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Stochastic Production Frontier Models to Explore Constraints on Household Travel Expenditures Considering Household Income Classes

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Abstract – This paper explores the variation of household travel expenditure frontiers (HTEFs) prior to congestion charging (CC) reform in Jakarta. This study incorporates the variation of household income classes into the modeling of HTEFs and investigates the degree to which various determinants influence levels of HTEF. The HTEF is defined as an unseen maximum (capacity) amount of money that a certain income class is willing to dedicate to their travel. A stochastic production frontier is applied to model and explore upper bound household travel expenditure (HTE). Using a comprehensive household travel survey (HTS) in Jakarta in 2004, the observed HTE spending in a month is treated as an exogenous variable. The estimation results obtained using three proposed models, for low, medium and high income classes, show that HTEFs are significantly associated with life stage structure attributes, socio-demographics and life environment factors such as professional activity engagements, which is disclosed to be varied across income classes. Finding further reveals that considerable differences in average of HTEFs across models. This finding calls for the formulation of policies that consider the needs to be addressed for low and medium income groups in order to promote more equity policy thereby leading to more acceptable CC reform.

Keywords: household travel expenditure frontier, household income classes, stochastic frontier model, Jakarta.

Introduction

Congestion charge (CC) is currently under active development and remains under consideration as a way to mitigate acute traffic congestion in Jakarta, a capital of Indonesia (Sugiarto *et al.*, 2014b; Sugiarto, 2015). As a consequence of rapid growth on car ownership and car usage in current decade, the areas of city center are suffering from not only heavy traffic congestion but also unmaintained externalities including travel times, air pollution, additional energy consumption, and even serious economic loss. To counter negative effects of private mobility, Government has been introducing CC theme to deliver efficient road use and manage congestion in Jakarta (SITRAMP, 2002; JUTPI, 2012). This policy is regarded as a potentially powerful instrument aimed at not only changing road users' travel behavior (Cools *et al.*, 2011; Olszewsi, 2006) but also achieving efficient infrastructure use, managing congestion or even generating revenue (Link and Stewart-Ladewig, 2005; De Palma *et al.*, 2007). The revenues raising from CC reform can be utilized for other funds (i.e. public transport, constructing new facilities, or maintaining existing facilities (Manville and King, 2013).

However, generally speaking, transport reform such as CC scheme could induce significant influence on people's travel behavior. In this context, the amount of time, or cost that an individual dedicate on their daily routines may be seen as a result of complex interaction among an individual's travel patterns and constrained by their socio-demographics (i.e. income, or allocation of travel expenditure). These constraints are subjected to be varied across individuals, or household life stage structures (Sugiarto *et al.,* 2014a). An investigation conducted by Zahavi *et al.* (1980) revealed that an average car owning household spends about 10-11% of its income for their travel while an average non-car owning household spent about 3-5% of their income. Gunn *et al.* (1981) investigated the percentage of expenditure spent on the travel among different time of the year constraints. Travel expenditure tended to be higher in the second and third quarter of the year compared

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to those in first and four quarters. Tanner (1981) further concluded that generalized travel expenditure per person has increased over the years and appreciably faster than their real income.

Considering travel time expenditures, Mokhtarian *et al.* (2004) revealed that an individual's travel time expenditures is strongly related to household characteristics, attribute of activities, destinations of activities, or even the characteristics of residential areas. Furthermore, Banarjee *et al.* (2007) used the household attributes from national Household Travel Survey (HTS) in US, India and Switzerland to explore the travel time expenditure frontiers across international contexts. They found that comparison of average travel time frontier showed quite differences across counties. Further investigation by Susilo *et al.* (2013) utilized comprehensive HTS data in 2004 in UK to explore unseen temporal boundaries (origin and terminal vertex of prim) and the variations of the individual travel time overtime. They found that most of individuals may have not reached their limit yet to travel and may still be able to spend further time in travel activity. Their findings further revealed that some groups of population (e.g. high income households, younger people etc.) have a larger needs of spending minimum travel time and also bigger time constraints. This result is in line with Volosin *et al.* (2013), they found that the highest income group exhibits higher travel time expenditures than other income groups. They also further revealed that the variations in production frontier values as well as trends in the ratio of travel time expenditure to frontier values differ considerably across socio-demographic groups.

