How do people price air quality: empirical evidence from Hong Kong

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Abstract

We investigate how air pollution affects the transaction prices of high-rise apartments in Hong Kong. We use a three-dimensional Reynolds-stress turbulence model to simulate the air pollution level of each unit in high-rise apartment buildings in a densely populated area in Hong Kong (Study Area). We then verify the simulated results with site measurement data. Although the area is small, the variety of building forms and location of streets resulted in significant variation in air quality across apartment units. The apartments in the Study Area are actively traded and relatively homogenous. We estimate the implicit price by constructing a hedonic price model that includes the simulated apartment specific air pollution level as one of the explanatory variables. We find that the apartment prices are more sensitive to air quality in more polluted areas.

Keywords:

Air pollution, hedonic price model, Hong Kong, property prices

1. Introduction

With increased human and industrial activities, more air pollution such as a high concentration of suspended particulates or carbon monoxide is produced. Air pollution is also known to cause health problems (Pope, 2000a) and reduce productivity (Wargocki, 2000). Clean air becomes a highly valued commodity, especially in compact cities with high density development. Dockery et al. (1993) found that air pollution was positively associated with death from lung cancer and cardiopulmonary disease. Air pollution is also known to reduce productivity (Wargocki et al., 2000). Given the adverse impacts of air pollution, people should be willing to "buy" clean air. However, an explicit market for clean air does not exist at the microscopic level and its market value has to be estimated by indirect methods.

Although people do not trade clean air explicitly, variations in the air quality of different areas should be implicitly reflected in property prices. Homes that located in places with better air quality are expected to have higher value. This means that the value of clean air we can, in principle, be extracted from property prices. Since property is a heterogeneous commodity, previous research has generally applied the hedonic price model, theorized by Rosen (1974), to infer the implicit price for clean air, holding other factors (e.g. structural and locational attributes) constant. Some researchers found a significant negative relationship between air pollution and property values, while others produced insignificant results.

This study aims to assess the market value of clean air. In order to disentangle the genuine effect from the announcement effect, we will examine the relationship between air quality and property prices at a level that is much more microscopic than previous studies. Focusing on high-rise residential developments in Hong Kong, the air quality of each individual apartment unit (flat) will be estimated through computational fluid dynamics techniques using a three-dimensional Reynolds-stress turbulence model. The simulation results will be validated with field measurements. Property transaction prices in the same areas will then be collected to construct a hedonic price model, which includes the flat-specific air quality as one of the explanatory variables. If air quality is found to be significant, the property market will be more efficient than any studies had implied so far, since there had been no publicly available information on flat-specific air quality. If the air quality variable is not significant, there is potential for assisting market players (e.g. buyers, tenants, and developers) to make more informed decisions by making more air quality information available to the general public through research and field measurements. Furthermore, the results would have practical value for policy formulation and for assessing compensation in courts.

2. Literature Review

The earliest study on the relationship between air quality and property prices was Ridker and Henning (1967), who found a significant negative relationship between air sulphation level and property values in the St. Louis metropolitan area in 1960. Then, Anderson and Crocker (1971) used suspended particulate level as a measure of air pollution and produced similar results for Washington and Kansas City. Diamonds (1980) also found a significant negative effect in Chicago by using annual air particulate count. Repeating the study by Ridker and Henning, Wieand (1973), however, found no significant relationship between property values and the level of suspended particulates, SO_2 and SO_3.

A much larger number of cities were examined in further studies. Deyak and Smith (1974) found that the level of suspended particulates had a negative effect on property values in several major metropolitan areas in the United States. Murdoch and Thayer (1988) found a significant positive relationship between mean visibility (as a proxy for air cleanliness) and house prices in Californias South Coast Air Basin in 1979. Graves et al. (1988) obtained similar results for visibility and suspended particulate concentration in Los Angeles, Orange, Riverside and San Bernardino counties in California. Yet, Smith and Deyaks (1975) showed an insignificant effect for eighty-five central cities. Li and Brown (1980) also found a negative but insignificant effect for fifteen suburban towns in the Southeast sector of the Boston metropolitan area. They admitted that there might be specification problems in their regression analysis.

