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Impact of Built Environment on Gasoline Consumption in a Developing Megacity: Evidence from the Jakarta Metropolitan Area

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Abstract. This paper analyzes the impact of a built environment on household gasoline consumption using data collected from 948 households in the Jakarta metropolitan area, Indonesia. A structural equations model is developed to explain household gasoline consumption, using motorcycle and car ownership as mediating variables. The results show that a smaller residence lot size and shorter access time to the nearest bus stop significantly decrease gasoline consumption. The access time to the nearest bus stop does not have an indirect effect through the ownership of cars or motorcycles, but has a direct effect on gasoline consumption. Additionally, the distance to the nearest regional core affects gasoline consumption positively through motorcycle ownership, but does not affect it directly. Population density and neighborhood accessibility have a less significant impact on gasoline consumption, a finding supported by those of previous studies in developing cities. The results also show that the effect of residential self-selection is less significant. Finally, the estimated model is used to compute the potential impact of urbanization on gasoline consumption.

Keywords. built environment, gasoline consumption, developing cities, residential self-selection, urbanization

INTRODUCTION

A number of studies have investigated the impact of a built environment on travel behavior. Most evidence comes from empirical studies in developed regions, such as North America and Europe, including the studies of Ewing et al. (*1*) and the TRB-IOM (*2*). Evidence based on developing countries is poor. For example, Asian developing countries have been experiencing rapid urbanization, driven by high economic growth and sharp population increases. This urbanization can lead to potentially significant changes in both the built environment and vehicle kilometers traveled (VKT). However, the association between VKT and the built environment has not been well studied in these countries. One of the major reasons for this is poor availability of data relating the built environment to travel behavior. In addition, the findings from studies based on developed countries may not be directly applicable to developing countries. For example, although mixed land-use and/or compact city structures are often preferred in North America, most Asian megacities are already dense and mixed. Is the link between the built environment and travel behavior in Asian cities the same as that in developed cities? This paper reports empirical evidence on the impact of the built environment on travel behavior using data collected from the developing megacity, the Jakarta metropolitan area. Household gasoline consumption is used as a dependent variable, which is both an indicator of VKT and a direct measure of energy demand. A structural equations model explaining gasoline consumption is constructed, using ownership levels of motorcycles and cars as mediating variables. The residential self-selection effects are also considered using attitudinal variables related to neighborhood satisfaction. Based on the estimated model, potential impacts of urbanization will be analyzed.

This paper is organized as follows. A literature review of related studies on the built environment and travel behavior is presented after the introduction. Next, the methodology of the analysis is presented, which includes the data used, the model structure, and the estimation method. This is followed by a discussion of the estimation results and the potential impacts of urbanization. The final section summarizes the findings and presents possible policy implications.

LITERATURE REVIEW

Built Environment and Travel Behavior

Past studies on the association between a built environment and travel behavior have defined the built environment in various ways, depending on their analytical units. When a "neighborhood" is assumed to be the basic analytical unit, studies typically use the densities of residences or jobs, street layout (grid or cul-de-sac), the availability of parks, sidewalks, bicycle paths, and land-use mix (*2*). These are often categorized as the "3 Ds" – density, diversity, and design (*3*). Neighborhood accessibility is also used when an analysis is based on the neighborhood (*4*). The size of the region, the distribution of jobs and commerce relative to residences, the supply of transportation facilities, the distance to the city center, and the location of new developments in relation to existing cities are often used in a region-based analysis (*2*, *5*). Numerous studies have observed that higher-density, mixed-use neighborhoods ("new urbanism" or "compact city") help people live within walking or cycling distance of regular destinations, such as work, shops, schools, and parks, as well as transit stops. If they choose to use a car, trips are shorter than in lower-density, single-use residential areas (*1*, *6*). Ewing and Cervero (*7*) reviewed 50 empirical studies and summarized the results as follows. Trip frequency is primarily a function of the socio-economics of travelers, and secondarily of the built environment. Trip length is primarily a function of the built environment, and secondarily of socio-economics. Finally, mode choice depends on both, although probably more on socio-economics. More recently, VKT has become an important indicator of travel behavior in policy discussions on climate change and greenhouse gas emissions (*1, 8*). In addition to VKT, gasoline consumption is also used as an outcome of travel behavior (*9*).

