Provincial Economies and Loss from Traffic Accidents: Evidence from Thailand

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Abstract

This study examines the relationship between provincial economic development and road traffic accident outcomes in Thailand from 2010 to 2020. Using a panel dataset compiled from official sources—including the Center for Road Safety, and the Office of the National Economic and Social Development Council (NESDC)—the research explores whether accident rates, injuries, and fatalities follow nonlinear patterns with respect to gross provincial product (GPP) per capita. The findings reveal that both accident and injury rates follow an inverted U-shaped curve, peaking at mid-income levels before declining, while fatality rates demonstrate a U-shaped pattern—rising again in high-income provinces. These results highlight the complex interplay between economic growth and road safety, underscoring the need for region-specific and income-sensitive traffic policy interventions. The study employs instrumental variable regression to validate the observed trends, contributing new evidence to the literature on development and transport safety. The study recommends targeted government subsidies: increased support for high-risk provinces with heavy traffic flows, and incentive-based funding for provinces with low fatality rates. These dual strategies promote both risk prevention and sustained safety performance across diverse provincial contexts.

Keywords: Road Traffic Accidents, Gross Provincial Product, An Inverted U=shape Path of Development, Thailand

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Introduction

Road traffic accidents (RTAs) pose significant challenges to public safety, health systems, and economic development across the globe. In Thailand, RTAs have consistently ranked among the leading causes of death and injury, particularly in rural provinces where limitations in traffic enforcement, substandard infrastructure, and public awareness exacerbate risks (World Health Organization, 2018). Beyond the immediate human costs, traffic accidents generate substantial economic losses—including medical expenditures, property damage, productivity reduction, and long-term impacts on regional economic growth (Asian Development Bank, 2011).

An expanding body of international literature has examined the multifaceted relationship between economic development and road safety. Ajide (2020), for example, assessed accident patterns within the Nigerian transport sector and demonstrated that socioeconomic and institutional factors—such as criminal activities, weak regulatory oversight, and governance deficits—can intensify road accident risks especially at time of economic expansion. This perspective underscores that economic development alone does not automatically translate into improved road safety; rather, outcomes depend on the extent to which institutional capacity, enforcement quality, and regulatory frameworks evolve alongside economic growth. Complementing this view, Kopits and Cropper (2005) identified a global inverted U-shaped relationship between income and traffic fatalities, in which accident risks rise during the initial phases of economic development due to increased mobility and exposure, but decline after income thresholds are reached as countries invest in safer infrastructure, enforcement systems, and vehicle technologies. These findings collectively highlight the complex and nonlinear mechanisms through which economic growth shapes road safety outcomes.

Drawing on these insights, this study examines the relationship between provincial economic growth and traffic accident losses in Thailand. It pursues two primary objectives. First, it presents a comprehensive provincial panel dataset covering 11 years (2010–2020 or B.E.2553–B.E.2563) that illustrates patterns in accidents, injuries, and fatalities across Thailand's provinces, serving as indicators of the scale and evolution of road-related losses over time. Second, it empirically tests the hypothesis that the relationship between accident losses and economic development follows an inverted U-shaped trajectory—an analytical structure often associated with the Environmental Kuznets Curve (Grossman & Krueger, 1995) but applied here in the context of road safety. Under this framework, accident rates are expected to rise with economic expansion up to a certain threshold, after which improvements in infrastructure, regulatory effectiveness, and public awareness begin to mitigate these effects.

Understanding the dynamic interplay between road safety and economic development at the provincial level is crucial for designing targeted and evidence-based policy interventions. Insights derived from this study can help guide the prioritization of road safety measures and inform broader development strategies in emerging economies such as Thailand.

Literature Review

A growing body of international literature has explored the nexus between economic development and road traffic accidents (RTAs), revealing nuanced patterns across diverse national and urban contexts. Mahata, Narzary, and Govil (2019) conducted a spatio-temporal analysis of RTAs in 13 major Indian cities and found a 28 percent rise in accidents and an 85 percent increase in fatalities between 2000 and 2015. Cities with higher accident frequency, such as Mumbai, generally exhibited lower severity levels, while cities like Kanpur experienced higher fatality rates despite fewer incidents. These contrasts underscore the importance of urban infrastructure, traffic management, emergency response capacity, and the heightened vulnerability of two-wheeler users and the working-age population. Similarly, Zanne, Groznik, and Twrdy (2016) examined crash patterns on Slovenian motorways and highlighted the growing safety implications of freight transport. Truck-related crashes accounted for more than 27 percent of total motorway accidents and 33 percent of fatal crashes between 2001 and 2012. Their use of safety performance functions (SPFs) and economic costing demonstrated that a 1 percent increase in truck traffic corresponded to a 2.5–3 percent rise in crash risk, indicating a substantial and often underestimated burden associated with freight movement.

Long-term macro-level evidence from Algeria further illustrates the link between economic activity and traffic risks. Bougueroua and Carnis (2016), applying cointegration and vector error correction models to data from 1970 to 2013, found that GDP per capita and fuel consumption—used as a proxy for mobility—were positively associated with accident rates in both the short and long run. Their findings suggest that accident risks typically rise during periods of economic expansion, particularly before investments in safety infrastructure and regulatory mechanisms begin to counterbalance increased exposure. Urban-level analysis from Hong Kong offers additional insights. Li, Wu, and Yang (2018) employed ARDL and VECM models to examine a 31-year dataset and found that population growth and car ownership significantly increased accident frequency. In contrast, road network expansion contributed to long-term reductions in accidents. The influence of GDP was ambiguous, implying that its effects on RTAs may be mediated by broader socioeconomic or behavioral factors. Collectively, these studies point to a common pattern: economic development often increases

mobility and traffic exposure, thereby heightening accident risks during early stages of growth. However, long-term development—when accompanied by targeted investment in road infrastructure, effective regulation, and systemic improvements in traffic management—can contribute to enhanced road safety outcomes.

Although the empirical results indicate nonlinear relationships between GPP per capita and accident outcomes, the theoretical mechanisms explaining these patterns require further elaboration. Economic development does not influence road safety directly; rather, its effects are mediated through several pathways widely recognized in international road-safety research. First, increases in GPP per capita are commonly associated with higher vehicle ownership and greater traffic exposure, leading to elevated accident risks during early stages of development (Kopits & Cropper, 2005). Rising household income enables more frequent acquisition of private vehicles—especially motorcycles, which are strongly linked to accident vulnerability in many developing economies (Mahata et al., 2019). Second, economic growth intensifies commercial activity, freight movement, and commuting flows. These changes contribute to increased traffic volume and congestion, thereby raising the likelihood of collisions (Zanne et al., 2016). Third, variations in road infrastructure quality, urban design, and enforcement capacity moderate the influence of economic conditions on accident outcomes. While more affluent provinces may have better roads and safer vehicles, they also experience higher travel speeds, denser mobility networks, and more complex traffic patterns that can heighten crash severity (Li et al., 2018). Finally, income growth shapes behavioral and institutional factors—such as risk-taking behavior, alcohol consumption, and the strength of emergency-response systems—that further influence both accident frequency and fatality outcomes. Recognizing these mediating mechanisms clarifies that GPP per capita should not be treated as a direct causal determinant of road accidents, but rather as a broader structural factor operating through mobility, infrastructure, behavioral, and institutional channels. This perspective is consistent with the empirical patterns observed in Thailand and aligns with theoretical expectations in the broader road-safety literature.

To further strengthen the literature review, incorporating more recent post-2020 studies on the so-called Road Safety Kuznets Curve (RSKC), particularly those utilizing panel datasets and advanced econometric approaches, would enhance the theoretical grounding of the nonlinear relationships identified in the study. Such evidence could either reinforce or challenge the observed inverted U-shaped and U-shaped patterns. Additionally, the literature review would benefit from a clearer articulation of the theoretical pathways linking the control variables—economic density, number of establishments, and size of the labor force—to accident severity. Elaborating on how these

structural characteristics of provincial economies shape traffic volume, mobility pressure, congestion, and ultimately the frequency and lethality of road traffic incidents would strengthen the conceptual coherence between the model specification and the study's empirical findings.

