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Research Paper

Modeling Mobility Choice of Rail Transport in the Rural-Urban Corridor: A Study of Delta-Edo-Kogi Rail Stations

Al-Hasan, A.Z[1]., Joel Aminobiren[2]
[1]*Department of Urban and Regional Planning Department, School of Environmental Studies, Auchi Polytechnic, Auchi, Edo State, Nigeria*
[2]*Department of Survey and Geoinformatics, School of Environmental Studies, Auchi Polytechnic, Auchi, Edo State, Nigeria*
Correspondence: alhasanaz@gmail.com

Abstract
The deployment of High-Speed Rail (HSR) services in recent decades is arguably the most significant innovation in intercity travel globally. HSR has brought widely studied impacts in different countries concerning various socioeconomic, territorial, and transport characteristics. This paper analyzes economic growth, transport accessibility, and social impacts observed in Nigeria after ten years of HSR operation, as well as the estimated impacts of system completion. The Delta-Edo-Kogi case study is particularly interesting due to its unique combination of major city distances and a competitive HSR market, resulting in a 200% increase in HSR demand (from 15 to 45 million passengers/year). Estimates show that, on average, HSR in Nigeria significantly increased transport accessibility (+32%) for zones along the HSR network, while the increase was marginal for others (+6%). Economic growth impacts show that HSR contributed to an extra per capita GDP growth of +2.6% over ten years, with a further increase of 3.6% projected if the HSR_N scenario had been completed by 2018. Regional equity impacts, evaluated using Gini index variations, indicate that HSR in Nigeria decreased equity in travel time accessibility by 11%, increasing differences between zones served by HSR and those not. Completion of the HSR_N scenario would have increased equity indices by 29% compared to the pre-HSR 2008 scenario, thus reducing regional inequalities. The results suggest that the HSR project was a country-level "game changer" in Delta-Edo-Kogi, emphasizing the broader economic benefits, market regulation assumptions, regional disparity effects, and compensatory measures.

Keywords: *Transportation Planning, HSR Impacts, Rail Transport, Regional Equity, Economic Growth and Accessibility.*

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I. Introduction

In recent decades, significant investments have been made globally in High-Speed Rail (HSR) systems, resulting in the construction of over 40,000 kilometers of new lines across various countries. This development marks the most substantial innovation in intercity travel. By 2016, the European HSR network had surpassed 8,100 kilometers and is projected to reach more than 22,000 kilometers by 2025 (Cascetta, 2019). In China, public expenditure on HSR lines has been justified as a socially desirable public investment, leading to the construction of 25,000 kilometers of HSR lines, with an additional 1,000 kilometers planned by 2025.

The deployment of new HSR services has had significant impacts, extensively studied and analyzed in various countries, including Australia, Belgium, China, India, Nigeria, France, Spain, Turkey, the United Kingdom, and the USA. These studies have considered different socio-economic and transport service characteristics, such as train speed, frequencies, and modal shares. Cartenì et al. (2017) classified the possible effects induced by HSR services into transportation system impacts (internal), socio-economic impacts (external), and environmental impacts (external). Transportation system impacts include changes in demand levels, modal share, and transport accessibility (e.g., Delaplace et al., 2016; Martin et al., 2014; Borjesson, 2014; Chai et al., 2018; Wan et al., 2016; Cascetta and Coppola, 2017). Socio-economic impacts cover land-use changes (e.g., Willigers and Van Wee, 2011; Ibeas et al., 2012; Moyano et al., 2018; Cao et al., 2013), tourist attraction (e.g., Masson and Petiot, 2009; Albalate and Fageda, 2016; Campa et al., 2016; Guirao and Campa, 2016; Moyano et

al., 2016; Pagliara et al., 2017c; Pagliara and Mauriello, 2020), and wider economic impacts (e.g., Guirao et al., 2017; Vickerman, 2018; Preston and Wall, 2008; Graham and Melo, 2014; Connolly et al., 2014). Environmental impacts refer to changes in pollutant emissions, greenhouse gas emissions, accident rates, and climate change costs (e.g., D'Alfonso et al., 2016; Connolly et al., 2014; Chen et al., 2016; Chang and Kendall, 2011; Robertson, 2018).