There were also studies which took a further step to estimate the demand for clean air. Harrison and Rubinfeld (1978) showed that marginal air pollution damages increased with the levels of both air pollution and household income. Nelson (1978) reported a price elasticity of demand for clean air between -1.2 and -1.4, and an income elasticity of demand of about 1 for Washington, D.C. Based on a meta-analysis of 37 previous cross-sectional studies, Smith and Huang (1995) found a higher willingness to pay for clean air for locations with less air pollution and higher income levels. In particular, reducing 1 μg/m3 particulates raised property prices by 0.05-0.1%, although a few studies found a reverse relationship. More recently, Chattopadhyay (1999) revealed that households were willing to pay more for the reduction in particulate pollution than in sulphur pollution in Chicago. Zabel and Kiel (2000) confirmed the results of the above studies using a set of panel data for Chicago, Denver, Philadelphia and Washington, D.C. Chay and Greenstone (2005) used the instrumental variables approach and found that the elasticity of housing values with respect to particulates concentrations ranges from -0.2 to -0.35.

3. Problems in previous studies

As shown in the meta-analysis of Smith and Huang (1995), the hedonic approach is sensitive to model specifications, which may account for the mixed results in various studies. Apart from this, we postulate two other major reasons for the inconclusiveness. One is the diverse use of different air pollution measures such as sulphate levels, suspended particulate levels, and visibility by previous studies. It is obvious that some measures have been brought to the public's attention through public announcements (public information), while other measures, notably those compiled by researchers, cannot be easily observed or sensed by the public (private information). Failure to take this into account may result in divergent conclusions.

The second reason is that most studies had a macroscopic focus, and were conducted at the district or metropolitan level. This is likely to cause estimation problems because the wide variations in the many attributes of properties in the same district may introduce too much noise to their models, and thus invalidate their results. Moreover, district-wide pollution data cannot reflect variations in pollution levels at the microscopic level, especially in densely populated areas where local air quality could vary substantially within the same district. A recent survey conducted by Greenpeace (2005) has revealed that some people questioned the reliability of the district-level Air Pollution Index in Hong Kong. Thus, housing prices may not correlate well with district or region-wide air quality data.

4. Research Design

Apart from the functional form problems pointed out by Cropper, *et al*. (1988), there are two main reasons for this inconclusiveness. One is the diverse use of different air pollution measures such as sulphate levels, suspended particulate levels, and visibility by previous studies. It is obvious that some measures have been brought to the public's attention through public announcements (public information), while other measures, notably those compiled by researchers, cannot be easily observed or sensed by the public (private information). Failure to take this into account may result in divergent conclusions. The second reason is that most studies had a macroscopic focus, and were conducted at the district or metropolitan level. This is likely to cause estimation problems because the wide variations in the many attributes of properties in the same district may introduce too much noise to their models, and thus invalidate their results. Moreover, district-wide pollution data, such as API, cannot reflect variations in pollution levels at the microscopic level, especially in densely populated areas where local air quality could vary substantially within the same district. Thus, housing prices may not correlate well with district or region-wide air quality data.

This study uses the hedonic price method to assess the market value of clean air. Our method differs from previous studies in two significant ways. First, we do not rely on publicly available air quality indices but simulate the air quality data on our own. This allows us to disentangle the effect of the genuine response of market participants to variations in air quality from the effect of the air pollution levels announced to the general public. Second, we will examine the relationship between air quality and property prices at a microscopic level so as to reduce district-level noise. Focusing on high-rise residential developments in Hong Kong, the air quality of each individual apartment unit (flat) will be estimated through computational fluid dynamics techniques using a three-dimensional Reynolds-stress turbulence model. In this way, we can account for the vertical variation in air quality that previous studies have always ignored. The simulation results are validated with field measurements. Property transaction prices in the same areas are then be collected to construct a hedonic price model, which includes the flat-specific air quality as one of the explanatory variables.

4.1. The simulation model

The Reynolds Stress Model (RSM) is chosen as the turbulence model used in this simulation. This model is preferred over the more popular k-ε model because the latter does not always ensure an accurate prediction of the air pollutant dispersion in the urban domain, especially near the street canyon where shear is significant (Murakami, *et al.*, 1990).

