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# Spatial Econometric Analysis of Automobile and Motorcycle Traffic on Indonesian National Roads: Is It Local or Beyond City Boundaries?

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# Spatial Econometric Analysis of Automobile and Motorcycle Traffic on Indonesian National Roads: Is It Local or Beyond City Boundaries?

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**Abstract**

This paper investigates the spatial dimensions of automobile and motorcycle trips on national roads between neighboring cities in Indonesia, using spatial econometric models. Vehicle trips are measured in terms of vehicle kilo- meters traveled (VKT) for both types of vehicles. The study finds that motorcycle trips are characteristically local because there is no sign of a spatial correlation with neighboring cities for such trips; by contrast, automobile trips are often made across city boundaries, although the models demonstrate only small spatial correlations among neighboring cities for automobile trips. The models also indicate that road capacity, gasoline prices, income in the region, population and worker density, city size, and number of public buses, have significant effects on VKT. The results suggest that in general, urban transportation policies for national roads could be less complex because local solutions may be more effective in solving the traffic problems of individual Indonesian cities.

**Keywords**: road transport, Indonesian traffic, spatial autocorrelation

**JEL codes**: R41, R49, R53

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# 1 Introduction

The demands on private vehicle usage for automobiles and motorcycles in one city can be affected by neighboring cities. For example, the residents of one city often make routine trips to neighboring cities for work, study, business, or other pursuits. National road networks are designed to facilitate not only intracity trips but also intercity trips. Although traffic-counting surveys on national roads are conducted nearly every year, given the absence of origin-destination (OD) surveys for national roads in Indonesia, the spatial extent of trips on national roads cannot be precisely determined. Currently national roads are primarily developed and maintained by the central government of Indonesia, however, recent movement of decentralization gives rise to an argument of the local governments' autonomy in the field of transportation. Therefore, using traffic-counting data and spatial econometrics methods, specifically the spatial lag model (SLM) and the spatial error model (SEM), this study pioneers to examine whether the spatial extent of trips that are taken on national roads in Indonesia is beyond the city boundary. Vehicle trips in this study are represented by the vehicle kilometers traveled (VKT) of automobiles and motorcycles; the VKT values are derived from the traffic-counting data.

This study starts out by hypothesizing that there is a positive spatial correlation for trips on national roads between neighboring cities and that this correlation should be stronger for automobiles than for motorcycles. The results demonstrate that the spatial correlation for trips on national roads between cities in Indonesia is relatively weak as for motorcycle trips that are not spatially correlated with that in neighboring cities, and automobile trips demonstrate only weak spatial correlations for intercity trips. Furthermore, an analysis of the explanatory variables reveals that Gross Domestic Regional Product (GDRP) has a different impact for automobile trips than for motorcycle trips, but various other variables, such as the roughness of the roads, national road capacity, city size, and population density, produce similar effects on both automobile and motorcycle trips.

This study uses cross-sectional data because many variables in the transportation sector do not change significantly in the short term, although a number of these variables, such as road length, city size, public Su used 20 years of panel data for 85 urban areas to find variations across time, but it is very difficult to find a continuous set of transportation data for many developing countries, including Indonesia. Su (2010) used dynamic panel data but was not aware of the possibility of spatial dependence. Thus, instead of focusing on the time variability of Indonesian transportation data, this study focuses on the spatial interdependencies among geographical units and explores the possibility of determining the use levels of automobiles and motorcycles by assessing the relationships between cities with the SLM and the SEM. LeSage and Pace (2009) described the SLM as a model that uses dependent variables from neighboring cities as independent variables for other cities. These researchers also defined the SEM as a model that examines dependencies in disturbance; these dependencies imply that there is a spatial dependence in an unobserved variable.

The VKT variable is probably the most reliable data available in Indonesia to represent the country-wide usage levels of vehicles. VKT has been used in this context in studies conducted by Senbil, Zhang, and Fujiwara (2006), Tanner (1978), Su (2010), Wen, Chiou, and Huang (2011), Huo et al. (2012), Duranton and Turner (2011), and Mulley and Tanner (1978). Tanner (2011) attempted to use GDP, income, demographic characteristics, and the price of fuel to predict VKT; Su (2010) used urban spatial characteristics to predict VKT per capita, with results showing that road density and city size have a positive impact on VKT per capita. Wen, Chiou, and Huang (2011) subsequently concluded that income had a negative relationship with VKT, males used motorcycles more often than females, a greater number of commuting and recreational days increased VKT, and the frequency of motorcycle usage was positively correlated with motorcycle engine size. In addition, Duranton and Turner (2011) used road infrastructure (measured in terms of the number of kilometers of lanes) to measure its effect on VKT. In Indonesia, two institutions use VKT to establish policies, namely, the Ministry of Public Works and the Ministry of Transportation. These two institutions have different goals and use different approaches to measure VKT. The Ministry of Public Works applies the traffic-counting method to generate VKT and considers VKT to be one important performance metric to indicate the utilization level of a particular road. By contrast, the Ministry of Transport uses VKT as a tool to measure CO2 emissions from various transportation sectors and derives VKT from JICA household trip survey data.

