Bi-level modelling for linking transport activities with location choice in the urban area

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Abstract

Linking transport activities and location choice has been a subject of various researches. Recent works of Chang and Macket on bi-level modelling (BLM) and the mixed-spatially correlated logit (MSCL) model from Bhat and Guo have paved the way to develop a combination of both approaches in describing the two way relation between land use and transport. This paper examines further development of the approaches for two income levels and their implications on the transport demand estimation for the city of Yogyakarta, Indonesia.

The result shows that the bi-level modelling is an appropriate approach to estimate the location choice and thus gives a better estimate of the travel demand to urban locations. The case study demonstrates that land value (in 10^{-4} Rp/m^2) for the higher income group has a demand elasticity of -2.05 to the distance and the lower income group is -1.38. The research has indicated that the lower income group is affected by an inversed comparable-distance from the city centre. The equation can be used for policy makers to improve transport planning for the urban poor. Future works should be directed to provide theoretical and empirical foundation for disaggregated travel demand for lower income groups living in the urban core.
Keywords: bi-level modelling, land use, transport impedance, income distribution, urban location.

1 Introduction

Estimation and understanding of urban travel demand has been instrumental to develop proper policies and strategies in both regulatory frameworks and in the allocation of resources. The review of the World Bank [1] has identified that

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economies of agglomeration generate the growth of cities. As cities grow, and particularly as they become richer, their vehicle fleets grow more rapidly than the available road space. As they extend spatially, average trip lengths increase, so that traffic increases more rapidly than vehicle fleets. Increased congestion and traffic generated air pollution produce both waste resources and inhibit growth. Freight movement in cities is also hindered by congestion. In many developed countries this has already led to a relocation of freight movement intensive activities to peripheral locations accessible to ports or inter-city trunk road systems. The transport sector strategy is thus frequently charged with the task of finding a way to reconcile city growth with sustained economic efficiency.

Further, the review identified that for the mega-cities at least, no such reconciliation is possible; that cities have simply become inefficiently large. Activities should therefore be moved out of mega-cities, and new development should be concentrated in medium-sized cities. Unfortunately, it is not clear at what city size the economies of agglomeration run out. Furthermore, experience suggests that a policy of de-concentration is very difficult to implement.

Another school of thought pins its hopes on the planning and provision of adequate and well structured road space that is provided as the city grows. In newly developing or growing cities roads are clearly a necessary component of urban infrastructure. The inadequacy of current road capacity to carry traffic has resulted in congestion, damaged the city economy, increased negative environmental impacts, and, often harshly impacted the poor. Critics of this school argue that such an emphasis on road capacity merely fosters a level of motorization which will create auto-dependency and eventually overtake space availability.

In another review for urban transport strategy, Cracknell [2] describes that all urban areas require a good road network and the construction of additional road space. Cracknell states that correcting deficiencies in the network can alleviate some of the effects of congestion. However, new roads, even if they are affordable, generate new traffic, and benefits will be offset by future congestion unless growth in traffic is managed. Inevitably, demand management policies will be needed which will involve balancing the increased cost of car use and making public transport more attractive.

Integrated land use and transport is a long term planning goal of most cities. As travel demand is related to land use disposition, it should theoretically be possible to reduce overall demand for travel and to plan efficient transport systems through the control of land-use development. Few cities have been successful in administering land use development controls in relation to transport.

Cities with more than 1,000,000 inhabitants are obviously facing difficulties in estimating their travel demands, not only because of the magnitude of their daily travel demand, but also because they have complex chain. People are no longer travelling in simple patterns, that is, home-work-home, home-school-home, but are also making multi-origins and multi destination trips. In Indonesia's case, Parikesit *et al.* [3] found that with more than 42% of people currently living in urban area the situation is even more complicated because the distribution of urban income is skewed and thus creates a segmented travel demand. A study of willingness to pay for urban public transport users in Jakarta, Parikesit *et al.* [4] identified that the demand elasticity of travel for short-trips is different to those of longer trips. This situation affects the location choice of the urban community – especially for the poor. For short trips, it becomes evident that the inelastic demand creates an inability for poor people to have an option when the fare is increased. They are "trapped" in the existing cost structure and thus every increase in the fare will reduce the surplus enjoyed by public transport users. On the other hand, the elastic demand for longer trips means that a marginal increase in the fare will induce a mode shift towards other motorized modes, resulting in higher fuel consumption, the creation of air pollution and the promotion of a less sustainable environment.