While a research on travel expenditures has mainly focused on travel time and treated it as a dominant tenet on travel behavior research in particular related to the activity-based travel analysis. Yet, compared to travel time expenditure, travel cost expenditures has not been examined systematically, particularly for the proposed of an *ex-ante* assessment under CC transport reform proposal in the developing world. It is argued that travel cost expenditure may more crucial issue because having direct burden to the individual's money constraints. For instance, certain people or other household members unable to afford participating in extra activities due to income limitation, and consequently there may exist the variability of travel patterns due to money constraints.

In accordance with the government intends to implement CC policy, it hypothesizes that individuals or households travel cost expenditure are considerably constrained by capacity and authority constraints. Certain income groups are subjected to save their travel expenditure attributable to their income limitation. It could important to understand and evaluate how far commuters could be expected to adapt and be change their travel behavior in terms of travel expenditures given their complex household attributes and life environments in order to formulate better transportation planning and policies. Therefore, this study explores the variation of household travel expenditure frontiers (HTEFs) prior to CC reform in Jakarta. This study incorporates the variation of household income classes into the modeling of HTEFs and investigates the degree to which various determinants influence levels of HTEF. The amount of HTEF dedicates for commuting trips can be seen as a result of complex interactions among life stage structure attributes, socio-demographics and life environment factors such as activity engagements, which is assumed to be varied across income classes. The HTEF is defined as an unseen maximum (capacity) amount of money that a certain income class is willing to dedicate to travel. The modeling framework adopted in this study is derived from the concept of stochastic frontier model (SFM) of prism vertices (Kitamura *et al.,* 2000; Pendyala *et al.* 2002). A SFM is applied to a comprehensive household travel survey (HTS) in Jakarta in 2004, the observed household travel expenditure (HTE) spending in a month is treated as an exogenous variable. HTEs are treated as unobserved production frontier (refers to a terminal vertex in prism vertices theorem) that influences the actual travel expenditures observed in HTS. The expenditures do not necessarily constitute the upper bound of the amount of money that households are dedicating to spend to travel. In this context, HTEF represents an upper limit on the amount of money that households are able to dedicate to travel in a month.

The rest of this report is structured as follows. Section 2 gives a brief description of the data and their distributions. In section 3, we describe the formulation of the proposed methodology. We then present model estimates associated with the SFM and discuss the findings. Finally, the conclusions of the study are presented at the end of the paper.

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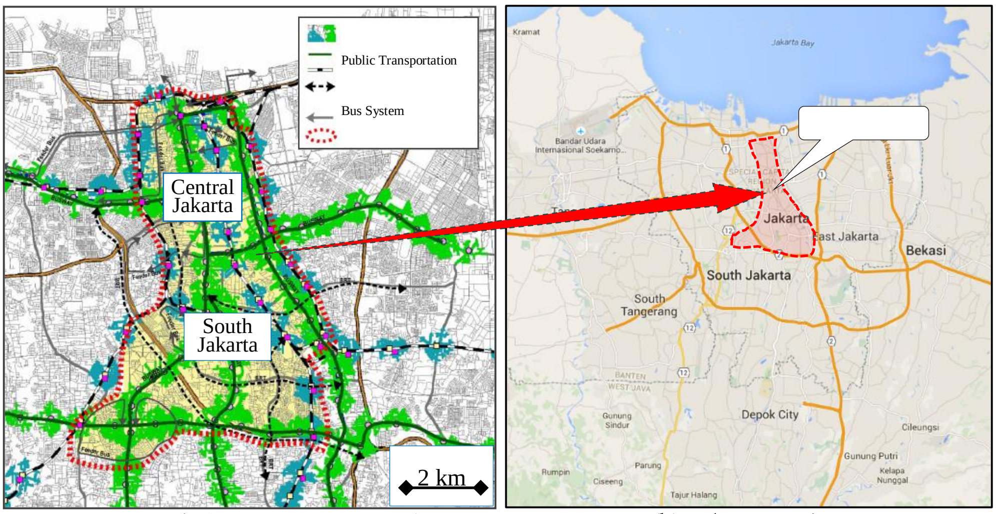
Materials and Methods