Senbil, Zhang, and Fujiwara (2006) studied motorcycle usage in Indonesia by utilizing a 2003 survey of household trips that was conducted by JICA. However, the area of study for this survey was limited to the Jakarta metropolitan area, and household trip surveys are infrequently conducted in Indonesia due to their high implementation costs. Thus, analyzing the existing household trip survey data from Indonesia would be highly limited in time and place and would not be representative of other Indonesian cities because Jakarta is a primary city with no domestic equal in terms of population or economy. This study attempts to create a model that can represent vehicle usage in various Indonesian cities by capturing the characteristics of a larger number of cities and observing the spatial correlations among these cities.

In the following section we start by reviewing the current status of road transportation in Indonesia in detail. In Section 3 we introduce the data. Section 4 sets up the spatial econometric models to be estimated. Section 5 presents the results, and finally Section 6 concludes.

## 2 Road Conditions and Traffic in Indonesian Cities

Studies tracking the usage of private automobiles and motorcycles could become an important input for urban transportation policy because the rapid motorization of urban areas is a common situation that is being addressed in many modern Indonesian cities. In contrast to the motorization of developed countries, both cars and motorcycles play important roles in the motorization process in many developing countries. For this reason, many large Asian cities, such as Bangkok, Jakarta, and Hanoi, have become motorcycle cities and are referred to by certain transportation experts as "traffic disaster cities" (Kenworthy, 2011). As Kenworthy's study noted, there is typically only one meter of road space per capita in developing countries compared with five to eight meters per capita in developed countries; because of this extremely low ratio of road availability per capita in developing nations, the motorization of these nations creates severe traffic congestion. Kenworthy (2011) also observed that many individuals in developing countries who had previously walked, operated non-motorized vehicles, or used low-cost public transportation have migrated to the use of motorcycles; the author argued that this migration was not only a result of individual decisions but also an outcome that was promoted by governmental policies that encouraged road building, vehicle ownership, urbanization, and suburbanization. Moreover, as Dimitrou (2011) demonstrated, the rapid rates of motorization in Asia are closely related to the region's economic growth rates.

The rapid motorization of Indonesia's cities can be observed by examining the average speed of vehicles in large, medium-sized and small cities. The average vehicular speed in large cities has dropped significantly from 2007 to 2010: in Surabaya, the average vehicular speed fell from 24 km/h to 21 km/h, and in Medan, the average vehicular speed decreased from 39.4 km/h to 23.4 km/h. This decrease in speed can also be observed in small- and medium-sized cities such as Padang, where the average vehicular speed was dramatically reduced from 40.9 km/h in 2007 to 30.9 km/h in 2010, and in Padang Panjang, where the average vehicular speed declined from 38.8 km/h in 2007 to 25.62 km/h in 2010.

The number of private vehicles in Indonesia has increased significantly, more than doubling from about five million in 2003 to almost 12 million in 2009. The number of motorcycles has increased even more rapidly during the same period, growing from some 23 million to 60 million in just seven years. Conversely, during the same period, the total road length in Indonesia only increased by approximately 35%, from 328,314 km to 446,278 km. The increase in the number of private vehicles has been associated with a rise in the number of accidents, especially for accidents involving motorcycles, which increased 17 times from 9,386 to 164,431. Information regarding the demand for travel by car and motorcycle and the correlations among cities in terms of travel can provide better input for regulators to craft policies to more effectively manage the motorization process.

This study utilizes the database of the Indonesia Road Management System (IRMS). The IRMS is managed by the Ministry of Public Works' Directorate General of Highways and is used for the planning, programming, and budgeting of national roads in all Indonesian provinces. Several different surveys and inventories are used to collect data for input into the IRMS, all of which are included in this study: data from traffic surveys are utilized to measure the VKT values for cars and motorcycles, roughness data are used to compute the International Roughness Index (IRI) variables, and inventory data are used to determine the national road capacity and the number of kilometers of lanes.

Prior to an analysis of the model and the regression results, a separate assessment of each of the variables used in the model, particularly the variables derived from the road data, can provide a great deal of information about the conditions for road transportation in Indonesia's urban areas. More than 50% of both Indonesia's national economic activity and the Indonesian population is concentrated on the island of Java; for this reason, it is common to discuss and analyze Indonesia in terms of Java and "outer Java", a term used to refer to the other Indonesian islands. Another term that is frequently used is "large cities", which are defined as cities with a population of at least 500,000. Cities with populations of less than 500,000 are categorized as medium-sized and small cities.