A three-dimensional numerical model with the commercial code CFX-5 is applied to accomplish this task. This commercial software has the advantage of being able to solve all the hydrodynamic equations as a single system with an advanced solver. It boasts a high processing speed than other software for solving all necessary transport equations. CFX-5 also needs fewer iteration processes to arrive at a converged solution than many other commercial codes.

The governing equations of mass, momentum, and energy conservation in CFX-5 include the *Continuity Equation* (Eq. (1)), the *Momentum Equations* (Eq. (2)), and the *Energy Equation* (Eq. (3)) (Pope, 2000b).

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{U}) = 0, \tag{1}$$

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla(\rho \mathbf{U} \otimes \mathbf{U}) = \nabla(-\rho \boldsymbol{\delta} + \mu(\nabla \mathbf{U} + (\nabla \mathbf{U})^T)) + \mathbf{S}_M, \tag{2}$$

$$\frac{\partial \rho h_{tot}}{\partial t} - \frac{\partial p}{\partial t} + \nabla(\rho \mathbf{U} h_{tot}) = \nabla(\lambda \nabla T) + S_E, \tag{3}$$

$$\frac{\partial C}{\partial t} + \boldsymbol{U} \cdot \nabla C = \nabla\left(\boldsymbol{D} \cdot \nabla C\right) \tag{4}$$

where ρ is the fluid density, t is the time, $\boldsymbol{U}$ is the velocity vector, δ is the idempotent matrix, μ is the fluid dynamic viscosity, $\boldsymbol{S}_M$ is the external momentum sources, h_{tot} is the total fluid enthalpy, T is the temperature, $\boldsymbol{S}_E$ is the external energy sources, C is the pollutant concentration, and $\boldsymbol{D}$ is the combined natural and eddy diffusivity vector. By solving the above equations, we can obtain the detailed air flow and pollutant dispersion pattern within the region under consideration. In effect, the detailed pollutant distribution pattern at any point in space can be calculated accurately using the above model.

4.2. Boundary conditions

In this simulation task, the simulation model is considered a rectangular domain with the dimension L×W×H: 925m x 590m x 270m. It is reasonable to conclude that traffic emissions are the major source of air pollutants in Mongkok, since it is an area of commercial and residential focus. The locations of the air pollution source were set at two major roads in the chosen area, namely Yin Chong Street and Kwong Wa Street. Line source pollutants with accurate emission factors from the Hong Kong Transport Department (2004) were assigned to simulate traffic emissions in the domain.

The boundary conditions for the system are listed in Table 1. The system is set to the non-buoyant buoyancy mode. The reference pressure was 1.01×10^5 Pa. The domain temperature is 288 K in isothermal heat transfer mode. The template fluid is set as air at a standard temperature and pressure. All these boundary conditions are set with regard to the general atmospheric environment of Hong Kong. The maximum finite mesh element with size varied from 3m to 6m. The Reynolds number for this simulation was kept at the order magnitude of 10^7, in reflection of typical airflow of Hong Kong. Based on these boundary conditions, the Reynolds stress model (RSM) model was used to generate the air pollution level for each flat of the buildings in the chosen area (Figure 1). To validate the model, field measurements are conducted to validate the ground level pollutant concentration using real-time particulate matter samplers.

