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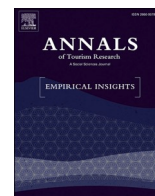
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Does improved accessibility translate into tourism growth? A difference-in-differences analysis of bridge infrastructure in Indonesia

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ABSTRACT

Tourism growth relies heavily on transport infrastructure. In regions with unique geography, enhanced accessibility can significantly boost tourism. This study examines the impact of the Suramadu Bridge on tourism on Madura Island, Indonesia, using a difference-in-difference (DiD) approach. Unlike prior research focusing on rail transport, this study highlights the overlooked role of bridges in regional tourism. Findings reveal that, unexpectedly, the bridge did not significantly boost tourism, aligning with Leiper's open system framework. Despite the enhanced accessibility, internal barriers to tourism remain. The study highlights the need for integrated planning, multi-stakeholder strategies, and complementary policies to maximize infrastructure benefits. It also emphasizes the importance of viability studies to guide future projects.

1. Introduction

Island destinations often possess exceptional natural and cultural endowments that make them highly attractive to both domestic and international tourists. However, their geographic isolation presents significant challenges, particularly in terms of accessibility and connectivity. For such regions, the development of transport infrastructure is critical to enabling mobility, reducing travel costs, and integrating peripheral areas into national and regional tourism circuits (Parra-López & Martínez-González, 2018). Empirical evidence from various island tourism destinations indicates that improved infrastructure can lead to substantial growth in the tourism sector (Khadaroo & Seetanah, 2007).

Despite the growing academic interest in the relationship between transport infrastructure and tourism development, most studies have concentrated on air transport and high-speed rail (Pagliara et al., 2015), while fixed-link systems such as bridges remain notably understudied (Chu et al., 2021; Jeong et al., 2019; Xie et al., 2018). This research gap is particularly relevant for archipelagic and island nations, where fragmentation and poor inter-island connectivity pose unique mobility constraints. Studying the tourism impacts of bridge infrastructure thus

provides not only empirical insights but also significant policy relevance, especially in contexts where infrastructure investments are capital-intensive and often financed through public debt or external aid (Solihin et al., 2024).

Indonesia exemplifies this challenge. With over 17,000 islands and substantial tourism potential rooted in its rich natural and cultural diversity, the country has long faced persistent barriers to tourism growth due to inadequate infrastructure (World Economic Forum, 2019). In 2023, the tourism sector contributed just 4.8 % to Indonesia's GDP—well below neighboring countries such as Malaysia (8.6 %), Thailand (10.4 %), Vietnam (6.8 %), and the Philippines (17.9 %) (World Travel & Tourism Council, 2022). Poor transport infrastructure, particularly in inter-island and intra-island connectivity, continues to constrain tourism expansion (Ouariti & Jebrane, 2020; Van Truong & Shimizu, 2017).

To address these structural constraints, the Indonesian government has prioritized large-scale infrastructure projects aimed at enhancing regional connectivity. Among them, the Suramadu Bridge—which links Madura Island to Java via Surabaya, the capital of East Java—stands out as a flagship initiative. Completed in late 2009, the bridge was

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envisioned as a catalyst for economic and tourism development in Madura by reducing travel time, improving accessibility, and integrating the island into Java's broader economic system. However, nearly 15 years later, tourism growth in Madura remains limited, with little change in key indicators such as the tourism sector's contribution to GDP (Statistics Indonesia, 2024a, 2024b).

The construction of the Suramadu Bridge involved a substantial financial commitment—approximately USD 450 million—funded through a mix of public debt, concessional loans, and bilateral technical assistance (Wasserman, 2014). Given this scale of investment, evaluating the bridge's impact on tourism is not only important for assessing returns on public spending but also for informing future infrastructure planning in developing contexts where resources are constrained and trade-offs are common (Solihin et al., 2024).

The broader literature has investigated how various forms of transport infrastructure—such as airports, highways, and rail networks—affect tourism. However, studies specifically examining bridge infrastructure remain sparse, particularly in archipelagic settings where fixed-link connections play a strategic and often indispensable role. Moreover, much of the existing literature faces the challenge of endogeneity, especially reverse causality: not only can infrastructure promote tourism, but growing tourism demand can also drive infrastructure investments (Hussain, 2023; Khan et al., 2017). This calls for rigorous empirical strategies to isolate causal impacts.

Against this backdrop, this study investigates the causal impact of the Suramadu Bridge on tourism growth in Madura Island. It makes three main contributions. First, it expands the limited empirical literature on the tourism impacts of bridge infrastructure, offering evidence from a developing archipelagic country. Second, it provides a context-specific analysis focused on Indonesia, where enhancing physical connectivity is essential for balanced regional development. Third, it applies a quasi-experimental design, using the Suramadu Bridge opening as a natural experiment and employing a difference-in-differences (DiD) approach to estimate its effect on tourism outcomes, while addressing confounding factors.

Beyond its empirical contributions, this study engages with the theoretical debate on whether transport infrastructure alone is sufficient to stimulate tourism development. Drawing on Leiper's tourism system framework, which emphasizes the interaction between transport, destinations, and tourists, the study examines why enhanced accessibility may not automatically translate into tourism growth if other systemic components are missing.

The remainder of the paper is structured as follows. Section 2 reviews

the theoretical framework and related literature. Section 3 outlines the data and methodology, including the empirical strategy. Section 4 presents the results and discussion. Section 5 concludes the paper and discusses policy implications.

2. Literature review

2.1. Case study background

The construction of the Surabaya-Madura (Suramadu) Bridge began in August 2003 and was completed in June 2009. Spanning approximately 5.4 km, the bridge connects Java and Madura, significantly enhancing accessibility between the two regions, which previously relied solely on maritime transportation. Madura comprises four administrative districts: Bangkalan, Sampang, Pamekasan, and Sumanep. On the Madura side, the bridge connects to Bangkalan District, while on the Java side, it connects to Surabaya, the capital city of East Java Province (See Fig. 1).

Before the construction of Suramadu, mobility between Surabaya and Madura relied exclusively on water transportation via ferries, which took around 30 min per trip and cost Rp. 73,000 (approximately USD 4.3) for cars and Rp. 6000 (approximately USD 0.35) for motorcycles in 2008 (Jannah & Trilaksana, 2016). The operations were dependent on weather conditions and passenger demand, with schedules ranging from 30-min to one-hour intervals, and the queue was long (Firman, 2017). With the completion of Suramadu in 2009, a new mode of transportation became available, significantly reducing travel time to just 10 min. Additionally, the cost of using the bridge was lower: Rp. 30,000 (approximately USD 2) for cars and Rp. 3000 (approximately USD 0.18) for motorcycles (East Java Provincial Communication Office, 2010). Meanwhile, the bridge provided unrestricted 24-h access, eliminating weather-related uncertainties and improving mobility (Firman, 2017; Sufiatin & Sumarno, 2019). Furthermore, the Indonesian government abolished the access tariff at the end of 2018 by changing its status from a toll road to a public road (Presidential Regulation No. 98 of 2018). Nevertheless, the lack of reliable and integrated transportation networks within the island, such as poor road conditions and limited public transportation, still hinders mobility within the region (Firman, 2017).