This paper examines the approach in linking urban transport characteristics and location choices. Further, it assesses the implication of a proposed theory to transport – location interaction using a combination of empirical and synthetic (generated) data for the city of Yogyakarta, Indonesia.

2 Review of literature

The intricate connection between land use and transport means that any policy, whether relating specifically to land use development or to the provision of transport facilities, according to Webster *et al.* [5], will inevitably affect the other dimension, though not necessarily on the same time scale The term land use covers a variety of topics, including activities such as residing, working and shopping; physical infrastructures such as homes and workplaces, and the outcomes of market processes, such as property and land values. All of these topics can be influenced by changes in transport, which will have a consequential effect on travel. Mackett [6] states that the two-way process between land use and transport is sometimes labelled as the "integrated land-use transport model"

Among others, the early works linking transport and location choice are those of Von Thünen on the theory of location, Weber's on the industrial location model, Christaller and Lösch's on the explanation of market area and its geometrical arrangement to form regions. According to de la Barra [7] their application to the urban framework was explained by Wingo and Alonso. Von Thünen and Weber approach have been known as two contrasting paradigms of which the former talks about land use while the latter focuses on location paradigm. Von Thünen's method was adopted by Wingo for the study if urban residential locations.

A recent review from Chang and Mackett [8] identified that there are 4 (four) major models linking transport and urban location, namely spatial interaction models, mathematical programming models, random utility models and bid-rent models. Furthermore, the review expresses that although each group of models has a unique mathematical structure, the interpretation of the model outcomes between the groups is interrelated. These connections however, do not mean that the groups of the models agree on the responses of model output, but they are rather complimentary to each other. In addition, Chang and Mackett [8] proposed the use of bi-level modelling looking at the utility maximisation of the household with respect to private goods, locational value, and transport impedance as follows:

$$\text{Max } U^{r\sigma}_{H\in m}(g, \varphi^r, u^{r\sigma}_H; \beta) \tag{1}$$

Subject to

$$\sum_j \rho_j g_j + \phi(z/r) + \sum_{h\in H} u^{rs}_h = y_H \tag{2}$$

$$g_j \geq 0, \varphi^r \geq 0, u^{rs}_h \geq 0, z_i \geq 0 \forall h, i, j, r, s$$

U is the utility function of a household in the competition for locations; g is the vector of private goods, namely $g = (\ldots, g_j, \ldots)$ ∀j € J; ur is the value of a location r; the value is functionalized with the hedonic vector $z = (\ldots; z_i; \ldots)$ ∀i € I; u_H^{rs} is the minimum transport cost of a household H that belongs to a household class m ∀m € M. The cost is calculated by adding up the minimum transport cost of each members between a residential location r and their activity locations s, namely $u_H^{rs} = \Sigma_{h \in EH} u_h^{rs}$; and β is the vector of parameters.

Assuming that private goods are perfectly competitive, the above formulation can be suppressed and employ only locational attractiveness and transport costs as two determining variables. The above model shows composite decision making, involving the locator and non-locator behaviour of urban activities. The locators face the decision of moving the location activities, and the non-locators are only interested in minimizing transport impedance. The formulation is thus categorized as two levels of decision, namely transport decision and location decision. In the following section, these decision types will be elaborated and tested further.

The residential location model proposed by Cheung and Black [9] used the intervening opportunities model initially developed by Stouffer. It assesses the relationship between urban green-field areas and their economic, social and environmental sustainability. They found that in the case of Sydney and Canberra, intervening opportunity has produced a specific preference function. Furthermore, the research argues that the gravity model is unlikely to accurately model trip distribution and also generates significant spatial bias.