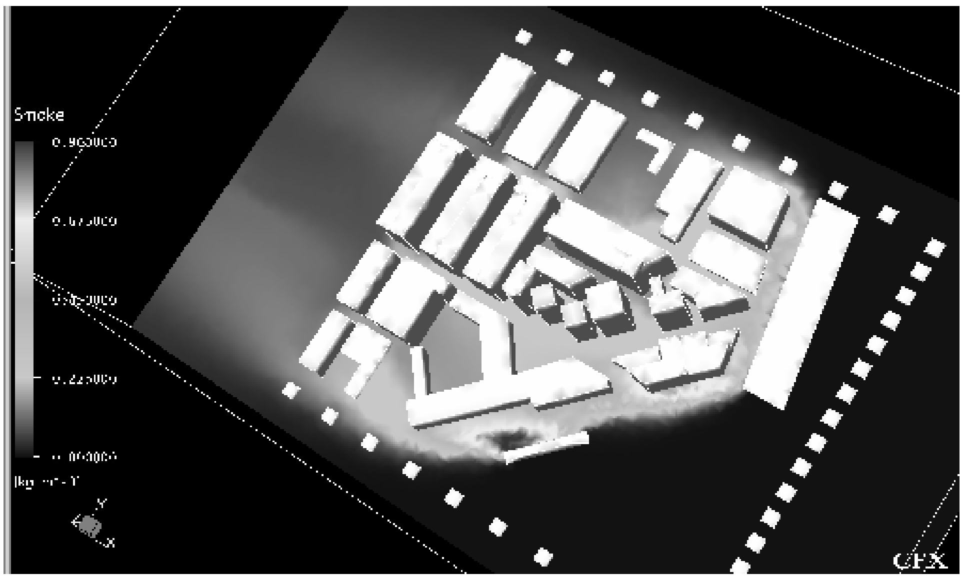
Table 1: Boundary conditions

Surface	Nature	Input Values
1	Wind Inlet	3.0 m/s
2	Ground	Roughness height = 0.01m
3	Wind Outlet	Relative Pressure = 0.0 Pa
4	Atmosphere	Free slip
5	Atmosphere	Free slip
6	Atmosphere	Free slip

4.3. The Hedonic pricing model

Based on the flat-specific air quality data simulated in the previous section, a hedonic pricing model was constructed to examine the relationship between air quality and property prices. This model assumed that property prices (P) are a function of property attributes, one of which is flat-specific air pollution levels (AP). Other relevant attributes of apartment buildings include building age (AGE), the floor level of a flat (*FLR*), flat size (*SIZE*), and development scale (*EST*).[1] Since property transactions do not occur at the same time, time effects have to be controlled with a residential property price index (*TIME*), which is compiled by the Rating and Valuation Department of the HKSAR Government. The buildings in our sample are in very close proximity to each other, sharing highly similar neighbourhood characteristics (e.g. views and access to public transportation). This meant that they need not be incorporated into the model.

Figure 1: Pollutant concentration slice plane – Mongkok



Since hedonic pricing models have often been criticised for their choice of functional forms, three specifications were estimated to allow more flexibility:

$$\ln P = \beta_1 AP + \alpha_0 + \alpha_1 AGE + \alpha_2 FLR + \alpha_3 SIZE + \alpha_4 EST + \alpha_5 TIME + \varepsilon \qquad (5)$$

$$\begin{aligned}\ln P = {} & \beta_1 AP + \beta_2 AP^2 + \alpha_0 + \alpha_1 AGE + \alpha_2 AGE^2 + \alpha_3 FLR + \alpha_4 FLR^2 + \\ & \alpha_5 SIZE + \alpha_6 SIZE^2 + \alpha_7 EST + \alpha_8 TIME + \alpha_9 TIME^2 + \varepsilon\end{aligned} \qquad (6)$$

$$\begin{aligned}P^{(\lambda_0)} = {} & \beta_1 AP^{(\lambda_1)} + \alpha_0 + \alpha_1 AGE^{(\lambda_2)} + \alpha_2 FLR^{(\lambda_3)} + \alpha_3 SIZE^{(\lambda_4)} + \\ & \alpha_4 EST + \alpha_5 TIME^{(\lambda_5)} + \varepsilon\end{aligned} \qquad (7)$$

Eq. (5) is a semi-log model with natural log of property transaction price as the dependent variable.[2] The semi-log model has been commonly used in hedonic studies, partly because natural log transformation on the dependent variable can usually remove heteroskedasticity in the error term. On the right hand side, β and α are the unknown

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1 For simplicity, we defined development scale as a dichotomous measure indicating if a development has more than one tower. *EST* was set to equal 1 if a development has at least two towers (so called an "estate"), and zero if otherwise.

2 Taking log gives marginal effects a convenient interpretation of percentage changes.

coefficients to be estimated, and ε is the error term with a mean of zero. Adding quadratic terms to Eq. (5) becomes the quadratic semi-log model in Eq. (6), which allows for the flexibility of non-linear price effects of the non-dummy variables. Equation (7) is a highly flexible Box-Cox model, which can take many continuous functional forms by applying the transformation $X^{(\lambda)} = (X^{\lambda} - 1) / \lambda$ to each positive variable (X), where λs are free parameters to be estimated empirically. This model includes the linear, semi-log, log-linear, and reciprocal models as special cases. For example, when λ_0 equals zero and λ_1 to λ_5 equal unity, Eq. (7) is reduced to Eq. (5), the semi-log model. The estimated optimal Box-Cox model was tested against special case models to see if any special case models could be used as a good approximation. If all special case models were rejected, a simple non-linear model (with variables transformed using the estimated λ_t's) would be re-estimated using the Ordinary Least Squares (OLS) technique to facilitate a comparison of results across the three models. This allowed us to check the robustness of the results across different specifications of the hedonic price model.