Research Method

This study adopts a quantitative panel data approach to examine the economic determinants of road traffic accident outcomes across Thailand's provinces over the 11-year period from 2010 to 2020 (B.E.2553–B.E.2563). The unit of analysis is the province, comprising 77 provinces (including Bungkan, established in 2011).

Key steps and components of the research method include:

1. Data Collection

- The panel dataset was compiled from official sources, including the Center for Road Safety, and the Office of the National Economic and Social Development Council (NESDC).
- Key variables include:
  - Dependent variables: Number of road accidents, number of injuries, and number of fatalities—normalized by population to per 1,000 or per 100,000 units.
  - Independent variable: Gross Provincial Product per capita (GPPcap).
  - Control variables: Number of business establishments, total workforce size.

2. Model Specification

The study estimates three primary equations corresponding to:

- Eq.1: Determinants of Road Accidents per 1,000 Population

  $accipop1000_{it} = \beta_0 + \beta_1 GPPcap_{it} + \beta_2 GPPcap_{it}^2 + \beta_3 Establishment_{it} + \beta_4 Worker_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

  - Variables
    1) <u>Dependent variable:</u>
       1.1) accipop1000 = number of road accidents per 1,000 population
    2) <u>Key independent variables:</u>
       2.1) GPPcap = provincial gross product per capita
       2.2) $GPPcap^2$ = squared term to test the inverted U-shaped relationship
    3) <u>Control variables:</u>
       3.1) Establishment = number of business establishments
       3.2) Worker = number of workers in the province
    4) <u>Fixed effects:</u>
       4.1) province fixed effects (μ_i) and year fixed effects (λ_t)

- Eq2: Determinants of Road Accidents per 1,000 Population

  $injurypop1000_{it} = \alpha_0 + \alpha_1 GPPcapit + \alpha_2 GPPcapit2 + \alpha_3 Establishmentit + \alpha_4 Workerit + \mu_i + \lambda_t + \varepsilon_{it}$

  - Variables
    1) Dependent variable:
       1.1) accipop1000 = number of road accidents per 1,000 population
    2) Key independent variables:
       2.1) GPPcap = provincial gross product per capita
       2.2) GPPcap² = squared term to test the inverted U-shaped relationship
    3) Control variables:
       3.1) Establishment = number of business establishments
       3.2) Worker = number of workers in the province
    4) Fixed effects:
       4.1) province fixed effects (μ_i) and year fixed effects (λ_t)
- Eq3: Determinants of Road Fatalities per 100,000 Population

  $fatalitypop100kit = \gamma_0 + \gamma_1 GPPcapit + \gamma_2 GPPcapit2 + \gamma_3 Establishmentit + \gamma_4 Workerit + \mu_i + \lambda_t + \varepsilon_{it}$

  notation:

  fatalitypop100k = number of fatalities per 100,000 population
- Each equation incorporates GPP per capita and its squared term to test for nonlinear relationships (e.g., inverted U-shaped or U-shaped), along with establishment and labor force variables as controls.

3. Econometric Technique

- Instrumental Variable (IV) Regression is used to address potential endogeneity between economic variables and accident outcomes.
- LOWESS (locally weighted scatterplot smoothing) is employed to visually identify nonlinear patterns in the relationship between income and road safety indicators.

4. Research Questions and Hypothesizes

This study investigates how provincial economic growth in Thailand relates to road traffic accident outcomes. It examines whether accidents and injuries follow an inverted U-shaped pattern with income (as per the Kuznets-type hypothesis), whether fatalities exhibit a U-shaped pattern at higher income levels, and how economic activity, labor force size, and urbanization across regions influence both the frequency and severity of traffic incidents.

H1: Traffic accident and injury rates per 1,000 population follow an inverted U-shaped relationship with gross provincial product (GPP) per capita.

H2: Traffic fatality rates per 100,000 population follow a U-shaped relationship with GPP per capita, rising again in high-income provinces.

Research Results

Table 1 summarizes the descriptive statistics of the variables used in the analysis, based on a panel dataset of 847 province-year observations across Thailand from B.E.2553 to B.E.2563 (2010–2020). On average, provinces in Thailand experienced 3,732 road accidents annually, with a considerable standard deviation of 4,334.7, suggesting large variation across provinces and years. The number of reported accidents ranged from 609 to a maximum of 51,264, indicating a concentration of traffic-related incidents in certain areas.

The average number of injuries resulting from traffic accidents was 4,244.4 per year, with a maximum of 61,727, further reflecting the uneven burden of road injuries across provinces. The average number of deaths was 130.6, with the range spanning from 14 to 651 fatalities, and a relatively lower standard deviation (91.5) compared to injuries, suggesting more consistency in fatality levels across provinces. Economic indicators reveal substantial disparities among provinces. The GPP averaged 181,292 million baht, but with a large standard deviation of 525,877.5, and a maximum of 5,709,940 million baht, indicating the dominance of a few economically advanced provinces. The GPPcap also demonstrated wide variation, with a mean of 169,756.4 baht, and values ranging from 32,673 to over 1.4 million baht per person.

In terms of business- and labor market dynamics, provinces had on average 5,667.6 business establishments, with the number ranging from 393 to 155,426. The number of workers also varied significantly, with a mean value of 133,562.8 and a maximum of 4,050,171, reflecting stark differences between rural and urban provinces. When adjusting for population size, the injury rate per 100,000 people (injurepct) averaged 113.35, with relatively low variability (SD = 4.25), indicating a stable rate across provinces. Conversely, the death rate per 100,000 people (deadpct) had a mean of 4.04, with values ranging from 1.10 to 10.19, pointing to a moderate variation in fatality risks per capita. These descriptive results highlight significant heterogeneity in both traffic accident outcomes and economic indicators across provinces, reinforcing the importance of disaggregated provincial-level analysis when examining the link between economic development and traffic-related losses.

Table 1. Descriptive Statistics of Variables of Interest in the Model

Variable	Obs	Mean	Std. dev.	Min	Max
Nacci (Number of Accidents)	847	3,732.3	4,334.7	609	51,264
Injured (Number of Injuries)	847	4,244.4	5,097.3	676	61,727
Dead (Number of Deaths)	847	130.6	91.5	14	651
Gpp (Gross Provincial Product, million baht)	847	181,292.0	525,877.5	-	5,709,940
Gppcap (GPP per capita, baht)	846	169,756.4	203,930.6	32,673	1,413,819
Estb (Number of Establishments)	846	5,667.6	16,829.8	393	155,426
Worker (Number of Workers)	846	133,562.8	417,839.4	5,650	4,050,171
Injurepct (Injured per 100,000 population)	847	113.35	4.25	103.68	130.50
Deadpct (Deaths per 100,000 population)	847	4.04	1.41	1.10	10.19

Source: Center for Road Safety (2024)

**Unit of analysis and time frame: 77 provinces over the period 2010-2020 (prior to in the year 2011, there were 76 provinces; the new province namely "Bungkan" was established in 2011)

Figure 1 illustrates the annual total number of traffic accidents (nacci) and injuries (injured) in Thailand from B.E.2553 (2010) to B.E.2563 (2020). From 2010 to 2020 (B.E.2553–B.E.2563), Thailand experienced a consistent rise in road traffic accidents and injuries. Accidents grew from around 200,000 in 2010 to over 390,000 by 2019, while injuries rose from 230,000 to more than 440,000 during the same period. Although a slight dip occurred in 2020—likely due to COVID-19 mobility restrictions—the overall trend reflects a worsening road safety situation. The number of injuries consistently outnumbered accidents, indicating that many incidents involve multiple victims. These findings highlight the urgent need for stronger and more targeted road safety measures.