Data

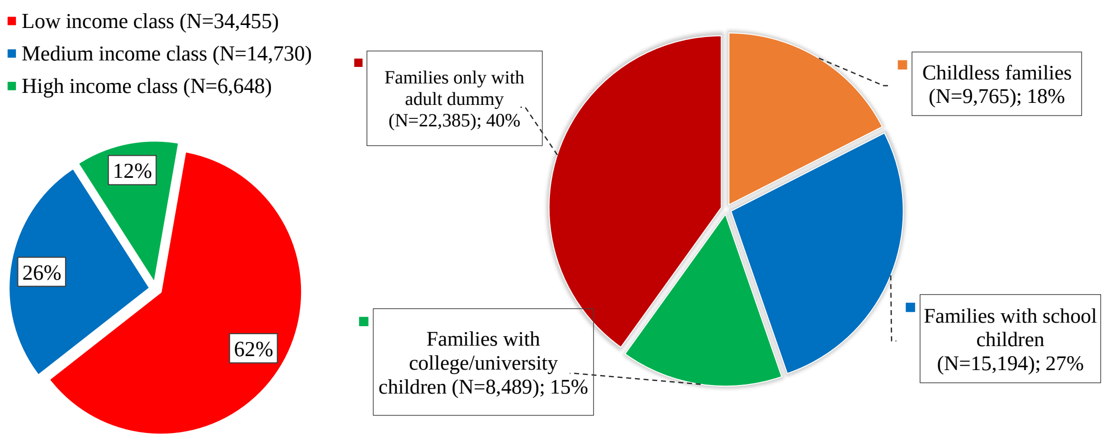
The Household Transportation Survey (HTS) data provided by The Study on Integrated Transportation Master Plan (SITRAMP, 2004) is utilized in this study. The HTS provided a large scale of data on socio-economic indicators, daily activity transportation patterns, time of the day movements, mode and destination choices. This data set provides the most comprehensive data as covers as many as 166,000 households with providing daily transportation patterns on a weekday. The large data set provides a unique opportunity to conduct this analysis, and among 166,000 households 55,833 (33.6%) are aggregated and utilized in this study.



(a) Proposed charging zone in Jakarta (SITRAMP, 2004)

(b) Jakarta regions

Figure 1. Proposed charging zone



(a) household income class classifications

(b) household life stage aggregations

Figure 2. The aggregation results of household income levels, life stage structures and their HTE distributions

Data aggregations and distributions

Prior to the analysis, sample aggregation is conducted as following procedures: 1) extracting households which include person who commute to city centers (proposed charging zone, as illustrated in Figure 1); 2) households are classified into three income classes according to SITRAMP (2004), which is low income class (< 2 million IDR), medium income class (2≤million IDR<5), and high income class (≥5 million IDR). Noted that 1 USD is approximately equal to 12,000 IDR in current currency rate. According to a preliminary study by Japan International Cooperation Agency (JICA) as reported in SITRAMP (2004) disclosed that low to medium income classes are more sensitive in terms of charging their travel behavior. Therefore, we interested in investigating HTE taking into account household income aggregation. Along with income we also aggregate household life stage structures by referring the previous works of Zimmerman (1982) and Sun (2009). Noted an exploration of travel cost expenditure frontier based on life stage structures has been conducted by Sugiarto *et al.*, (2014.a). However, in this study we incorporate life stage attributes such as household members, families with school children, families with college/university children and families only with adult as key of explanatories.