Our central interest lay in the marginal effect of air pollution on property prices, and we added other variables as controls to maintain the *ceteris paribus* condition. Eqs. (5) and (6) are linear in coefficients and can be estimated by the OLS method. Eq. (5) assumes a fixed marginal effect of air quality on property price, which is β_1, while Eq. (6) allows the marginal effect to vary with the level of air pollution, which is $\beta_1+2\beta_2 AP$. Eq. (7) is nonlinear in coefficients and had to be estimated by the Maximum Likelihood Estimation (MLE) method, assuming the error term was normally distributed. The resulting marginal effect is approximately $\beta_1\lambda_1 AP^{\lambda_1-1} / \left(\lambda_0 \overline{P}^{\lambda_0-1}\right)$, where $\overline{P}$ is the expected property price.

5. Empirical Results

Corresponding to the chosen area for the simulation of air pollution levels, our sample of property transactions was collected from 24 apartment buildings in Mongkok, with a total of 1,700 usable transaction records during the period April 1991 to August 2004. Table 2 presents the descriptive statistics of the data.

Table 2: Descriptive statistics

	Variable	Mean	Std dev	Min	Max
Property price (HK$mil)	*P*	1.58	0.72	0.25	5.41
Air pollution level (μg/m^3)	*AP*	0.15	0.11	0.00	0.72
Building age (month)	*AGE*	179.32	92.28	1.00	391.00
Floor level	*FLR*	13.43	7.42	1.00	39.00
Flat size (sq. ft.)	*SIZE*	409.55	134.40	226.00	890.00
Estate development	*EST*	0.32	-	-	-
Price index (100 in year 1999)	*TIME*	100.40	30.44	53.32	172.90

The OLS estimates of Eqs. (5) and (6) are shown in Table 3. The explanatory power of the models is fairly high, with adjusted R-squared values of 84% and 87%, respectively. Most coefficients were also statistically significant at the 1% level and of the expected sign. White's (1980) test revealed the residual exhibited heteroskedasticity. The null hypothesis of homoskedasticity was rejected at the 1% level. Accordingly, we used White's method to adjust for heteroskedasticity. Since the dependent variable was in log scale, the coefficients should be interpreted as a percentage change in property prices, given a unit change in an independent variable. A detailed discussion of the results is given below.

Table 3: OLS results

	Eq. (5) (semi-log)	**Eq. (6) (quadratic semi-log)**	**Eq. (8) (Box-Cox)**
Variable	**Coefficient**	**Coefficient**	**Coefficient**
Constant	-1.010 ***	-1.929 ***	-1.945 ***
Air pollution			
AP	-0.128 ***	0.174 *	
AP^2		-0.608 ***	
$AP^{3.2}$			-0.139 ***
Building age			
AGE	-0.002 ***	-0.003 ***	
AGE^2		$2.38\text{x}10^{-6}$ ***	
$AGE^{0.5}$			-0.011 ***
Floor level			
FLR	0.008 ***	0.005 **	
FLR^2		$1\text{x}10^{-4}$	
$FLR^{0.6}$			0.007 ***
Flat size			
SIZE	0.002 ***	0.005 ***	
$SIZE^2$		$-2.82\text{x}10^{-6}$ ***	
$SIZE^{0.1}$			1.266 ***
Estate			
EST	0.031 ***	0.042 ***	0.009 ***
Time			
TIME	0.007 ***	0.013 ***	
$TIME^2$		$-2.73\text{x}10^{-5}$ ***	
$TIME^{0.2}$			0.331 ***
R-squared	0.843	0.867	0.876
Adj. R-squared	0.843	0.866	0.876

