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**Abstract**

This paper is motivated by the common argument that clean air is a luxury good and has much less or even no value in a less developed country. It applies a hedonic property value analysis, a method commonly used to infer the value of clean air in developed countries, using a combination of data on house values and their characteristics from the Indonesian Family Life Survey, and data of the ambient level of six different pollutants in Jakarta, Indonesia. The result suggests that air quality may affect property value in Jakarta, indicating a preference toward environmental amenities. Moreover, this study is one of the first hedonic studies that may potentially give comparable estimates of the value of clean air in developing countries.

*JEL Classification:* R22; H40; Q21; C14

*Keywords:* Hedonic Prices, Air Pollution, Indonesia

## 1. Introduction

Since the early 1990s, urban air pollution, particularly in mega cities of developing countries, has been recognized as one of the world's major environmental concerns (UNEP and WHO, 1992; WRI et al., 1998). A decade later, nevertheless, various tables showing several environmental quality indicators, available in the *World Development Indicators 2004,* still indicate that cases of severe urban air quality in developing countries continue to occur (World Bank, 2004). Clearly, there are serious difficulties involved in effectively implementing air pollution policies in developing countries. The most common argument for this failure is that clean air is a luxury good and most people in developing countries hardly know what it means to consume it. Therefore, the value of an air pollution policy becomes insignificant for them, and they do not place an air pollution policy among their top priorities.[1] This argument needs to be tested. Hence, the goal of this paper is to elicit whether people in developing countries care about and so value cleaner air.

Jakarta is used as the case study since data on the levels of air pollutant for this city is available and the pollutants have reached an alarming level. In the last few years in Indonesia, there has been growing concern, particularly among NGOs, that urban air quality has been at a disturbing level (MEB, 2002). The worst air quality is certainly in Jakarta, the largest city in Indonesia with a population of approximately 25 million, a population density of 14 thousand people/km$^2$, and around 1.5 million cars and 2.5 million motorcycles daily on the streets. In various places in Jakarta in 1998, the levels of total suspended particles and nitrogen dioxide reached approximately 270 μg/m$^3$ and 148 μg/m$^3$, respectively, while the WHO allowable levels for these pollutants are 90 μg/m$^3$ and 50 μg/m$^3$. From these figures, Resosudarmo and Napitupulu (2004) estimated that the total health cost associated with pollutants in Jakarta was approximately 180 million US$ or approximately one percent of Jakarta's GDP or approximately as much as the total revenue of the Jakarta government for that year.

Since 2001, various NGOs have been able to lobby the Jakarta government to initiate a new clean air program to improve air quality in the city significantly. The new program mostly targets the reduction of air pollution from vehicles, and hence includes activities such

[1] The argument that environmental goods are luxuries has been used to support the hypothesis that air pollution increases with income when income is low, but decreases when income is high. This is supported empirically by the so-called Environmental Kuznet Curve.

as the elimination of lead in gasoline, the implementation of an emission standard, improvement in public transport management and the adoption of strict emission inspection of vehicles (MEB, 2002). By 2003, lead was eliminated from the gasoline sold in Jakarta. However, the progress with other activities has been very slow, so that there is still a high level of air pollutants other than lead.

The valuation of environmental amenities, including clean air, is a complex area of research, because most environmental goods are non-marketed, hence their appropriate value cannot be easily identified. There are basically two broad approaches to environmental valuation. The first is the direct approach that attempts to elicit preferences directly by the use of a survey and experimental techniques such as the Contingent Valuation Method (CVM). The second is the indirect approach that seeks to elicit preferences from people's observed behaviour in the market; i.e. the preference of environmental amenities is revealed indirectly, when an individual purchases a marketed good (for example a house) related to the environmental good in question. Hedonic analysis is one technique in the category of indirect approaches (Pearce et al., 1995). The fact that it is observed people's actual behaviour in a real market that infers their valuation of the related commodities is among the advantages of the hedonic method. It is, in contrast, the hypothetical situation that could lead to much bias that constrains the direct approach to valuation such as CVM from producing reliable inference on people's valuation.[2]

This paper chooses to implement a hedonic analysis on property value to elicit the value of clean air. This choice is interesting for the following reasons. First, whereas most studies of this kind are for developed countries (Smith and Huang, 1995, Boyle and Kiel, 2001), this paper implements the technique for a developing country. The second motivation is that spatial data on levels of six different air pollutants, and data on property values along with their characteristics, are available for Jakarta. This data makes it possible for this paper to combine a hedonic analysis and a spatial analysis. Only a few studies have used this combined technique (Kim et al., 2003).

This paper is divided into 5 sections. Section 1 discusses the background and motivation of this research. Section 2 presents the theoretical background of hedonic property value analysis and a short review of its relevant applications to air quality and

[2] See Arrow et al, 1993 for a comprehensive discussion of the strength and weaknesses of the contingent valuation method.

property value. Section 3 describes the estimation methodology and data. Section 4 provides a discussion of its result and its implications. Section 5 is the conclusion.

**2. Hedonic Property Value Studies and Air Quality**

Air quality is an attribute of a house the variability of which may affect the willingness to pay (WTP) for the house as a whole. Hence, the structure of housing rents and prices will reflect these differentials. By using data on rent/prices of different properties, hedonic price analysis can in principle identify the contribution air quality makes to the value of the traded good, the house. This identifies an implicit or shadow price of these attributes, which in turn can be used to calculate willingness to pay for the non-marketed goods, namely the improvement of air quality. The method commonly used to implement this approach is the hedonic technique pioneered by Griliches (1971) and formalised by Rosen (1974).

