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Valuing Environmental Impact of Air Pollution in Moscow with Hedonic Prices

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***Abstract*—**The main purpose of this research is the calculation of implicit prices of the environmental level of air quality in the city of Moscow on the basis of housing property prices. The database used contains records of approximately 20 thousand apartments and has been provided by a leading real estate agency operating in Russia. The explanatory variables include physical characteristics of the houses, environmental (industry emissions), neighbourhood socio-demographic and geographic data: GPS coordinates of each house. The hedonic regression results for ecological variables show «negative» prices while increasing the level of air contamination from such substances as carbon monoxide, nitrogen dioxide, sulphur dioxide, and particles (CO, NO_2, SO_2, TSP). The marginal willingness to pay for higher environmental quality is presented for linear and log-log models.

***Keywords*—**Air pollution, environment, hedonic prices, real estate, willingness to pay.

I. Introduction

INVESTIGATIONS in the field of environmental economics are more frequent due to an increasing concern of the population for environmental problems. In recent decades, numerous national and international studies have shown that air pollution affects health, contributing to premature mortality and morbidity [1]-[3]. These studies challenge the city authorities to reduce the level of air pollution produced by industrial development and assess potential costs and benefits associated with its reduction [4].

A problem of assessing the benefits of clean air is the non-existence of the market, as in the case of other environmental goods. For this reason, two types of techniques have been developed in environmental economics in order to estimate the value of these assets: revealed preferences and stated preferences. The main difference between them is that the first one uses a real market and the second one is based on a hypothetical market. Both aim to calculate the willingness to pay (WTP) for improvements in environmental quality, or willingness to receive as a form of compensation for worse conditions.

The stated preference techniques are based on surveys and include the following methods: Contingent Valuation, Choice Experiments, Structural Equations and Delphi. Among them, the most widely used method is the Contingent Valuation, developed by Hanemann [5].

The techniques of revealed preferences include Travel Costs and Hedonic Prices (HP). Travel cost is used to assess environmental goods like forests, parks, lakes. The value is measured by the cost of travel and the number of visits.

In this study we employ the technique of Hedonic Prices for its advantage of using real market prices rather than imaginary prices. The hedonic price is defined as the implicit price of the attributes of differentiated products. The term "hedonic" has Greek roots. The price is called "hedonic" by the "pleasure" (in economic terms, utility) that the buyer obtains for the quality of the characteristics of the goods.

In case of air pollution, HP studies use housing market data and include the level of air pollution or distance to industries as one of the attributes. The expectations are that properties in areas with greater exposure to environmental contamination experience lower prices compared with properties in less polluted areas.

This study intends demonstrate the negative impact of air pollution externalities on housing prices in Moscow. The author believes that this is a first application of the HP method in Russia. The hypothesis is that, ceteris paribus, homes located in areas with less air pollution will have relatively higher prices.

To apply the method of HP a database of about 20 thousand flats was used, containing prices, structural characteristics, district socioeconomic data, and industry emission levels. The data source of housing has been provided by a leading real estate agency operating in the country: “Mian”.

The structure of this work is as follows: Section II reviews previous hedonic studies related to air pollution. Section III details the hedonic methodology; Section IV presents the empirical study: variables source and description. Section V includes the results, and finally Section VI cites conclusions and implications for the following investigations.

II. Literature Review

The first application of environmental hedonic price was conducted by Ridker and Henning in 1967 in USA in order to demonstrate the detrimental effect of air pollution to the housing prices [6]. The pollution measures were levels of sulphate and particles. The result of this study was the significant impact of air quality: reducing the sulphate level on 0.25 mg/day increased the value of houses between \$84 and \$245 (\$ 1960).

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Many of the first hedonic studies were conducted in the United States. Recently the hedonic method is applied in many countries of Europe, Asia and Latin America [7]-[9].

Most works are limited to the first stage of the HP method, estimating the implicit price of attributes. Relatively few studies, conducted the 2nd step, which consists of estimating the parameters of demand function [10]-[12].

In most studies the dependent variable is the price of housing. However, in [13] the dependent variable is the price per square meter of property, announced by agency, although in this case the fit quality is relatively low.