This mobility issue needs to be addressed because Madura holds significant tourism potential, especially for religious tourism. For instance, the cemeteries of Islamic religious leaders, royals, and other revered figures attract large numbers of pilgrims and visitors (Ekawati et al., 2021). The island also features diverse cultural tourism

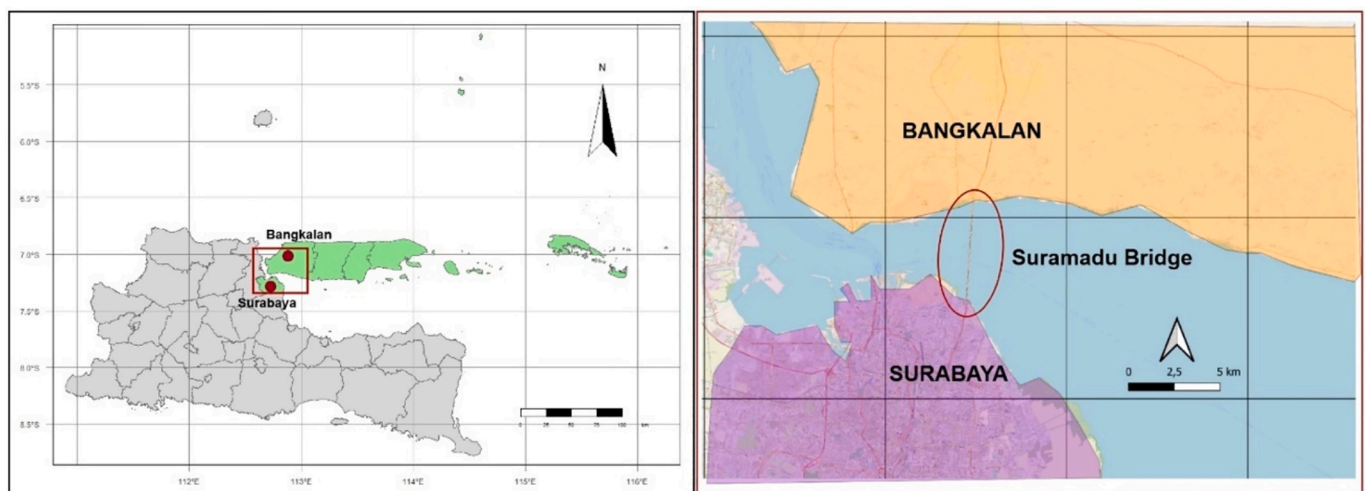


Fig. 1. Geographical illustration of Suramadu connecting Java and Madura.

Note: This figure shows the Suramadu Bridge connecting Surabaya (in purple) and Bangkalan (in orange), highlighting its strategic role in improving access between Java and Madura.

attractions, such as the Karapan Sapi (bull racing festival), Saronen music, and the Arokat (cleansing ceremony) tradition (Arifin, 2017). These are complemented by natural attractions, including pristine beaches and small offshore islands (known locally as *Gili*). Culinary tourism also represents a promising segment, as Madura is recognized for its distinctive cuisine (Suryandari, 2019).

In contrast, Surabaya, the second-largest metropolitan area after Jakarta, serves as a major economic hub. Characterized by strong industrial, trade, and service sectors, Surabaya functions as the province's economic engine and constitutes a significant source of outbound tourism demand. Surrounding urban regions such as Sidoarjo and Gresik share similar economic structures and demographic profiles, thereby reinforcing the broader regional potential for tourism development and inter-regional visitor flows.

2.2. Leiper's tourism framework

According to Leiper Framework (Leiper, 1979, 1990), tourism is a complex and interconnected system comprising three main elements: geographical, human, and industry-related factors, as depicted in Fig. 2 (Varvaressos, 2018). The geographical element includes the physical spaces that facilitate tourism activities, such as tourist-generating regions, transit regions, and tourist destinations. The human element comprises key stakeholders: tourists, local communities, and workers. Meanwhile, the industry-related factors encompass the facilities and services necessary for tourism, such as accommodations and attractions (See Fig. 2). These elements interact as a system, and deficiencies in any one of them can affect the overall system. In this framework, the geographical elements consist of the tourist-generating, transit/connector, and destination regions. In this context, the tourist-generating region is Java Island, serving as an economic hub that generates tourism demand, while the tourist destinations include various attractions in Madura. Suramadu functions as the connector linking these regions.

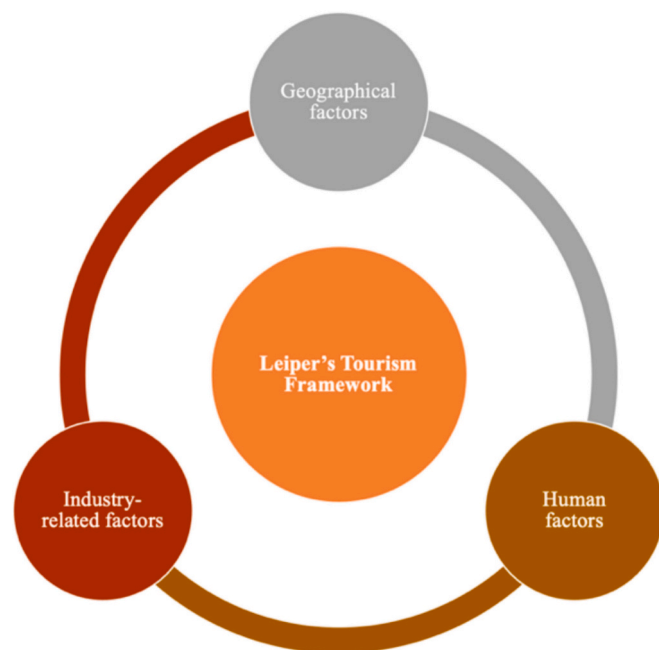


Fig. 2. Illustration of Leiper's tourism framework.

Note: This figure illustrates Leiper's tourism framework, consisting of three interconnected components—geographical, industry-related, and human—which collectively influence tourism growth.

2.3. Empirical research and hypothesis construction

The existing empirical literature has extensively examined the role of transport infrastructure in promoting tourism growth. Table 1 summarizes earlier studies relied on broad measures of infrastructure, such as aggregate transport capital stock (e.g., Khadaroo & Seetanah, 2007, 2008). Over time, scholarly attention has shifted toward more specific types of transport infrastructure, particularly high-speed rail (HSR), with more focus on China and European countries.