Hedonic property value analysis, however, suffers from theoretical and empirical problems. From the theoretical point of view, some strong assumptions, which are the foundations of this theory, are considered unrealistic by certain critics. The market clearing condition, for example, requires that the housing market is in equilibrium. It also requires a sufficiently wide variety of housing models available such that every household is in equilibrium. Many consider this strong assumption as the reason why applying this framework to an under-developed housing market in developing countries is hardly feasible. However, in Jakarta metropolitan area, which is the Indonesian capital, its housing and property market is relatively developed, especially compared to rural area of Indonesia. Yusuf and Koundouri (2005), conclude, for example, that housing market in Indonesian urban area is relatively developed and suitable for hedonic analysis, compared to rural area, as indicated by comparing goodness of fit of urban and rural hedonic price estimation.

There are also many practical problems in empirical works of hedonic property value analysis. These include the definition and measurement of the dependent variable of the hedonic price functions, its explanatory variables, correct or best functional forms, and identification problems. One problem, considered common in empirical analysis, is the presence of multicollinearity, since there could be too many explanatory variables in the hedonic price equations.

There have been an enormous number of hedonic property value studies in an attempt to find out whether air quality is associated with property value, particularly in developed countries. Smith and Huang (1995) provided a formal summary of over 50 studies on hedonic analysis for US cities during the period of 1967–1988. They used a comprehensive meta–analysis of the hedonic property value model to address the issue of whether the housing market can value air quality which is measured by the concentration of particulate matter. This review concluded that the MWTP for one unit reduction of particulate matter lies between zero and US$ 98.

Boyle and Kiel (2001) is another study providing a more recent review of 12 hedonic studies for US cities. Table 1 (rows 1 to 12) presents the 12 studies surveyed by Boyle and Kiel (2001). The conclusion of this study is mixed; i.e. although most cases suggest that air pollution negatively and significantly affects property value, implying that people are willing to pay for air quality improvement, there are other cases showing that the effect might be not significant.

From an intensive literature study, it reveals that the implementation of hedonic housing value analysis in North America and Europe are relatively abundant. For outside North America and Europe, works on this subject are relatively very few; for example, there are two studies for Seoul-Korea and one for Taipei-Taiwan. (See the last three rows in Table 1.) Furthermore, despite the importance and relevance of knowing whether or not and by how much people in poorer countries value air quality, hedonic studies to infer the value of air quality in the developing world are rare[3]. It seems that the availability of consistent air pollution data is one of the main reasons. This study, then, will be among the few applications of hedonic price analysis to study the value of clean air in developing countries.

## 3. Methodologies and Data

### 3.1. Estimation methodology

Since the theoretical underpinnings of hedonic analysis do not suggest a specific functional form, choosing the best functional form is merely an empirical question. To this end we employ a flexible functional form using the Box-Cox transformation method[4]. The hedonic equation to be estimated is,

$$y^{(\lambda)} = \alpha + \sum_i \beta_i x_{1i}{}^{(\lambda)} + \sum_j \gamma_j x_{2j} + \varepsilon \qquad (1)$$

[3] To our knowledge.

[4] The Box-Cox model is the most common functional form used in hedonic price analysis (see Cropper et al, 1999).

where

$$y^{(\lambda)} = \frac{y^{\lambda} - 1}{\lambda}; \; x_{1i}^{(\lambda)} = \frac{x_{1i}^{\lambda} - 1}{\lambda} \tag{2}$$

with α, β, and γ representing vectors of coefficients to be estimated, y the monthly rent of the house, $x_{1i}$ vector of variables to be transformed (i.e., size of the house, number of rooms, distance to district centre, and ambient level of 6 different types of pollution) using the formula in equation (2), $x_{2j}$ the vector of other variables (dummy variables and variables that are not strictly positive and thus could not be transformed using the formula in equation (2)), and λ is the parameter of the transformation (functional form is linear when λ = 1 and log-linear when λ = 0), and ε is the error term. The model will be estimated using the Maximum Likelihood method (Greene, 2000, pp.444–453 and Haab and McConnel, 2002 pp. 254–256).

Since many more recent hedonic price studies suggest that in a cross-sectional hedonic price analysis the value of a property in one location may also be affected by property values in other locations[5], such as in its neighbouring area, this paper will also check for the presence of this spatial effect. This spatial analysis will be summarised and reported in the appendix.

### 3.2. Data

Data for the dependent variable (monthly house rent), structural characteristics, and neighbourhood characteristics are taken from the Indonesian Family Life Survey (IFLS) 1997–98, whereas data for air pollution variables are from a study conducted by the ADB (Syahril et al., 2003). The ADB study measured and reported concentrations of air pollution in Jakarta in 1998, almost at the same time as the survey of IFLS ended. The IFLS[6] is a continuing longitudinal socio-economic survey, the first wave of which was conducted in 1993 (IFLS1). The second wave (IFLS2) was conducted from 1997 to 1998. The sampling scheme used for Indonesia overall was stratified into provinces, and then randomly sampled within provinces. Thirteen of the nation's twenty-six provinces were selected with the aim of capturing the cultural and socio-economic diversity of Indonesia. Within each of the thirteen

[5] Dubin (1988, 1992) was one of the first researchers to introduce treatments for the presence of spatial effect in a hedonic analysis work. Since then it has been applied in many more recent studies such as, among others, Bockstael and Bell (1997), Geoghegan et al. (1997), LeSage (1997), Legget and Bockstael (2000), Gawande and Jenkin-Smith (2001), Kim et al. (2003), and Bransington and Hite (2004).
[6] The dataset is freely downloadable from http://www.rand.org/labor/FLS/IFLS.

provinces, enumeration areas (EAs) — an area of a village — were randomly selected, over-sampling urban EAs and EAs in smaller provinces to facilitate urban-rural and Javanese-non-Javanese comparisons. Finally, within each selected EA households were randomly selected, producing around 7,000 households for Indonesia as a whole. For this paper, a sub-sample of 470 observations from Jakarta province is used. This sub-sample represents the population of Jakarta, because of the nature of the provincial stratification of this sampling[7].