// *insert Table* 1 *here* //

// *insert Table* 2 *here* //

As shown in Tables 1 and 2, the mean VKT value for motorcycles is almost three times greater for cities in Java than those in outer Java; however, this difference is statistically insignificant due to large variation over cities. The mean VKT value for motorcycles is five times greater in large cities than in small- and medium-sized cities, however even this large difference is not statistically significant. Similarly, the difference in the mean VKT values for cars between Java and outer Java is statistically insignificant, despite the fact that this difference is greater than the difference in the mean VKT values for motorcycles between the regions. It is only that the differences in the mean VKT values for cars for different city sizes is statistically significant at the 10% level.

*// insert Table 3 here //*

The difference in IRI between Java and outer Java is also not statistically significant; in particular, the condition of national roads in urban areas in both Java and outer Java is fair because the mean value remains stable at approximately 5 (see Table 3). However, this value is only meaningful within city limits. Large cities do not differ in a statistically significant degree from small- and medium-sized cities with respect to IRI. Thus, the IRI values in Indonesian cities do not vary significantly between the geography and types of cities.

*// insert Table 4 here //*

Table 4 shows that the mean national road capacity of cities in Java is almost twice the mean national road capacity of those in outer Java, but this difference is not statistically significant. The mean national road capacity of large cities is approximately three times greater than the mean national road capacity of small- and medium-sized cities; this difference is statistically significant only at 10% level.

*// insert Table 5 here //*

Motorcycles dominate city roads in many Asian countries, and the same phenomenon occurs in Indonesian cities, as indicated by data regarding the proportion of motorcycles in daily traffic on national roads (see Table 5). Furthermore, the mean proportion of motorcycles in outer Java is 50% of the daily traffic, which is much higher than the 39% found in Java; at the 5% level, this difference in the proportion of motorcycles is statistically significant. The mean proportion of motorcycles in daily traffic is approximately 6% lower in large cities than in small- and medium-sized cities, which is not statistically significant.

*// insert Table* 6 *here //*

As shown in Table 6, the proportion of private cars in daily traffic on national roads is less than that of private motorcycles. In Java, the mean proportion of private cars is approximately 20%, which is 3% higher than the proportion in outer Java; this difference is significant at the 10% level. For big cities, the mean proportion of cars is approximately 21%, and for small- and medium-sized cities, the proportion is lower at 18%, and the difference is statistically significant.

# 3 Data

This section explains the dependent and independent variables used in the study. The dependent variables are the VKT values for automobiles and motorcycles, and the explanatory variables for each city are road roughness, Gross Domestic Regional Product (GDRP) per capita, population density, city size, national road capacity, volume capacity ratio, the price of gasoline, number of working residents per area, number of public buses, and the sex ratio. Table 7 summarizes these data.

*// insert Table* 7 *here //*

The data for this study were obtained from two sources: the Ministry of Public Works and the Local Statistics Bureau. The study uses cross-sectional data for 77 cities across Indonesia that vary in size from small- to medium-sized cities with populations of approximately 50 thousands to large cities with populations of approximately nine million. Geographically, the sample of cities is representative of all of the major Indonesian islands because there are only 93 administrative cities in all of Indonesia.

## 3.1 Dependent variables

The dependent variable in this study is vehicle kilometers traveled for private cars and motorcycles. The VKT values are obtained from traffic data for national roads in 77 Indonesian cities. The traffic-count survey is conducted annually by the Ministry of Public Works and characterizes vehicles into

12 different types: motorcycles, private cars, utility passenger vehicles, utility freight vehicles, small buses, large buses, trucks with two axles and four wheels, trucks with two axles and six wheels, trucks with three axles, tow trucks, semi-trailers, and non-motorized vehicles. The traffic-count survey is conducted using both an automatic and a manual traffic count over a period of approximately 40 hours.

The VKT values for cars and motorcycles are calculated as the sum of the average amount of traffic per day for each road segment multiplied by each road's length over all segments within the city for the 77 cities. The VKT is limited to national road segments in this study, meaning that the VKT provides information on the movement of vehicles on national roads for one year; this metric can also be interpreted as a measurement of the level of utilization of national roads. The units for VKT values are vehicle kilometers, and in the regression, the measurement is denoted by VKTCAR for private car VKT values and by VKTMTC for motorcycle VKT values.

The VKT values measure the amount of movement in a defined area; for the purposes of this study, the defined areas are the cities that are examined. Because traffic movement can be either restricted to the inner city or expanded to include intercity movement, the VKT in one city may be influenced by neighboring cities. Thus, there is a possibility of spatial dependence in the VKT variable; to overcome potential problems of spatial dependence, this study employs a spatial econometrics model.

### 3.2 Independent variables

The explanatory variables are proxies for road characteristics, economic factors, demographics, and urban factors. The independent variables that represent road characteristics are the International Roughness Index (IRI), the capacity of the national roads, and the volume capacity ratio. The price of gasoline and the GDRP per capita are proxies for economic factors, and the sex ratio is a proxy for demographic factors. Population density, the number of working residents per $km^2$, and city size are the variables that represent urban factors. Public transportation considerations are incorporated by considering the number of public buses that exist within a city. The IRI measures the roughness of pavement. The index was created by the World Bank in the 1980s as a tool to measure road quality and user cost, and it is a continuous metric that begins at 0 mm/m.[1] A higher IRI value indicates

[1] A roughness survey is conducted annually by Indonesia's Ministry of Public Works using various car-based tools, such as ROMDAS or NAASRA; the tool records the bumps on the road, and the results can later be converted to an IRI value.

that the road pavement has higher roughness.