***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

From Eq. (5), the negative and highly significant coefficient of *AP* shows that air pollution has a significant negative impact on property prices. Specifically, an increase of 0.1 $\mu g/m^3$ in the air pollution level (suspended particulates) lowers property prices by 1.28%. This result suggests that homebuyers are concerned about street level air quality, and their concerns, as reflected in property prices, are consistent with our simulated air pollution levels even though they do not have any technical information on the air quality of the flats they purchase. This also means that the property market is more efficient than any studies have implied so far. Such a result is not unreasonable, as people are likely to care more about air quality in densely populated areas such as Hong Kong and gather information on local air quality level through various sources such as real estate agents and, more importantly, repeated site visits (it is very common for prospective buyers to visit apartments several times before they decide to purchase). Moreover, the Hong Kong property market has been very liquid and transparent, thereby facilitating the transmission of information through property prices.

The coefficients of the control variables also showed the expected sign and were consistent with previous results. The negative coefficient of *AGE* is largely a result of physical deterioration of a property. The positive coefficient of *FLR* reflects a better view and quieter environment at higher levels. The positive coefficient of *SIZE* simply shows that larger units are more expensive. The positive coefficient of *EST* supports apartment units in estate type developments that are better managed and share more facilities than units in stand alone buildings. The positive *TIME* coefficient indicates that individual property prices co-move with the general property price level.

Eq. (6), in fact, produces similar conclusions with regard to the negative impact of air pollution on property prices. Since the quadratic terms (except for FLR^2) were significant, the additional insight from Eq. (6) is that the price effects are not linear. For instance, buildings depreciate at a diminishing rate, and the premiums paid for bigger flats rise at an increasing rate. More importantly, the coefficient of AP^2 was negative and significant. This finding suggests that the negative impact of air pollution on property prices increases as the level of pollution increases (see Figure 1). The marginal effects of air pollution on prices was 0.17–1.22 x *AP*, which was positive over a very small range of *AP* (0 <AP < 0.14). Although the quadratic semi-log model showed non-linearity in the marginal effects of air pollution, this specification was not entirely satisfactorily, as the marginal effect (which was 0.17–1.22 x *AP*) was positive over a small range of *AP* (0 <*AP* < 0.14). It is likely that this small anomaly arose due to the fact that the quadratic semi-log functional form was not flexible enough to adequately model the true underlying non-linear relationship between price and air pollution. This problem can be resolved by using the Box-Cox model below.

Finally, the Box-Cox model of Eq. (7) also supports a nonlinear specification, with its transformation parameters reported in **Error! Reference source not found.**. Taking these transformation parameters (up to 1 d.p.) as given, we re-estimated Eq. (7) using the OLS method based on the following functional form:

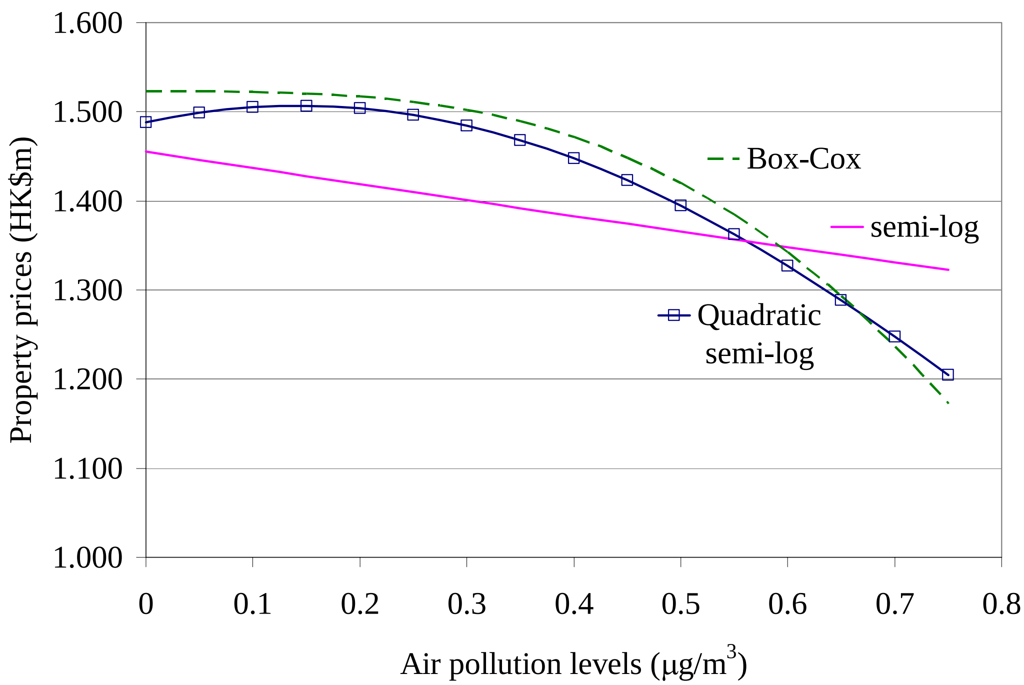
$$\begin{aligned} P^{0.2} &= \beta_1 AP^{3.2} + \alpha_0 + \alpha_1 AGE^{0.5} + \alpha_2 FLR^{0.6} + \alpha_3 SIZE^{0.1} + \\ &\quad \alpha_4 EST + \alpha_5 TIME^{0.2} + \varepsilon \end{aligned} \tag{8}$$