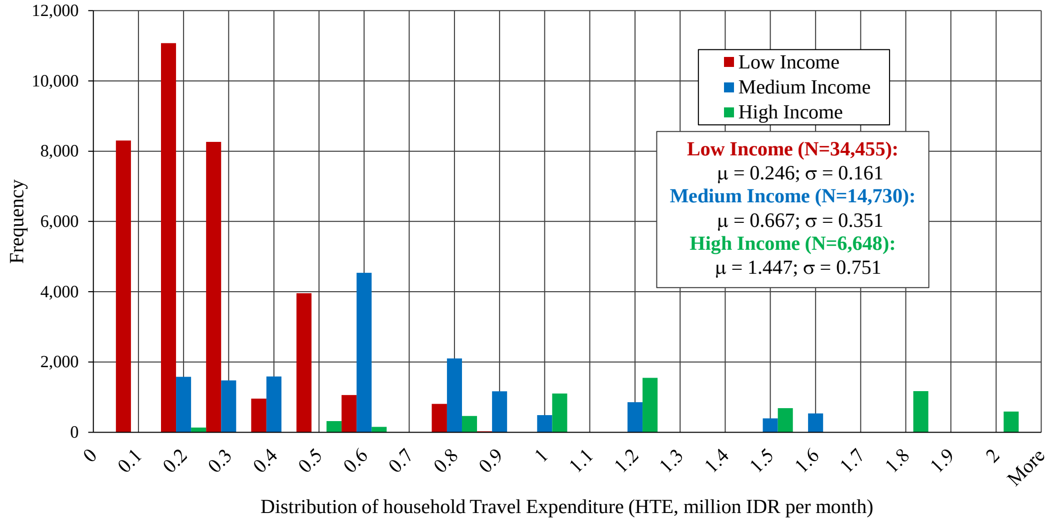


Figure 3. Distribution of HTE across household income classes

An aggregation result of household income classes is presented in Figure 2(a). This discloses that low income household was the most dominated sample size, with accounting close to 62% of the total, and followed by household with medium (26%) and high (12%) income levels. It appears that CBD commuters are predominant by low and medium income households (88% of total samples). Investigating an aggregation result of household life stage structure is illustrated in Figure 2(b). It shows the household life stages distribution in the Jakarta. It can be seen that families only with adults substantially dominate sample size for about 40% of the total. Moreover, families with school children also contribute more than a quarter of the samples. The smallest portion goes back to the childless families and families with college/university children. Overall, it implies that households are prospectively dominated by families with adult and school children, with shares close to 70% of the total. Lastly, Figure 3 discloses that each of household income group has considerably different distribution of household travel expenditure. Average HTE across households have shown 0.246, 0.667, and 1.447 million IDR (1 USD≅13,000 IDR) for low, medium and high income households, respectively.

Modeling framework

This section describes the research methodology used in this paper. The concept of a stochastic frontier model (SFM) of prism vertices (Kitamura *et al.*, 2000; Pendyala *et al.*, 2002) is adopted in this paper. While the application of SFM of prism vertices has been focused on travel time expenditure exploration. However, in this study, we adopt the SFM of prism vertices to model and explore to explore a terminal vertex of prism (upper bound constraints) on household travel cost expenditures. In its origin concept, prism vertices consist of two temporal boundaries (i.e. origin and terminal vertex) and the prism itself is located between them as

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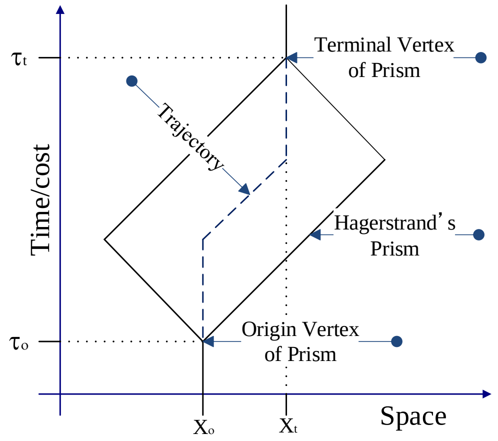
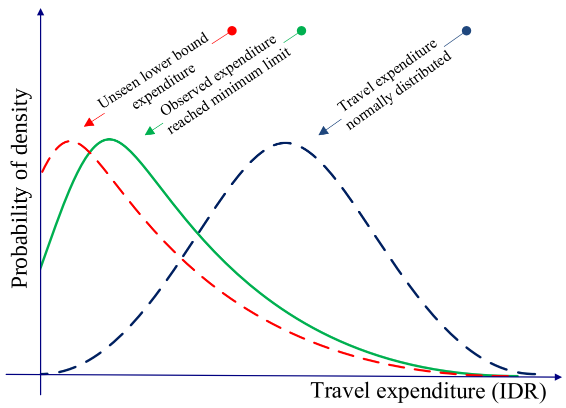
illustrated in Figure 4. By the origin definition that a trip in a prism always start at or after the origin vertex of the prism and ends at or before its terminal vertex (Kitamura *et al.*, 2000).