A few studies have also analyzed the influence of air transport infrastructure (e.g., Doerr et al., 2020; Tang et al., 2023). Meanwhile, the role of bridge infrastructure remains underexplored. Only some examine the impact on tourism empirically (e.g., Chu et al., 2021; Jeong et al., 2019; Xie et al., 2018). In addition, a geographic imbalance is evident in the existing research. Most were conducted in East Asia and Europe, leaving a critical gap for research in Indonesia. This omission is particularly notable given Indonesia's archipelagic geography, where bridges can improve access to underdeveloped tourism regions.

More recently, research has increasingly focused on causal inference techniques, including DiD, propensity score matching (PSM), and the synthetic control method (SCM). These approaches address endogeneity concerns, particularly reverse causality, which makes it difficult to disentangle the true direction of the causal relationship.

Across modalities and regional contexts, numerous empirical studies have demonstrated the positive impact of transport infrastructure on tourism growth. Whether through enhanced rail, air, or multimodal connectivity, the evidence suggests that improved accessibility stimulates tourism activity. This consistent finding provides an empirical foundation for expecting similar benefits from fixed-link infrastructure such as bridges.

Suramadu presents a compelling case for empirical investigation. By linking Surabaya, a tourism-generating region, with Madura, a culturally rich but less-developed tourism destination, the bridge serves as a quasi-natural experiment. As such, it is well-suited for a difference-in-differences (DiD) framework, which allows for identifying the causal impact of the bridge by comparing changes in tourism indicators over time between treated and control areas.

Building on Leiper's tourism system framework, the case study background, and the consistent findings from prior empirical studies, this study hypothesizes that Suramadu positively influences tourism growth in Madura by improving accessibility.

3. Data and methodology

3.1. Data

To measure the impact of Suramadu on the development of tourism in Madura, this study uses panel data at the district level from 2006 to 2017. The year 2010 marks the start of the intervention period, corresponding to the bridge's initial operation. Accordingly, years 2006–2009 are designated as the pre-intervention period, while 2010–2017 represent the post-intervention period. This study intentionally focuses on the pre-2017 period to isolate the causal impact of the bridge's physical provision, independent of later changes in financial accessibility. Including the post-2017 period would confound the analysis, as any observed tourism changes could not be clearly attributed to either the bridge itself or the subsequent toll removal. By excluding this period, the study maintains a clearer identification strategy centered on infrastructure-induced accessibility.

Suramadu provision is used as the main intervention; hence, Bangkalan, Sampang, and Pamekasan are used as treatment districts. Sumenep was excluded due to significant data gaps, particularly for key variables such as gross domestic product (GDP) during the early period of the study (before 2010). While the exclusion of Sumenep is a limitation, we believe it does not significantly affect the generalizability of our findings because the regions included in the analysis are largely

Table 1
Previous empirical research.

| No | Author(s) | Types of transport infrastructure | Methodology | Context | Finding |
|----|-----------------------------|---|---|-----------------------------------|-------------|
| 1 | Khadaroo and Seetana (2007) | Aggregate measure of infrastructure stock | Static Panel and GMM | Mauritius | Significant |
| 2 | Khadaroo and Seetana (2008) | Stock of road, air transportation, and port | GMM | Asia, Africa, Europe, and America | Significant |
| 3 | Wang et al. (2012) | High speed rail (HSR) | The gravitational model | China | Significant |
| 4 | Yan et al. (2014) | HSR | ARMA | China | Significant |
| 5 | Pagliari et al. (2015) | HSR | Logit | Spain | Significant |
| 5 | Campa et al. (2016) | HSR | Fixed Effect | Spain | Significant |
| 6 | Pagliari et al. (2017) | HSR | Generalized linear model | Italy | Significant |
| 7 | Bo and Ningqiao (2018) | HSR | DiD | China | Significant |
| 8 | Campa et al. (2019) | HSR | Fixed Effect | Spain | Significant |
| 9 | Li and Chen (2019) | HSR | Comparison | China | Significant |
| 10 | Gao et al. (2019) | HSR | DiD and IV | China | Significant |
| 11 | Yang and Li (2020) | HSR | PSM and DiD | China | Significant |
| 12 | Yao et al. (2022) | HSR | DiD | China | Significant |
| 13 | Shi et al. (2022) | HSR | DiD | China | Significant |
| 14 | Chen et al. (2022) | HSR | Panel Regression | China | Significant |
| 15 | Shen et al. (2023) | HSR | Geographically Weighted Poisson Regression | China | Significant |
| 16 | Ren et al. (2023) | HSR | Spatial DiD | China | Significant |
| 17 | Li et al. (2023) | HSR | DiD | China | Significant |
| 18 | Wang et al. (2023) | HSR | DiD | China | Significant |
| 19 | Zhang et al. (2023) | HSR | DiD and Spatial Durbin Model (SDM) | China | Significant |
| 20 | Di Matteo (2023) | HSR | DiD | Italy | Significant |
| 21 | Zhuang et al. (2024) | HSR | Gravity model | China | Significant |
| 22 | Wang (2025) | HSR | PSM-DiD | China | Significant |
| 23 | Zhao et al. (2025) | HSR | DiD | China | Significant |
| 24 | Doerr et al. (2020) | Number of Airports | DiD and Synthetic Control Method (SCM) | Germany | Significant |
| 25 | Tang et al. (2023) | Number of International air routes | GMM and Static Panel | China | Significant |
| 26 | Xie et al. (2018) | Bridge | CLUE-S model | China | Significant |
| 27 | Jeong et al. (2019) | Bridge | Angular Segment Analysis (ASA) | South Korea | Significant |
| 28 | Chu et al. (2021) | Bridge | Interrupted Time Series Analysis (ITSA) and Random Forest | China | Significant |
| 29 | Guan et al. (2024) | Bridge | Regression | China | Significant |

Note: This table summarizes key empirical studies on the relationship between transport infrastructure and tourism growth, with a focus on HSR in China, followed by air and bridge infrastructure. Methods range from static panel regressions to advanced causal inference, consistently showing a positive impact of improved transport on tourism.

homogeneous in terms of socioeconomic and geographic characteristics, making them representative of the broader context.

Additionally, other districts in Indonesia that resemble the treatment districts—i.e., those with similar levels of economic development and tourism growth prior to the bridge provision, as indicated by no statistically significant differences in the means of GDP per capita and tourism growth—were selected as control districts. These districts include Situbondo, Gresik, Madiun, Pacitan, Trenggalek, Jepara, Manggarai Barat, Rote Ndao, Lembata, Sumba Timur, Alor, Sumbawa, Sumbawa Barat, Way Kanan, Bengkulu Selatan, Kaur, and Mukomuko.