Some current works include those of Bhat and Guo [10] which use a spatially correlated logit model and its application to residential choice modelling. Other works such as the work of Hunt *et al.* [11] highlight applications of land use-transport models in various cities of developed countries. In Chang and Mackett's [8] model, their proposed approach can be categorized as a random utility model, whilst Bhat and Guo [10] expand the approach further by using the MSCL (Mixed Spatially Correlated Logit) model to improve data fit and make a realistic assessment of the effect of socio-demographics, the transportation system and land-use changes on residential location choices. They argued that MSCL is superior to the commonly employed MNL (Multinomial logit) and

SCL (Spatially Correlated Logit), and its elasticity (direct and cross elasticity). Other model such as MLM (Mixed Logit Model) framework by Vichiensan *et al.* [12] and the Lot-based Micro Simulation Model by Sugiki *et al.* [13] have promoted structuralized spatial effects indicating that the relative distance between zones is the major effect to determine the applicability of the proposed model and the mismatch between building stock and new urban activity generations.

3 Development of the model

3.1 Conceptual basis of the model

The proposed model for linking transport and urban location choice is based upon the competition for urban land space. Since the urban space is a scarce resource, private actors are competing for owning and utilizing its location.

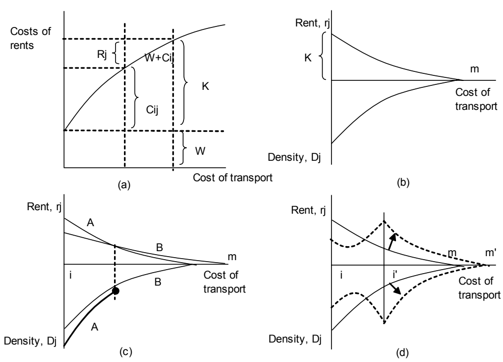


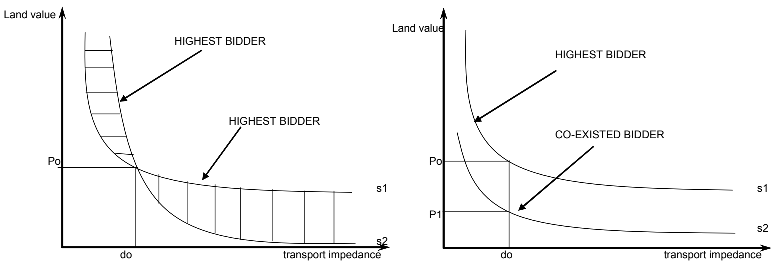
Figure 1: Wingo's Model (Source: de la Barra, 1989, p. 35).

Known as the bid-rent principle proposed initially by Martinez in a 5-stage transport modelling exercise, the understanding of the market value of urban space will create a basis for urban space economics. Location choice will determine the principle for dynamic interaction between transport and land use and can thus be used as a robust principle of the model.

The introduction of new employment centres will create a new y axis, and thus shift the maximum cost of transport to a higher level. In the case of multi centre production areas, Christaller and Lösch introduced a theory of market area which basically explains the equilibrium and intersection between many producers of a same type of commodity and also the location of complementary products.

In a competitive environment, the land market principle applies, that is when two particular land seekers bid for a single urban location, the highest bidder will take all of the location and the lower one will be pushed out of the land market (see figure 2(a)). In various developing urban areas, the situation is rather different. The emergence of the urban poor which has difficulty in gaining access to a formal system, often bids for an urban location which is spatially competitive but at the lower market price. The existing urban structure often allows such situations, for example in the case of urban slum and riverbanks. In such case, both players can co-exist in an urban location market (see figure 2(b)).

The conceptual arrangement of both scenarios is shown below.



(a) (b)

Figure 2: Urban location in a competitive environment (a) and market co-existence (b).