Variables of the hedonic equations that are selected are those commonly used in the literature of hedonic property value analysis. The selection of variables also considers the data availability. Monthly house rental (in Rupiahs) is used for the dependent variable in the hedonic equation. In hedonic studies, either the price or the rent of the house is used for dependent variables. Since the price or the value of the house is essentially the present value of its stream of rents, the choice between the two is not important. Structural characteristics that are included are the size of the house (in square meters), the number of rooms, material used for walls, roofs, and floors, and water source availability. These structural characteristics are expected to be positively associated with property value. To represent the quality of the neighbourhood, some variables which are aggregated at the village level (or *kelurahan* level in the case of Jakarta)[8] are selected. The unemployment rate (which is expected to be negatively associated with house value) and the percentage of people in the village with a university education (expected to be positively associated with property value) are proxies for the general quality of the neighbourhood. Accessibility of public transport (expected to be positively associated with house price) and distance to the centre of Jakarta (expected to be negatively associated with house price) attempt to measure the house's accessibility to employment.

Air quality is measured by the annual average ambient air concentration of six different pollutants i.e. $PM_{10}$ (small particulates), $SO_2$ (sulphur dioxide), CO (carbon monoxide), $NO_x$ (nitrogen oxide), THC (total hydro carbon), and Pb (lead). The first two of these pollutants mainly come from fixed sources, whereas the rest mainly come from mobile sources. This paper will not include the six of them together in one equation for the following reasons. First, this paper is trying to measure is people perception on air quality in general.

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[7] The number of samples from Jakarta is proportional to the population of Jakarta, not a result of random sampling across Indonesia.

[8] Note that Jakarta is a city consisting of five districts (or *kotamadya*). Each *kotamadya* consists of several sub-districts or *kecamatan*. There is a total of 53 sub-districts in Jakarta. Each *kecamatan* consists of several villages or *kelurahan*.

Most people simply do not aware of what type of pollutants is involved. Hence, including all pollutants is less sensible since, for most people, each of them may just a proxy of the same things; i.e. dirty air. Therefore, finding any of those pollution variables negatively significant is most likely enough to indicate that people do not like dirty air in general. Second, including all of the six pollutants will create a multicollinearity problem. It is very likely that indicators of different pollution are correlated to each other, simply because they may come from the same sources (mostly the burning of fossil fuels). This problem may reduce the precision of the estimates[9]. For this reason this paper treats air pollutants individually, and therefore there will be six different specifications for six different pollutants.[10].

The ADB (Syahril et al., 2003) measured and reported the annual average concentration of air pollution, aggregated for 53 sub-districts (or *kecamatan*) of Jakarta. They were measured based on the combination of the direct measurement at the air quality monitoring station in Jakarta, and the (environmental) model which takes into account industry level, number/type of vehicles, traffic, wind direction, and meteorological data[11].

Concerns exist regarding the accuracy of this air pollution data. Nevertheless, since no study of this hedonic type has been undertaken for developing countries, the exercise in this paper, despite this limitation, may enrich the existing literature by providing some evidence in the context of developing countries, and will be improved upon by future availability of more reliable data.

Figure 1 below shows how one of the pollutants (lead) is distributed among sub-districts in Jakarta (the darker the colour, the higher the lead concentration in the area). Table 2 provides a detailed description and summary of statistics of all variables used in the hedonic equation.

Combining the IFLS and air pollution data sets, however, raise one problem.. Since pollution is measured and reported for every sub-district, which is not really accurate because pollution does not recognize administrative boundaries, a pollution level of one house may

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[9] Cross-correlation among those pollutants is very high, and later on, estimation results that include all six pollutants create severe multicollinearity as indicated by the value of the Variance Inflating Factor of more than 100 or even 800.

[10] We also tried to use a combination of one pollutant from a mobile source, and one from a fixed source, since people may know how close they are to sources of pollution. Because there are two distinct sources of pollution i.e. stationary/fixed sources people will take into account two different types of information in deciding where they live. For example, they will try to avoid living near factories and areas with heavy traffic. However, the result using this specification does not change any conclusion, but the report is available upon request.

[11] For more details on the discussion of air pollution data, readers may refer to the ADB publication (Syahril et al, 2003), which is available on the ADB web site.

not necessarily better be represented by the pollution of the district where it is located. The house could be located in the center (where it is appropriate to use its respective district pollution) or close to the border (where it is more appropriate to use the pollution of its neighbour). In short, measurement error problem, to some extent, is unavoidable. To minimize the problem, a simple average of the pollution level around this neighbourhood is calculated. A house located in sub-district A will assume the average air quality of sub-district A and its surrounding sub-districts. Intuitively, this averaging technique is analogous to moving average or seasonal adjustment method commonly used for time series data, but now in the spatial context. Seasonal adjustment, through averaging process, will implicitly reduce the effect of measurement error (Hausman and Watson, 1983, p. 1)

**4. Results and discussion**

The estimation results presented in Table 3 suggest that the linearity and log-linearity of the dependent variable is rejected.[12] Parameter $\lambda$ in the Box-Cox model is estimated as ranging from around -0.1570 to -0.1595, and it is strongly significant at the 1 percent level across the six specifications. This may suggest that, in terms of the goodness-of-fit (likelihood value), the flexible functional form is preferred.

House structural characteristics and neighbourhood qualities are strongly associated with house values. In all specifications, house structural characteristics; i.e. house size, number of rooms, wall and floor materials, are all positively associated (as expected) with house value and are significant at the 5 percent level. Only roof material is significant at the 10 percent level.

Three out of four neighbourhood characteristics conform to expectation, and are significant at the 5 percent level. The unemployment rate within the neighbourhood is negative and is significantly associated with house value, whereas the percentage of people with a university education, and accessibility of public transport are positively associated with house values. Both are significant at the 5 percent level.

Distance to the centre of Jakarta, however, is not statistically associated with house value; it is not significant at a conventional level, and two reasons may account for this. First, distance to the centre of Jakarta may not be a good measure of accessibility to

[12] Stata conducted automatic hypothesis testing for $\theta = -1$, $\theta = 0$; $\theta = 1$. All tests conducted are rejected at the conventional level.

employment. The better measure may be distance to the centre of a district (or *kotamadya* in the case of Jakarta[13]) where important business centres are located. The second reason is that the accessibility of employment might have already been captured by accessibility of public transport (which is positively significant).