The capacity of the national roads is measured by totaling the total capacity of the national roads for each road segment and multiplying this capacity by the length of each road segment. The unit for this variable is km-PCE (passenger car equivalents) per hour. The road capacities are obtained from the road inventories survey, which assesses the carriage width, shoulders, type, and terrain for each road. The data from the inventories survey were used as an input to measure road capacity in PCE per hour. The inventories survey is conducted by manual observation and is not performed every year; rather, it is dependent on changes in road inventories. Duranton and Turner (2011) used road characteristics as the independent variable in their travel-demand study. The symbol for this variable is CAPNROAD.

The Volume Capacity Ratio (VCR) is used by traffic engineers and transportation planners to indicate travel time and traffic flow or congestion. A VCR value of 1 indicates that traffic volume is equal to road capacity. If the ratio is greater than 1, traffic flow is heavy, and traffic speed may decrease to inconvenient levels; conversely, a ratio below 1 indicates that traffic is flowing more freely and that travel time may be decreasing (and/or traffic speed may be increasing) to more convenient levels. Because not all of the cities included in this study collect data on average speeds, speed cannot be used as an explanatory variable because of the lack of adequate data; however, speed levels can be predicted using the VCR data.

The price of gasoline is obtained from household gasoline expenditures, which are collected by Indonesia's National Bureau of Statistics; in the regression, the variable is represented by PGASOLINE, with the rupiah as the price unit. The price of gasoline represents one of the costs of using any type of private vehicle, and Su (2010) and Tanner (1978) also used the price of gasoline as an explanatory variable for VKT values. The quantity of GDRP per km represents the relative level of wealth and is used as a substitute for income data because income data are more difficult to obtain. In the regression, the variable for GDRP per capita is represented by GDRPCAP and is expressed in rupiahs.[2] In addition, sex ratio is a demographic characteristic that indicates the ratio of males to females. Previous studies, such as the investigation by Wen, Chiou, and Huang (2011), demonstrated that gender can influence the demand for travel; this variable is represented by SEXRATIO in the model.

Population density, which is represented by POPDENS in the regression, is an important variable

[2]We take natural log of it in the analysis.

for travel demand because low population densities can cause automobile dependence (Kenworthy, 2011); population per km$^2$ also describes urban density and the level of sprawl in a region. The number of working residents per km$^2$, RWORKERPKM, is an indicator of the trips that result from work activities; this variable's value is obtained by dividing the number of working residents in a city by the city's area.

Public transportation variables can be very useful in explaining private vehicle usage behaviors for both cars and motorcycles. The variable for public transportation used in this paper is NUMPUBBUS, which indicates the number of public bus vehicles that are available.

## 4 The Spatial Lag and Spatial Error Models

This study tests the hypothesis that there is a strong correlation of spatial lags for trips on national roads between neighboring cities, and a stronger correlation is expected for automobile usage than for motorcycle usage because automobiles are more commonly employed for trips of longer distances.

Analyses of cross-sectional data typically use the ordinary least squares (OLS) method, and our paper proceeds as follows (see, for example, LeSage and Pace, 2009):

$$\begin{aligned} y_i &= x_i\beta + \varepsilon_i \\ \varepsilon_i &\sim N\left[0, \sigma^2\right] \end{aligned}$$

where $y_i$ is the VKT for a car/motorcycle in city $i$, and $x_i$ is the vector of independent variables in city $i$. In the cross-sectional OLS analysis, the values for the dependent variable for one city are assumed to be independent of the values for the other cities. Moreover, the expected value of errors between regions $E\left[\varepsilon_i\varepsilon_j\right]$ is zero.

However, cross-sectional observations often represent or relate to a spatial unit such as a geographic region; in such a case, the values that are observed in one region can be dependent on observations for other regions. Thus, the conventional OLS approach on cross-sectional data may be biased. Specifically, when there is a spatial correlation among $y_i$, the ordinary least squares is not consistent due to spatial interdependence; thus, to solve this endogeneity problem, a model that can perform simultaneous calculations of mutual interactions among neighboring cities is required. The spatial autoregressive model can resolve the endogeneity problem due to the spatial dependence of dependent variables across regions. In turn, if the relevant independent variables that are correlated with the variables for other regions are not included in the model, the omitted variables cause spatial correlation in the error term. When the errors are spatially correlated, the simple OLS cannot be consistent either, and the spatial error model (SEM) is appropriate. Therefore, we employ the spatial lag and spatial error models in this study to solve the spatial dependence problems.