Unlike previous studies that used the number of inbound and domestic tourist arrivals (Doerr et al., 2020; Heriqbaldi et al., 2023; Purwono et al., 2024; Yu, 2016; Zhang, Weng, & Bao, 2020), tourism revenue (Aspy et al., 2024; Li et al., 2020; Wang et al., 2023; Yu, 2016), and tourism firm value (Zhang, Liu, & Liu, 2020) as proxies for tourism development, we retrieved tourism sector share to GDP (*Tourism Share of GDP*) and tourism GDP growth (*Tourism GDP Growth*) as the main outcomes. This is relevant to the Indonesian tourism sector, which relies heavily on local visitors. Tourism GDP highlights the role of domestic tourism, as spending by domestic tourists and tourism workers contributes to national income as part of aggregate demand (Colacchio & Vergori, 2022, 2023). Furthermore, accommodation and food service activities, including hotels and restaurants, were calculated as part of tourism's GDP. An increase in the tourism shares of GDP indicates the sector's increasing potential and contribution to GDP relative to other sectors. Accordingly, tourism GDP growth indicates changes in the performance of tourism over time.

Additionally, we used GDP per capita (in million rupiahs), population size (number of people), literacy rate (percent), and poverty rate (percent) as covariates. These covariates were chosen to reflect each district's socioeconomic conditions that may influence the district's

main outcomes, following Balli et al. (2023), Li et al. (2020), and Wang et al. (2023). The inclusion of covariates helps account for pre-existing differences between the treatment and control groups before the intervention and improves the precision of the estimated treatment effects (Fredriksson & Oliveira, 2019). In this study, the inclusion of GDP per capita, poverty rate, population size, and literacy rate are to account for the socioeconomic characteristics of the regions that could potentially influence tourism development.

Higher GDP per capita reflects greater prosperity, which can stimulate tourism demand through increased disposable income and local spending power. Likewise, a lower poverty rate signals improved socioeconomic conditions that may support tourism growth. Population size also plays a key role, as a larger population can drive demand from both local and external visitors. Lastly, a higher literacy rate indicates a more educated population, potentially leading to improved service quality in tourism, such as enhanced hospitality standards. All data were collected from Statistics Indonesia (Badan Pusat Statistik/BPS) and the Indonesian Policy and Economic Research Database (INDO-DAPOER) by the World Bank.

3.2. Methodology

The current study employs a quasi-natural experiment tool called the Difference-in-Differences (DiD) approach to estimate the impact of Suramadu provision on regional tourism economic growth in Madura. This approach compares changes over time between the treatment group (those experiencing the intervention policy) and the control group (those who did not) before and after the intervention. DiD has been applied in recent studies to analyze the implication of transportation infrastructure development on tourism, e.g., Yu (2016), Albalade and Fageda (2016), Gao et al. (2019), and Zhang, Liu, and Liu (2020).

DiD is well-suited to evaluating causal relationships in the context of natural experiments, such as the construction of Suramadu. Specifically, the method allows the comparison of tourism outcomes in Madura (the treatment group) with those in a comparable region (the control group) before and after the construction (Doudchenko & Imbens, 2017). This approach accounts for time-invariant unobserved factors and shared temporal shocks that may influence tourism development in both regions, allowing for a more robust estimation of the bridge’s causal impact (Liu et al., 2024). In this study, direct experimental methods are impractical, so DiD provides a rigorous and reliable empirical strategy to identify causal effects.

One concern in estimating the impact of infrastructure on tourism is reverse causality, where areas with greater tourism potential may be more likely to receive infrastructure investment. However, in our case, the construction of Suramadu was a nationally planned megaproject, not targeted specifically based on local tourism performance. Its primary justification was to promote economic integration and connectivity between Java and Madura, rather than to boost tourism per se. We mitigate reverse causality concerns by applying DiD and comparing Madura to a set of similar, untreated districts over time. Our basic DiD model in this study is expressed by the following equation:

$$Y_{it} = \beta_0 + \beta_1 post_t + \beta_2 treated_i + \beta_3 post_t * treated_i + \epsilon_{it} \tag{1}$$

where i denotes region or district and t represents year. Y_{it} represents outcome variables of tourism, which are *tourism share of GDP* and *tourism GDP growth*. Then, $post_t$ is a year dummy variable (1 = year >2009, 0 = year ≤2009), $treated_i$ denotes region dummy variable (1 = treated region, 0 = control region), and $post_t \times treated_i$ is an interaction variable to represent the impact of Suramadu and hence β_3 serves as the coefficient of interest.

Moreover, we used year fixed effect to control time-specific shocks and annual trends of macroeconomic development (Yu, 2016; Zhang, Liu, & Liu, 2020), and region-fixed effect to control unobserved regional specific characteristics (Liu et al., 2023). Several control variables are also introduced in the model; hence, we extend Eq. (1) as follows:

$$Y_{it} = \beta_0 + \beta_1 post_t + \beta_2 treated_i + \beta_3 post_t * treated_i + \sum_{n=1}^4 \beta_n x_{it} + \mu_i + \theta_t + \epsilon_{it} \tag{2}$$

where x_{it} represents set of control variables (*GDP per Capita*, *Population*, *Literation Rate*, and *Poverty Rate*). Meanwhile, μ_i and θ_t are the region and time-fixed effect variable, respectively, and ϵ_{it} is error terms. Both in Eqs. (1) and (2), the coefficient of interest β_3 represents the impact of Suramadu on tourism sector development, denoted as D in the DiD regression table.

The DiD estimation depends on satisfying the parallel trends assumption, which posits that the treatment and control groups would have followed a common growth trend in the absence of the intervention (Deng et al., 2021). To validate this assumption, we assess the outcome variable trends for each group using both visual and statistical approaches. For the visual approach, we employ a graphical diagnostic using line graphs to compare the trajectory of the outcome variable between the treated and control groups before the intervention (Chang & Zhang, 2024). This allows for a straightforward evaluation of whether the trends are parallel before the intervention. Meanwhile, the statistical approach involves conducting a Wald test to examine whether the outcome trends between the two groups are statistically indistinguishable before the provision of Suramadu (Chauhan & Thangavel, 2025). The study also incorporates the Granger causality test to evaluate the possibility of anticipation effects before the construction. This test ensures that the outcomes are generated solely from the intervention, not from a predictive behavior, either from the treated or control region (Bergantino et al., 2025). The research process in the study is summarized and illustrated in Fig. 3.