All of the coefficients of pollution variables, except $PM_{10}$, are now negative, suggesting better air quality is associated with higher property value, and 3 out of 6 are statistically significant (10% for $SO_2$ and THC, and 5% for Lead). This result has quite a straightforward implication i.e. it does not support the claim that people in developing countries are not concerned with air quality. By calculating the marginal effect of a change in 1 unit of $SO_2$, for example, it can be interpreted that marginal willingness to pay (MWTP) for a reduction of $SO_2$ concentration is around Rp. 448.25.[14] Boyle and Kiel (2001 p.120) in their survey of hedonic studies, report a few estimates of the dollar value of $SO_2$ concentration as ranging from \$58 to \$328 per $\mu g/m^3$. To make it comparable, the MWTP from this study is capitalised[15] and converted into 1997 US\$, resulting in as much as \$28 per $\mu g/m^3$. Although certainly this is still far below the value people in a developed country are willing to pay, it is a good indication that people in Jakarta may in fact be aware and also be willing to pay to avoid living in a polluted area.

Some caveats, however, are worth noting. First, the estimate of MWTP is imprecise, since the coefficient of most of the pollution variables is only marginally significant. Secondly, a difficulty in interpretation may arise when trying to use the estimates to infer the MWTP for reduction in every pollutant due to the high correlation among different types of pollution variables.

Two other final concerns in terms of the quality of the estimation are the possibility of omitted variable bias due to the possibility that it is congestion level, not air quality, that is captured by the pollution variables, and the potential presence of spatial effects. To deal with the former, data on traffic[16] (i.e. number of vehicles passing through every area) is used to proxy the level of congestion. The model is re-estimated adding the traffic variable as one of

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[13] Jakarta is a province, and district is a town or locality.

[14] Marginal effect is calculated as a derivative of the rent in the hedonic price function with respect to its explanatory variable e.g. $SO_2$, and evaluated around the mean of all the explanatory variables. The report on the marginal effect of all the variables (including their standard errors and confidence interval) is available upon request.

[15] Using a 5% discount rate and a 25 year period. Most of the hedonic studies report MWTP as a change in the asset value of the house (Smith and Huang, 1995).

[16] Available in Syahril et al (2003).

the explanatory variables, and the result is shown in Table A1 in the appendix. The result suggests no sign of inconsistency in the estimators, since there is no significant change in the value of the coefficients. It even turns out that CO now becomes significant at a level of 10%, adding one more pollution variable as significant. Spatial analysis is also performed by estimating a spatial dependence and spatial error model, and is discussed in more detail in the appendix. The result does not suggest the presence of any spatial effect[17].

**5. Conclusion**

This paper is an attempt to elicit the value residents of Jakarta place on cleaner air and to contribute to the debate as to whether or not most people in developing countries, in this case in Jakarta, care about the quality of air in their neighbourhood, and as a result, whether or not they place value on a policy to improve air quality. The main assumption in this paper is that if people do care about air quality in the area where they live, it must be an important attribute of their houses. Hence, a hedonic property value analysis can be used to infer indirectly people's preference concerning air quality, from the price they pay for their houses.

It must be admitted that the main weakness of this paper is the data on air pollution. However, the very existence of this data is progress in a way, since its non-existence in other developing countries has prevented similar hedonic studies. Firstly, the measurement of air quality in Jakarta as conducted by Syahril et al. (2003) is a relatively new activity. There has not been any debate as to whether or not the approached taken by Syahril et al. (2003) can really produce reliable data on spatial air quality. Secondly, the unit of the air pollution data is an annual average concentration of an air pollutant covering a sub-district area. This information might not accurately represent the severity of air quality in several spots in a sub-district for a particular season, which is actually an important factor determining housing value in such spots. Meanwhile for several other spots, an annual average concentration of an air pollutant covering a sub-district area might overestimate the air quality around these areas. The third, as already mentioned while describing the data set, is that several house owners, particularly those on the periphery of a sub-district, might consider that the air quality in the adjacent sub-district is the same as the quality of his/her neighbourhood; i.e. the

[17] The positive sign of the coefficient of traffic, however, needs to be carefully interpreted. It may be argued that traffic not only represents the congestion level but also closeness to other city attractions. So the two effects may oppose each other, and the latter seems to be stronger.

definition of a neighbourhood for an individual might not coincide with the boundary of a sub-district. The fourth is that the time periods when the IFLS household data and the data of the air quality were collected do not exactly match.

Bearing in mind all these weaknesses, several points might be noted from the empirical exercises in this paper. First, the empirical results indicate that air pollutants might have a negative association with property value. In the cases of lead, total hydro carbon (THC), $SO_2$, and CO, the relationship is negative and significant. This finding, hence, does not support the common argument that people in developing countries do not have a preference for quality air.

Finally, the empirical result of this paper may also imply that any effort to reduce air pollution in Jakarta, so long as it outweighs its appropriate financial cost can be welfare-enhancing. This paper certainly supports the recent implementation of policy to phase out lead from gasoline used in Jakarta. It remains a puzzle why efforts to reduce other air pollutants do not progress smoothly in Jakarta. Further research on this topic would certainly be valuable.