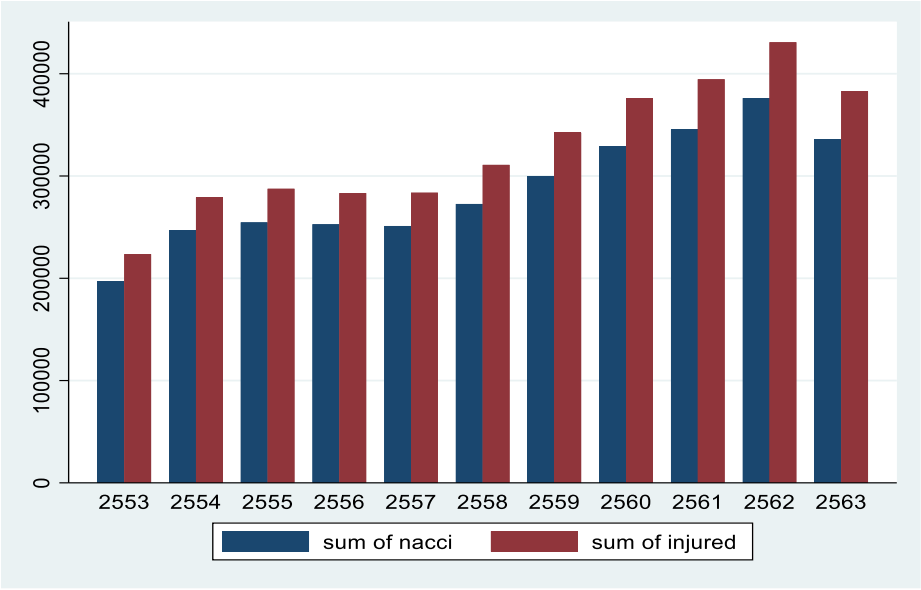


Figure 1. Number of Traffic Accidents and Injuries Over 11 Years (B.E.2553–B.E.2563)

Source: Center for Road Safety (2024)

Figure 2 presents the average ratio of road accidents per 1,000 population across 77 provinces in Thailand over the 11-year period from 2010 to 2020. Between 2010 and 2020 (B.E.2553–B.E.2563), Thailand's road accident rate per 1,000 population rose significantly—from 3.3 to a peak of 5.9 in 2019 (B.E.2562). Although rates remained stable from 2011 to 2014, a clear upward trend began in 2015. A minor decline in 2020 likely reflects reduced travel during the COVID-19 pandemic. The consistent rise in accident intensity, even when accounting for population growth, points to deeper systemic issues such as increased vehicle use, inadequate infrastructure, and weak enforcement. These findings highlight the need for focused policies targeting accident rates per capita, not just overall counts.

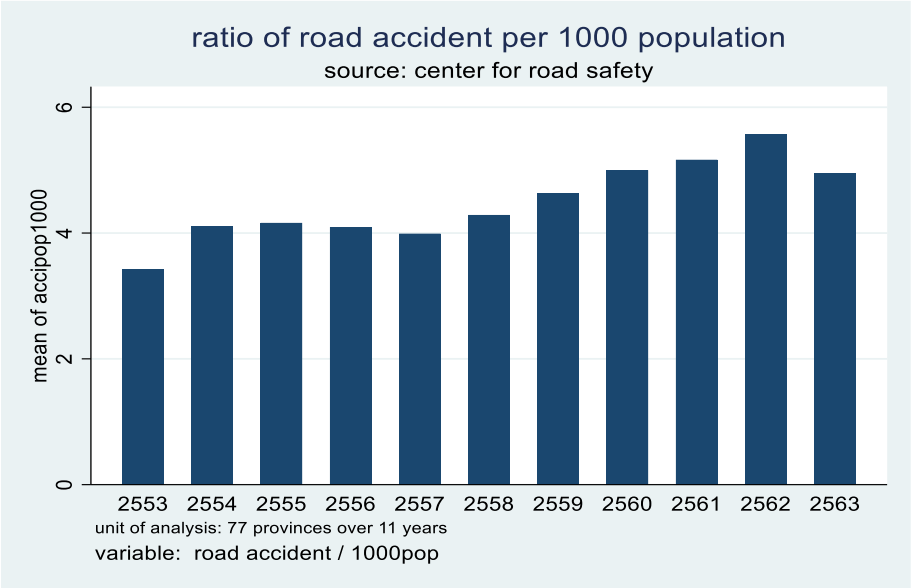


Figure 2. Ratio of Road Accidents per 1,000 Population (B.E.2553–B.E.2563)

Source: Center for Road Safety (2024)

Figure 3 displays the total number of fatalities from traffic accidents in Thailand from 2010 to 2020, in which the traffic fatalities in Thailand remained consistently high. Fatalities rose steadily from 2010 to 2012, exceeding 10,000 annually, then slightly declined but stayed above 9,500 until 2015. From 2016 to 2019, deaths rebounded and remained above 10,500, peaking in 2019. A sharp decline occurred in 2020, likely due to reduced travel from COVID-19 lockdowns. These trends highlight the ongoing severity of road fatalities and underscore the urgent need for stronger, long-term road safety measures.

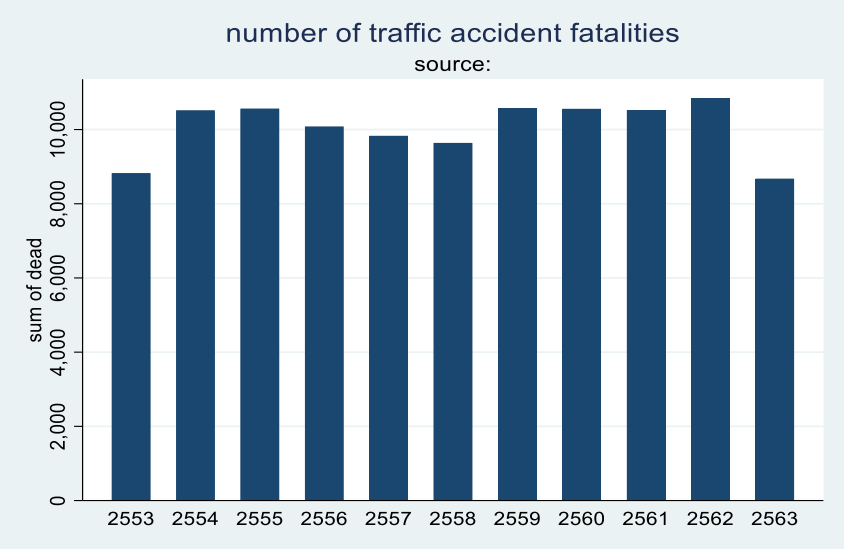


Figure 3. Number of Traffic Accident Fatalities (B.E.2553–B.E.2563)

Source: Center for Road Safety (2024)

Figure 4 reveals a positive but nonlinear relationship between traffic accident rates and fatality rates across Thai provinces. Most data points are concentrated in the range of 4–8 accidents per 1,000 population and 10–25 deaths per 100,000 population. However, considerable variation exists, especially at higher accident levels, with some provinces showing high fatality rates despite low accident rates. This suggests that accident severity and local safety conditions play a critical role. The findings emphasize the importance of addressing not only the frequency of accidents but also their lethality, calling for comprehensive road safety strategies tailored to both prevention and fatality reduction.