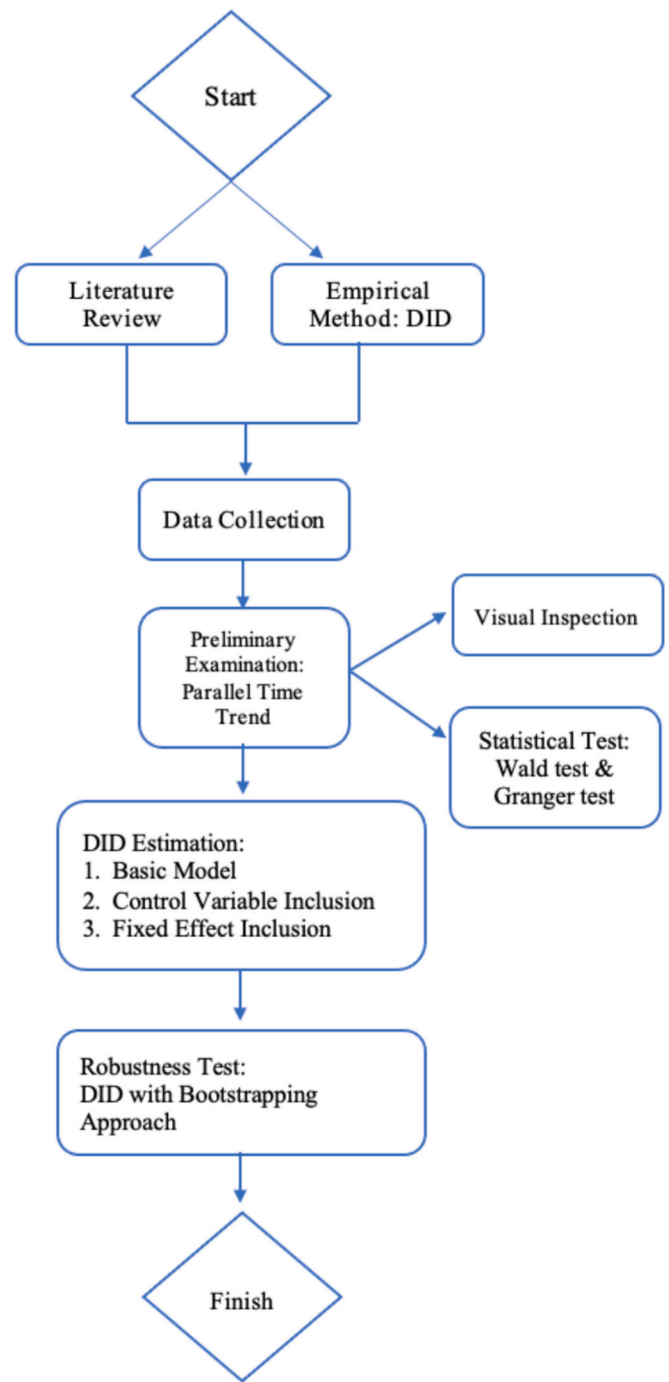


Fig. 3. Research workflow diagram.

Note: This figure summarizes the key stages from problem identification and literature review to empirical analysis and conclusion formulation, illustrating the methodological flow and logical structure guiding the investigation.

4. Results and discussion

Table 2 presents a summary of the statistics for both the dependent and explanatory variables across all districts in both the treated and control groups. The dataset consists of 240 observations, covering 20 districts for over 12 years. The data indicates that tourism plays a relatively minor role in the overall economy, contributing an average of only 1.2 % to GDP, despite an annual growth rate of 6.7 %. These figures highlight the negligible influence of tourism in the regions.

Table 3 presents the descriptive statistics of the variables before the

Table 2
Descriptive statistics.

| Variable | Observation | Mean | Std. dev. | Min | Max |
|---------------------------------|-------------|---------|-----------|--------|-----------|
| Tourism shares in GDP (%) | 240 | 1.196 | 0.940 | 0.160 | 4.464 |
| Tourism GDP growth (%) | 220 | 6.715 | 2.550 | -1.038 | 15.966 |
| GDP per capita (million Rupiah) | 240 | 20.764 | 30.667 | 2.061 | 180.016 |
| Population (people) | 240 | 504,271 | 350,409 | 94,974 | 1,285,018 |
| Literation rate (%) | 240 | 89.785 | 7.125 | 60.760 | 99.150 |
| Poverty rate (%) | 240 | 21.304 | 7.084 | 8.120 | 41.620 |

Note: This table presents summary statistics for key variables: number of observations, means, standard deviations, and minimum and maximum values—providing an overview of the distribution and variation in tourism performance, economic indicators, and demographic characteristics.

Table 3
Average comparison of the treated and control groups before the intervention.

| Variables | Pre-intervention | |
|-----------------------|-----------------------------|------------------------------|
| | Treated | Control |
| Tourism shares in GDP | 0.503 (0.167) | 1.264 (0.998) |
| Tourism GDP growth | 5.784 (2.382) | 5.118 (2.390) |
| GDP per capita | 10.752 (3.237) | 20.954 (36.431) |
| Population | 889,829.800 (55,568.230) | 422,845.800 (328,497.600) |
| Literation rate | 73.349 (8.010) | 90.369 (4.538) |
| Poverty rate | 32.698 (4.657) | 25.022 (7.287) |

Note: This table compares the mean values of key variables between treated and control groups before the intervention (standard deviations in parentheses), describing the group characteristics before the treatment.

intervention, comparing the treated and control groups. The average tourism sector’s share in GDP for the treated group is 0.50 %, with a standard deviation of 0.17 %. In the control group, the average tourism sector’s share in GDP is significantly higher at 1.27 %, with a larger standard deviation of 0.99 %. Meanwhile, the treated group has an average tourism GDP growth of 5.78 %, with a standard deviation of 2.38 %. The control group’s tourism GDP growth is slightly lower, averaging 5.12 %, with a similar standard deviation of 2.39 %.

The treated group reports an average GDP per capita of 10.752 million, with a standard deviation of 3.237 million. The control group has a much higher average GDP per capita of 20.954 million, though the standard deviation is larger at 36.431 million, indicating greater variability. The average population for the treated group is 889,830, with a relatively low standard deviation of 55,568. In contrast, the control group has a lower average population of 422,846, but with a much higher standard deviation of 328,498, suggesting significant population variance within the control group. The treated group has an average literacy rate of 73.35 %, with a standard deviation of 8.010. The control group exhibits a higher average literacy rate of 90.37 %, with a lower standard deviation of 4.53 %, indicating more consistent literacy levels. The poverty rate in the treated group averages 32.70 %, with a standard deviation of 4.66 %. The control group shows a lower average poverty rate of 25.02 %, with a higher standard deviation of 7.29 %, indicating more variability in poverty levels.

The reliability of the DiD regression model relies on the fundamental assumption of parallel time trends. This means that, before the intervention, both treatment and control units exhibit similar behavior of the

main outcome. To test this assumption, we provided a graphical analysis of the trajectory of the tourism share in GDP and tourism GDP growth. Fig. 4 shows the trajectories of tourism share in GDP and tourism GDP growth before 2010 (the intervention), which display similar trends, suggesting the fulfillment of the parallel time trend assumption. However, because graphical interpretation can be subjective, we also conducted a parallel-trends test and a Granger causality test (Toppar, 2023).