Regarding the source of the price data, some studies use the offer price [14], or estimated by the owner [11], and relatively few studies use the price of purchase transaction [15]. The reason might be due to difficulties in obtaining the data.

The explanatory variables included traditionally by authors are that of construction, like area in square meters, number of bedrooms, number of bathrooms, garage, age (year of construction). Some authors introduce interesting new variables, such as orientation to the sun - north, south, east or west [13].

Other important variable is the accessibility, which relates housing units with the city centre and some areas of interest: commercial zones, industries, parks, lakes and rivers, etc. These variables can be represented in the form of distance (km), time required to reach the zone, dummy (1 if the area is relatively close and 0 otherwise) or number of points of interest in the district (area). One of the most comprehensive studies with accessibility measures was conducted in [16].

The pollution variables, used in hedonic studies, are mostly physical measures such as annual average or maximum daily concentrations of CO, NO_2, TSP, SO_2, and other pollutants [10], [16]-[18]. In recent works with spatial statistics the GIS coordinates are used to calculate the distances between homes and "hazards", which can be industrial zones, power plants, landfills or other sources of pollution. They are called "hazard" because they represent danger to the closest residents. One of the example studies of spatial statistics is done in [15].

Other explanatory variables included in some hedonic studies are the socio-economic of neighbourhood: household income, percentage of whites, level of taxes, school quality, percentage of families with children, crime rates, etc. [10], [11], [17]-[19].

Finally, data on the buyer or owner are included in few hedonic studies as explanatory variables, due to the difficulties in obtaining them. Among possible variables are: income, family size, marital status, or race, among others [11], [18].

Several studies have used the hedonic method in other fields of environment, such as noise, odours, visibility, vicinity to landfills, contaminated water or soil, and so on [9], [12], [14], [20]. The review of hedonic studies related to the environment is offered by Boyle and Kiel in [21].

III. Methodology

The theoretical foundations of the hedonic method were developed by Sherwin Rosen in 1974 for heterogeneous or differentiated products [22]. Product differentiation implies that there is a wide range of alternatives between products. Another assumption about the product is the indivisibility, proposed by Lancaster [23]. It implies that products can not be divided nor attributes sold separately. The hedonic prices are defined as the implicit prices of the attributes of differentiated products, revealed from the observed prices.

The HP method consists of 2 steps. In the first step the equation is estimated and the implicit prices of the characteristics (marginal WTP) are calculated from the regressions. The second step estimates the parameters of the demand function of the characteristic of interest. Rosen proposed to use the marginal price of the first step as a dependent variable and socio-economic variables of consumers as explanatory variables ("Demand Shifters") [22]. This part of Rosen's work generated many discussions in the literature.

Most research studies are limited to the first step of the HP method, calculating the implicit price of attributes. The reason is that the second stage requires to have data from multiple markets [22], separated spatially or temporally. This study also conducts the first step of the hedonic model.

Let´s consider the housing market. A house is a differentiated product that consists of several attributes (z_1 to z_n) such as physical construction, ecological, social, neighbourhood, etc.

$$Z = (z_1, z_2, z_3 ... z_n) \quad (1)$$

The market reveals prices that correspond to each type of house. Therefore, the price of housing is determined by a combination of characteristics:

$$P_i(Z) = P(z_{1i}, z_{2i}, z_{3i} ... z_{ni,} u_i) \quad (2)$$

where P_i - price of housing, z_{ni} - characteristics (attributes) of housing and u_i - statistical error of estimation.

The value that individuals pay for improvements in extra unit of an attribute (quality of air) determines the WTP or the marginal implicit price. It is calculated as the partial derivative of the HP function with respect to one of its arguments:

$$MDAP_i = \partial P(Z) / \partial z_i \quad (3)$$

In case studies of the pollution effects, it is important to note that the method is applicable only when the population is aware of the existence of environmental externalities, and is free to choose an alternative in the market. Otherwise the significant relationship with house prices could not be perceived [14].