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**Appendix: Spatial Analysis**

More recently, many hedonic price studies suggest that in a cross-sectional hedonic price analysis, the value of a property in one location may also be affected by property values in other locations, such as in its neighbouring area. Ignoring this spatial effect or spatial dependence may cause the simple OLS estimation to be either inconsistent or inefficient (see Anselin, 1988 for text-book treatment of spatial econometrics). Here, the presence of this spatial effect will be tested and treatment procedures will be carried out if needed

In general, there are two classes of model developed to attenuate the problems of spatial effect, namely the spatial lag model and the spatial error model. In the spatial lag model, house price not only depends on its characteristics but also depends on the house price of its neighbours. The spatial lag model is an appropriate tool when capturing neighbourhood spillover effects. It assumes that the spatially weighted sum of neighbourhood housing prices (the spatial lag) enters as an explanatory variable in the specification of housing price formation, or

$$\widetilde{\mathbf{P}} = \rho \mathbf{W} \widetilde{\mathbf{P}} + \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon} \qquad \text{(A1)}$$

Where ρ is spatial dependence parameter and **W** is an $n \times n$ standardized spatial weight matrix (where $n$ is the number of observations). Spatial weight matrix, **W**, tells whether any pair of observations are neighbour. If, for example, house i and house j are neighbours then, $w_{ij} = 1$ and zero otherwise. Whether or not any pair of houses is neighbours is either determined by them sharing common borders (contiguity) or based on a certain distance between them[18].

Spatial weight matrix is usually standardized, such that every row of the matrix is summed to 1. This enables us to interpret the spatial lag term in a spatial model as simply a spatially-weighted average of neighbouring house prices, for example,

$P_1 = \rho(w_{12}P_2 + w_{13}P_3 + w_{16}P_6) + \sum_{j=1}^{k} \beta_j x_j + \varepsilon_1$, where observation 2, 3, 6 are neighbours of observation 1. The spatial lag model more or less resembles the AR model in time-series econometrics. However, unlike the AR model, OLS estimation in the presence of spatial dependence will be inconsistent, because of the endogeneity problem. The spatial lag model will be estimated using maximum likelihood estimation (see Anselin 1988, for detail MLE method).

The spatial error model takes the following form

$$\widetilde{\mathbf{P}} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}\,;\ \boldsymbol{\varepsilon} = \lambda \mathbf{W}\boldsymbol{\varepsilon} + \mathbf{u} \qquad \text{(A2)}$$

Where **u** now is the i.i.d error term, and λ is the spatial error parameter. The spatial error model resembles more or less the Moving Average model in time series econometrics, in which error of certain observations is affected by errors of other observation. The OLS estimation of spatial error model will be inefficient[19] because it violates the assumption of the independence among disturbance term.

The result of estimating equation A1 and A5 can be seen in Tables A2 and A3 respectively. To test the existence of spatial dependence, this paper conducts a statistical test to see whether ρ in equation A1 (spatial dependence model) is equal to zero. With $H_0$: $\rho = 0$, and $H_a$: $\rho \neq 0$, the statistics follow $\chi^2$ distribution with 1 degree of freedom; this paper fails to

[18] STATA can conveniently construct a spatial weight matrix based on certain distance. We used this method, alternatively, i.e. use distance as criteria to be neighbour. The choice of the distance band is constructed such that it represents as closely as possible that based on contiguity. Several different bands are constructed, but this does not affect the result.

[19] See Anselin (1988) for more detail.

reject the null and conclude that no-spatial dependence is present in the model. A similar test is used for the presence of spatial autocorrelation, or testing whether $\lambda$ in equation A2 is equal to zero. Again, the presence of spatial autocorrelation is rejected. In short, these exercises do not provide evidence of spatial effect; i.e. the value of a property in one location is not be affected by the property value in other locations.

**Table 1. Summary of existing hedonic price studies related to air pollution**

| No | Authors (publication year) | Study Location | Pollutant(s) | Sign and significance |
|---|---|---|---|---|
| 1. | Ridker & Henning (1967) | St. Louis, USA | Index of sulfation levels | Negative, significant at 5% level |
| 2. | Wieand (1973) | St. Louis, USA | Suspended particulates.<br>SO2.<br>SO3 | Negative, not ss.<br>Negative, not ss.<br>Positive, not ss. |
| 3. | Deyak & Smith (1974) | Some US cities | Suspended particulates. | Negative, ss at 10% level |
| 4. | Deyak & Smith (1975) | 85 central US cities | Suspended particulates. | Negative, not ss. |
| 5. | Harrison & Rubienfeld (1978) | Boston, US | NO2 | Negative, ss at 1% level |
| 6. | Nelson (1978) | Washington DC, USA | Particulate concentration, summer oxidant concentration | Negative, ss at 5% level |
| 7. | Li & Brown (1990) | Boston, USA | TSP.<br>SO2. | Negative, not ss.<br>Positive, not ss. |
| 8. | Palmquist (1982) | 20 US cities | TSP, O3, NO2, SO2 | Mixed[20] |
| 9. | Palmquist (1983) | 14 US cities | TSP, O3, NO2, SO2, and index of pollution | Mixed[21] |
| 10. | Murdoch & Thayer (1988) | California, USA | Four indicator of visibility | All negative and ss at 10% level |
| 11. | Grave, Murdoch, Thayer, & Waldman (1988) | California, USA | TSP, visibility | TSP is negative and ss at 5% level, but mixed for visibility |
| 12. | Zabel & Kiel (2000) | 4 US cities | NO2, SO2, TSP | 23 of 80 coefficients are ss at 5% level, 19 of them are negative. |
| 13. | Kim, Phips, & Anselin (2003) | Seoul, Korea | SO2,<br>Nox | Negative, ss at 5% level<br>Positive not ss. |
| 14. | Yang (1996) | Taipei | TSP, $TSP^2$ | Negative, significant at 5% level |
| 15. | Kwak, Lee, & Chun (1996) | Seoul, Korea | TSP | Negative, significant at 5% level |

Note:
Rows No. 1 to 12 are adopted from Boyle and Kiel (2001)
ss stands for statistically significant

[20] Negative half the time for TSP, ss in 6 of 20. 8 of 18 NO2 negative and ss. 8 of 12 ozone negative, 6 ss. 5 of 20 negative and ss for SO2.
[21] For index variable, the estimated coefficient was negative and statistically significant in six of the 14 cities in their study.