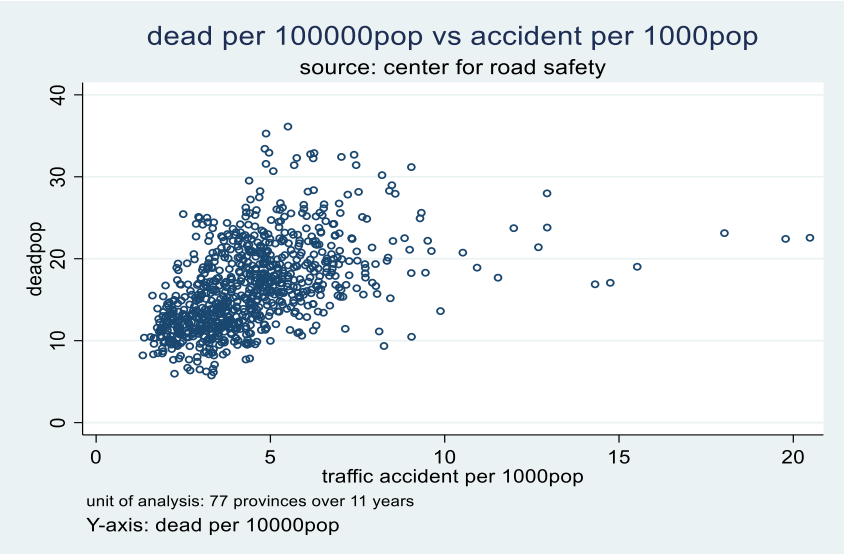


Figure 4. Relationship Between Traffic Accident Rate and Fatality Rate (per Population Basis)

Source: Center for Road Safety (2024)

Figure 5 illustrates the nonparametric relationship between GPPcap and the rate of road accidents per 1,000 population, using the LOWESS technique based on data from 77 provinces over 11 years. The curve demonstrates a clear inverted U-shaped pattern, indicating that road accident rates initially increase with rising income levels, peak at around 700,000–800,000 baht per capita, and then begin to decline as GPP per capita continues to grow. This pattern suggests that in the early stages of economic development, increasing income may lead to more vehicle ownership, mobility, and road use, thereby increasing accident risk.

However, at higher levels of income, the accident rate starts to decrease, possibly due to better road infrastructure, more stringent traffic regulations, safer vehicles, and improved public awareness. This finding is consistent with the Kuznets-type hypothesis applied in the context of road safety, suggesting that development can eventually lead to better safety outcomes once a certain income threshold is surpassed.

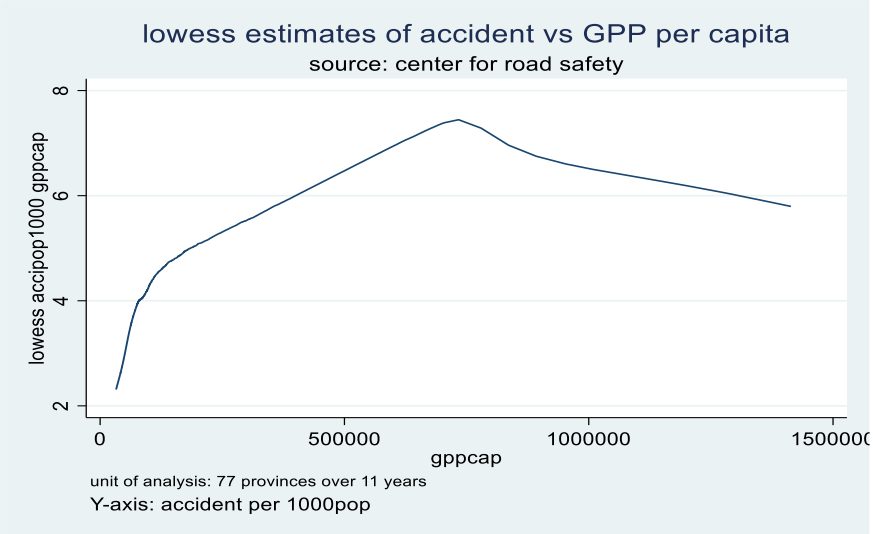


Figure 5. Relationship Between GPP per Capita and Road Accidents (Lowess Estimate)

Source: Center for Road Safety (2024)

Figure 6 shows a positive and nonlinear relationship between GPPcap and road traffic fatality rates. The fatality rate per 100,000 population consistently increases with rising income levels, from about 12 to over 30 deaths. The curve flattens slightly at the middle-income range but resumes an upward trend in higher-income provinces. This suggests that greater wealth does not necessarily lead to fewer traffic deaths, possibly due to increased travel intensity, high-speed driving, or insufficient safety measures. The result highlights the need for targeted interventions in high-income areas to address accident severity and emergency response, not just accident prevention.

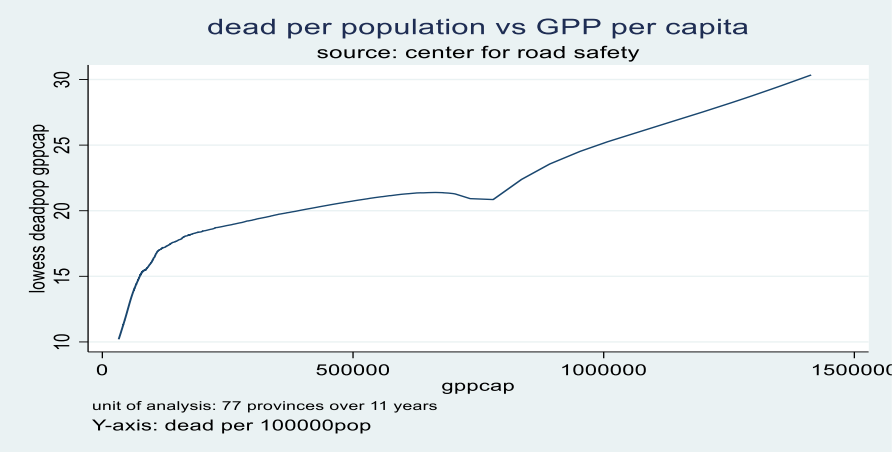


Figure 6. Relationship Between GPP per Capita and Traffic Fatalities (Lowess Estimate)

Source: Center for Road Safety (2024)

Figure 7 shows a nonlinear and widely dispersed relationship between GPPcap and road traffic fatality rates across Thai provinces. While provinces like Rayong and Chonburi have high income and high fatality rates, Bangkok stands out with the highest income and one of the lowest fatality rates. Some moderate-income provinces (e.g., Phuket, Ayutthaya) also report high fatalities, while low-income southern provinces (e.g., Yala, Narathiwat) show low death rates. The pattern highlights that income alone does not explain road fatality outcomes. Instead, local factors—such as urban infrastructure, traffic volume, enforcement, and regional mobility patterns—play a key role. These findings suggest the need for tailored, province-specific road safety strategies.

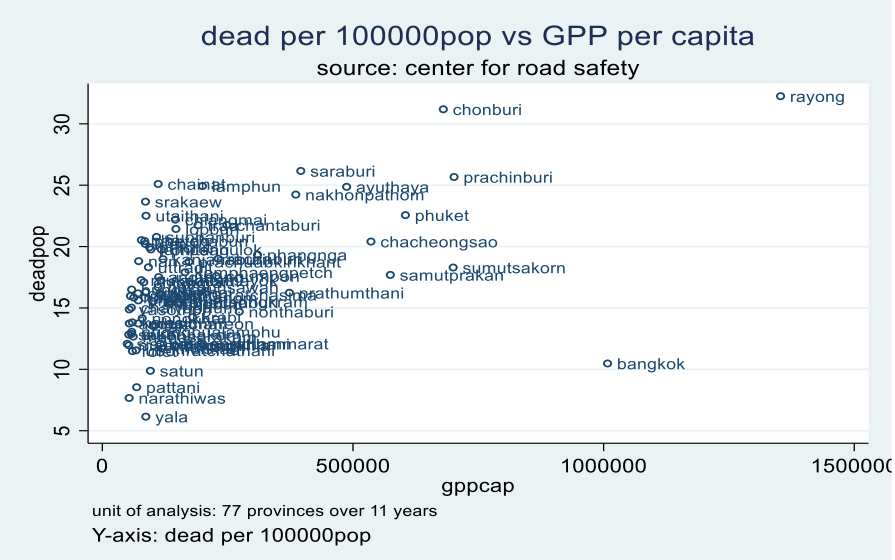


Figure 7. Provincial Distribution of Traffic Fatalities and GPP per Capita

Source: Center for Road Safety (2024)

Figure 8 shows regional disparities in traffic-related losses across Thailand. The central, eastern, and western regions report the highest fatality rates, while the northeast and north have lower death rates but moderate accident and injury levels. The Bangkok vicinity exhibits low accident and injury rates with moderate fatalities, likely due to better infrastructure and lower speed of traveling due to traffic congestion. The south also shows high fatality rates despite average accident levels. Across all regions, fatality rates consistently exceed accident and injury rates, emphasizing the need for region-specific policies to reduce both the frequency and severity of traffic incidents—particularly in high-risk regions like the central and eastern parts of the country.