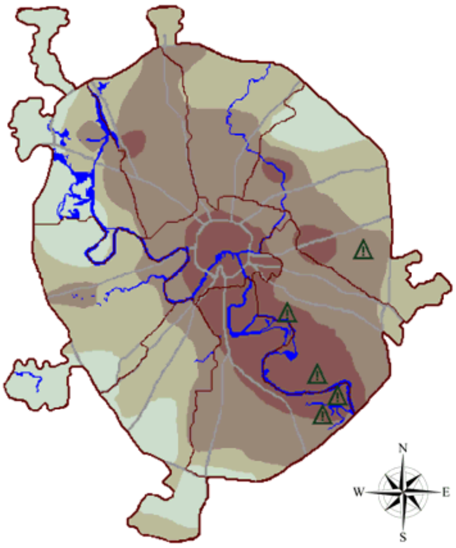

Fig. 1 Ecological map of Moscow

IV. Empirical Study

A. Ecological Situation in Moscow

Moscow is an industrial city with a high level of construction growth and population immigration, and as a consequence, with major problems of air pollution. Nowadays the population of Moscow exceeds 10 million inhabitants.

According to "MosEcoMonitoring" the basic source of the contaminating substances in the atmosphere of the city is auto transport (83%), followed by emissions from industrial companies (11%). The power plants are responsible for approximately 6% of the total volume of pollution.

In the territory of Moscow operate 31 thousand objects of industry and construction, 13 power plants and thermal stations, 63 regional and quarterly thermal stations and over a thousand small boilers. Thermal energy companies in Moscow use primarily natural gas. The most significant substance present in the waste is nitrogen dioxide. The geographical distribution of industries and energy companies is not homogeneous across the city; therefore the volume of emissions in the atmosphere is different between districts.

The highest level of contamination is in the vicinity of the main avenues in the Central district. Other most contaminated area is the southeast, due to the wind rose. In Fig. 1 the ecological map of Moscow is presented, where lighter areas correspond to lower levels of air contamination.

B. Data Source

As mentioned, the price and the physical characteristics of the dwellings have been provided by a real estate agency "Mian". The prices used are those of supply in November 2007. The final number of observations is 21,158 flats, after the process of database purification.

The socioeconomic data were obtained from 2 sources:

• Official site of "MosGorStat", Moscow statistics state body, for the data by administrative areas in 2006, and

• Project "Citysoft", for the data at the district level, year 2005.

The pollution data are industry emissions by administrative areas (in tons) and come from the "Annual statistical report of "MosGorStat" for atmospheric air in Moscow in 2006".

The GPS coordinates of each house were obtained from the Google maps site.

C. Classification and Description of Variables

The explanatory variables could be classified into 4 groups: construction and quality, accessibility, contamination, and neighbourhood. The list of variables with their definition, descriptive statistics, and expected sign could be seen in Tables I and II.

The construction and quality variables traditionally used are: area in m^2, number of bedrooms, garage, age of building and number of bathrooms [16], [18], [19]. For this study the following physical parameters of the flat were obtained: area in m^2, kitchen area in m^2, number of bedrooms, number of bathrooms, balconies, ceiling height, construction material (brick, stone, block), and added value characteristics like Jacuzzi, sauna, garage, etc.

The accessibility variable used in most hedonic studies is the distance to the centre [11]. Historically, a zero kilometer in Moscow is located at the entrance to Red Square, Kremlin. Therefore, in this study the variable distance to the centre is used, taking the Red Square as the starting point. The expected sign of this variable is negative, as more distance from the centre would lower the price of the apartment. Each flat of the sample was assigned its own distance.

A new variable of accessibility used in this study, is the distance to the metro, also for each flat. Traditionally flats near metro stations in Moscow are in more demand and therefore higher prices. We expect the impact of this variable is significant and negative, although less important compared to the variable accessibility to the centre.

The variables of contamination included comprise of the following industry emissions of pollutants by the administrative area in tons: particulates (TSP), sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbons (HC).

Regarding neighbourhood variables, the data used in hedonic studies include income, quality of schools, levels of crime and population density [15]. Income and crime data were not included due to the difficulty of obtaining them. As for colleges and other institutions (kindergartens, universities), their distribution by districts and zones is incorporated. Their frequency could cause variability in the choice of a better neighbourhood. The variables of theatres and museums number reflect a cultural development of the area and could also be defined as variables of accessibility to these places.