One of the critical factors related to the association between a built environment and travel behavior is the residential self-selection effect. If residential self-selection is not accounted for, the estimated impact of the built environment on travel behavior could be biased. For example, if individuals who prefer driving choose to reside in residential areas with a low density and a single land-use pattern, and individuals who prefer transit-use choose to reside in areas with a high density and a mixed land-use pattern, the impact of high density and mixed land-use patterns on transit use could be overestimated. Residential self-selection generally results from two sources: attitudes and socio-demographics (*6*). Although studies normally consider socio-demographics, it is also likely that individuals choose their neighborhoods based on their travel attitudes or preferences, since the built environment in which people reside can be considered the result of their residential choices. Thus, an unobserved portion of travel behavior could correlate with an unobserved portion of residential choice, through attitude, even when controlling for socio-demographics. This may produce an endogeneity bias in the estimation of the built environment impact.

One of the methodologies used to address the residential self-selection effect is to introduce people's attitudinal predisposition towards the built environment and travel as potential covariates between the built environment and travel behavior, in addition to socio-demographics. For example, using cross-sectional data in the San Francisco Bay Area, Kitamura et al. (*10*) found attitudes were more strongly associated with travel than land-use characteristics, while Bagley and Mokhtarian (*11*) concluded that neighborhood type has little influence on travel behavior after controlling for attitudinal, lifestyle, and socio-demographic variables. Chatman (*12*) pointed out that the built environment may affect attitudes through the process of cognitive dissonance reduction. In this case, controlling for attitudinal variables could lead to underestimating the impact of the built environment. Significant associations between changes in travel behavior and changes in the built environment have been found, even after accounting for attitudes, using quasi-longitudinal (retrospectively recorded) data in northern California and the northeast of England, (*13*, *14*, *15*). Various attitudinal variables, including the level of satisfaction with the built environment (*16*) and residential neighborhood type dissonance (mismatch) (*17*) have been used to analyze the residential self-selection effect in past studies.

The Built Environment and Travel Behavior in Asian Cities and Developing Cities

Ho and Yamamoto (*18*) analyzed vehicle ownership in the Ho Chi Minh metropolitan area, Vietnam, using attitudes/preferences to control for self-selection effects. Næss (*19*) analyzed the impact of the built environment on travel behavior in the Hangzhou metropolitan area, China. The location of the dwelling relative to the city center was found to exert a considerable influence on travel behavior. Lin and Yang (*20*) analyzed the impact of the built environment on trip generation and car/motorcycle use using aggregate data in Taipei, Taiwan. They found that density is positively related to trip generation and negatively associated with car and motorcycle use. While mixed land-use reduced trip generation, it increased motorized vehicle use. Wang et al. (*21*) analyzed the activities and travel behavior of both male and female heads in Beijing, China, using car ownership as a mediating variable. Pan et al. *(22)* compared the travel behavior of four neighborhoods in Shanghai, China. They concluded that non-work trips by transit and driving mode varied among the neighborhoods. Senbil et al. (*23*) analyzed the association between the built environment and vehicle ownership in the Jakarta metropolitan area, Indonesia. They showed that relative residential location and the level of transportation infrastructure provision had significant impacts on vehicle ownership. In addition, they found that none of the variables related to density and diversity had a significant impact on motorcycle ownership, and only a few had a significant impact on car ownership. Yamamoto (*24*) and Senbil et al. (*25*) compared vehicle ownership/use in the Osaka metropolitan area, Japan, and Kuala Lumpur, Malaysia. They showed that a lot of built environment variables had significant impacts on vehicle ownership and use. In Latin America, Cervero et al. (*26*) analyzed the built environment and non-motorized travel behavior in Bogotá, Colombia. They found that road facility designs are associated with walking and cycling, but that density and land-use mixtures were not. Zegras (*27*) analyzed the built environment and motor vehicle ownership/use in Santiago, Chile. Here, vehicle ownership decisions were found to be dominated by income and, to a lesser degree, by the built environment. Among the built environment variables, the distance to the city center and metro stations were found to be strongly associated with VKT.