The spatial lag model (SLM) assumes that the dependent variables in one region are dependent on the dependent variables in other regions. The following equation provides the model for the spatial lag:

$$y = \lambda W y + X\beta + \varepsilon$$

where $y$ is a VKT vector, $\lambda$ represents the spatial lag coefficient, $W$ represents the spatial weight matrices, and $X$ is a matrix of the independent variables. Furthermore, the spatial error model (SEM), expressed as follows, solves the problem of spatial error dependence:

$$\begin{aligned} y &= X\beta + u \\ u &= \rho W u + \varepsilon \end{aligned}$$

where a scaler $\rho$ represents the spatial correlation among the error terms.

We define the spatial weight matrix $W$ to indicate the proximity between cities such that the matrix value is one (before row normalization) for cities whose centers are not more than 100 km apart; a pair of cities that does not meet this definition is given a value of zero in the matrix. A common alternative is the matrix value is one when two cities share a common border and zero otherwise; however, this study does not use a contiguity matrix because there are many small- and medium-sized cities in Indonesia that are close to each other but do not share borders.

The use of the least squares method for calculating the spatial dependence model creates a problem of inconsistencies in the estimated parameters and standard errors; this problem can be mitigated through the use of the maximum likelihood method (MLE) for spatial dependence problems (LeSage and Pace, 2009). To attain consistency in the SLM and SEM estimations above, we use the maximum likelihood method instead of the least squares approach. The generalized spatial two-stage least squares (GS2SLS) method also generates consistent estimates in the models with spatial dependence. Thus, this study evaluates both the maximum likelihood and the GS2SLS methods to determine which approach produces more accurate results.

For each of the two dependent variables namely, the VKT of cars and the VKT of motorcycles, five regression models are estimated: OLS, SLM via MLE, SLM via GS2SLS, SEM via MLE, and SEM via GS2SLS. The maximum likelihood model assumes that errors are normally distributed. If the model fails the normality test, then the maximum likelihood approach cannot be used, and the problem can only be solved through the GS2SLS method. Therefore, we first estimate the OLS model and conduct the normality test of the error distribution in preparation for the MLE.

In our settings, if there are omitted variables that are spatially Correlated, then the spatial error model (SEM) will attain, and if there is no spatial dependence at all, then the plain OLS model will attain. However, in our context, we expect car travel to produce more inter-city Trips; therefore, the best model to explain the usage of cars is expected to be the spatial lag model (SLM). All of the explanatory variables for cars and motorcycles are the same and are as listed in the previous section.

# 5 Results

## 5.1 Tests for Spatial Correlation

In the preliminary tests for spatial correlation, namely, Lagrange-multiplier and robust-Lagrange-multiplier tests, we found that the VKT of motorcycles showed no indication of spatial correlation both in spatial error and spatial lag. On the contrary, there was an indication, with 10% significance, of spatial correlation in the VKT spatial lag model for cars. This can be seen both from that the LM and RLM statistics in Table 8 that $LM_{lag}$ and $RLM_{lag}$ are consistently higher than $LM_{err}$ and $RLM_{err}$ for cars.

*// insert Table 8 here //*

*// insert Table 9 here //*

In the Jarque-Berra normality test, the null hypothesis assumes that the model has a normal distribution, meaning that if the null hypothesis is rejected, the maximum likelihood approach cannot be used to solve the spatial correlation in this study. As shown in Tables 10 and 11, the normality result is only weakly (at the 10% level) significant for cars, and for motorcycles, the normality result is insignificant; therefore, this study uses both the MLE and the GS2SLS method. The estimation results from both methods produce nearly identical results.

*// insert Table* 10 *here //*

*// insert Table* 11 *here //*

With respect to automobiles, the spatial lag coefficient $\lambda$ in both SLM models via MLE and GS2SLS are significant at the 5% level, implying that the spatial dependence of the VKT values for automobiles supports our initial hypothesis that auto travel on national roads in Indonesia is beyond city boundaries. However, the coefficient of $\lambda$ is quite low (0.2). This result can be interpreted to mean that cross-boundary trips between cities are existent, but they are not necessarily a major part of the traffic. For motorcycle VKT, there is no evidence of spatial dependence between neighboring cities in terms of the dependent variables: for both the MLE and GS2SLS regressions, the values of $\lambda$ are not statistically significant. This result indicates that unlike auto travel, motorcycle trips are limited to within city boundaries. As for SEM, the spatial error correlation parameter $\rho$ is statistically insignificant for both cars and motorcycles, providing no evidence of spatial dependence in the models' error terms.

### 5.2 Impact of Socio-Economic Variables

Estimated coefficients for the independent variables obtained from the SLM and SEM do not show different results from the findings of the OLS approach, but the significance of some of the independent variables in the SLM and SEM are improved compared with the OLS approach. For automobiles, the significance levels for the price of gasoline and VCR are greater for the OLS approach than for either the SEM or the SLM approaches.