The parallel trend test proves the significance of the treated-control gap change before the treatment is implemented (H0: the linear trend is parallel). The Granger test detects the existence of a lead effect or anticipatory influence that could affect the estimation (H0: there is no presence of lead effect). Based on Table 4, the *P*-value for the parallel trend test and Granger test is greater than 5 %, implying that the null hypotheses of both tests cannot be rejected. Therefore, the parallel trend assumption is satisfied, fulfilling the requirement of DiD.

This study evaluates the impact of Suramadu construction on tourism through a DiD regression analysis. Two proxies are used as dependent variables to measure tourism development: the share of tourism in GDP and tourism GDP growth. The results are summarized in Table 5, where columns (1) to (4) present tourism’s share in GDP, and columns (5) to (8) show tourism’s GDP growth. Each model specification differs based on the inclusion of control variables, regional fixed effects, and year-fixed effects.

The variable of interest, *D*, represents the differential effect of Suramadu construction on tourism. Across all model specifications, the coefficients for *D* are statistically insignificant for both proxies, irrespective of the inclusion of control variables or fixed effects. These findings indicate that the construction of Suramadu does not have a statistically measurable impact on tourism development. For instance, in column (1), where the dependent variable is tourism’s share in GDP with no control variables, regional fixed effects, or year fixed effects, the coefficient for *D* is 0.0469, which is statistically insignificant. Similarly, in column (5), where the dependent variable is tourism GDP growth without covariates and fixed effects, the coefficient for *D* is 0.537, which is also statistically insignificant. Even in models with more comprehensive specifications—such as columns (3), (4), (7), and (8), which include both regional and year-fixed effects—the results remain consistent. For example, in column (4), the coefficient for *D* is statistically insignificant despite the inclusion of controls and fixed effects. In summary, this analysis provides no strong evidence to support the hypothesis that Suramadu enhances tourism’s contribution to GDP or the sector’s GDP growth in Madura.

To ensure the reliability of our estimation results, we conducted a robustness test using DiD combined with the bootstrap method. Given the limited sample size of this study (covering only 20 districts), which could be sensitive to outliers and uneven data distribution, the findings are susceptible to bias. To address these issues, we applied the bootstrap method, following Zhang, Liu, and Liu (2020), which addresses small-sample issues by recovering the statistical distribution through repeated resampling and re-estimation of the model across a specified number of trials (Brewer et al., 2018).

Table 6 displays the results of the DiD-bootstrap estimation. Columns (1) and (2) use tourism’s share of GDP as a proxy, while Columns (3) and (4) use tourism’s GDP growth. All models account for both year and regional fixed effects, differing only in whether additional control variables are included. These robustness tests corroborate the consistency of the main estimation results presented in Table 5.

The coefficient of interest, denoted as (*D*) in Table 6, remains statistically insignificant across all models. This indicates that even with the DiD method and the bootstrap approach, which mitigates potential biases from small samples and outliers, the directionality of the observed relationship remains unchanged. This further strengthens the reliability of the main estimation results obtained in Table 5. Overall, the robustness tests demonstrate the reliability of the results across different model specifications and resampling approaches. By employing the bootstrap method in line with Zhang, Liu, and Liu (2020) and trials Brewer et al.

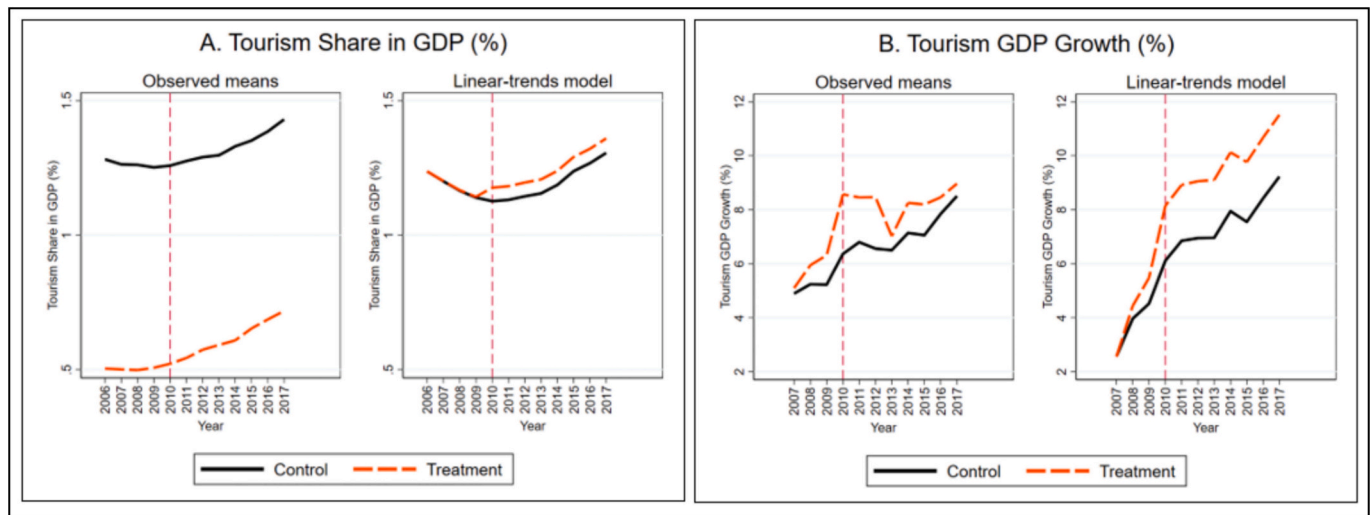


Fig. 4. Graphical diagnostic of the parallel trend assumption test.

Note: This figure offers visual diagnostics to assess the parallel trend assumption in the DiD approach. Panel A shows observed means and fitted trends for tourism’s share in GDP (%), and Panel B for tourism GDP growth (%), with the dashed red line indicating the intervention year. These visuals help evaluate the validity of the common trend assumption.

Table 4

F-test and P-value of parallel trend test and Granger test.

| Outcome | Parallel trend | Granger test |
|----------------------|----------------|----------------|
| Tourism Share in GDP | 0.01 (0.94) | 0.25 (0.86) |
| Tourism GDP growth | 1.00 (0.33) | 0.48 (0.63) |

Note: This table presents the F-statistics and p-values for the parallel trend and Granger causality tests on two outcome variables: tourism share in GDP and tourism GDP growth. The parallel trend test checks the validity of the common trend assumption in DiD, while the Granger test examines reverse causality. If the p-value exceeds 5 %, the outcomes are free from statistical issues like non-parallel trends or lead effects. With both variables having p-values greater than 5 %, the models satisfy the parallel trend assumption and are free from lead effects.