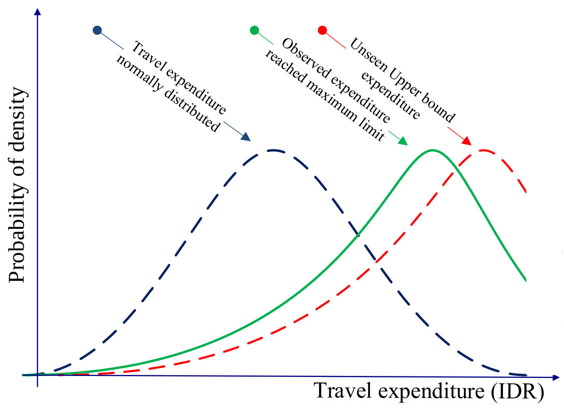
The origin and terminal vertices of the prism are always unobserved (unseen). There are always unobserved conditions that might cause household not be able dedicate money as much as they desire. The amount of the money dedicated for traveling by household are constrained by boundary walls that each household could not encroach. Although households may be constrained by walls of a prism that represent the unseen upper bound of travel expenditure that they would like to dedicate, there may also be another set of boundary wall that represent the hidden lower bound of travel expenditure that they would need to spend for travelling. However, in this study we only focus on a terminal vertex that represents unseen upper bound of household travel expenditure (HTE) due to unavailable HTS data to predict origin vertex. Therefore, modeling approach adopted in this study is to model and explore constraints with respect to terminal vertex of HTE. The idea of stochastic (hidden) travel expenditure is originated from understanding that the amount of money (expenditure) spend by households for travelling can be formulated as a result of complex monthly interaction between household members, life stage structures and socio-demographics, which expected to be varied across income classes.



(a) time/cost-space prism modify from Kitamura *et al.* (2006)



(b) cost function to define unseen lower bound travel expenditure (origin vertex)



(c) production function to define unseen upper bound travel expenditure (terminal vertex)

Figure 4. Prism vertices concept and its adoption to formulate travel expenditure

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To explore the hidden an upper bound HTE condition, SFM (Aigner *et al.*, 1977) is used and the concept of a production frontier is adopted to predict household travel expenditure frontier (HTEF). By considering HTEF is always greater than or equal to the observed HTE. Therefore, a modeling approach is adopted to estimate HTEF based on inequality and non-negative terms. To ensure positive predictions due to the highly skewed nature of the HTE distribution, a log transformation is normally applied (see Banarjee *et al.*, 2007; Volosin *et al.*, 2013).

$$\text{Let } T_{\text{i}} = ln(t_{\text{i}}), \text{ and } T_i = \tau_i - u_i \tag{1}$$

where T_{i} is a natural log of t_i, t_i is total monthly household travel expenditure (HTE) for household i, τ_i represents unobserved HTEF for household i that is always greater than or equal to t_i and u_i is nonnegative random component assumed to follow a half normal distribution. Then, the HTEF can be formulated, as given by:

$$\tau_i = \beta' X_i + v_i \tag{2}$$

Accordingly, specified function in Equation (1) can be reformulated as follows:

$$T_i = \beta' X_i + \varepsilon_i = \beta' X_i + v_i - u_i \tag{3}$$

where β' represents vector of unknown parameters, X_i represent vector exogenous variables, v_i is a random error component such that $-\infty < v_i < \infty$.

The random variables of v_i is assumed to be IID as $\text{N}(0, \sigma v^2)$. By assuming a half normal distribution for u_i and a normal distribution for v_i, then, the distribution of ε_i can be derived as:

$$h(\varepsilon_i) = \frac{2}{\sqrt{2\pi\sigma}} \left[1 - \Phi\left(\frac{\varepsilon_i \lambda}{\sigma}\right)\right] \exp\left(-\frac{{\varepsilon_i}^2}{2\sigma^2}\right) \tag{4}$$

where $\sigma = \text{var}\,(v_i + u_i) = \sigma_v^2 + \sigma_u^2$, where σ_v and σ_u are mutually independent; $\lambda = \frac{\sigma_v}{\sigma_u}$, with $v_i \sim \text{N}(0, \sigma v^2)$. Then, the density function of u_i can be gives as:

$$g(u_i) = \frac{2}{\sqrt{2\pi\sigma_i}} \exp\left(-\frac{{u_i}^2}{2\sigma^2}\right), u_i \geq 0 \tag{5}$$

with,

$$E(u_i) = \sqrt{2/\pi}\ \ \sigma_{\text{u}}\text{ , and Var }(u_i) = \left(1 - \frac{2}{\pi}\right) {\sigma_{\text{u}}}^2 \tag{6}$$

