure, such as ice road deviations. These communities may benefit from deviations by accessing new markets or resources that were previously less accessible due to shorter routes (Southcott and Walker, 2015; Duhaime, 2008). This finding supports Mann's (1984) theory of infrastructural power, where state infrastructure investments, such as roads, significantly bolster economic activities by providing essential services. However, the study also highlights the vulnerability of these communities to climate change, which threatens the viability of ice roads. Rising temperatures shorten the ice road season, directly threatening the economic stability of the NWT by disrupting the region's ability to sustain its current levels of economic activity (Stephenson et al., 2011). This threat is particularly concerning for remote low income communities that rely on these roads for essential supplies and economic connectivity. For low-income communities in the Northwest Territories (NWT), the impact of transportation infrastructure is often negative. These communities typically depend on a narrow range of economic activities, such as resource extraction, small-scale trade, and subsistence practices, all of which are highly vulnerable to transportation disruptions. For instance, deviations in ice road access can severely disrupt these activities, reducing productivity and income generation (Southcott, 2013). Furthermore, ice roads play a vital role in supplying essential goods like food and fuel to remote northern communities. Delays caused by deviations in ice road accessibility often led to supply chain disruptions, driving up the prices of basic necessities. This disproportionately affects low-income households, which already allocate a larger share of their income to essential goods (Ford, 2009; Galloway McLean, 2010). These findings are consistent with the broader literature on infrastructure and inequality. For example, Banerjee and Somanathan (2007) and Calderón and Chong (2004) point out that infrastructure development often worsens income disparities by favoring wealthier regions or populations. Similarly, Lu et al. (2022) and Li and DaCosta (2013) highlight how transportation improvements can widen economic gaps, particularly in marginalized or remote areas. This body of research indicates that infrastructure development frequently fails to address the needs of vulnerable communities, instead deepening their economic vulnerabilities. Thus, while infrastructure development can stimulate economic growth, its benefits are not equitably distributed. For low-income communities in the NWT, transportation disruptions can have severe consequences, further entrenching economic disparities and perpetuating cycles of poverty.

The study also uncovers a complex challenge regarding education's impact on low-income families. Although education generally associates with higher income levels (Becker, 1993; Card, 1999), in the NWT, it has a negative impact on lower-income families. This suggests that the formal education system may not align with the traditional knowledge and skills vital for these communities' livelihoods (Natcher & Hickey, 2002; Berman, 2014). The misalignment between formal education and the economic realities of low-income families in the NWT emphasizes the need for culturally relevant education programs that integrate traditional knowledge with formal educational content. Thus, the contrasting effects of education on income in low- and high-income communities stem from structural, economic, and social disparities. In low-income communities, education's negative effect on income is often linked to a mismatch between education systems and labor market demands. Card (1999) notes that in regions with limited industrial diversification, the absence of high-skill job opportunities can result in educated individuals being underemployed or unemployed, as their skills are incompatible with available roles. Similarly, Kelly et al., (2023) suggest that low-income areas frequently lack industries that require or reward higher education, limiting the potential for education to translate into economic gains. While, Southcott et al., (2018) highlights that these communities often operate in low-skill, resource-dependent economies that fail to capitalize on the advanced skills of educated individuals.

Moreover, limited economic opportunities and structural barriers intensify the issue. Brain drain, as discussed by Faggian et al., (2007), is a significant challenge in low-income communities, where educated individuals migrate to urban or wealthier regions in search of better employment prospects, depriving their home communities of potential economic benefits. Compounding this issue are systemic inequities, including discrimination, lack of infrastructure, and restricted access to financial capital, which hinder the ability of individuals in these regions to leverage their education effectively (Ford et al., 2010). These factors collectively reduce the return on investment in education in low-income communities, rendering it an ineffective tool for income growth in such areas.

In contrast, education has a strongly positive effect on income in high-income communities due to a combination of economic diversification, better resource access, and social capital. Psacharopoulos and Patrinos (2018) emphasize that high-income communities typically feature diversified economies with a demand for high-skill labor, ensuring that education is rewarded with higher wages. Wealthier regions also tend to have superior schools, specialized training programs, and strong connections to employers, which enhance the employability and earning potential of educated individuals (Duhaime, 2008). Additionally, Southcott and Walker (2015) highlight the role of professional networks and social capital in amplifying the economic returns on education in these communities, as individuals are better connected to lucrative opportunities and supportive systems.

The study also finds that social assistance programs effectively raise incomes for low-income families. Previous studies (Moffitt, 2003) highlight that social assistance is a safety net for vulnerable populations However, the study notes a negative relationship between social assistance and income levels among higher-income families, suggesting a potential crowding-out effect, where increased social assistance might reduce incentives or opportunities for income generation among those less reliant on these programs (Bitler, et al., 2017). As can be seen, the findings point to significant economic challenges in larger communities, especially among lower-income households. These challenges stem from higher living costs, greater competition for jobs, or more pronounced income disparities within these communities (Donaldson, 2018; Dumas & Játiva, 2024). These insights suggest that while infrastructure improvements are crucial, they must be accompanied by targeted social and economic policies that address the unique challenges faced by remote and marginalized populations to ensure that infrastructure investments contribute to inclusive and sustainable development.

8. Conclusion

Ice roads, then, were crucial to the increase income in the Northwest Territories. Introduced after the Second World War, these roads made the movement of the necessities of life more affordable (Prowse et al., 2009). They also facilitated the transport of heavy equipment and supplies vital to the mining and petrochemical industries. There are 10 highways in the Northwest Territories, along with a number of community access roads and winter roads. Of the 33 communities in the Northwest Territories, 19 have road access, 10 have winter road access only, and 4 are without road access (Barrette et al., 2022).