Table 4: MLE estimates of transformation parameters in Eq. (7)

Variable	*P*	*AP*	*AGE*	*FLR*	*SIZE*	*TIME*
Parameter	λ_0	λ_1	λ_2	λ_3	λ_4	λ_5
ML Estimate	0.190	0.452	0.588	0.104	3.173	0.184
***p*-value**	0.000	0.000	0.001	0.160	0.038	0.108

The OLS results of Eq. (8) are shown in the rightmost column of Table 3. All the coefficients not only produced expected signs, but were also highly significant at the 1% level. Based on log-likelihood ratio tests, all the special case models, including the semi-log (Eq. 5) and the quadratic semi-log (Eq. 6) models, were rejected in favour of the Box-Cox model (Eq.8). This means that the Box-Cox model provided a better fit of data than the other models and is considered a better model when no *a priori* information on the functional form of the hedonic price model is available. Most importantly, the coefficient of AP was negative and significant, and its power transformation coefficient λ_1 was larger than one. Given that the derivative of $\overline{P}$ (expected property price) with respect to AP is $P' = \beta_1 \lambda_1 AP^{\lambda_1 - 1} / \left(\lambda_0 \overline{P}^{\lambda_0 - 1}\right)$, which is always negative (as β_1<0, λ_0,λ_1>0) (i.e., the marginal effects of air pollution on property prices are always negative).. Moreover, this negative effect increases (in magnitude) as AP increases, since the second derivative of $\overline{P}$ with respect to AP, namely $P'' = \left(\frac{\lambda_1 - 1}{AP} - \frac{\lambda_0 - 1}{\overline{P}}\right) P'$, was also negative (as λ_1>1, λ_0<1, P'<0). The result reinforced the finding that the negative impact of air pollution on property prices increases as the level of pollution increases (see Figure 1), which suggest that clean air is highly valued, especially in location where the air pollution is high. The results of also provide important information for assessing the value of clean air.

Figure 1: The effect of air pollution levels on property prices



6. Conclusion

This study does not merely set out to confirm the conclusions of many previous studies that air quality is reflected in property prices. Rather, the main contribution of this study is more general in nature – the property market, at least the one subjected to our tests, was more efficient in reflecting external factors, like air quality, than any studies have implied so far, as property prices reflected street level air quality information that was not publicly available. Apart from this, our study is the first to use microscopic air quality and property price data at the individual apartment unit level to control for the effects of other factors that might affect property prices. Our results also suggested that the negative impact of air pollution on property prices is not linear, but increases as the level of pollution increases. Since the negative impact of air pollution on property prices implies that buyers are willing to pay more for a less polluted environment, the approach adopted in this study can also be used to assess the market value of clean air in a densely populated urban area.

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References

ANDERSON, R.J. Jr. and CROCKER, T.D. (1971) Air pollution and residential property value, *Urban Studies*, 8, pp.171-180.

CHATTOPADHYAY, S. (1999) Estimating the demand for air quality: new evidence based on the Chicago housing market, *Land Economics*, 75(1), pp.22-38.

CHAU, K.W., YIU, C.Y., WONG, S.K. and LAI, L.W.C. (2003) Hedonic price modelling of environmental attributes: a review of the literature and a Hong Kong case study, in *Understanding and Implementing Sustainable Development* (eds. L.W.C. Lai and F.T. Lorne), Nova Science, pp.87-110.