Although literature based on developing cities is limited, some common aspects can be identified. First, the built environment seems to have a limited impact on (motorized) vehicle ownership. If any, a regional scale of a built environment seems to have an impact, rather than a neighborhood scale. Instead, level of income has a far more dominant influence on car ownership. Second, both regional and neighborhood built environment variables have an impact on (short-term) travel behavior. However, this result is sometimes different to that in developed cities. For example, density and land-use mix have a less significant effect on travel behavior. One of the reasons for this is that most cities still have a higher concentration in the historical urban center, and mixed land-use is common. This produces little statistical variation and non-significant results (*19*, *26*). In other words, since the average density and land-use mix in many developing cities is high compared to developed cities, studies find small marginal effects for these factors. This study contributes to the current body of knowledge on the association between the built environment and travel behavior in developing cities.

METHODOLOGY

Data

Our empirical analysis uses data collected from the Jakarta metropolitan area (Jabodetabek), which includes the Special Capital Region of Jakarta (DKI Jakarta), four municipalities (Bogor, Depok, Tangerang, and Bekasi), and three regencies. FIGURE 1 shows a map of Jabodetabek. As of 2010, Jabodetabek had a population of about 28 million, and an area of approximately 6,400 square kilometers. The population of Jabodetabek has been growing at an annual rate of about three percent. The data was collected by conducting face-to-face interviews using paper-based questionnaires. The respondents were selected from Jabodetabek using a random sampling method. First, 90 target areas were randomly selected, considering the distribution of the population. Each target area was a 250 m by 250 m grid zone. Next, a *Rukun Tetangga* (RT) was chosen randomly from each target area. An RT is an official government organization that includes between 30 and 100 households, with a chief elected by the residents. Then, a list of all households in the selected RT was prepared. Based on this household list, ten target households were selected randomly. Finally, a household head or spouse was selected from each of these households as a respondent. The questionnaire included questions about the personal attributes of the respondent and his/her household, the daily activities of the respondent and household members, the respondent's activity diaries, and the respondent's individual values. The interview survey was conducted from November to December, 2011. In total, data were collected from 948 households. The location of each respondent's residence was geocoded and geographical information was obtained from each respondent. The details of the survey are described in Furuhashi and Kato (*28*).

[FIGURE 1]

TABLE 1 summarizes the descriptive statistics of the sample data used in our empirical study. Our model uses gasoline consumption and the number of motorcycles and cars in a household as endogenous variables. Household income, the number of adults in a household, the number of children in a household, the age of the household head, the weekly communication frequency with neighbors, and the period of living at the current residence are used as household attribute variables. Note that gasoline consumption was estimated from the original data of the household's monthly expenditure for gasoline under the assumptions of 4,500 rupiahs/liter and 34.2 MJ/liter. The gasoline consumption of 302 households was zero, so the distribution was censored at zero. Motorcycle ownership is nearly one per household, which is higher than the level of car ownership. The distribution of car ownership is also strongly censored at zero and its variation is limited.

TABLE 1 also shows the variables related to the built environment, namely the lot size of the residence, the population density, the time taken to reach the nearest bus stop, the distance to the nearest regional core, the distance to the city center, a DKI Jakarta dummy, and the distance to the nearest facilities. First, "population density" is defined as the average population density in the nine grid zones, with an area of 750 m by 750 m. The center of the nine zones includes a respondent's residence. Second, the regional cores are defined as the *Monumen Nasional* (Monas) and the four municipal offices of Bogor, Depok, Tangerang, and Bekasi. Third, the city center is defined as the Monas, which is a tower located in central Jakarta. Fourth, the DKI Jakarta dummy takes the value 1 if the respondent's residence is located in DKI Jakarta, and 0 otherwise. Finally, the "distance to the nearest facilities" is defined as the straight-line distance from the respondent's residence to six types of facilities: a hospital, place of religion, educational institution, business and commercial place, post office, and cultural place. To define the accessibility indicator for a neighborhood, the distances to the six facilities are summarized in two principal components (PCs) using a principal component analysis. The results show that 46.4 percent and 17.7 percent of the original variations are explained by the first and second PC, respectively. High overall factor loadings of the first PC indicate that it shows general accessibility. The second PC has a positively high loading on the business-related variable, and a negatively high loading on the educational variable. Thus, we describe the two orthogonal variables as "general accessibility" (mean (SD): 0 (1.7)) and "highly accessible to education, but poorly accessible to business" (mean (SD): 0 (1.0)), respectively. In the model, we use household income and the built environment variables other than PC1, PC2, and the DKI Jakarta dummy in the logarithmic values.