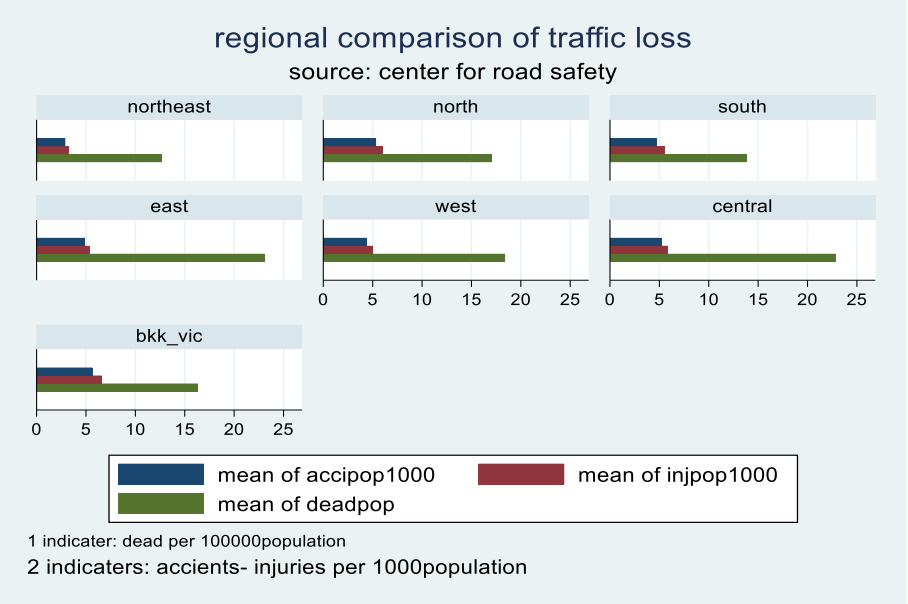


Figure 8. Regional Comparison of Traffic Loss in Thailand

Source: Center for Road Safety (2024)

Figure 9 shows the regional distribution of provinces by road accident rate quintiles (accidents per 1,000 population) for 2019. The northeast dominates the lowest accident group, while the north and Bangkok vicinity are concentrated in the highest quintiles, indicating greater traffic risks in these areas. The central and east regions have provinces in high-risk groups as well, suggesting localized issues in economically active areas. In contrast, the south and west show more even and moderate distributions. These results highlight regional disparities in accident intensity and underscore the need for targeted road safety strategies tailored to high-risk regions, particularly the north and metropolitan areas.

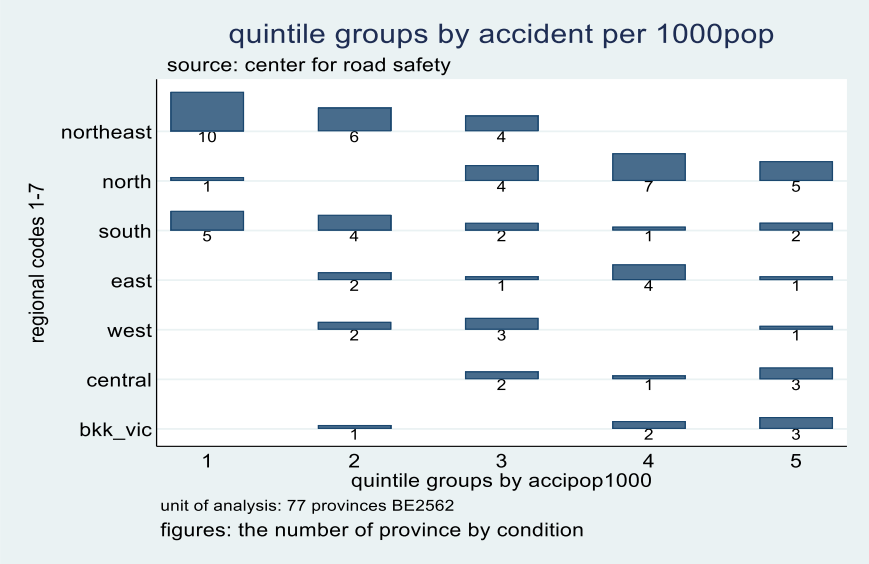


Figure 9. Regional Distribution of Provinces by Road Accident Quintiles (Per 1,000 Population)

Source: Center for Road Safety (2024)

Figure 10 highlights regional differences in road traffic injury rates across Thailand in 2019. The northeast leads in the lowest quintile, indicating generally lower injury rates, while the north and Bangkok vicinity show a clear concentration in the highest quintiles, reflecting a higher injury burden. The central region also has several provinces in upper quintiles, suggesting elevated risk. Meanwhile, the south, east, and west show more balanced and moderate injury distributions. These findings confirm persistent regional disparities, with northern and metropolitan areas facing higher injury rates, and support the need for targeted, region-specific traffic injury prevention policies.

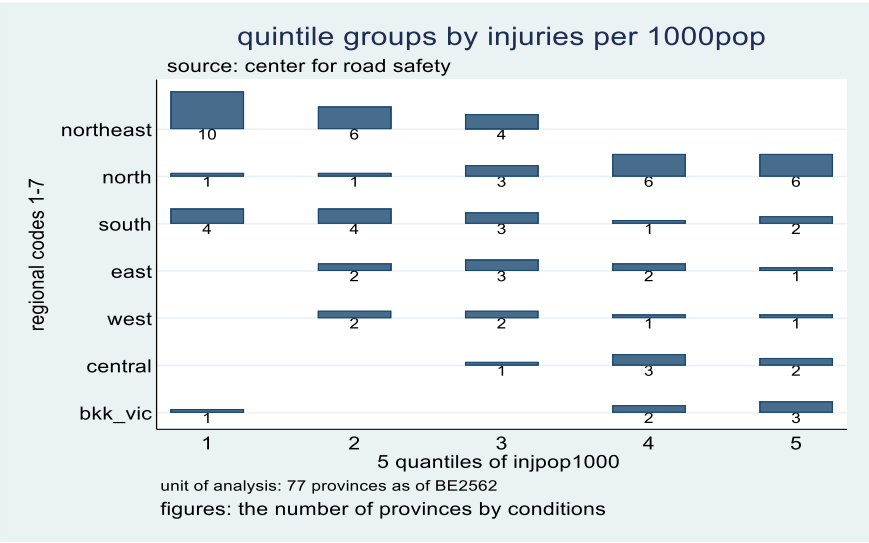


Figure 10. Regional Distribution of Provinces by Road Injury Quintiles (Per 1,000 Population)

Source: Center for Road Safety (2024)

Figure 11 highlights regional disparities in road traffic fatality rates across Thailand's provinces in 2019. The northeast shows moderate death rates, while the north and east regions are concentrated in the highest quintiles, signaling a high fatality burden. The south stands out for its low fatality rates, with most provinces in the bottom quintiles. The central and west regions display elevated risks in specific provinces, and the Bangkok vicinity reflects mixed outcomes. These findings emphasize the need for targeted road safety policies focused on high-risk regions—particularly the north, east, and parts of the central region—to effectively reduce road traffic deaths.