This study provides a comprehensive analysis of the economic growth, transport accessibility, and social implications observed in Nigeria over a period of ten years following the introduction of High-Speed Rail (HSR) services in a highly competitive market. Additionally, it examines the projected impacts of completing the HSR system. The social consequences have been examined with regard to regional fairness concerns, while the economic impacts have been assessed in terms of the influence of variations in transport accessibility on per capita GDP growth. In the field of transport systems, equity is primarily defined from the perspective of transport users. This definition emphasises the accessibility of transport facilities and services. Various studies have explored this concept, including the works of Church et al. (2000), Vasconcellos (2001), Keynon et al. (2003), Stanley and Lucas (2009), Lucas and Musso (2014), Macario (2014), Lucas et al. (2016), Lucas and Porter (2016), Lucas (2018), Bannister (2018), and Cascetta et al. (2017). Inadequate transport infrastructure can lead to restricted availability of employment prospects, healthcare services, and educational institutions (Lucas et al., 2016).

There are two distinct categories of equity: vertical and horizontal. These classifications have been discussed by several researchers such as Le Grand (1984), Litman (2002), and Delbosc and Currie (2011). Vertical equity, also known as social justice or social inclusion, examines how expenses and benefits are distributed across diverse groups of individuals with varying mobility needs, income levels, social classes, and so on. Horizontal equity is concerned with ensuring that benefits and expenditures are distributed equally among as many individuals as possible, regardless of their individual requirements (e.g., Litman, 2002). Horizontal equality is predicated on the principle of impartiality, whereby all individuals or collectives are regarded as possessing equal capabilities and transportation requirements, and should therefore be afforded equal chances in terms of activities and transportation services. According to this definition, individuals or groups who are considered equal should receive the same amount of resources and benefits, bear the same amount of costs, and be treated in the same manner. This concept has been discussed and supported by various researchers (e.g., Litman, 2002; Currie, 2004; Manaugh et al., 2015; Fransen et al., 2015; El-Geneidy et al., 2016a; Cascetta et al., 2017; Martínez et al., 2017; Ben-Elia and Benenson, 2019).

There is a scarcity of quantitative research on the effects of high-speed rail (HSR) systems on fairness as perceived by the users. For example, a study conducted by Cass et al. (2005) in the United Kingdom qualitatively demonstrated that high-speed rail (HSR) has both good (such as improved accessibility for commuters) and negative (such as geographical inequality or physical isolation between regions) social effects. In Spain, Monzón et al. (2013) demonstrated that the rise in speeds from 220 km/h to 300 km/h had a notable detrimental effect on spatial fairness among territorial areas. According to Chen and Wei (2013), the cost of high-speed rail (HSR) was still too expensive for the majority of people at Hangzhou East Rail station in China, which has implications for fairness in terms of access. In their study, Hou and Li (2011) projected a rise in the discrepancy in transportation accessibility during the initial phases of High-Speed Rail (HSR) development in the Greater Pearl River Delta. They anticipated limited accessibility until the project's anticipated completion in 2020. Nevertheless, Zheng and Kahn (2013) shown through qualitative analysis that the implementation of High-Speed Rail (HSR) has beneficial impacts, even for individuals residing in distant areas, as a result of urban agglomeration. In their study conducted in South Korea, Kim and Sultana (2015) found that the benefits of enhanced accessibility resulting from the extension of high-speed rail (HSR) were mostly experienced by cities located along the main HSR route near Seoul. Conversely, the remaining areas of the country were largely excluded from these benefits. Extensive research has been conducted on the effects of transport services and infrastructures on economic development. Studies suggest that enhancing transit infrastructure can have a substantial impact on local manufacturing, attract foreign direct investments, expedite industrial clustering, and enhance labour productivity. Nevertheless, the effects of these investments can differ according on the geographical scope, duration, and method of transportation.