[TABLE 1]

In addition, "satisfaction with neighborhood" is also introduced as an attitudinal variable in our model. This is defined as a indicator of the respondent's satisfaction with their neighborhood, and is a latent variable extracted by using the factor analysis. The factor analysis was conducted using respondents' answers, on a four-point scale, to questions on the following seven issues in the questionnaire: social relationship among individuals in the neighborhood, sanitary quality, convenience for living, safety in the neighborhood, green open space, risk of flooding, and cost of housing. The latent variable explains 38 percent of the original variations. The higher of this latent variable indicates greater satisfaction with neighborhood.

Model Structure and Estimation Method

FIGURE 2 shows our hypothesis of the model structure. First, the model contains household attributes to control for potential covariates regarding the built environment and travel behavior. Next, it is assumed that short-term travel behavior is directly influenced both by vehicle ownership (middle-term travel decision) and by the built environment, and that vehicle ownership itself is also influenced by the built environment. This results in an indirect effect of the built environment on short-term travel behavior through vehicle ownership (*16*, *29*, *30*). The model uses motorcycle ownership, car ownership, and gasoline consumption as endogenous variables. As a result, the model consists of two components. The first component deals with car/motorcycle ownership and the second component deals with gasoline consumption which explains the use of a car/motorcycle.

[FIGURE 2]

Structural equations modeling (SEM) is applied to estimate multiple causalities simultaneously. SEM enables us to divide the effects of the built environment on travel behavior into a direct effect and an indirect effect through vehicle ownership. Note that the built environment could be treated as endogenous by incorporating residential choice into the model, but we did not do so here. Gasoline consumption is assumed as the censored variable. The software Amos (version 21.0.0) was used for the SEM modeling. We used a Bayesian approach with an MCMC simulation to estimate the model. Here, we estimated the posterior distribution for each coefficient. The standard convergence statistic in Amos was used in the estimation process.

RESULTS

Estimation Results

TABLE 2 shows the estimation results of our model. TABLE 3 shows the built environment and income elasticities of gasoline consumption computed from the estimated model. Note that we used observed gasoline consumption rather than estimated gasoline consumption to compute the elasticities in TABLE 3 because gasoline consumption is a censored variable *(32)*. The elasticities were computed by dividing the effects by the mean gasoline consumption (= 1,100MJ). The results indicate that the model for gasoline consumption explains 55 percent of its variation, while the models for motorcycle and car ownership explain 30 percent and 8.1 percent of their variations, respectively. The goodness-of-fit indexes for SEM models are not computed in the Bayesian approach.

First, TABLE 3 shows that the estimated "lot size of residence" elasticity is 0.13, the highest among those of the built environment variables, followed by "access time to the nearest bus stop." The "lot size of residence" affects gasoline consumption indirectly. This means that an individual residing on a larger land area owns more motorcycles and cars, which leads to an increase in household gasoline consumption. This may be a reflection that larger houses have more parking space for cars. The "access time to the nearest bus stop" has a positive elasticity of 0.12 as a direct effect only. This means that an improvement of bus accessibility does not influence the ownership of motorized vehicles, but does discourage the use of motorized vehicles. The "access time to the nearest bus stop" elasticity estimated from our model is greater than that of previous studies in developed cities. A meta-analysis shows that the average elasticity of VKT with respect to the distance to the nearest transit stop is 0.05 (*33*). One of the possible reasons for the higher bus-accessibility elasticity in our model is that the marginal effect of transit supply is higher in Jabodetabek than other cities, as the current transit supply is extremely low in Jakarta (*34*).

Second, TABLE 3 shows that the effects of "population density," "general accessibility," and "highly accessible to education, but poorly to business" are not significant. These findings are consistent with previous studies in developing cities, which also tend to report that the density or land-use mix variables have a less significant impact on travel behavior (*19, 26*). Note that, although population density and lot size of residence were expected to have a strong negative correlation, this was not the case in our sample (the correlation coefficient is -0.23). This may support that both population density and lot size of residence are included in the model.