(2018), we confirm that the main findings in Table 5 are less influenced by the limitations associated with small sample sizes. These results reinforce the consistency of the conclusions drawn from Table 5.

The results from the DiD analysis in both Tables 5 and 6 show no evidence that Suramadu enhances tourism development in the region. While this outcome is counterintuitive, it is consistent with previous

findings by Albalate and Fageda (2016) and Albalate et al. (2017) in Spain, which tested the impact of high-speed rail (HSR). Specifically, Albalate and Fageda (2016) found limited evidence that HSR had a positive impact on tourism development. They argued that it might be due to its competitiveness with other modes of transportation, such as air travel. HSR may appeal to premium travelers willing to pay higher fares for time savings. In contrast, most tourists prioritize cost over time, making HSR less attractive and limiting its impact on tourism. Similarly, Albalate et al. (2017) found no strong evidence supporting the benefits of HSR in increasing the number of tourists or the length of their stay. They suggested it could be attributed to the inadequate transportation connections in Spain, as well as competition between HSR and other public transportation services.

Our findings differ from previous research conducted in other countries, such as Xie et al. (2018) and Chu et al. (2021) in China, Jeong et al. (2019) in South Korea, and Doerr et al. (2020) in Germany. These studies highlight the important role of transportation infrastructure, such as bridges, in boosting tourism. For instance, Chu et al. (2021) concluded that the construction of the Hangzhou Bay Bridge significantly influenced tourism development in the surrounding areas. The bridge enhanced accessibility to key tourism destinations, making them more attractive to visitors. Additionally, changes in land use and cover revealed growth in tourism-related infrastructure, such as hotels,

Table 5

DiD estimation results.

| Variables | Tourism share in GDP | | | | Tourism GDP growth | | | |
|-----------|----------------------|-------------------|----------------------|-------------------|---------------------|-------------------|---------------------|------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| D | 0.0469 (0.052) | -0.086 (0.108) | 0.0469 (0.055) | 0.0504 (0.055) | 0.537 (1.179) | 0.557 (1.203) | 0.537 (1.261) | 1.656 (1.172) |
| Constant | 1.264*** (0.248) | 2.063 (2.510) | 0.737*** (0.0340) | 1.886* (0.913) | 5.118*** (0.511) | -0.277 (4.730) | 5.175*** (0.956) | 0.263 (12.40) |
| Control | No | Yes | No | Yes | No | Yes | No | Yes |
| Region FE | No | No | Yes | Yes | No | No | Yes | Yes |
| Year FE | No | No | Yes | Yes | No | No | Yes | Yes |
| N | 240 | 240 | 240 | 240 | 220 | 220 | 220 | 220 |
| R-squared | 0.079 | 0.466 | 0.995 | 0.995 | 0.153 | 0.189 | 0.527 | 0.557 |

Note: () is robust standard errors in parentheses, *** p < 0.01, ** p < 0.05, * p < 0.1.

This table presents DiD results evaluating the impact of Suramadu on tourism development in Madura, using two outcome variables: tourism’s share in GDP (columns 1–4) and tourism GDP growth (columns 5–8). The model specifications vary by the inclusion of control variables, regional fixed effects, and year fixed effects. The coefficient for the treatment variable (D) is statistically insignificant across all models, indicating that Suramadu does not have a measurable impact on either tourism share in GDP or tourism GDP growth (robust standard errors in parentheses).

Table 6
DiD bootstrapping estimation results.

| Variables | Tourism share in GDP | | Tourism GDP growth | |
|-----------|----------------------|--------------------|---------------------|------------------|
| | 1 | 2 | 3 | 4 |
| D | 0.0469 (0.0554) | 0.0504 (0.0546) | 0.537 (1.261) | 1.656 (1.172) |
| Constant | 0.737*** (0.034) | 1.886** (0.913) | 5.175*** (0.956) | 0.263 (12.4) |
| Control | No | Yes | No | Yes |
| Region FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| N | 240 | 240 | 220 | 220 |
| R-squared | 0.995 | 0.995 | 0.527 | 0.557 |

Note: () is robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

This table presents robustness checks using a DiD-bootstrap to address concerns about small sample sizes and potential data irregularities. Columns (1) and (2) show results for tourism's share of GDP, while columns (3) and (4) reflect tourism GDP growth. All specifications control for year and regional fixed effects, with and without additional covariates. The coefficient of interest (D) remains statistically insignificant across all models, reinforcing the reliability and consistency of the main findings in Table 5.

recreational facilities, and other amenities supporting tourism. Similarly, Jeong et al. (2019) emphasized the positive impact of bridges on tourism growth in South Korea. Meanwhile, Doerr et al. (2020) assessed the causal impact of commercial airport construction on tourist inflows in Allgäu, Germany. They found that airport construction led to a substantial increase in foreign tourists across various regions, with notable gains of 69 % in Lower Allgäu, 45 % in Upper Allgäu, and 17 % in East Allgäu. However, there was no significant impact observed in West Allgäu.

The provision of transportation infrastructure, particularly bridges, is pivotal in enhancing accessibility and mobility (Gao et al., 2019; Khadaroo & Seetanah, 2008). However, findings from our DiD analysis indicate no significant impact, suggesting that factors beyond the bridge's infrastructure may be more influential to tourism development in Madura.

According to Leiper's tourism framework, Suramadu functions as a connector between tourist-generating regions and destinations. However, the bridge alone addresses only one aspect of the geographical element. For tourism to develop, other factors, such as improved road networks and integrated transportation systems within Madura, must also be considered. Many tourist attractions in Madura remain difficult to access due to poorly maintained and narrow roads (Efendi, 2023; Indahsari & Wulandari, 2023; Muhaimin, 2024; Rohman, 2023), which also means limited accessibility to tourist attractions (Kalvelage et al., 2021). The transportation system in Madura is not integrated, public transport options are limited, and the connectivity between key tourism nodes is poor (Radar Madura, 2019; Rohman, 2023). This forces visitors to rely on private vehicles, which may not be convenient or accessible, particularly for international visitors unfamiliar with the region.

Local communities are central to tourism development, yet Madura's Human Development Index (HDI) remains below the national average. For instance, Bangkalan's HDI in 2023 was 66.82, significantly lower than the national average of 74.39 (Statistics Indonesia, 2024c). This disparity underscores skill gaps in language proficiency, hospitality, and entrepreneurial knowledge (Croes, 2021; Deale, 2016), which hinders engagement in tourism activities. Furthermore, Sartika (2020) shows that Bangkalan's community has a low level of conceptual, communication, and negotiation skills, which hinders the operation of the tourist industry. The locals cannot access the potential benefits of tourism (Goodwin, 2002), which often leads to unsustainable practices, such as tourist exploitation (Alamineh et al., 2023).