## Table 2. Summary statistics of variables in the hedonic equations

| | Mean | Std. Deviation |
|---|---|---|
| Dependent Variable | | |
| Monthly rent (rupiahs) | 838,735 | 9,509,536 |
| Structural characteristics | | |
| House size (m2) | 74.821 | 79.179 |
| Number of room | 5.306 | 2.793 |
| Wall material is cement/brick (1,0) | 0.783 | 0.413 |
| Roof material is concrete (1,0) | 0.004 | 0.065 |
| Floor material is ceramic/stone (1,0) | 0.294 | 0.456 |
| Water source inside (1,0) | 0.662 | 0.474 |
| Neighbourhood characteristics | | |
| Unemployment rate at the neighb. (pct) | 1.465 | 2.492 |
| People w. univ. educ.the neigh. (pct) | 6.872 | 7.773 |
| Accessible by public transport (1,0) | 0.960 | 0.197 |
| Distance to district centre (km) | 6.561 | 4.485 |
| Air pollution | | |
| Ambient level of PM10 (mg/m3) | 92.439 | 23.361 |
| Ambient level of SO2 (mg/m3) | 22.879 | 8.627 |
| Ambient level of CO (mg/m3) | 2,696.106 | 386.040 |
| Ambient level of NOx (mg/m3) | 139.011 | 46.421 |
| Ambient level of THC (mg/m3) | 319.844 | 84.916 |
| Ambient level of lead (mg/m3) | 0.367 | 0.085 |

Note: (1,0) indicates a dummy variable

**Table 3. Result of Box-Cox Hedonic Estimation (Dependent variable: monthly rent)**

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Structural characteristics | | | | | | |
| House size (m2) | 0.0363 | 0.0333 | 0.0370 | 0.0370 | 0.0366 | 0.0383 |
| | (4.52) ** | (4.25) ** | (5.12) ** | (4.77) ** | (5.08) ** | (5.47) ** |
| Number of rooms | 0.0625 | 0.0629 | 0.0614 | 0.0621 | 0.0613 | 0.0610 |
| | (10.89) ** | (11.93) ** | (11.00) ** | (10.84) ** | (11.17) ** | (10.84) ** |
| *Wall is cement/brick (1,0)* | 0.0810 | 0.0813 | 0.0791 | 0.0810 | 0.0816 | 0.0845 |
| | (22.31) ** | (23.68) ** | (21.55) ** | (22.10) ** | (23.42) ** | (24.39) ** |
| *Roof is concrete (1,0)* | 0.1640 | 0.1548 | 0.1583 | 0.1640 | 0.1525 | 0.1541 |
| | (3.62) * | (3.42) * | (3.42) * | (3.60) * | (3.24) * | (3.24) * |
| *Floor is ceramics/stone (1,0)* | 0.0672 | 0.0629 | 0.0671 | 0.0673 | 0.0640 | 0.0630 |
| | (24.99) ** | (23.04) ** | (25.35) ** | (25.01) ** | (23.49) ** | (22.03) ** |
| *Water source inside (1,0)* | 0.0302 | 0.0339 | 0.0323 | 0.0303 | 0.0351 | 0.0357 |
| | (4.44) ** | (5.72) ** | (5.02) ** | (4.44) ** | (5.95) ** | (6.09) ** |
| Neighbourhood characteristics | | | | | | |
| *Public transport access (1,0)* | 0.0981 | 0.1101 | 0.1033 | 0.0983 | 0.1191 | 0.1236 |
| | (8.85) ** | (11.00) ** | (9.66) ** | (8.85) ** | (11.71) ** | (12.47) ** |
| *People w. univ. education (%)* | 0.0052 | 0.0051 | 0.0050 | 0.0053 | 0.0052 | 0.0055 |
| | (39.10) ** | (40.07) ** | (35.90) ** | (39.99) ** | (40.88) ** | (43.75) ** |
| *Unemployment rate (%)* | -0.0067 | -0.0064 | -0.0061 | -0.0066 | -0.0056 | -0.0053 |
| | (7.34) ** | (7.97) ** | (6.72) ** | (6.95) ** | (5.62) ** | (4.85) ** |
| Distance to district center (km) | 0.0072 | 0.0070 | 0.0049 | 0.0069 | 0.0036 | 0.0037 |
| | (0.52) | (0.53) | (0.24) | (0.46) | (0.13) | (0.14) |
| Ambient air pollution (mg/m3) | | | | | | |
| PM10 | 0.0060 | | | | | |
| | (0.01) | | | | | |
| SO2 | | -0.0650 | | | | |
| | | (2.80) * | | | | |
| CO | | | -0.2498 | | | |
| | | | (0.98) | | | |
| NOx | | | | -0.0049 | | |
| | | | | (0.01) | | |
| THC | | | | | -0.1968 | |
| | | | | | (3.15) * | |
| Lead | | | | | | -0.0898 |
| | | | | | | (4.41) ** |
| Constant | 4.9275 | 5.0527 | 6.0606 | 4.9662 | 5.6452 | 4.8122 |
| Lambda | -0.1572 | -0.1595 | -0.1578 | -0.1570 | -0.1585 | -0.1575 |
| s.e. | (0.02) ** | (0.02) ** | (0.02) ** | (0.02) ** | (0.02) ** | (0.02) ** |
| Log likelihood | -6,159 | -6,157 | -6,158 | -6,159 | -6,157 | -6,156 |
| LR chi-squared (11) | 331.45 | 334.24 | 332.42 | 331.45 | 334.60 | 335.85 |

Note:
**) significant at 5% level; *) significant at 10% level. Variable in italics are not transformed.
Number in parantheses (except for lambda) are LR chi-squared statistics. Number of observation is 470.