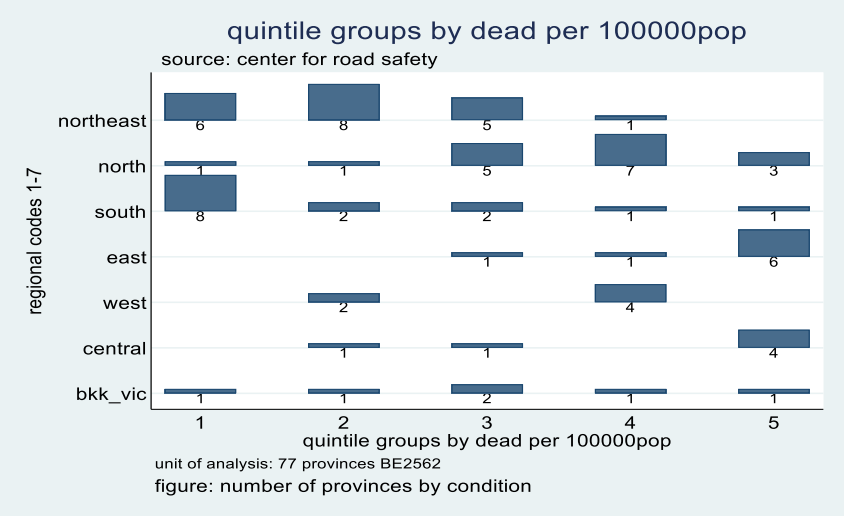


Figure 11. Regional Distribution of Provinces by Road Fatality Quintiles (Per 100,000 Population)

Source: Center for Road Safety (2024)

Figure 12 illustrates that most Thai provinces experienced stable or gradually rising traffic accident rates between 2010 and 2020, typically within 2–8 accidents per 1,000 population. However, a few provinces exhibited sharp increases, surpassing 15 accidents per 1,000, especially during 2015–2019. A notable decline in 2020 likely reflects the impact of COVID-19 lockdowns and mobility restrictions. The growing disparity between high- and low-rate provinces over time suggests increasing regional inequality in road safety, underscoring the need for region-specific interventions, especially for provinces with consistently high or rapidly rising accident rates.

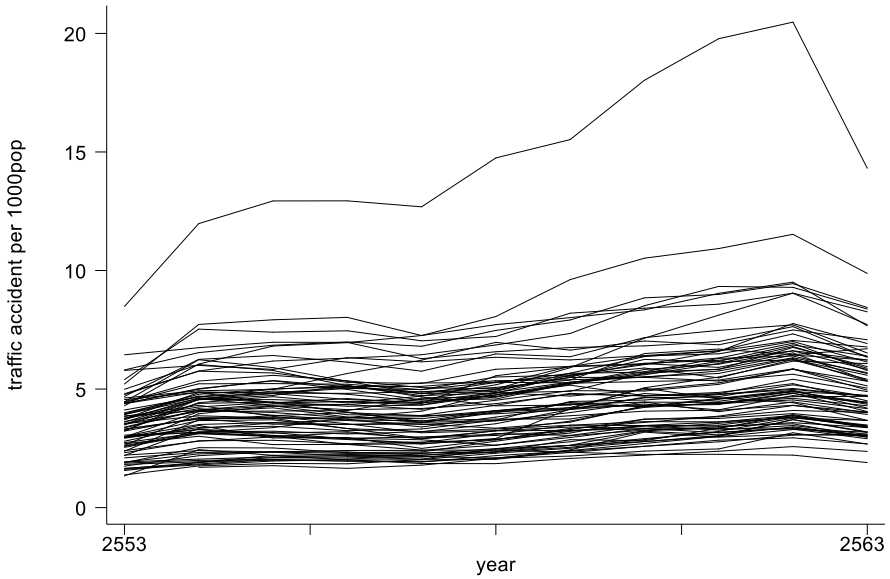


Figure 12. Provincial Trends in Traffic Accident Rates per 1,000 Population (B.E.2553–B.E.2563)

Source: Center for Road Safety (2024)

Table 2 uses an IV regression to examine the determinants of road accidents per 1,000 population. The results reveal a nonlinear, inverted U-shaped relationship between income (GPP per capita) and accident rates—accidents rise with income but decline after a certain threshold, supporting the Kuznets hypothesis. Additionally, both number of establishments and number of workers are positively associated with accident rates, suggesting that economic activity and workforce size contribute to greater traffic risk. Instrument validity tests confirm the strength of the IV model. These findings underscore the need for targeted road safety policies in economically active and rapidly developing areas, integrating traffic safety into broader economic and urban planning strategies.

Table 2. IV Regression Results – Determinants of Road Accidents per 1,000 Population

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R-squared:                                      Obs per group:
     Within  = 0.4519                                        min =         10
     Between = 0.4035                                        avg =       11.0
     Overall = 0.3967                                        max =         11

                                                Wald chi2(9)      =     291.48
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000
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accipop1000	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
gppcap	.0000101	1.02e-06	9.88	0.000	8.07e-06	.0000121
shagr	.0283032	.0083208	3.40	0.001	.0119946	.0446117
shser	.0789599	.0076993	10.26	0.000	.0638695	.0940502
reg						
north	2.5128	.5161855	4.87	0.000	1.501095	3.524505
south	.9842035	.5531937	1.78	0.075	-.1000361	2.068443
east	.0657751	.7676058	0.09	0.932	-1.438705	1.570255
west	1.660613	.7350819	2.26	0.024	.2198787	3.101347
central	2.30386	.7614583	3.03	0.002	.8114289	3.796291
bkk_vic	-.3303351	.8481355	-0.39	0.697	-1.99265	1.33198
_cons	-2.986047	.7126925	-4.19	0.000	-4.382899	-1.589196
sigma_u	1.5095541					
sigma_e	.6379608					
rho	.84846157	(fraction of variance due to u_i)				

```
Instrumented: gppcap
 Instruments: shagr shser 2.reg 3.reg 4.reg 5.reg 6.reg 7.reg estb worker
```

Source: Center for Road Safety (2024)

Table 3 shows that road injuries per 1,000 population are positively linked to GPP per capita, but the relationship is nonlinear—forming an inverted U-shape. Injury rates rise with economic growth but decline after reaching a certain income level, aligning with the Kuznets-type hypothesis. Both the number of establishments and number of workers are also positively and significantly associated with injury rates, suggesting that economic activity and labor force size increase exposure to traffic-related injuries. Instrument tests confirm the robustness of the IV model. These findings underscore the need for growth-sensitive road safety policies, especially in fast-developing provinces where risks are highest during early stages of economic expansion.

Table 3. IV Regression Results – Determinants of Road Injuries per 1,000 Population

```
G2SLS random-effects IV regression              Number of obs     =        846
Group variable: pvcode                          Number of groups  =         77

R-squared:                                      Obs per group:
     Within  = 0.4580                                         min =         10
     Between = 0.3857                                         avg =       11.0
     Overall = 0.3817                                         max =         11

                                                Wald chi2(9)      =     309.33
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000
```

injpop1000	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
gppcap	.0000125	1.19e-06	10.42	0.000	.0000101	.0000148
shagr	.0346655	.0097616	3.55	0.000	.0155331	.053798
shser	.0948144	.0090305	10.50	0.000	.077115	.1125138
reg						
north	2.860439	.6047019	4.73	0.000	1.675245	4.045633
south	1.247426	.6480904	1.92	0.054	-.0228076	2.51766
east	-.3210048	.8994979	-0.36	0.721	-2.083988	1.441979
west	1.922052	.8611433	2.23	0.026	.2342418	3.609861
central	2.538694	.8920915	2.85	0.004	.7902269	4.287161
bkk_vic	-.501689	.9938398	-0.50	0.614	-2.449579	1.446201
_cons	-3.853159	.8357303	-4.61	0.000	-5.49116	-2.215158
sigma_u	1.7782905					
sigma_e	.75295891					
rho	.84797347	(fraction of variance due to u_i)				

```
Instrumented: gppcap
 Instruments: shagr shser 2.reg 3.reg 4.reg 5.reg 6.reg 7.reg estb worker
```

Source: Center for Road Safety (2024)

Table 4 shows that road fatalities per 100,000 population do not follow the same inverted-U pattern seen in accidents and injuries. While GPP per capita is not significantly associated with fatalities, its squared term is positive and significant, suggesting a U-shaped relationship—fatalities may rise again in high-income provinces. Additionally, both the number of establishments and number of workers are positively and significantly linked to higher fatality rates, indicating that economic activity and labor density increase fatal crash risk. These results highlight the need for advanced, region-specific safety strategies, particularly in wealthier provinces, where traffic deaths may increase despite development. Road safety policy must therefore address not just accident frequency, but also severity and risk behaviors in high-exposure environments.