The unknown parameters can be estimated by maximizing the log-likelihood function, as formulated below:

$$LL = \sum_{i=1}^{I} \ln[h(\varepsilon_i)] = \sum_{i=1}^{I} \ln\left[\frac{2}{\sqrt{2\pi\sigma}} \left[1 - \Phi\left(\frac{\varepsilon_i \lambda}{\sigma}\right)\right] \exp\left(-\frac{{\varepsilon_i}^2}{2\sigma^2}\right)\right] \tag{7}$$

In this study, the log-likelihood function is written and implemented in GAUSS econometric software, version 3.2.32.

The natural log of the household travel expenditure is taken into account to ensure positive predictions due to the highly skewed nature of the household travel expenditure distribution. The parameters of the models for each household income classes were estimated using HTS data which describe in section 2. For further analysis, we incorporate life stage status, housing status, vehicle ownership, education and social, occupation status and travel status as summarized in Table 1. Moreover, endogenous and exogenous variables and their empirical setting are described in Table 1.

Results and Discussion

Stochastic production frontier models (SFM) were estimated for three income levels (i.e. low income, medium income, and high income). The observed household travel expenditure is treated as continuous apparent endogenous variable, with the unit in thousands of Indonesian Rupiah (IDR). Three models are separately estimated in this study including SFM-1, SFM-2 and SFM-3 for low, medium and high income class models, respectively. Table 2 exhibits the parameter results of estimation of three proposed models. Examining the parameter coefficients presented in Table 2, respecting to life stage status, the parameter of household member has a positive sign for low and medium income households, while it has a negative effect on the high income class. This indicates that household members contribute as one of important determinants in influencing HTE; that is, the more household members are, the more money will be needed to travel expenditure for low and medium income classes. It is reasonable that the more members within a household the more activities are attracted by them, and consequently the more additional money spending on their transportations. However, it does not affect for disbursement of high income group. Investigating variable of having school and college/university children are significantly positive for all income classes. It appears that household who has school and college/university children is more likely to be constrained that expenditure is spent more on transportation. Looking at the variable families only with adult dummy, there is a strong negative correlation to travel expenditure being spent by low and high income households. While it discloses a positive contribution to medium income household disbursements. This partially might due to the fact that large share of families only with adult (Table 1, close 50%) across medium income class thereby likely to be affected on their travel expenditure.

Table 1. Empirical setting and description of endogenous and explanatory variables

Description of variables	Descriptive statistics					
	Low income household		Medium income household		High income household	
	Mean	Std.	Mean	Std.	Mean	Std.
Travel Expenditure (thousand IDR)	246.09	160.57	666.72	351.38	1,446.95	751.05
Income (million IDR)	1.107	0.353	2.749	0.747	5.867	0.881
Life stage structure attributes:						
Household Members (person)	3.578	1.407	3.651	1.393	3.241	1.567
Families with school children dummy	0.740	0.438	0.707	0.455	0.710	0.454
Families with college/university children dummy	0.848	0.359	0.844	0.363	0.858	0.349
Families only with adult dummy	0.344	0.475	0.489	0.500	0.499	0.500
Housing status:						
Permanent housing dummy	0.715	0.451	0.891	0.312	1.000	0.012
Vehicle ownership:						
Car ownership dummy	0.047	0.212	0.280	0.449	0.855	0.352
Motorcycle ownership dummy	0.360	0.480	0.494	0.500	0.288	0.453
Education and social:						
Diploma or higher dummy	0.154	0.361	0.270	0.444	0.448	0.497
Student dummy	0.213	0.410	0.200	0.400	0.177	0.382
Retired dummy	0.196	0.397	0.163	0.370	0.124	0.330
Occupation status:						
Professional employed dummy	0.253	0.435	0.356	0.479	0.526	0.499
Self-employed dummy	0.070	0.256	0.085	0.279	0.049	0.215
Travel distance:						
Distance to work from home (Km)	15.861	18.598	16.129	18.778	16.121	18.399
Within charging zone (≤15Km)	0.634	0.482	0.632	0.482	0.625	0.484