3.2 General framework

The basic question for the general research framework is: *"what would be the land value for the urban poor (LV_j) in a particular urban choice for a given travel impedance from the city centre (d_j) for two different income distribution curves (I_1 and I_2) in a co-existed market"*

The idea of the model is to replicate individuals who attempt to maximise their utility, whereby one individual may behave differently at a different time or occasion despite the similar condition he or she may have to face. Therefore there would be behavioural variation that has to be considered. In a case of a group or aggregate behaviour, the variations in behaviour become larger due to factors such as intra individual/option, lack of information, spatial location, and problem of second best choice (that is, individuals may not choose their highest utility due to their perceptions which are not necessarily fully rational).

The basic function for a random utility is as follows:

$$u^{sk} = U^s(X^k, \zeta) \tag{3}$$

where X represents the measurable attributes (of option k) and ζ represent the random variation. The main outcome of a random utility function lies in the probabilistic function as follows:

$$P^{sk} = Prob[U^s(X^k, \zeta) > U^s(X^q, \zeta)] .... \forall q \in B^s, k \neq q \tag{4}$$

Pearmain and Kroes [14] stated that the utility function is defined as having a systematic part V, which is a function of the measured attributes and residual random part which reflect tastes, observational or measurement errors. Omitting random variation, and assuming that the function itself is random, the equation (4) can be modified into:

$$P^{sk} = Prob[V^{sk} + \varepsilon^{sk} > V^{sq} + \varepsilon^{sq}]\ldots\ldots\ldots \forall q \in B^{s}, k \neq q$$
$$P^{sk} = Prob[\varepsilon^{sq} < \varepsilon^{sk} + (V^{sk} - V^{sq})]\ldots\ldots\ldots \forall q \in B^{s}, k \neq q \qquad (5)$$

The distribution of the residual random part is unknown and can be denoted as $f(\varepsilon) = f(\varepsilon_1, ..., \varepsilon_n)$. Equation (5) can then be written simply as:

$$P^{sk} = \int_{R_N} f(\varepsilon) d\varepsilon \qquad (6)$$

where:

$$R_N = \begin{cases} \varepsilon^{sq} < \varepsilon^{sk} + (V^{sk} - V^{sq}), \ldots\ldots\ldots \forall q \in B^{s}, k \neq q \\ V^{sk} + \varepsilon^{sk} \geq 0 \end{cases}$$

Assuming that the distribution is as Weibull, Domencich and McFadden [15] found, the equation (6) can be written as:

$$P^{sk} = \frac{exp(\beta^{s} V^{k})}{\Sigma_k \, exp(\beta^{s} V^{k})} \qquad (7)$$

Using integration, a formula associated with the average benefit perceived by a certain group, group s can be introduced. The utility function is determined from a basic random utility function as follows:

$$S^{s} = \frac{1}{\beta^{s}} ln\left[\Sigma_k \, exp(\beta^{s} V^{sk})\right] \qquad (8)$$

S^s is the average benefits perceived by group *s*, β^s is parameter, and V^{sk} denotes utility of measurable attributes for group *s* and option *k*.

The basic property of the above function is the negative exponential that is, the ever decreasing value of property relative to the increase of measurable attributes. In this research, the prominent attribute is reflected by the travel impedance of various urban locations to the city centre.

3.3 Upper and lower linkages

Group s, depicted in the equation (8) can be represented by the spending level as a proxy of social-economic behaviour in location-travel choice. The relationship between the upper and lower groups of the community is revealed by the distance in the spending vis-à-vis income distribution of both groups. When the income distribution is translated into a continuous equation, the relative aggregate distance between the two income groups can be formulated in the following function.

$$\delta_I = \int_0^i [\alpha.I_i.\exp(-\beta.I_i) - \gamma.I_i.\exp(-\lambda.I_i)].dI \tag{9}$$

where δ_I is the relative spending vis-à-vis income distance, $\alpha, \beta, \gamma, \lambda$ represent income-class associated parameters, whilst I_i is spending vis-à-vis income at i.