The IRI values, which are typically used to evaluate the results of road maintenance, have only an insignificant influence on the VKT values for automobiles, but the capacity of national roads has a significant, positive effect for automobile VKT values. This result implies that capacity expansion and new roads induce significantly greater car usage, although this effect is not guaranteed; only a large increase in capacity could significantly increase car usage. GDRP per capita, city size, resident worker density, and VCR also positively increase car usage. By contrast, gasoline prices and population density negatively influence the VKT values for cars. In addition, the number of public buses has a significant, negative impact. The negative effect of the number of public buses on automobile VKT is statistically significant at the 10% confidence level, and the negative effect of the number of public buses on the usage of motorcycles is significant at the 5% level. Another difference between the VKT results for motorcycles and cars is that in the OLS regression, GDRP per capita is not significant for motorcycles.

## 6 Policy Implications and Concluding Remarks

This study investigated the spatial correlations of private automobile and motorcycle usage on national roads among neighboring Indonesian cities. The results demonstrate that on national roads, motorcycle trips exhibit the characteristics of local trips and do not show significant spatial interdependencies with neighboring cities. Conversely, automobile trips evince cross-city-boundary characteristics, but with weak spatial correlations. For automobiles, the results of the SLM provide evidence that spatial correlation of traffic between neighboring cities exists; however, the small number of spatial lag coefficients indicates that this correlation is rather weak. That is, for automobile travel, the spatial correlation coefficient lambda is positive with 5% significance, although the magnitude of lambda is only 0.20. In other words, while some significant portion of it passes beyond city boundaries, automobile excursions on a city's national roads are dominated by intracity trips. The results from the SEM indicate that there appears to be no other omitted variable that is spatially correlated. For motorcycles, there are no signs of spatial interdependencies of the VKT values or omitted variables that are spatially related between neighboring cities. Thus, motorcycle trips made on the national roads in Indonesia are most likely to be local trips within city boundaries.

The result that private vehicle trips on a city's national roads continue to be dominated by local trips advocates for increasing local municipalities' responsibilities for national road development and maintenance, and local solutions to traffic problems on national roads could be effective in solving traffic problems in cities. However, the weak relationship regarding vehicle trips between neighboring cities could be a sign of low interactions between cities, including economic interactions.

Concerning other socioeconomic variables, this study finds that the roughness of roads and the city's sex ratio have no significant impact on the VKT values of automobiles and motorcycles. The gross domestic regional product per capita (GDRPCAP) has no significant influence on motorcycle trips but is a significant influence on automobile trips. Moreover, the capacity of national roads, city size, and worker resident density have a positive impact on vehicle usage. By contrast, the price of gasoline, population density, and the number of public buses negatively impact the VKT values for both automobiles and motorcycles.

This study does not include buses, trucks, and other heavy vehicles that are typically used for public or commercial purposes and for longer distances; however, these types of vehicles make up only a small portion of national road traffic. In general, the traffic on national roads in Indonesia is still dominated by local trips by private vehicles; therefore, this study concludes that the required policy solutions are less complex than they would be if the traffic patterns showed strong intercity tendencies.[3] This paper thus suggests that decentralizing the autonomy of policy making concerning road development and maintenance to local governments will bring about welfare gain to the Indonesian economy.

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Table 1. Testing two means for VKT for motorcycles

| Islands | Mean (thousand VKT) |
|---|---|
| Outer- Java | 122,000 |
| Java | 337,000 |
| Total | 193,000 |
| t-stat | 0.954 |
| p-value | 0.349 |

| Cities | Mean (thousand VKT) |
|---|---|
| Small and Medium Cities | 80,700 |
| Big and Metropolitan Cities | 435,000 |
| Total | 193,000 |
| t-stat | 1.536 |
| p-value | 0.138 |

Table 2. Testing two means for VKT for cars

| Islands | Mean (thousand VKT) |
|---|---|
| Outer- Java | 42,700 |
| Java | 150,000 |
| Total | 77,900 |
| t-stat | 1.170 |
| p-value | 0.253 |

| Cities | Mean (thousand VKT) |
|---|---|
| Small and Medium Cities | 24,800 |
| Big and Metropolitan Cities | 193,000 |
| Total | 77,900 |
| t-stat | 1.7915 |
| p-value | 0.086 |

Table 3. Testing two means for IRI

| Islands | Mean |
|---|---|
| Outer- Java | 4.6570 |
| Java | 4.6098 |
| Total | 4.6415 |
| t-stat | -0.1563 |
| p-value | 0.876 |

| Cities | Mean |
|---|---|
| Small and Medium Cities | 4.7363 |
| Big and Metropolitan Cities | 4.4368 |
| Total | 4.6415 |
| t-stat | -0.9784 |
| p-value | 0.332 |

Table 4. Testing two means for national road capacity

| Islands | Mean |
|---|---|
| Outer- Java | 89,034 |
| Java | 147,474 |
| Total | 108,267 |
| t-stat | 1.270 |
| p-value | 0.214 |

| Cities | Mean |
|---|---|
| Small and Medium Cities | 65,829 |
| Big and Metropolitan Cities | 199,933 |
| Total | 108,267 |
| t-stat | 2.890 |
| p-value | 0.008 |