Shifting to the variable of housing status and vehicle ownerships permanent housing dummy, it is implicated that there is a strong positive contribution to travel expenditure being spent by all income levels. Further looking to the variable of car and motorcycle ownership, it shows positive impacts on HTE for all income classes. It appears that private mode usage (i.e. car, motorcycle) has imposed household monthly travel expenditure rather than public mode usage. Furthermore, examining education and social status, variable of student dummy exhibits positive contribution to HTE across income households. It appears more significant influence to impose household transport expenditure compared to the dummy variables of diploma/higher education and retired dummy. Retired social status has negative impact across income groups. It seems that less income or activities for retired or jobless tends to limit their transportation expenditure. With regard to the variable of professional and self-employed dummy, both of the variables have positive sign and effect on the TEFs. This is quite consistent with expectations as a household with high position both professional and self-employed might have many activities, and consequently will be imposed to the household transportation expenditure.

Table 2 Estimation results of SFMs

Variable	SFM-1: Low Income Class	SFM-2: Medium Income Class	SFM-3: High Income Class
	Estimates	Estimates	Estimates
Constant	4.864**	6.192**	6.323**
Life stage structure attributes:			
Household Members (person)	0.049**	0.045**	-0.018**
Families with school children dummy	0.131**	0.052**	0.412**
Families with college/university children dummy	0.044**	0.077**	0.282**
Families only with adult dummy	-0.039**	0.062**	-0.466**
Housing status:			
Permanent housing dummy	0.312**	0.495**	0.546(*)
Vehicle ownership:			
Car ownership dummy	0.351**	0.060**	0.551**
Motorcycle ownership dummy	0.237**	0.092**	0.596**
Education and social:			
Diploma or higher dummy	0.00097(*)	0.019(*)	0.067**
Student dummy	0.063**	0.008**	0.033**
Retired dummy	-0.108**	-0.047**	-0.037**
Occupation status:			
Professional employed dummy	0.093**	0.031**	0.095**
Self-employed dummy	0.067**	0.051**	0.031(*)
Travel distance:			
Distance to work from home (Km)	0.000612**	0.000452(*)	0.000350(*)
Within charging zone (≤15Km)	0.012(*)	0.009(*)	0.010(*)
σ_v/σ_u	0.613/0.290	0.355/0.658	0.109/0.839
λ	0.473**	1.851**	7.694**
R	0.748	0.518	0.432
Summary of statistics			
Sample size (N)	34,455.00	14,730.00	6,648.00
LL (β)	-33,380.43	-11,412.18	-4,329.14
Shares of income classes (%)	61.71	26.38	11.91

Note: *(*)p < .1, *p < .05, **p < .01.*

Conclusions

The implementation of stochastic frontier analysis (SFA) is able to clarify how commuters in Jakarta spending their money for their travel expenditures by emphasizing on the income level aggregations. The empirical results are used for analyzing and comparing the behaviors of transport expenditure among income levels in order to acknowledge difference constraints of them. Empirical results revealed that considerable differences in average of TEFs among household life stages. The estimation results obtained using three proposed models, for low, medium and high income classes, show that HTEFs are significantly associated with life stage structure attributes, socio-demographics and life environment factors such as professional activity engagements, which is disclosed to be varied across income classes. Finding further reveals that considerable differences in average of HTEFs across models. The variation of HTEF values as well as the trends in the ratio of HTE to HTEF values considerably differ across income classes. This finding calls for the formulation of policies that consider the needs to be addressed for low and medium income groups in order to promote more equity policy thereby leading to more acceptable CC reform. The empirical result shows that people in Jakarta are saving their money for transportation expenditure or have limitations for spending the money for transportation expenditure and considerably varies across life stage structures. This evidences provide insight for Jakarta transport-related policy makers to consider monetary constraints across household incomes in particular when government decide how much of the levy rate must be applied for generating revenue of congestion charging policy. Government have to consider to which income groups such policy will be imposed monetary expenditure for their commuting to CBDs inside of changing zone.

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