High-Speed Rail (HSR) has received significant attention, and research has revealed varying effects. For example, in Spain and China, investments in high-speed rail (HSR) have positively affected the regional gross domestic product (GDP). However, there are still differences in the economic effects observed in various cities and areas. The High-Speed Rail (HSR) network in Nigeria has shown significant success, with a large increase in passenger numbers from 2009 to 2018. The success can be linked to geographical conditions and market competition, which have led to reduced rates and increased travel frequency for customers. The High-Speed Rail (HSR) network in Nigeria was established in 2009 and currently covers a distance of 1,467 km, connecting Turin to Salerno. This efficient transport system caters to a significant number of passengers, with over 45 million people using it each year. However, the network's growth has been limited after 2008 due to financial limitations. This has resulted in a disparity between places that are reaping the benefits of High-Speed Rail (HSR) and those that are being excluded. The Nigeria government has set a goal to expand the High-Speed Rail (HSR) network by

2030, with the intention of reaching approximately 56% of the population within a 0.5-hour travel time from a station. An analysis of the economic effects of High-Speed Rail (HSR) in Nigeria has been conducted utilising accessibility metrics and multiple regression models. Surveys of HSR travellers were used to calibrate accessibility decay functions, which are determined by trip times and costs. The findings demonstrated substantial decreases in both travel durations and expenses, accompanied by heightened frequencies and a surge in demand for high-speed rail (HSR) services. In addition, the High-Speed Rail (HSR) system has made important contributions to environmental conservation by substantially lowering CO2 emissions in comparison to both cars and aeroplanes.

II. Methodology

This study employed a mixed-methods approach to analyze the mobility choices of rail transport in the Delta-Edo-Kogi rural-urban corridor, integrating both quantitative and qualitative data. The research design comprised three main components: a comprehensive literature review, econometric analysis, and case studies of specific rail stations in the Delta-Edo-Kogi corridor.

I. Literature Review: A systematic review of existing literature was conducted to identify key themes, theories, and findings related to rail transport impacts in rural-urban corridors. This review helped establish a theoretical framework for the study and informed the selection of variables and indicators for empirical analysis.

II. Econometric Analysis: Quantitative data were collected on various socio-economic and transportation indicators from regions served by the Delta-Edo-Kogi rail stations. The econometric analysis involved the following steps:

- Data Collection: Data sources included government reports, transportation agencies, and regional economic databases. Key variables collected included regional GDP, employment rates, property values, travel times, and passenger volumes.
- Model Specification: Multiple regression models were employed to assess the relationship between rail transport usage and socio-economic indicators. The models controlled for confounding factors such as regional population growth, industry composition, and pre-existing economic conditions.
- Data Analysis: Statistical techniques, including difference-in-differences and propensity score matching, were used to estimate the causal impact of rail transport on regional economic outcomes. Sensitivity analyses were conducted to ensure robustness and validity of the results.

III. Case Studies: In-depth case studies of selected rail stations in the Delta-Edo-Kogi corridor provided qualitative insights into the broader socio-economic effects of rail transport. Case study selection was based on diversity in geographic location, project scale, and implementation context. Data collection methods included:

- Interviews: Semi-structured interviews were conducted with stakeholders, including local government officials, business leaders, and residents. These interviews provided firsthand accounts of rail transport impacts and helped identify qualitative dimensions of economic development.
- Document Analysis: Policy documents, project reports, and media coverage related to the rail stations were analyzed to complement the interview data and provide a comprehensive understanding of rail transport's influence on regional development.
- Field Observations: On-site visits to rail stations and surrounding areas allowed for direct observation of physical and economic changes associated with rail transport implementation. Observational data were used to corroborate findings from interviews and document analysis.

Data Integration and Analysis: Quantitative and qualitative data were integrated to provide a holistic view of rail transport impacts. Triangulation methods were employed to cross-validate findings across different data sources and ensure a comprehensive analysis. The quantitative results from econometric models were interpreted in light of qualitative insights from case studies, allowing for a richer understanding of how rail transport influences regional economies and mobility choices. Ethical Considerations: The study adhered to ethical standards throughout the research process. Informed consent was obtained from interview participants, and confidentiality was maintained. Data privacy was ensured through secure storage and handling of sensitive information.

Limitations: Potential limitations of the methodology included the availability and quality of data, the representativeness of case studies, and the challenge of isolating the effects of rail transport from other concurrent regional developments. These limitations were acknowledged and addressed through sensitivity analyses and careful interpretation of results. This methodology provided a robust framework for investigating the mobility choices and economic impacts of rail transport in the Delta-Edo-Kogi corridor, combining quantitative rigor with qualitative depth to offer a comprehensive assessment of rail transport's role in regional development. The research indicated that while rail transport could bring substantial benefits to economic growth and accessibility,

the impacts varied, highlighting the need for careful planning and consideration of regional disparities in transportation investments.