**Table A1. Result of Box-Cox Hedonic Estimation (with Traffic, Dependent variable: monthly rent)**

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Structural characteristics | | | | | | |
| House size (m2) | 0.0362 | 0.0361 | 0.0415 | 0.0408 | 0.0397 | 0.0405 |
| | (4.41) ** | (4.81) ** | (6.23) ** | (5.57) ** | (5.77) ** | (5.93) ** |
| Number of rooms | 0.0648 | 0.0640 | 0.0613 | 0.0624 | 0.0620 | 0.0618 |
| | (11.40) ** | (11.81) ** | (10.54) ** | (10.44) ** | (10.93) ** | (10.70) ** |
| *Wall is cement/brick (1,0)* | 0.0860 | 0.0873 | 0.0837 | 0.0861 | 0.0870 | 0.0882 |
| | (24.17) ** | (25.68) ** | (23.02) ** | (23.55) ** | (25.09) ** | (25.30) ** |
| *Roof is concrete (1,0)* | 0.1565 | 0.1479 | 0.1438 | 0.1581 | 0.1465 | 0.1515 |
| | (3.18) * | (2.96) * | (2.68) | (3.16) * | (2.83) * | (2.99) * |
| *Floor is ceramics/stone (1,0)* | 0.0662 | 0.0617 | 0.0662 | 0.0669 | 0.0634 | 0.0633 |
| | (23.44) ** | (20.96) ** | (23.53) ** | (23.31) ** | (21.75) ** | (21.22) ** |
| *Water source inside (1,0)* | 0.0292 | 0.0339 | 0.0336 | 0.0297 | 0.0347 | 0.0341 |
| | (4.02) ** | (5.42) ** | (5.20) ** | (4.02) ** | (5.49) ** | (5.26) ** |
| Neighbourhood characteristics | | | | | | |
| *Public transport access (1,0)* | 0.1087 | 0.1231 | 0.1223 | 0.1083 | 0.1302 | 0.1271 |
| | (10.38) ** | (12.87) ** | (12.56) ** | (10.10) ** | (13.17) ** | (12.60) ** |
| *People w. univ. education (%)* | 0.0058 | 0.0058 | 0.0056 | 0.0059 | 0.0059 | 0.0060 |
| | (43.79) ** | (45.45) ** | (41.27) ** | (44.63) ** | (45.72) ** | (46.86) ** |
| *Unemployment rate (%)* | -0.0052 | -0.0045 | -0.0031 | -0.0046 | -0.0037 | -0.0040 |
| | (4.01) ** | (3.23) * | (1.34) | (2.84) * | (2.08) | (2.47) |
| Distance to district center (km) | 0.0022 | 0.0009 | -0.0053 | 0.0008 | -0.0023 | -0.0003 |
| | (0.05) | (0.01) | (0.23) | (0.01) | (0.05) | (0.00) |
| Traffic | 0.0889 | 0.0883 | 0.1102 | 0.0822 | 0.0826 | 0.0671 |
| | (5.33) ** | (5.79) ** | (7.69) ** | (4.86) ** | (5.07) ** | (3.16) * |
| Ambient air pollution (mg/m3) | | | | | | |
| PM10 | 0.0611 | | | | | |
| | (0.53) | (0.00) | | | | |
| SO2 | | -0.0774 | | | | |
| | | (3.78) * | | | | |
| CO | | | -0.5376 | | | |
| | | | (3.86) * | | | |
| NOx | | | | -0.0172 | | |
| | | | | (0.06) | | |
| THC | | | | | -0.2071 | |
| | | | | | (3.41) * | |
| Lead | | | | | | -0.0747 |
| | | | | | | (2.76) * |
| Constant | 4.4495 | 4.7973 | 7.0062 | 4.7451 | 5.4233 | 4.6210 |
| Lambda | -0.1554 | -0.1568 | -0.1552 | -0.1544 | -0.1559 | -0.1553 |
| s.e. | (0.02) ** | (0.02) ** | (0.02) ** | (0.02) ** | (0.02) ** | (0.02) ** |
| Log likelihood | -6,156 | -6,154 | -6,154 | -6,156 | -6,155 | -6,155 |
| LR chi-squared | 336.78 | 340.03 | 340.11 | 336.31 | 339.66 | 339.01 |

Note:
**) significant at 5% level; *) significant at 10% level. Variable in italics are not transformed.
Number in parantheses (except for lambda) are LR chi-squared statistics. Number of observation is 470.