[TABLE 2]

[TABLE 3]

Third, TABLE 3 shows that the “distance to the nearest regional core” affects gasoline consumption positively through motorcycle ownership, but does not do so directly. The indirect effect through motorcycle ownership means that motorcycle ownership increases as the distance to the regional core increases. No direct effect could mean that vehicle trip frequency decreases as the distance to the regional core increases, because a longer trip length is canceled out by a lower trip frequency. This may be because the households residing far from the regional core shop there less frequently, but when they do, they buy more goods than those residing near the regional core. This promotes owning a motorcycle for carrying goods. Additionally, the imbalance between high family size and low vehicle ownership could cause a strong willingness of households to own more vehicles, even though they make fewer trips to the regional core. The “DKI Jakarta dummy” does not significantly affect car/motorcycle ownership, but does have a direct negative effect on gasoline consumption. This reflects a better public transit service, particularly the bus service in urbanized areas.

Fourth, TABLE 3 shows that the income elasticity of gasoline consumption is 1.34, which is the highest of the variables in the model. It also shows that the direct effect is lower than the total effect. This means that the income elasticity of gasoline consumption including the control for car/motorcycle ownership is lower than that without the control. A meta-analysis on both the short-run and long-run income elasticity of gasoline demand shows similar results to ours (*35*). Note that Indonesia’s goal is to achieve an energy elasticity of less than unity by 2025 (*36*). Energy elasticity is the rate of change in total primary energy supply divided by the rate of change in GDP.

Fifth, there are potentially two types of residential self-selection in our model: self-selection on the association between the built environment and vehicle ownership; and self-selection between the built environment and gasoline consumption. TABLE 2 shows that the effects of “satisfaction with neighborhood” are significant on gasoline consumption and on motorcycle ownership. When this variable was added to the model, the absolute effects of built environment variables slightly decreased. These mean that, although the attitudes of respondents on the built environment are associated with travel behavior, they are not strongly associated with the actual built environment in which they reside. There are two potential reasons for this result. The first assumes a causality from respondents’ attitudes towards the built environment to the actual built environment (i.e., residential choice). This means that transportation issues have a lower priority when selecting a residence. For example, security is one of the most critical factors for high-income people residing in the new towns in Jakarta (*37*), which could be more critical than transportation factors. However, note that the chance of residential choice seems limited in the context of Jakarta. The average period of residing at the current residence is 17.2 years (SD = 15.7 years). This is longer than the values in the US (e.g., *12*) and Columbia (e.g., *26*). The second reason assumes a causality from the actual built environment to the attitude towards the built environment. This is one of the possible reasons for the association between the built environment and travel behavior (*6*). Although the second reason may be more likely in our case study, it has less of an impact.

Potential Impacts of Urbanization on Gasoline Consumption

Here, we discuss the potential impact of urbanization on travel behavior in terms of the association between the built environment and travel behavior, along with the estimated results. We use three types of residential built environments: kampung areas, planned residential areas, and farm areas. Note that Kato et al. (*38*) classified all residential areas in Jabodetabek, defined using 250 m by 250 m grids, into the three types of built environments based on geographic information. Kampungs are urban villages that are partly informal settlements, and are home to mainly low- to middle-income groups. Some of the inner-city kampungs date back to the colonial period, whereas a growing number of informally established kampungs have appeared, particularly at the metropolitan edge and on undeveloped land prone to flooding. At the same time, a growing number of newer housing developments, including gated communities, have been constructed at the edges of the city, mainly for the middle- and upper-income groups. Sizable amounts of agricultural land on the fringes of Jakarta have been converted to provide sites for these new town projects (*37*, *39*, *40*). TABLE 4 shows the characteristics of the three types of residential built environments in the target area, as calculated from the data collected from our survey. Note that, because of constraints on the availability of data, the target area covers only DKI Jakarta and three municipalities, namely Bogor, Tangerang, and Bekasi.

[TABLE 4]

Next, we analyze the impact of urbanization in terms of land-use change under a fixed total population and fixed urban terrain, where all socio-economic aspects are controlled using the results shown in TABLE 3. Suppose a scenario of urbanization in which the kampung areas and the farm areas are replaced by planned residential areas. This is a hypothetical case, but similar to the current trend in Jakarta. This case can be interpreted as the relocation of homogenous households from the kampung or farm areas to planned residential areas under a fixed total population and fixed urban terrain. Additionally, the characteristics of the three built environments are assumed to be fixed at the current levels.