Table 5. Testing two means for proportion of motorcycles in national road daily traffic

| Islands | Mean |
|---|---|
| Outer- Java | 0.50 |
| Java | 0.39 |
| Total | 0.46 |
| t-stat | -2.556 |
| p-value | 0.014 |

| Cities | Mean |
|---|---|
| Small and Medium Cities | 0.48 |
| Big and Metropolitan Cities | 0.42 |
| Total | 0.46 |
| t-stat | -1,561 |
| p-value | 0.125 |

Table 6. Testing two means for proportion of cars in national road daily traffic

| Islands | Mean |
|---|---|
| Outer- Java | 0.17 |
| Java | 0.20 |
| Total | 0.18 |
| t-stat | 1.861 |
| p-value | 0.067 |

| Cities | Mean |
|---|---|
| Small and Medium Cities | 0.16 |
| Big and Metropolitan Cities | 0.21 |
| Total | 0.18 |
| t-stat | 3.658 |
| p-value | 0.001 |

Table 7. Summary of Variables

| Variable | Variables Description | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| VKTMTC | Vehicle Kilometre Travelled for motorcycle on national roads (vehicle km) | 197,000,000 | 661,000,000 | 4,111,711 | 5,810,000,000 |
| VKTCAR | Vehicle Kilometre Travelled for automobile on national roads (vehicle km) | 79,500,000 | 271,000,000 | 879,662.40 | 2,370,000,000 |
| IRI | Average international roughness index on national roads (m/km) | 4.5951 | 1.2572 | 2.7476 | 7.7364 |
| CAPNROAD | Total capacity of national roads in the city (km-PCE) | 109,927.50 | 146,081.30 | 9,703.45 | 1,148,825 |
| VCR | Average volume capacity ratio | 0.5229 | 0.363 | 0.0369 | 2.2441 |
| PGASOLINE | Price of gasoline (Rp./Lt) | 5,773.81 | 1,185 | 3,450.71 | 11,643.03 |
| GDRPCAP | Gross domestic regional product per-capita the city (Rp) | 13.2269 | 16.321 | 3.232 | 135.2922 |
| SEXRATIO | Sex ratio of the city | 101.0859 | 4.1882 | 93.6972 | 113.1609 |
| POPDENS | Population density of the city (population per Km) | 3,979.65 | 3,878.33 | 92.0866 | 14,469.34 |
| RWORKERPKM | Number of worker residence per $km^2$ | 1,601.84 | 1,616.47 | 36.2254 | 6,489.75 |
| NUMPUBBUS | Number of public buses (vehicles) | 2,256.75 | 5,517.84 | 0 | 39,208 |

Table 8. LM, and Robust LM test results for VKT Car

| Test | Statistic | p-value |
|---|---|---|
| Spatial error: | | |
| - Lagrange multiplier ($LM_{err}$) | 0.151 | 0.698 |
| - Robust Lagrange multiplier ($RLM_{err}$) | 0.087 | 0.768 |
| Spatial lag: | | |
| - Lagrange multiplier ($LM_{lag}$) | 3.789 | 0.052 |
| - Robust Lagrange multiplier ($RLM_{lag}$) | 3.725 | 0.054 |

Table 9. LM, and LM Robust test results for VKT Motorcycles

| Test | Statistic | p-value |
|---|---|---|
| Spatial error: | | |
| - Lagrange multiplier ($LM_{err}$) | 1.793 | 0.181 |
| - Robust Lagrange multiplier ($RLM_{err}$) | 1.917 | 0.166 |
| Spatial lag: | | |
| - Lagrange multiplier ($LM_{lag}$) | 1.052 | 0.305 |
| - Robust Lagrange multiplier ($RLM_{lag}$) | 1.176 | 0.278 |