Moreover, negative stereotypes portraying the locals as temperamental, conflict-prone, and violent (Suryandari, 2019) further tarnish

the region's image as a tourist destination. These issues are exacerbated by ineffective policies and regulations from local governments, which often lack long-term vision and inter-agency cooperation (Dias et al., 2024). For example, as of late 2024, the strategic planning documents for tourism, known as the *Rencana Induk Pembangunan Pariwisata Kabupaten* (RIPPARKAB), remained unfinished in several districts in Madura (Basri, 2019; Kabar Madura, 2023). The delay hampers the development of strategies and funding essential for sustainable tourism. Overcoming these challenges calls for coordinated efforts between local communities and government institutions.

In poorly regulated environments and areas with low human development, unregulated practices such as extortion, bribery, and unauthorized fees often emerge (Alamineh et al., 2023). For example, some individuals or groups might exploit tourists by charging excessive or unauthorized fees for services such as guiding, parking, or access to attractions. These malpractices can be attributed to the absence of a structured tourism industry that emphasizes fair and transparent practices. Over time, such issues erode trust, tarnish the island's reputation, and contribute to a decline in tourist numbers. For instance, reviews of Google for Jaddih Hill Tourist Site in Bangkalan and Lon Malang Beach in Pamekasan reveal widespread visitor dissatisfaction, citing issues such as extortion, unregulated parking fees, and poor site management.

The third component of Leiper's framework emphasizes the role of industry-related elements such as hotels, restaurants, and tourist attractions. Among these, tourist attractions are regarded as a fundamental driver of tourism activities. Well-maintained and organized attractions play a critical role in creating tourist demand, which stimulates the development of complementary industries, including hotels and restaurants. While these attractions provide recreational value, many tourist attractions in the regions are not well-maintained or developed due to limited government budgets (Danafia, 2024; Koran Madura, 2024). Furthermore, the region lacks a distinctive landmark that could enhance its uniqueness and competitiveness in the broader tourism market. Literature suggests that iconic landmarks can increase a destination's appeal, attracting more tourists (Zhang et al., 2024). This presents an opportunity to attract more tourists and generate economic benefits.

The limited empirical evidence on the impact of Suramadu on tourism reflects the need for integrated, multi-stakeholder strategies to realize the bridge's potential. This study highlights the importance of coordinated efforts involving government institutions, the private sector, non-governmental organizations (NGOs), and local communities to address infrastructure gaps, investment barriers, and socio-economic disparities.

From a policy perspective, the government should develop a plan that provides a legal and strategic framework to reduce investment uncertainty, guide spatial planning, and prioritize key tourism assets. Designating Madura as a National Strategic Project may further catalyze development by unlocking fiscal support for essential infrastructure, including roads, utilities, and public transport systems, thereby enhancing destination accessibility and investor confidence. For the private sector, the findings reveal an underexplored tourism market with considerable investment opportunities in accommodation, attractions, hospitality services, and facilities. Strategic investment in these areas, alongside workforce development in hospitality, tour guiding, and customer service, can improve service quality and competitiveness. NGOs also play a role in strengthening local capacities and promoting inclusive development. Beyond skills training, NGOs can empower communities through participatory tourism models that ensure local benefits.

To maximize the development impact of large-scale infrastructure projects such as Suramadu, future interventions must be preceded by rigorous feasibility assessments and collaborative governance mechanisms. Aligning tourism development policies with infrastructure provision and community empowerment is critical to ensuring that such projects deliver long-term sustainable benefits.

5. Conclusion

This study evaluated the impact of Suramadu on tourism development in Madura using district-level data and DiD with tourism GDP as the main outcome. The analysis found limited evidence of the bridge's effect on tourism. Aligned with Leiper's tourism system framework, these findings suggest that while the bridge improves geographic accessibility, it has not unlocked Madura's tourism potential due to poor internal roads, lack of public transport integration, limited institutional capacity, and underdeveloped attractions. Infrastructure alone is insufficient to drive tourism growth; complementary interventions, such as strategic tourism planning, community empowerment, improved site management, and stronger coordination among government, private sector, and civil society, are required.

This study contributes to theoretical debates by empirically testing the limits of the "infrastructure-led tourism growth" hypothesis in a developing, archipelagic context. While much of the literature highlights infrastructure, especially high-speed rail and air connectivity, as primary catalysts for tourism, our findings emphasize the role of supporting factors. By applying Leiper's framework, we show that the absence of synergy among its core components—geographical, human, and industry-related—can render even major transport projects like Suramadu ineffective. This research shifts the discourse from unidimensional explanations to a systems-based understanding of tourism development and fills a geographic gap in the literature, which is often dominated by East Asian and European cases.

Theoretically, our findings extend Leiper's framework by offering empirical validation in an underrepresented context: an archipelagic developing country. Practically, the results highlight the need for integrated policy design where infrastructure investments are aligned with institutional strengthening, local capacity building, and coordinated tourism governance. This reinforces the view that transport infrastructure is a necessary but insufficient condition for tourism growth.

Lastly, several limitations warrant consideration. First, this study intentionally focuses on the period prior to the removal of the Suramadu Bridge toll in 2017 to isolate the causal impact of the bridge's physical provision on tourism growth. This temporal restriction enhances internal validity by avoiding potential confounding effects associated with the subsequent elimination of toll fees, which introduced a significant change in financial accessibility. Including the post-2017 period would make it difficult to disentangle the effects of infrastructure provision from those of reduced travel costs. Although anecdotal evidence suggests that traffic volumes increased following the toll removal, assessing the separate or combined effects of physical and financial accessibility lies beyond the scope of this study. Future research could build on these findings by examining the longer-term and potentially synergistic impacts of both dimensions of accessibility on tourism development.

Second, the exclusion of Sumenep Regency due to data limitations may restrict the generalizability of the findings across Madura. Future studies should explore big data or alternative sources to achieve a more comprehensive spatial coverage. While this study relies on quantitative analysis, future research could adopt mixed-methods approaches to uncover the institutional, cultural, and governance-related barriers that may explain the bridge's limited tourism impact. Lastly, focusing on a single case study limits generalizability. Comparative studies on similar bridge projects in other regions could offer broader insights into the factors shaping infrastructure effectiveness.

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Wardana, Haryanto, Heriqbaldi, and Ajija are faculty members in the Department of Economics at Universitas Airlangga. Wardana and Haryanto specialize in development issues with a focus on the agriculture sector, while Heriqbaldi and Ajija concentrate on macroeconomics. Jamil is a researcher at the RISED, specializing in industrial economics. Ismail is a professor at Universiti Sains Malaysia with expertise in

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Author's contribution statement

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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.

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Appendix A. Supplementary data

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