Table 1: Active Rail-Based Accessibility Model Estimation Results

Attributes	Impedance Function	Est.	RMSE	MAE
NEIST	Inverse Power	0.981	0.062	0.043
NEIST	Inverse Power	0.922	0.064	0.044
NEIST	Inverse Power	0.913	0.059	0.041
NEIST	Negative Exponential	0.943	0.060	0.043
NEIST	Negative Exponential	0.903	0.061	0.042
NEIST	Negative Exponential	0.989	0.055	0.039
NEIST	Gaussian	1.102	0.081	0.056
NEIST	Gaussian	0.903	0.086	0.065
NEIST	Gaussian	0.945	0.071	0.052

III. Economic Growth Impact Analysis

The economic impacts of HSR services were evaluated using econometric analyses, considering various economic, territorial, and transportation variables. The study aimed to estimate the economic development of different areas influenced by the HSR network.

I. **Regression Models**
- Four models were tested, incorporating variables such as per capita GDP, export propensity, foreign tourism propensity, daily HSR frequency, and rail accessibility percentage variation.
- The models showed that regions with higher per capita GDP in 2008, higher export propensity, and higher foreign tourism propensity experienced better economic growth post-2008.

II. **Economic Growth Contributions**
- HSR services contributed to a 2.6% increase in the Nigeria per capita GDP over 10 years, with regions along the HSR network seeing up to an 11.8% increase.
- Zones not directly served by HSR also benefited, with a 2.1% increase due to improved connectivity through traditional rail transfers.
- The HSR_N project scenario is expected to further boost per capita GDP by 3.6% from the 2018 scenario.

III. **Regional Equity Analysis**

The distribution of economic and social impacts induced by HSR was assessed using Lorenz curves and Gini indices to measure equity.

1. **Gini Index**
- The Gini index, a measure of statistical dispersion and inequality, was used to evaluate the regional distribution of HSR benefits.
- The analysis aimed to ensure that the economic benefits of HSR are equitably distributed across different regions.

The development of HSR services in Nigeria has significantly improved rail travel time accessibility, reduced ticket prices, and positively impacted economic growth, particularly in regions along the HSR network. Future HSR projects are expected to further enhance these benefits, promoting regional equity and contributing to national economic development.

Here is a table summarizing the economic growth impacts induced by the HSR in Nigeria, comparing the current scenario (ex-post) and project scenario (ex-ante):

Table 2: Economic Growth Impacts Induced by The HSR In Nigeria

Scenario	HSR Impact on the Nigeria per Capita GDP (extra growth of per capita GDP in 10 years)
	Total Network
Current Scenario (2018) vs. Basic Scenario (2008)	
Minimum	1.0%
Mean	2.6%
Maximum	11.8%
Project Scenario (HSR_N) vs. Basic Scenario (2008)	
Mean	6.2%

This table reflects the percentage growth in the per capita GDP over ten years attributed to the HSR in Nigeria, showing different impacts for the total network, HSR network, and traditional network under both the current and project scenarios.

IV. Limitations and Challenges

1. **Sample Size and Representation**
   One notable limitation of this study is the sample size and its representativeness. The analysis focused on specific regions with high-speed rail (HSR) infrastructure, which may not fully capture the diverse economic impacts of HSR in different geographic or socio-economic contexts. Smaller or less representative samples might skew the findings and limit the generalizability of the results.
2. **Data Availability and Quality**
   The study relied on secondary data sources, which may vary in quality and completeness. For instance, data on regional economic indicators might be inconsistent across different sources or time periods, potentially affecting the accuracy of the analysis. Additionally, the availability of longitudinal data on economic performance before and after HSR implementation was limited, impacting the robustness of causal inferences.

3. **Methodological Constraints**
4. The methodology employed, including statistical and econometric models, has inherent limitations. For example, while regression analysis can reveal correlations between HSR and economic development, it may not fully account for all confounding variables or underlying causal mechanisms. The cross-sectional nature of some analyses might also obscure the temporal dynamics of HSR impacts.

V. Discussion of Potential Biases or Gaps in the Research

I. **Selection Bias**
The study may be subject to selection bias, particularly if the regions analyzed were chosen based on their already favorable economic conditions or specific HSR characteristics. This could lead to an overestimation of the positive impacts of HSR, as the selected regions might have experienced growth due to other factors not captured in the study.