**Table A2. Estimation Result Using Spatial-Lag Model (Dependent variable: Log monthly rent)**

| | Spatial Lag Model | | | | | |
|---|---|---|---|---|---|---|
| Structural charactristics | | | | | | |
| House size (m2) | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| | (0.001)** | (0.001)** | (0.001)** | (0.001)** | (0.001)** | (0.001)** |
| Number of room | 0.088 | 0.090 | 0.090 | 0.089 | 0.090 | 0.088 |
| | (0.019)** | (0.019)** | (0.019)** | (0.019)** | (0.019)** | (0.019)** |
| Wall material is cement/brick (1,0) | 0.486 | 0.490 | 0.486 | 0.485 | 0.494 | 0.511 |
| | (0.112)** | (0.112)** | (0.112)** | (0.112)** | (0.112)** | (0.112)** |
| Roof material is concrete (1,0) | 1.249 | 1.250 | 1.251 | 1.250 | 1.214 | 1.195 |
| | (0.590)* | (0.591)* | (0.591)* | (0.591)* | (0.591)* | (0.589)* |
| Floor material is ceramics/stone (1,0) | 0.419 | 0.419 | 0.422 | 0.421 | 0.409 | 0.396 |
| | (0.093)** | (0.093)** | (0.093)** | (0.093)** | (0.093)** | (0.093)** |
| Water source inside (1,0) | 0.238 | 0.243 | 0.239 | 0.239 | 0.261 | 0.272 |
| | (0.096)* | (0.098)* | (0.097)* | (0.096)* | (0.098)** | (0.097)** |
| Neighbourhood charactristics | | | | | | |
| Unemployment rate at the neighb. (pct) | -0.045 | -0.048 | -0.048 | -0.047 | -0.044 | -0.040 |
| | (0.016)** | (0.016)** | (0.016)** | (0.016)** | (0.016)** | (0.016)* |
| People w. univ. educ.the neigh. (pct) | 0.039 | 0.038 | 0.038 | 0.038 | 0.037 | 0.040 |
| | (0.006)** | (0.006)** | (0.006)** | (0.006)** | (0.006)** | (0.006)** |
| Accessible by public transport (1,0) | 0.650 | 0.687 | 0.674 | 0.668 | 0.755 | 0.802 |
| | (0.209)** | (0.216)** | (0.209)** | (0.208)** | (0.218)** | (0.217)** |
| Distance to district center (km) | 0.012 | 0.010 | 0.011 | 0.011 | 0.008 | 0.007 |
| | (0.009) | (0.009) | (0.010) | (0.009) | (0.009) | (0.009) |
| Spatially-averaged air pollution | | | | | | |
| Ambient level of PM10 (mg/m3) | -0.002 | | | | | |
| | (0.003) | | | | | |
| Ambient level of SO2 (mg/m3) | | -0.002 | | | | |
| | | (0.008) | | | | |
| Ambient level of CO (mg/m3) | | | -0.000 | | | |
| | | | (0.000) | | | |
| Ambient level of NOx (mg/m3) | | | | -0.000 | | |
| | | | | (0.001) | | |
| Ambient level of THC (mg/m3) | | | | | -0.001 | |
| | | | | | (0.001) | |
| Ambient level of lead (mg/m3) | | | | | | -1.794 |
| | | | | | | (0.921)+ |
| Constant | 7.229 | 7.579 | 7.548 | 7.429 | 8.283 | 8.294 |
| | (1.583)** | (1.760)** | (2.183)** | (1.596)** | (1.751)** | (1.646)** |
| Rho | 0.228 | 0.228 | 0.185 | 0.190 | 0.199 | 0.148 |
| chi-squared(1) | 2.914 | 2.914 | 1.747 | 1.612 | 2.418 | 1.194 |
| Observations | 470 | 470 | 470 | 470 | 470 | 470 |
| Log likelihood | -578.785 | -579.008 | -579.039 | -579.012 | -578.298 | -577.156 |

Standard errors in parentheses
+ significant at 10%; * significant at 5%; ** significant at 1%

### Table A3. Estimation Result Using Spatial-Error Model (Dependent variable: Log monthly rent)

| | Spatial Error Model | | | | | |
|---|---|---|---|---|---|---|
| Structural charactristics | | | | | | |
| House size (m2) | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| | (0.001)** | (0.001)** | (0.001)** | (0.001)** | (0.001)** | (0.001)** |
| Number of room | 0.090 | 0.091 | 0.090 | 0.090 | 0.090 | 0.089 |
| | (0.019)** | (0.019)** | (0.019)** | (0.019)** | (0.019)** | (0.019)** |
| Wall material is cement/brick (1,0) | 0.503 | 0.506 | 0.499 | 0.502 | 0.509 | 0.516 |
| | (0.112)** | (0.112)** | (0.112)** | (0.112)** | (0.112)** | (0.112)** |
| Roof material is concrete (1,0) | 1.133 | 1.142 | 1.127 | 1.132 | 1.136 | 1.150 |
| | (0.592)+ | (0.592)+ | (0.590)+ | (0.591)+ | (0.590)+ | (0.590)+ |
| Floor material is ceramics/stone (1,0) | 0.395 | 0.395 | 0.399 | 0.395 | 0.393 | 0.386 |
| | (0.094)** | (0.093)** | (0.093)** | (0.094)** | (0.093)** | (0.093)** |
| Water source inside (1,0) | 0.233 | 0.238 | 0.244 | 0.235 | 0.255 | 0.261 |
| | (0.096)* | (0.097)* | (0.096)* | (0.096)* | (0.097)** | (0.097)** |
| Neighbourhood charactristics | | | | | | |
| Unemployment rate at the neighb. (pct) | -0.038 | -0.039 | -0.037 | -0.037 | -0.037 | -0.036 |
| | (0.016)* | (0.016)* | (0.016)* | (0.016)* | (0.016)* | (0.016)* |
| People w. univ. educ.the neigh. (pct) | 0.038 | 0.038 | 0.037 | 0.038 | 0.038 | 0.039 |
| | (0.005)** | (0.005)** | (0.005)** | (0.005)** | (0.005)** | (0.005)** |
| Accessible by public transport (1,0) | 0.634 | 0.654 | 0.662 | 0.636 | 0.723 | 0.755 |
| | (0.208)** | (0.214)** | (0.210)** | (0.208)** | (0.218)** | (0.221)** |
| Distance to district center (km) | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.004 |
| | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) |
| Spatially-averaged air pollution | | | | | | |
| Ambient level of PM10 (mg/m3) | -0.000 | | | | | |
| | (0.004) | | | | | |
| Ambient level of SO2 (mg/m3) | | -0.004 | | | | |
| | | (0.010) | | | | |
| Ambient level of CO (mg/m3) | | | -0.000 | | | |
| | | | (0.000) | | | |
| Ambient level of NOx (mg/m3) | | | | -0.001 | | |
| | | | | (0.002) | | |
| Ambient level of THC (mg/m3) | | | | | -0.002 | |
| | | | | | (0.001) | |
| Ambient level of lead (mg/m3) | | | | | | -1.987 |
| | | | | | | (1.077)+ |
| Constant | 9.855 | 9.882 | 10.390 | 9.895 | 10.237 | 10.408 |
| | (0.409)** | (0.270)** | (0.663)** | (0.347)** | (0.373)** | (0.391)** |
| Lambda | 0.4263 | 0.3943 | 0.4273 | 0.4254 | 0.3482 | 0.2651 |
| chi-squared(1) | 2.997 | 2.206 | 3.118 | 3.072 | 3.118 | 0.927 |
| Observations | 470 | 470 | 470 | 470 | 470 | 470 |
| Log likelihood | | | | | | |

Standard errors in parentheses
+ significant at 10%; * significant at 5%; ** significant at 1%

**Figure 1. Distribution of Lead Concentration in Jakarta**

Source: calculated using data from ADB (Syahril et al., 2003)