Analogous to Theil's Index, following Morichi [16], the economic disparity between the two income distributions can be formulated by amalgamating within and between income group distributions. Assuming the two groups have different distribution characteristics (namely $\mu_1 \neq \mu_2$), their difference can be tested using Ho: $\mu_1 - \mu_2 = 0$. Its test formulation is as follows:

$$\hat{\sigma}^2 = \frac{(n_1 - 1).s_1^2 + (n_2 - 1).s_2^2}{n_1 + n_2 - 2} \tag{10}$$

$$\delta = \frac{(\bar{x}_1 - \bar{x}_2) - E(\bar{x}_1 - \bar{x}_2)}{\sqrt{\hat{\sigma}^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\hat{\sigma}^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{11}$$

where σ represent the aggregate variation of the two groups, n is the data size, x is the mean income level and s reflects the within group variation. This index (δ: income gap index) will be an important property to the determination of the bi-level model since it aggregates the cost function of urban location and travel choice. Once the characteristics of each income distribution are known, the information can then be used to reveal the difference between the two income groups in selecting their choice of location and travel.

4 Application of the bi-level model to urban location choice

4.1 Background

The bi-level model can be used to describe the transportation behaviour of urban activities in relation to their relative costs of travel to the city centre. The conventional microeconomic theory of land use regards a continuous and aggregate demand for transport and location as a sum of individual demand, and most cities recognize that the urban poor are sometimes regarded as out-liar and thus excluded from the urban transport policy decisions. It creates an in-equilibrium in transport demand and supply – the transport supply fails to recognize this demand and thus induces the city's failure to perform efficiently. The decline in urban public transport patronage (Parikesit *et al.* [4]), inelastic public transport demand for short distance travel (Parikesit *et al.* [3]), and the rise of motorcycle traffic represent only some of the consequences for failing to recognize such demand.

This paper examines the application of the proposed model to investigate the link between transport supply (that is the distance to the city centre), and the choice of an urban location for the city of Yogyakarta. The city of Yogyakarta is a middle-sized city in Indonesia with around 475,000 inhabitants. It has developed into an urban area with a population of around 1,800,000 people, living in places beyond the city's administrative boundaries. With 32.50 km^2 of area, its population density ranges from 7,327 people/km^2 to 27,373 people/km^2, creating a densely populated city and thus an ideal place for public transport operations. In the suburban area, the density remains low with the population of around 5,000 people per km^2. The city also has 238,249 km of road networks covering approximately 5% of the city area. It means that the roads are relatively narrow, with low capacity. It should be pointed out that the attempt to widen the roads is unlikely to happen due to high building density along the roads. The urban area of Yogyakarta is an agglomeration of the city of Yogyakarta and two nearby regencies, Bantul and Sleman.

4.2 Results of data collection and analysis

Using land price as a proxy of land value, data on 22 urban locations and their relative distance to the city centre were collected. The data reflects 4 types of urban land use (high income residential, low/medium income residential, business/office, and industry) as well as 3 location rings (the urban core, middle ring and urban periphery).

Land price data was collected and verified directly from the survey since it is not possible to use published data (for example the tax-object sale value) since the existing market value of land is often under-priced.

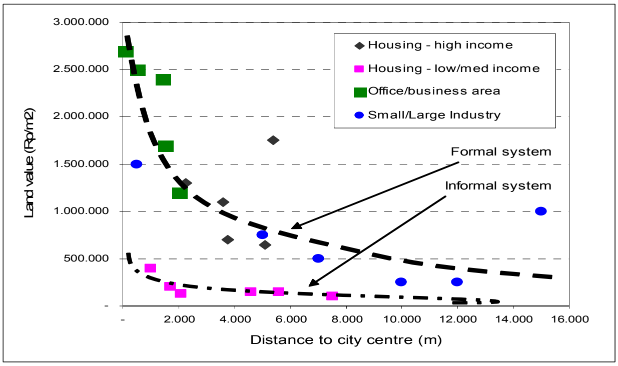


Figure 3: Relation between transport impedance to city centre and urban location.