CHAY, K.Y. and GREENSTONE, M. (2005) Does air quality matter? Evidence from the housing market, *Journal of Political Economy*, 113(2), 376-424.

CROPPER, M.L., DECK, L.B. and McConnell, K.E. (1988) On the choice of functional form for hedonic price functions, *Review of Economics and Statistics*, 70(4), pp.668-675.

DEMOGRAPHIA (2004), *Hong Kong Urban Area Sectors: 2001 Population & Density*, http://www.demographia.com/db-hkuza1.htm, March 8, 2004.

DEYAK, T.A. and SMITH, V.K. (1974) Residential property values and air pollution: some new evidence, *Quarterly Review of Economics and Business*, 14(4), pp.93-100.

DIAMOND, D.B. (1980) The relationship between amenities and urban land prices, *Land Economics*, 56, pp.21-32.

GRAVES, P., MURDOCH, J.C. and THAYER, M.A. (1988) The robustness of hedonic price estimation: urban air quality, *Land Economics*, 64(3), pp.220-233.

GREENPEACE (2005) *Hongkongers demand accurate API*, http://www.greenpeace.org /china/en/press/releases/hongkongers-demand-accurate-ap, February 24, 2005.

HARRISON, D. Jr. and RUBINFELD, D.L. (1978) Hedonic housing prices and the demand for clean air, *Journal of Environmental Economics and Management*, 5, pp.81-102.

HONG KONG ENVIRONMENTAL PROTECTION DEPARTMENT, *Air Pollution Index*, Hong Kong SAR Government, http://www.epd-asg.gov.hk.

HONG KONG TRANSPORT DEPARTMENT (2004), *The Annual Traffic Census 2004*, Hong Kong SAR Government.

LI, M.M. and BROWN, H.J. (1980) Micro-neighborhood externalities and hedonic housing prices, *Land Economics*, 56(2), pp.125-140.

MURAKAMI, S., MOCHIDA, A., and KAZUKI, H. (1990) Examining the k-e model by means of wind tunnel test and large-eddy simulation of the turbulence structure around a cube. *Journal of Wind Engineering and Industrial Aerodynamics* 35, pp. 87-100.

MURDOCH, J.C. and THAYER, M.A. (1988) Hedonic price estimation of variable urban air quality, *Journal of Environmental Economics and Management*, 15(2), pp.143-146.

NELSON, J.P. (1978) Residential choice, hedonic prices, and the demand for urban air quality, *Journal of Urban Economics*, 5(3), pp.357-369.

POPE, C.A., III. (2000a) Review: epidemiological basis for particulate air pollution health standards, *Aerosol Science and Technology*, 32(1), pp.4-14.

POPE, S.B. (2000b) *Turbulent Flows*, Cambridge University Press.

RIDKER, R.G. and HENNING, J.A. (1967) The determinants of residential property values with special reference to air pollution, *Review of Economics and Statistics*, 49(2), pp.246-257.

ROSEN, S. (1974) Hedonic prices and implicit markets: product differentiation in pure competition, *Journal of Political Economy*, 82, pp.34–55.

SMITH, V.K. and DEYAK, T.A. (1975) Measuring the impact of air pollution on property values, *Journal of Regional Science*, 15(3), pp.277-288.

SMITH, V.K. and Huang, J. (1995) Can markets value air quality? A meta-analysis of hedonic property value models, *Journal of Political Economy*, 103(1), pp.209-227.

WARGOCKI, P., WYON, D.P., SUNDELL, J., CLAUSEN, G. and OLEFANGER, P. (2000) The effects of outdoor air supply rate in an office on perceived air quality, Sick Building Syndrome (SBS) symptoms and productivity, *Indoor Air*, 10(4), 222-236.

WHITE, H. (1980) A heteroskedasticity-consistent covariance matrix and a direct test for heteroskedasticity, *Econometrica*, 48, pp.817-838.

WIEAND, K.F. (1973) Air pollution and property values: a study of the St. Louis area, *Journal of Regional Science*, 13(1), pp.91-95.

ZABEL, J.E. and KIEL, K.A. (2000) Estimating the demand for air quality in four U.S. Cities, *Land Economics*, 76(2), pp.174-194.