First, TABLE 4 shows that the lot size of residences is significantly different between the planned residential areas and the farm areas. As shown in TABLE 3, a reduction in the lot size of a residence leads to a decrease in gasoline consumption, so a reduction in gasoline consumption is expected in this scenario. Second, TABLE 4 shows that the “access time to the nearest bus stop” is significantly different between the kampung areas and the planned residential areas. The bus accessibility of the kampung areas is the lowest. This may be because the kampung areas include suburban poorly planned areas that have lower accessibility to bus services. Since TABLE 3 shows that a reduction in the access time leads to a decrease in household gasoline consumption, the transition from the kampung areas to the planned residential areas reduces gasoline consumption. Third, changes to the “DKI Jakarta dummy” lead to a reduction in gasoline consumption because its level in the planned residential areas is significantly larger than in the farm areas. Finally, the impact of changes in “distance to the nearest regional core” is unclear, because its level in the planned residential areas is smaller than in the farm areas, but larger than in the kampung areas.

A synthesis of these effects may result in a reduction in household gasoline consumption. Land-use change per se reduces gasoline consumption under the control of a population increase, physical expansion in an urban area, and socio-economics. This is reasonable because the urbanization process, in which land-use patterns change from agricultural or informal residential to planned residential, leads to a more compact urban structure if population increase and physical expansion are fixed. The impacts of a population increase and physical expansion in an urban area, which may generate more gasoline consumption, should be addressed in future research.

CONCLUSIONS

The impact of the built environment on household gasoline consumption was analyzed using the data collected from the Jakarta metropolitan area. A structural equations model was developed using motorcycle and car ownership as mediating variables. Our results added empirical evidence to existing studies on the association between a built environment and travel behavior in developing countries. The results showed that population density and neighborhood accessibility have a less significant impact on gasoline consumption, a finding that is supported by previous empirical studies on developing cities. On the other hand, the lot size of residences and the access time to the nearest bus stop both have a significant impact on gasoline consumption. The access time to the nearest bus stop does not have an indirect effect through the ownership of cars or motorcycles, but does have a direct effect on gasoline consumption. In addition, a larger scale of built environment, such as the distance to the nearest regional core, affected gasoline consumption. The results also showed that the effect of residential self-selection was relatively small, though it was not fully addressed in the study.

Our results suggest that appropriate changes in built environments may result in less gasoline consumption. For example, reducing the lot size of a residence and/or access time to the nearest bus stop could lead to a reduction in gasoline consumption. Our results also indicate that improving bus accessibility does not influence the ownership of motorized vehicles, but does discourage the use of motorized vehicles. Although the ownership of motorized vehicles may inevitably increase during times of economic growth, the use of vehicles can be controlled through transit improvements.

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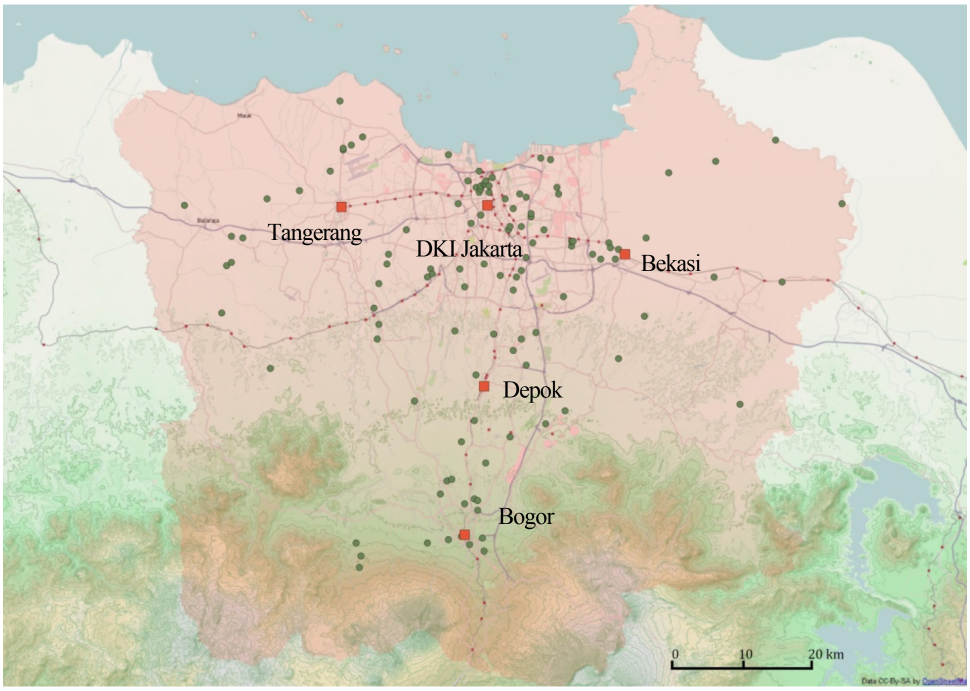