Figure 3 demonstrates the results of the data collection. The x axis is the relative distance of the urban location to the city centre; that is a proxy for the transportation impedance, whilst the y axis represents the land value in Rp/m^2 showing the competing capability of urban location. The figure shows clearly that urban location choice creates two systems of demand curve. The first curve reflects the "formal system" in the urban location choice incorporating office/business, high income residential and industrial area. When the out-liars are removed, each of the three types have their own demand curve and they can be amalgamated into an aggregate demand for urban location, relative to their transport impedance to the city centre.

The second curve reflects the informal system in the urban location choice whereby low income residential areas are accommodated within the city's spatial constellation. With the idea of competing bidders for urban location, travel choice does obviously not exist. The relative distance in the community's economic capacity creates a "shadow" location and travel choices for wider social and economic class. Using urban-rural spending and assuming that the proportion of their disposable income is similar, the distribution function can be used as a proxy of the high-low income distribution. As depicted in Figure 4, the distribution shows that the distance is not constant, and is distributed according to income level, (Central Bureau of Statistics [17]).

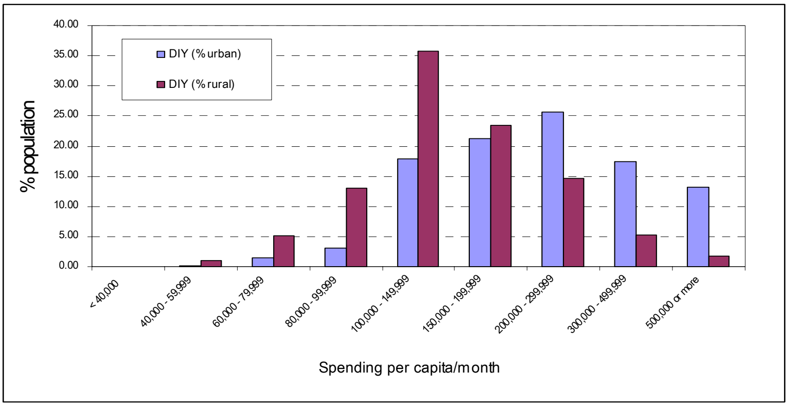


Figure 4: Income distribution function of lower and upper economic classes for the Province of Yogyakarta (DIY).

Utilizing equation (11), δ value indicating the difference (a) within the income groups of I_1 (I_1, σ_1) or I_2 (I_2, σ_2) and (b) between income groups $[(I_1, I_2); (\sigma_1; \sigma_2)]$ can be calculated. When Figure 4 above is translated into the equation function as depicted in (13), it yields the following result.

$I_1 = 15.50126$ $\qquad$ $\sigma_1 = 16.0096$

$I_2 = 9.0263$ $\qquad$ $\sigma_2 = 17.7149$

$\delta_{12} = 0.2742$

Using equation (8) above and data collected from primary and secondary survey, the relation between urban location and travel choice can be formulated as follows:

$$LV_2 = K + k_1^{\delta_{12}} LV_1 + \frac{k_2.\delta_{12}}{d_j}$$
$$LV_2 = K + k_1^{\delta_{12}}.\exp\left(-\beta.d_j\right) + \frac{k_2.\delta_{12}}{d_j} \quad (12)$$

The term δ_{12} in the second term of equation (12) regulates the land price to achieve similar land price to the upper level function when its value is approaching zero, that is, they both have identical I and δ. The constant term K allows an unknown value (deterrence value) to differentiate the two groups. Integrating income distribution index simplifies equation (12) into the following form.

$$LV_2 = K + k_1^{\delta_{12}}.\exp\left(-\beta.d_j\right) - \frac{k_2^{'}}{d_j} \quad (13)$$

The calibration of the above formulation is undertaken by a linearization of equation sets and use data collected from the land value survey. Synthetic data are generated using an individual exponential function and are used to calibrate equation (13) above. Two-stage regression analysis was undertaken and the goodness-of-fit of the equation is tested. The result of calibration yields the following equation:

$$LV_2 = 73{,}774.76 + \left(11.943\times10^{-5}\right)^{\delta_{12}}\left[2.19\times10^{6}\exp\left(-2.05\times10^{-4}d_j\right)\right] + \frac{92{,}812.03}{d_j} \quad (14)$$