Table 4. IV Regression Results – Determinants of Road Fatalities per 100,000 Population

```
R-squared:                                      Obs per group:
     Within  = 0.0467                                        min =         10
     Between = 0.6894                                        avg =       11.0
     Overall = 0.5560                                        max =         11

                                                Wald chi2(9)      =     164.58
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000
```

deadpop	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
gppcap	3.67e-06	3.07e-06	1.20	0.232	-2.34e-06	9.68e-06
shagr	-.0050019	.02614	-0.19	0.848	-.0562354	.0462315
shser	-.1172445	.0216433	-5.42	0.000	-.1596646	-.0748244
reg						
north	3.51989	.9782113	3.60	0.000	1.602631	5.437149
south	.5401782	1.081187	0.50	0.617	-1.578909	2.659265
east	6.578938	1.60255	4.11	0.000	3.437997	9.719879
west	4.413069	1.391934	3.17	0.002	1.684928	7.14121
central	7.718056	1.46255	5.28	0.000	4.851509	10.5846
bkk_vic	1.380062	1.742437	0.79	0.428	-2.035051	4.795175
_cons	19.36527	1.940422	9.98	0.000	15.56212	23.16843
sigma_u	2.8618596					
sigma_e	2.4698712					
rho	.57312466	(fraction of variance due to u_i)				

```
Instrumented: gppcap
 Instruments: shagr shser 2.reg 3.reg 4.reg 5.reg 6.reg 7.reg estb worker
```

Source: Center for Road Safety (2024)

Figure 13 reveals that Phuket had the highest road accident rate in 2019, exceeding 20 accidents per 1,000 population, likely due to tourism and traffic congestion. Other high-risk provinces—Samut Sakhon, Samut Prakan, Nonthaburi, and Bangkok—are located in the Bangkok Metropolitan Region, reflecting the effects of urban density and mobility.

Several central and eastern provinces (e.g., Chonburi, Rayong, Pathum Thani) also show high accident rates, pointing to risks in industrial and economically active areas. Even the lowest among the high-accident group (e.g., Nakhon Nayok, Prachin Buri) still exceed the national median. The results highlight the need for targeted road safety strategies in urban, industrial, and tourism-intensive provinces, especially where accident intensity is disproportionately high.

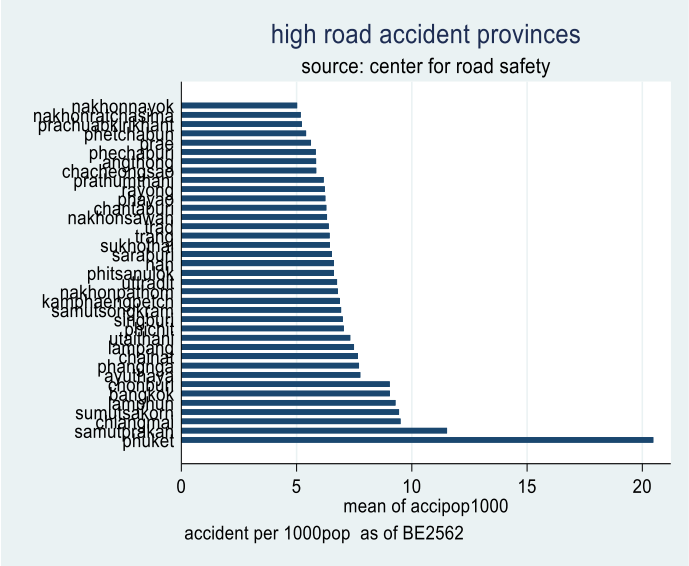


Figure 13. Provinces with Highest Road Accident Rates per 1,000 Population (B.E.2562)

Source: Center for Road Safety (2024)

Figure 14 shows that provinces with the lowest road accident rates in 2019—such as Narathiwat, Nong Bua Lam Phu, and Maha Sarakham—recorded fewer than 2 accidents per 1,000 population. Most of these provinces are located in the northeast, with some from the south and central regions. Their low rates likely reflect lower traffic density and urbanization. However, the lower accident rates may also result from underreporting or limited traffic flow, not necessarily better road safety systems. As rural areas grow, investment in traffic monitoring and infrastructure remains crucial to maintain and improve safety outcomes.

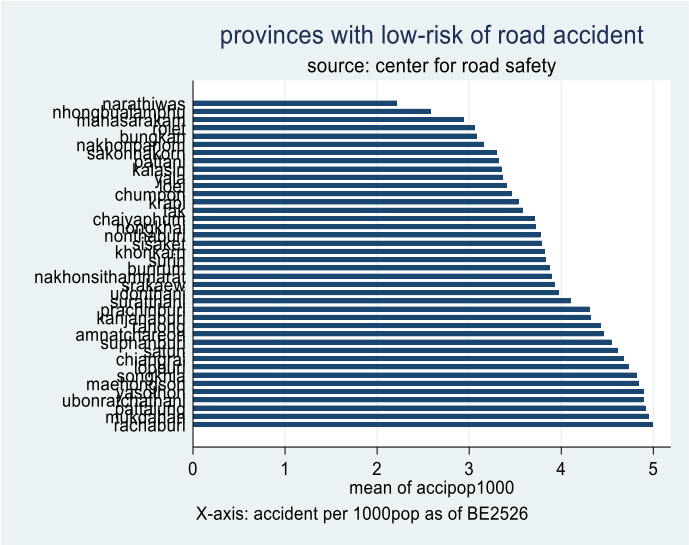


Figure 14. Provinces with Lowest Road Accident Rates per 1,000 Population (B.E.2562)

Source: Center for Road Safety (2024)

Figure 15 identifies the 20 provinces with the highest fatality rates per road accident in 2019. Sakaeo, Prachinburi, and Loei were top in the list, with over 5 percent of accidents resulting in death, highlighting severe traffic risks. Provinces like Bungkan, Rayong, and Chumphon also show consistently high death-to-accident ratios. Notably, some provinces with lower accident frequency—such as Nonthaburi and Ratchaburi—still report high accident severity, underscoring that fewer crashes can still be more lethal. This points to the urgent need for targeted road safety interventions, especially in high-fatality areas, focusing on: Improved emergency response systems, Safer Road design, Stronger enforcement of safety laws, and Speed management.