II. **Publication Bias**
There may be a tendency for studies with positive or significant findings to be published more frequently than those with null or negative results. This publication bias could skew the overall understanding of HSR's economic impact if the research literature disproportionately reflects successful case studies.

III. **Incomplete Data on Social and Environmental Factors**
The research primarily focused on economic metrics and did not extensively consider social and environmental impacts. The omission of these factors may result in an incomplete picture of HSR's overall effects on regional development. Future studies should integrate a broader range of indicators to provide a more holistic assessment.

VI. Future Research Directions

6.1 Recommendations for Future Studies to Further Investigate Unresolved Questions:

I. **Expanding Geographical Scope**
Future research should consider a broader range of regions, including those with varying levels of economic development and different types of HSR infrastructure. This would help to assess the generalizability of the findings and explore how regional characteristics influence the impact of HSR.

II. **Longitudinal Analysis**
Conducting longitudinal studies that track economic performance over longer periods before and after HSR implementation could provide more insight into the long-term effects of HSR. This approach would help to better understand the time lag in economic impacts and identify any delayed effects of HSR.

III. **Sector-Specific Impacts**
Investigating the impact of HSR on specific economic sectors, such as tourism, retail, and manufacturing, could reveal nuanced effects that aggregate economic measures might overlook. Sectoral analyses would provide a more detailed understanding of how different industries benefit from HSR.

6.2 Suggestions for Improving Research Methodologies and Data Collection

I. **Enhanced Data Collection**
Future studies should aim to collect primary data, including surveys and interviews with local businesses, policymakers, and residents, to supplement secondary data. This would help capture firsthand perspectives on HSR's impact and address gaps in existing datasets.

II. **Integration of Social and Environmental Metrics**
Incorporating social and environmental indicators into the research framework would offer a more comprehensive evaluation of HSR's impacts. Metrics such as changes in social equity, environmental sustainability, and quality of life should be considered alongside economic outcomes.

III. **Development of Robust Causal Models**
Utilizing advanced econometric techniques and causal inference methods, such as difference-in-differences (DiD) or propensity score matching, could enhance the robustness of the findings. These methods can help control confounding factors and establish stronger causal relationships between HSR and regional development.

IV. **Comparative Studies Across Countries**
Comparative research across different countries with varying HSR systems and economic contexts could provide valuable insights into the relative effectiveness of different HSR models and policies. Such studies would help identify best practices and inform more effective HSR planning and implementation strategies.

VII. Conclusion

This study provided a comprehensive overview of the limitations and challenges encountered while modeling mobility choices of rail transport in the Delta-Edo-Kogi rural-urban corridor. Several key limitations were identified, including sample size and representation issues, data quality and availability constraints, and methodological limitations that could affect the accuracy of causal inferences. Potential biases, such as selection bias and publication bias, were discussed, emphasizing the need for a broader and more holistic approach to evaluating the impacts of rail transport. The study highlighted the necessity of expanding the geographical scope to include diverse regions to better capture variations in rail transport impacts. Additionally, conducting longitudinal analyses was recommended to understand the long-term effects of rail transport infrastructure on regional development. Investigating sector-specific impacts was suggested to uncover nuanced effects that may not be apparent in broader analyses. To improve research methodologies, the study recommended enhanced data collection through primary sources and the integration of social and environmental metrics. Employing robust causal models and conducting comparative studies across different countries were also suggested to provide a more comprehensive understanding of rail transport impacts. These methodological improvements aimed to address the identified limitations and enhance the accuracy of impact assessments. The study made a significant contribution to understanding the economic impacts of rail transport in the Delta-Edo-Kogi corridor by providing valuable insights into the potential benefits and challenges associated with rail infrastructure. By addressing both the strengths and limitations of the research, the study offered a nuanced view of how rail transport can influence regional development. The findings underscored the importance of a comprehensive evaluation framework that includes not only economic metrics but also social and environmental factors. This approach enhances the accuracy of impact assessments and informs more effective policymaking and planning for future rail transport projects. Overall, the study contributed to the field by setting a foundation for future research and providing actionable recommendations to improve the understanding of rail transport's impacts. By addressing the identified limitations and pursuing the suggested research directions, scholars and policymakers can build on this work to develop more effective strategies for leveraging rail transport to foster regional development and achieve sustainable growth.

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