This research draws on data about ice road length in the northwest Territories in Canada and social variables from the communities profiles from 1990 to 2022. As already noted, this study significantly advances our understanding of how transportation infrastructure, particularly ice roads, impacts the economies of remote Indigenous communities in the NWT. By examining the effects of ice road deviations on income levels, the research underlines the vital role these seasonal roads play in the region's economic development.

I find that maintaining and potentially expanding ice road infrastructure could help mitigate some of the adverse effects of climate change on these communities. However, the long-term viability of this strategy remains uncertain as environmental changes continue to accelerate (Stephenson, 2012; Jochem et al., 2016)

In particular, the study finds that ice road deviations contribute to higher income in wealthier communities, as their diversified economies enable adaptation and exploitation of new market and resource opportunities (Southcott & Walker, 2015; Duhaime, 2008). In contrast, low-income NWT communities experience heightened disparities and poverty due to transportation disruptions, highlighting the unequal distribution of infrastructure benefits. Moreover, the study emphasizes the need for more culturally relevant education programs and social assistance policies tailored to the unique economic and social conditions of the NWT (Ahmed, Poelzer, et al., 2024). In low-income communities, targeted interventions to align education systems with local labor market needs, create job opportunities, and address structural inequities are essential to improve the economic returns on education. For high-income communities, policies should continue to support higher education and skill development to sustain and enhance their economic advantages. Addressing these disparities requires a vigorous approach, recognizing the distinct challenges and opportunities within different socioeconomic contexts.

As the region confronts increasing challenges from climate change, policymakers must develop strategies that not only sustain existing transportation infrastructure but also foster economic resilience amid environmental uncertainties (Vogel & Bullock, 2021; Ford et al., 2021).

Future research should explore alternative transportation solutions, such as constructing permanent roads, which could provide more stable and reliable access to remote communities (Berman & Schmidt, 2019). Additionally, further investigation into the interplay between education, traditional livelihoods, and income generation in the NWT could offer valuable insights for designing more effective education and economic policies (Ahmed & Hall, 2025; Berman, 2014; Natcher & Hickey, 2002). Finally, a more research of the relationship between social assistance and income distribution in these communities could inform the development of programs that better support economic mobility across different income groups (Bitler, et al., 2017).

CRediT authorship contribution statement

Fatma Ahmed: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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.

Appendix 1

Table A1
The Department of Infrastructure's Community Access Program (CAP) contribution funding to communities across the Northwest Territories for the construction and rehabilitation of transportation and marine infrastructure.

Region	Community	Project	Amount Approved	Amount Spent
Sahtú	Délı̨ne	14-Mile Ice Road to Whiskey Jack Point (page 3)	$57,520	$57,520
Sahtú	Tulita	Four Mile Creek Quad/Walking Trail – Continuation Construction (Winter) (page 3)	$75,000	$75,000
Sahtú	Tulita	Four Mile Creek Quad/Walking Trail – Continuation Construction (Summer) (page 4)	$140,160	$140,160
Sahtú	Tulita	Our Ancestor's Traditional Trail	$106,955	$0
Beaufort Delta	Tsiigehtchic	32KM (20 Miles) Arctic Red River Ice Road (page 4)	$35,000	$35,000
Beaufort Delta	Aklavik	80KM Section – Peel River Ice Road from Aklavik to Esau Creek (page 5)	$65,000	$65,000
Beaufort Delta	Fort McPherson	80KM Section – Peel River Ice Road from Fort McPherson to Esau Creek (page 5)	$60,000	$60,000
Beaufort Delta	Tuktoyaktuk	Husky Lakes Trail – Continuation Construction (page 6)	$100,000	$100,000
Beaufort Delta	Paulatuk	ATV Trail – Continuation Construction	$100,000	$0
South Slave	Town of Hay River	Access Road Upgrade – Continuation Construction (page 6)	$139,159	$139,159
South Slave	Town of Hay River	Ski Trails Safety and Accessibility Improvements (page 7)	$49,750	$49,750
South Slave	Salt River First Nation	Thebacha Village Access Road (page 7)	$3,000	$3,000
South Slave	Fort Smith Métis Council	Grande de Tour Winter Road (page 8)	$12,000	$12,000
South Slave	Fort Resolution	Nagel Channel Access Road/Slave River Road Upgrade	$40,000	$0
South Slave	Kakisa	Cultural/Community Camp Trail – Continuation Construction (page 9)	$20,000	$20,000
South Slave	Kakisa	Marine Docking Facility – Continuation Construction	$75,000	$0
North Slave	Wekweètì	Wekweètì Access Road – Continuation Construction (page 10)	$136,640	$60,976
North Slave	Gamètì	Duck Pond Access Road – Continuation Construction	$103,500	$0
North Slave	Behchokǫ̀	Ice Road "Connector" (page 11)	$41,004	$41,004
North Slave	Łutselk'e	Łutselk'e Bay Access Trail (page 12)	$84,445	$84,187
North Slave	Łutselk'e	Austin Lake Access Road (page 13)	$100,000	$100,000
North Slave	Yellowknife/YKDFN	Access Trails Brushing and Clearing	$50,000	$0
Dehcho	Nahanni Butte	Access Trails Continuation Construction – Arrowhead, Bluebell, Swan Point, Achinea Trails (page 14)	$20,000	$20,000
Dehcho	Nahanni Butte	Boat Launch and Boat Launch Access Road – Continuation Construction (page 15)	$91,400	$91,400
Dehcho	Wrigley	Airport Lake Dock Replacement Construction (page 16)	$38,663	$37,971

Data availability

Data will be made available on request.

References

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