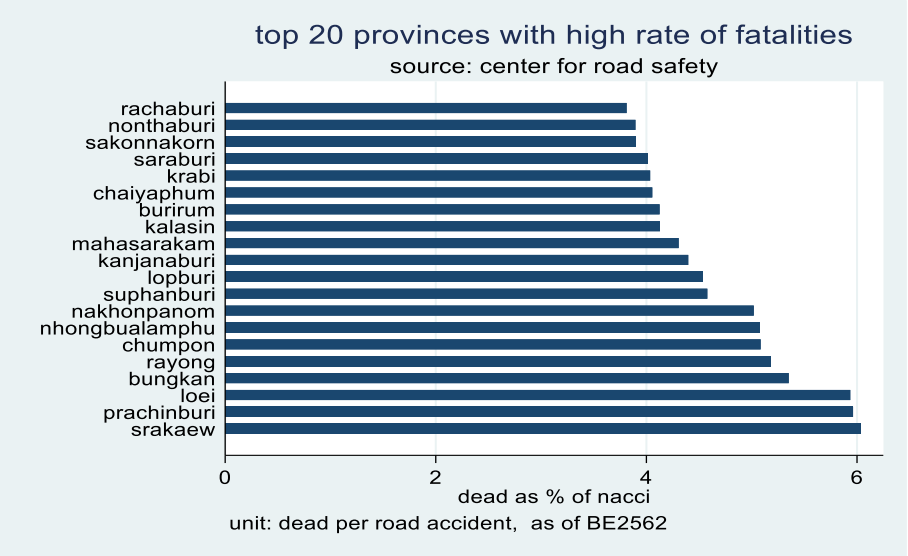


Figure 15. Top 20 Provinces with Highest Fatalities per Accident (as of B.E.2562)

Source: Center for Road Safety (2024)

Discussion

The findings of this study reveal that provincial economic development in Thailand is associated with traffic accident outcomes in nonlinear and differentiated ways, a pattern that aligns with international evidence linking economic growth to changes in mobility, exposure, and transport-system risks. The inverted U-shaped relationship found for accidents and injuries is consistent with the Kuznets-type hypothesis, whereby rising income initially increases road exposure and motorization before improvements in infrastructure and regulation eventually moderate accident rates (Grossman & Krueger, 1995; Kopits & Cropper, 2005). Similar tendencies have been observed in India and Algeria, where economic expansion intensified mobility and accident risks during early development stages (Mahata et al., 2019; Bougueroua & Carnis, 2016). The positive association between economic activity—

captured through the number of workers and establishments—and accident outcomes further supports theories emphasizing the structural role of economic density and freight movement in shaping crash risks, consistent with the Slovenian motorway evidence linking increased heavy-vehicle traffic to higher accident probabilities (Zanne et al., 2016). Meanwhile, the inconsistent effect of income on fatalities reflects findings from Hong Kong showing that GDP influences road safety indirectly through behavioral, infrastructural, and demographic channels (Li et al., 2018). Taken together, these results reinforce the theoretical view that economic development functions not as a direct causal factor but as a broader structural driver that shapes vehicle ownership, travel demand, infrastructure pressure, enforcement capacity, and behavioral norms. This framework provides a coherent explanation for the nonlinear and regionally varied accident patterns observed across Thai provinces.

Although the article correctly notes that the decline in accidents, injuries, and fatalities in 2020 (B.E.2563) is largely attributable to COVID-19 mobility restrictions and should be interpreted as a temporary disturbance rather than a structural change, this point could be emphasized more explicitly in the Discussion. Specifically, it would be valuable to state that the econometric models (Tables 2–4) employ panel data techniques and fixed effects, which help to reduce—but cannot entirely remove—the influence of this outlier year on the estimated coefficients. Highlighting this methodological consideration would assist readers in interpreting both the robustness and the limitations of the findings during the pandemic period.

The relationship between provincial economic development and road traffic accident outcomes can be explained through established theories and supporting empirical evidence. The independent variable, GPP per capita, reflects economic development and influences road safety indirectly through mobility, exposure, and behavioral mechanisms. Consistent with the Kuznets-type hypothesis, rising income initially increases accidents and injuries because economic growth expands vehicle ownership and traffic volume—patterns also observed in India, Algeria, Slovenia, and Hong Kong (Mahata et al., 2019; Bougueroua & Carnis, 2016; Zanne et al., 2016; Li et al., 2018). The Thai results similarly reveal an inverted U-shaped relationship, indicating that accident risks rise during early development but decline after income surpasses a certain threshold, when improvements in infrastructure and traffic enforcement begin to take effect. In contrast, fatalities follow a U-shaped pattern: although accident frequency falls at higher income levels, fatality risks rise again due to high-speed travel, more powerful vehicles, and complex mobility networks in wealthier provinces—reflected in the positive coefficient of squared GPP per capita in the Thai data. The control variables—number of business establishments and workers—capture the structural intensity of economic activity.

Higher concentrations of firms and labor increase commuting, freight movement, and overall traffic flow, thereby elevating crash risks. These effects parallel findings from Slovenia's freight corridors and Hong Kong's dense labor-driven mobility systems. In the Thai dataset, both variables consistently show positive associations with accidents, injuries, and fatalities, reinforcing their role as mediating pathways through which economic development shapes road safety outcomes. Overall, the synthesis indicates that GPP per capita affects road safety not directly but through its influence on exposure, mobility, infrastructure pressure, and behavioral factors, while the control variables amplify these mechanisms. The coexistence of inverted U-shaped and U-shaped patterns underscores the complex interaction between income, mobility, and institutional capacity, highlighting the need for region- and income-sensitive road safety policies in Thailand.

A more explicit integration of the regional disparities observed in Figures 8–11 would further strengthen the discussion and sharpen the policy implications. The evidence shows that high-risk regions vary not only in accident frequency but also in accident severity. For example, the North and Bangkok vicinity consistently fall into the highest quintiles for accidents and injuries, reflecting intense mobility, urban congestion, and population density. These areas require policies centered on frequency reduction, such as congestion management, traffic-calming measures, and improved enforcement. In contrast, the East and parts of the Central region exhibit disproportionately high fatality rates despite moderate accident counts, indicating problems related to severity, such as high-speed corridors, freight-related risks, and slower emergency response times. These regions therefore need interventions focused on severity mitigation, including speed management, upgraded emergency medical services (EMS), safer road design, and targeted enforcement on highways and industrial transport routes. Integrating these regional patterns into policy recommendations would ensure that provinces receive interventions tailored to the dominant type of risk—frequency or severity—rather than uniform measures that overlook local conditions.

Conclusion

This study explored the intricate relationship between provincial economic growth and traffic accident outcomes in Thailand using 11 years of panel data. The results demonstrate a distinct and nonlinear association between economic development and road safety outcomes, with important implications for public policy. The empirical evidence supports two main hypotheses. First, road accidents and injuries exhibit an inverted U-shaped relationship with GPP per capita—rising in the early phases of economic growth and declining after surpassing a certain income threshold. This aligns with

the Kuznets-type hypothesis and suggests that economic advancement can eventually contribute to improved road safety outcomes, provided that investments in infrastructure, regulation, and public awareness keep pace with development. Second, the relationship between GPP per capita and road traffic fatalities diverges from this pattern, instead forming a U-shaped curve. Fatality rates tend to rise again at higher income levels, highlighting the potential for increased severity of accidents in wealthier and more mobile provinces.

The findings also reveal significant regional disparities in accident rates, injury rates, and fatality risks. Urbanized and economically active areas such as Bangkok, the central region, and industrial provinces face elevated risks of both accident frequency and severity. Meanwhile, lower-income provinces often report fewer accidents but may still face challenges in terms of emergency response capacity or underreporting.

Overall, the study underscores that economic growth, while offering pathways for enhanced road safety, also poses new challenges. As such, policymakers must adopt a two-pronged approach: one that focuses on preventing accidents through better infrastructure and enforcement, and another that reduces accident severity through emergency response improvements and education campaigns. Targeted, data-driven strategies that are sensitive to the economic and spatial contexts of each province will be essential in achieving sustainable road safety improvements across Thailand.

Future research should further examine the role of specific policy interventions, vehicle types, enforcement intensity, and health system capacities in shaping traffic safety outcomes. Incorporating qualitative insights and household-level data could also enrich the understanding of behavioral factors contributing to road risks. Ultimately, traffic safety must be recognized not only as a transport issue, but as an integral component of inclusive and resilient economic development.

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