FIGURE 1 Map of Jabodetabek and respondents' locations.

Note: The green dots represent the locations of chosen RTs and orange squares represent the five regional cores.

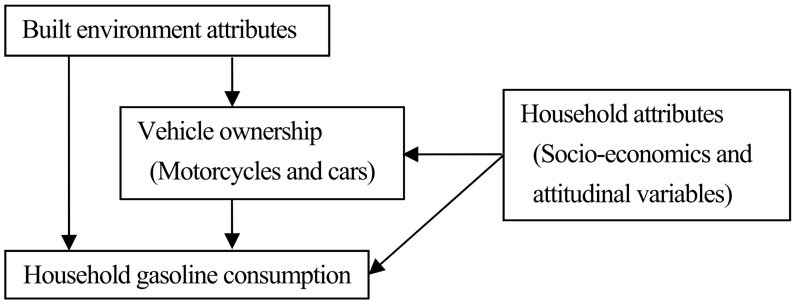

FIGURE 2 The model structure.

TABLE 1 Descriptive Statistics of Sample Data (N = 948)

	Mean	Median	SD	Factor loadings	
				PC1	PC2
Endogenous variables					
Household gasoline consumption (MJ/month)	1,100	758	1580		
Motorcycle ownership	0.89	1.00	0.77		
Car ownership	0.03	0	0.19		
Household attributes					
Household income (million rupiahs/month)	2.2	1.9	1.3		
Number of adults	2.7	2.0	1.2		
Number of children (less than 18 years old)	1.3	1.0	1.1		
Age of household head	44.9	43.0	12.7		
Weekly communication frequency with neighbors (days)	4.1	4.0	2.5		
Period residing at the current residence (years)	17.2	12.0	15.7		
Built environment attributes					
Lot size of residence (m^2)	101	70	130		
Population density (/km^2)	13,900	12,100	11,200		
Access time to the nearest bus stop (minutes)	19.2	10.0	21.4		
Distance to the nearest regional core (km)	8.7	7.9	6.0		
Distance to city center (km)	21.3	18.3	13.5		
DKI Jakarta dummy	0.33	0	0.47		
Distance to the nearest facilities (km)					
Hospital	1.6	1.4	1.1	-0.60	0.04
Place of religion	0.50	0.36	0.41	-0.74	-0.23
Educational institution	0.55	0.42	0.40	-0.66	-0.57
Business and commercial place	2.2	1.8	1.7	-0.73	0.38
Post office	3.6	3.0	2.6	-0.55	0.71
Cultural place	12	10	7.7	-0.77	-0.19

Note: PC 1 represents the first principal component and PC 2 represents the second principal component, as derived from the principal component analysis. The eigenvalue (variance) of the first is 2.8 (prop. 46%) and the second is 1.1 (prop. 18%).