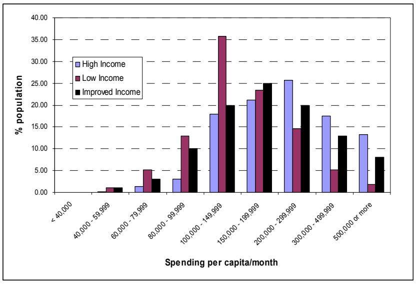
(2.611) (3.58) (10.784) (-11.616) (0.012) *(adj. R2: 0.467)*

The figures in brackets are the t-values of the equation.

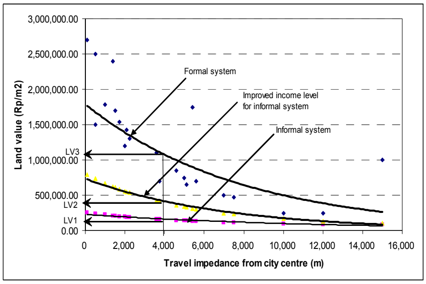
The above finding has demonstrated the feature of market co-existence. Individual tests show that the demand elasticity of land value (in 10^{-4} Rp/m^2) with respect to travel distance to the city centre is -2.05 for mainstream demand, i.e. high income groups and -1.38 for informal system, that is low income groups. Equation (14) relates the lower system to its upper system, creating a dependence function. As the distance from the city centre increases, the gap between the formal and informal system become narrower which is indicated by the inverse distance function in the third component of equation (14). By equating individual curve functions, both curves will converge in a distance of 28.434 km which indicates that both systems are significantly separated but also interdependent. Using an income index to decompose the k_2' of the equation (14), it can be calculated that an increase in the income distribution function for lower income groups will shift the demand curve upward and reduce the distance travelled by similar lower income groups to the city centre.

$$LV_2 = 73{,}774.76 + \left(11.943\times10^{-5}\right)^{\delta_{12}}\left[2.19\times10^{6}\exp\left(-2.05\times10^{-4}d_j\right)\right] + 338{,}463.2\frac{\delta_{12}}{d_j} \quad (15)$$

Using the equations above, one can estimate that an approximate increase in 40% of the average income, distributed with a standard deviation of 15.81 will enable the lower income to shift its demand curve upward to increase its property value to between 30.8% - 210.88% with an average of 151.89%. Figure 5 illustrates the change in the income distribution (5a) and its subsequent impacts on the urban location curve in relation to travel impedance to city centre (5b). Narrowing the gap between upper and lower systems is instrumental when the policy maker is confronted with improving urban transportation systems. The equation has also demonstrated that improving the accessibility and mobility of the urban poor allows them to choose current urban locations without the expense of lower land values. Therefore, travel improvement for the urban poor will enable them to improve their property value as a proxy of their income.



(5a)



(5b)

Figure 5: Effects of the improved income to the property values relative to their travel impedance to the city centre.

5 Summary and conclusions

The research has illustrated the theoretical framework for integrating mainstream demand for urban locations with informal system in respect to their travel impedance to the city centre. Both systems have their own characteristics in urban location choice. The empirical finding demonstrates that land value (in 10^{-4} Rp/m^2) for the higher income group has a demand elasticity of -2.05 to the distance whilst the lower income group is -1.38. It is also found that the distance between the two income groups tends to diminish as the distance increases.

The case study indicates that integrating upper and lower level income groups enables policy makers to identify intervention in narrowing the gap currently experienced by the urban poor. While the income index can be used as a robust measure of the income distribution gap, it can also be used as one of the variables in determining the presence of an informal system in an urban location choice. The lower income index reflects the indifference between the two systems/income groups. The equation developed in this research can assist city government to assess the impact of travel improvement for the urban poor to their property value and income distribution. Future works should be directed to provide theoretical and empirical foundations for the disaggregated travel demand for lower income groups living in the urban core.

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