The socio-economic variables differ by the level of data collection (district or area) and can be distinguished by the first letter D or AO, which correspond to district or administrative zone respectively. Moscow is divided into 10 administrative zones and 123 districts.

TABLE I
NUMERIC VARIABLES: DESCRIPTIVE STATISTICS, DEFINITION AND EXPECTED SIGN

	N	Min	Max	Media	St. div.	Definition	Source	Exp. Sign
Dependent:								
PRICE_MIL$	21155	42	10204	383,1	383,0	Total flat price, thou.$	1	
PRICE_M2*	21155	1183	20000	5399,6	2232,6	Flat price per m2	1	
Independent variables:								
Construction and quality:								
Floor*	20189	1	45	6,6	4,9	N of floor	1	no
Total_floors*	19902	1	49	12,3	5,8	Total floors in the building	1	no
N_rooms	21155	1	12	2,3	1,0	Total N of rooms	1	+
AREA_TOT	21155	12,9	700,0	65,8	34,6	Total flat area, m^2	1	+
AREA_LIV	19515	8,0	305,0	37,7	19,8	Total living area, m^2	1	+
AREA_KITCH	19325	3,0	60,4	9,4	3,5	Kitchen area, m^2	1	+
CEILING_H	2274	2,0	4,0	3,1	0,3	Ceiling height, m	1	+
N_bathroom	10223	1	4	1,2	0,4	N of bathrooms	1	+
N_Balcon	14587	0	5	1,1	0,6	N of balconies	1	+
Accessibility								
Dist_H_centre	21155	0,693	39,620	11,3	5,8	Dist. to city centre, km	G	-
Dist_H_metro	21155	0,004	28,203	1,9	2,6	Dist. to nearest metro, km	G	-
Environment						Emissions of (ton):		
Emis_TSP	21045	7	550	172,7	144,8	Total suspended particles	2	-
Emis_SO2	21045	0	9003	2605,9	2538,8	sulphur dioxide	2	-
Emis_CO	21045	182	1120	529,7	257,9	carbon monoxide	2	-
Emis_NOx	21045	435	7841	4370,2	2443,8	nitrogen dioxide	2	-
Emis_HC	21045	2	4743	470,6	1353,9	Hydrocarbons	2	-
Neighbourhood socio-demographic								
D_School	21019	1	30	13,6	5,6	N of public schools	3	+
D_Kinderg	21017	1	37	19,0	8,1	N of kindergartens	3	+
D_pub_tr_stops	20955	10	161	79,0	31,5	N of public transport stops	3	+
D_Itinerary	20953	10	505	232,3	100,5	N of transport itineraries	3	+
D_Fire_gen	20955	0	9	2,6	2,0	N of fires in general	3	-
D_Fire_hous	20955	0	8	1,7	1,6	N of fires in housing	3	-
AO_PoblKm2	21155	6	12	9,8	1,6	Population per km2	4	+
AO_NetMort	21155	589	6985	3775,0	1540,5	Net mortality, pers.	4	-
AO_Migrat	21155	1211	9571	5857,1	2331,6	N of immigrants, pers.	4	-
AO_Unempl	21155	1496	6495	3593,1	1445,3	N of unemployed, pers.	4	-
AO_UnivPubl	21155	2	41	12,9	12,1	N Public Universities	4	+
AO_UnivPriv	21155	0	56	15,8	16,7	N Private Universities	4	+
AO_teatre	21155	0	67	12,5	22,4	N theatres	4	+
AO_museum	21155	1	41	8,0	13,6	N museums	4	+
AO_hospital	21155	3	30	16,5	7,1	N hospitals	4	+
AO_hazards	21155	8	78	55,5	18,6	N hazards	4	-

* Only descriptive statistics (not included in regression).