TABLE 2 Estimation Results

	Endogenous variables								
	Household gasoline consumption			Motorcycle ownership			Car ownership		
Intercept	-14000	(-7.4)	***	-9.46	(-14.4)	***	-1.69	(-9.3)	***
Built environment attributes									
Ln (lot size of residence)				0.122	(5.0)	***	0.0178	(2.6)	**
Ln (population density)									
General accessibility (PC1)									
Highly accessible to education, but poorly to business (PC2)									
Ln (access time to the nearest bus stop)	193	(3.5)	***						
Ln (distance to the nearest regional core)				0.0524	(1.8)				
Ln (distance to the city center)									
DKI Jakarta dummy	-400	(-3.4)	***						
Household attributes (control variables)									
Ln (household income)	945	(7.1)	***	0.689	(15.4)	***	0.116	(9.2)	***
Number of adults				0.147	(6.9)	***	-0.0150	(-2.7)	**
Number of children	-103	(-2.2)	*				-0.0104	(-2.0)	*
Age of household head	-16.3	(-3.3)	***	-0.00869	(-4.4)	***			
Communication frequency with neighbors	-46.0	(2.6)	*						
Period of residing in the current residence	9.89	(2.5)	**				0.000690	(1.7)	
Satisfaction with neighborhood	-93.5	(-1.8)		0.0315	(1.6)				
Vehicle ownership (endogenous variables)									
Motorcycle ownership	1560	(18.6)	***						
Car ownership	1840	(7.2)	***						
Error covariance between vehicle ownership	-0.00493	(-1.3)							
R-squared	0.55 [a]			0.30			0.081		

Note 1: Estimated coefficients represent the means of their posterior distributions in the Bayesian approach.

Note 2: z-statistic in parentheses: *** p<0.001, ** p<0.01, * p<0.05.

Note 3: [a] McKelvey and Zavoina's pseudo R-squared (*31*).

TABLE 3 Built Environment Elasticities and Income Elasticities of Gasoline Consumption

	Indirect						Direct			Total		
	Motorcycle ownership			Car ownership								
Lot size of residence	0.11	(4.8)	***	0.02	(2.5)	*	–			0.13	(5.3)	***
Population density	–			–			–			–		
General accessibility	–			–			–			–		
Highly accessible to education, but poorly to business	–			–			–			–		
Access time to the nearest bus stop	–			–			0.12	(3.5)	***	0.12	(3.5)	***
Distance to the nearest regional core	0.05	(1.8)		–			–			0.05	(1.8)	
Distance to the city center	–			–			–			–		
DKI Jakarta dummy	–			–			-0.24	(-3.4)	***	-0.24	(-3.4)	***
Income	0.65	(11.9)	***	0.13	(5.7)	***	0.57	(7.1)	***	1.34	(13.6)	***

Note 1: z-statistic in parentheses. The delta method was used to calculate the z-statistic of indirect and total effects: *** $p<0.001$, ** $p<0.01$, * $p<0.05$.

Note 2: The values of the DKI Jakarta dummy are defined as the percent change in the gasoline consumption when it changes from 0 to 1.

Note 3: "–" indicates that the effect is not statistically significant.

TABLE 4 Characteristics of Three Residential Built Environments in Jabodetabek

	Kampung areas (N = 240)	Planned residential areas (N = 196)	Farm areas (N = 109)	Target area total (N = 545)	Non-parametric test
	Median	Median	Median	Median	
Lot size of residence (m^2)	45	41	70	50	K:F**, P:F**
Population density (/km^2)	20,200	18,700	10,900	18,300	K:F**, P:F**
General accessibility	1.48	0.99	-0.27	0.79	K:F**, P:F**
Highly accessible to education, but poorly to business	-0.32	-0.14	0.016	-0.21	K:P**, K:F**
Access time to the nearest bus stop (min)	15	10	10	10	K:P*, K:F*
Distance to the nearest regional core (km)	4	7.5	8.5	7.1	K:P**, K:F**, P:F*
Distance to the city center (km)	9.1	9.1	21	10	K:F**, P:F**
DKI Jakarta dummy	0.69	0.72	0.073	0.58	K:F**, P:F**
Estimated percentage in the target area	42.7%	32.5%	24.8%	100%	

Note 1: The values of the DKI Jakarta dummy are mean values. The percentage in the target area was estimated in Kato et al. *(38)*.

Note 2: The non-parametric test uses the Kruskal-Wallis test followed by Steel-Dwass multiple comparisons; K, P, and F represent kampung areas, planned residential areas, and farm areas respectively; "K:P" means the pattern of kampung areas is significantly different to that of planned residential areas; ** $p<0.001$, * $p<0.01$.