Table 10. Regression results of models for car VKT as dependent variable

| Dependent Variable: LVKTCAR | OLS | SLM (ML) | SLM (GS2SLS) | SEM (ML) | SEM (GS2SLS) |
|---|---|---|---|---|---|
| IRI | 0.0628 | 0.0546 | 0.0544 | 0.0664 | 0.064 |
| | [0.0939] | [0.0722] | [0.0722] | [0.0746] | [0.0743] |
| CAPNROAD | 3.76e-06*** | 3.89e-06*** | 3.89e-06*** | 3.79e-06*** | 3.77e-06*** |
| | [1.12e-06] | [1.23e-06] | [1.23e-06] | [1.22e-06] | [1.23e-06] |
| PGASOLINE | -0.0002* | -0.0003*** | -0.0003*** | -0.0002*** | -0.0002*** |
| | [0.000121] | [7.47e-05] | [7.47e-05] | [7.63e-05] | [7.56e-05] |
| LGDRPCAP | 0.408** | 0.415*** | 0.415*** | 0.377** | 0.399** |
| | [0.158] | [0.154] | [0.154] | [0.168] | [0.160] |
| SEXRATIO | -0.016 | -0.0093 | -0.0091 | -0.0108 | -0.0144 |
| | [0.0329] | [0.0271] | [0.0271] | [0.0296] | [0.0279] |
| POPDENS | -9.25E-05 | -0.0001** | -0.0001** | -8.81E-05 | -9.13e-05* |
| | [5.80e-05] | [5.34e-05] | [5.34e-05] | [5.46e-05] | [5.34e-05] |
| LCITSIZE | 0.562*** | 0.579*** | 0.580*** | 0.599*** | 0.574*** |
| | [0.161] | [0.137] | [0.137] | [0.152] | [0.140] |
| lRWORKERPKM | 1.041*** | 1.079*** | 1.080*** | 1.061*** | 1.048*** |
| | [0.272] | [0.189] | [0.189] | [0.194] | [0.192] |
| NUMPUBBUS | -4.33e-05* | -5.16e-05* | -5.19e-05* | -4.86e-05* | -4.51E-05 |
| | [2.50e-05] | [2.83e-05] | [2.83e-05] | [2.95e-05] | [2.86e-05] |
| VCR | 1.000** | 1.005*** | 1.005*** | 0.986*** | 0.995*** |
| | [0.417] | [0.276] | [0.276] | [0.280] | [0.281] |
| Constant | 8.492** | 7.575** | 7.551** | 7.629** | 8.220** |
| | [4.214] | [3.092] | [3.092] | [3.545] | [3.208] |
| $\lambda$ | | 0.199** | 0.204** | | |
| | | [0.0993] | [0.0994] | | |
| $\rho$ | | | | 1.596 | 1.082 |
| | | | | [2.544] | [2.857] |
| $R^2$ | 0.728** | | | | |
| Jarque-Bera LM test | 5.304* | | | | |

Variables with initial L indicates natural log of the original variables; *: 10%, **: 5%, ***: 1% significance.

Table 11. Regression results of models for motorcycle VKT as dependent variable

| Dependent Variable: LVKTMTC | OLS | SLM (ML) | SLM (GS2SLS) | SEM (ML) | SEM (GS2SLS) |
|---|---|---|---|---|---|
| IRI | -0.0656 | -0.061 | -0.0612 | -0.0761 | -0.0693 |
| | [0.0744] | [0.0692] | [0.0692] | [0.0697] | [0.0697] |
| CAPNROAD | 6.19e-06*** | 6.13e-06*** | 6.13e-06*** | 6.06e-06*** | 6.14e-06*** |
| | [1.25e-06] | [1.18e-06] | [1.18e-06] | [1.10e-06] | [1.12e-06] |
| PGASOLINE | -0.0004*** | -0.0004*** | -0.0004*** | -0.0004*** | -0.0004*** |
| | [0.000113] | [7.16e-05] | [7.16e-05] | [7.15e-05] | [7.04e-05] |
| LGDRPCAP | 0.258 | 0.256* | 0.256* | 0.207 | 0.245 |
| | [0.191] | [0.148] | [0.148] | [0.156] | [0.151] |
| SEXRATIO | -0.0356 | -0.0392 | -0.0391 | -0.0317 | -0.0347 |
| | [0.0231] | [0.0261] | [0.0261] | [0.0269] | [0.0266] |
| POPDENS | -0.0001* | -0.0001** | -0.0001** | -8.57E-05 | -0.0001** |
| | [6.78e-05] | [5.10e-05] | [5.10e-05] | [6.01e-05] | [5.17e-05] |
| LCITSIZE | 0.239* | 0.229* | 0.230* | 0.269** | 0.244* |
| | [0.135] | [0.131] | [0.131] | [0.134] | [0.132] |
| lRWORKERPKM | 0.588** | 0.569*** | 0.570*** | 0.529*** | 0.564*** |
| | [0.222] | [0.181] | [0.181] | [0.179] | [0.179] |
| NUMPUBBUS | -5.99e-05** | -5.57e-05** | -5.59e-05** | -6.59e-05** | -6.20e-05** |
| | [2.79e-05] | [2.72e-05] | [2.72e-05] | [2.60e-05] | [2.64e-05] |
| VCR | 1.625*** | 1.623*** | 1.624*** | 1.598*** | 1.620*** |
| | [0.281] | [0.264] | [0.264] | [0.258] | [0.259] |
| Constant | 17.53*** | 18.02*** | 18.00*** | 17.32*** | 17.56*** |
| | [2.953] | [2.970] | [2.970] | [3.144] | [3.103] |
| $\lambda$ | | -0.0969 | -0.0934 | | |
| | | [0.0925] | [0.0926] | | |
| $\rho$ | | | | 3.221* | 2.433 |
| | | | | [1.825] | [1.881] |
| $R^2$ | 0.709 | | | | |
| Jarque-Bera LM test | 3.8293 | | | | |

Variables with initial L indicates natural log of the original variables; *: 10%, **: 5%, ***: 1% significance.