TABLE II
DUMMY VARIABLES: DESCRIPTIVE STATISTICS, DEFINITION AND EXPECTED SIGN

Dummies	Dummy=1	Dummy=1 (%)	Dummy=0	Dummy=0 (%)	Definition	Source	Exp. Sign
Construction and quality							
Ground_floor	1700	8,0	18493	87,4	Flat on the ground floor	1	-
brick	5361	25,3	15794	74,7	Constr. material - brick	1	+
monolith	1773	8,4	19382	91,6	Constr. material - monolith	1	+
panel	7469	35,3	13686	64,7	Constr. material - panel	1	-
Garage*	1343	6,3	19812	93,7	Flat with a garage place	1	+
Attic_2floor*	166	0,8	20989	99,2	Penthouse or 2 level flat	1	+
jacuzzi_sauna*	305	1,4	20850	98,6	Jacuzzi or sauna built-in	1	+
Guard*	597	2,8	20558	97,2	Private guard in building	1	+
video_surv*	448	2,1	20707	97,9	Video surveillance	1	+
Reception*	2051	9,7	19104	90,3	Receptionist at the entrance	1	+
Furniture*	2081	9,8	19074	90,2	Furniture built-in	1	+
Neighbourhood							
lake_river*	474	2,2	20681	97,8	Lake or river in vicinity	1	+
Silence*	1755	8,3	19400	91,7	Silent area	1	+
Green*	1628	7,7	19527	92,3	Green area	1	+

* The dummies were created using the comments of property owners in the supply database and may not fully reflect the information, so that a flat without any comments might have the same qualities. In any case the value of the table is a guaranteed minimum.

Sources: 1) real estate agency “Mian”, Moscú (www.mian.ru); 2) Statistical report “MosGorStat”; 3) Project “Sitysoft” (http://citysoft.mosmap.ru/); 4) Official page of “MosGorStat” (www.mosstat.ru); G) generated variable with GPS coordinates.

The variable AO_NetMort (net mortality) is related to AO_hazards (number of polluting industries by zone). The correlation of Pearson equals 0.599 (Sig = 0.01). While explaining mortality is not the aim of our study, if we perform a simple regression, the results show that an additional industry plant causes 50 deaths annually. Y = 1024.8 + 49.6 X (R^2 = 0.359).

V. Estimation of the Hedonic Equation

This section aims to estimate the hedonic equations for the real estate market of Moscow and to calculate the willingness to pay for marginal changes in air quality using the statistical package SPSS.

Market segmentation: It is necessary to decide the size of the market and the need for segmentation. Goodman [25] defines a housing market as the geographic area where the price per unit of service (attribute) is constant and the individual characteristics are available for purchase. In practice the authors assume one market for the same city. In this study the territory of Moscow is also defined as a single market.

Functional form: Regarding the hedonic equation, there are few indications of the best functional form in the literature. Authors often present results of estimates of several functional forms, such as linear, log-linear, log-log, or Box-Cox [10], [11]. In this paper 2 functional forms are used: linear and log-log.

Heteroskedasticity test: Goldfred & Quandt test was applied in order to contrast if the variance is related to one of the explanatory variables in the regression model [26], **Error! Reference source not found.**. The results show heteroskedasticity. Therefore, the estimator applied is generalized least squares (GLS).

A. Linear Model

The first model to be estimated is the linear model, which takes the price as the dependent variable in thousands of $, and explanatory variables without any transformation (see Table II).

In order to avoid the multicolinearity problem some highly related variables were excluded from the equation. Most of the social variables (number of public universities, private universities, theatres, museums and hospitals) are highly related, with the highest Pearson coefficient reaching 0.959. In the final regression these variables are represented with the number of public universities.

As for pollution data, the correlations between emissions of TSP, SO_2, CO and HC are also high (0.832 - 0.916). Therefore, separate regressions for each pollutant are performed. In this case the value of beta is overestimated for this pollutant. However, the vast majority of hedonic studies use a single variable of pollution in one equation.

The variables included in the final regression show stability in alternative equations and expected signs. The level of significance for all variables is 99% (Sig = 0.01), all t-ratios > 2. As for the fit quality, the adjusted R^2 is between 0.722 and 0.724, implying that the equation can explain 72% of cases. Finally, the model has no multicolinearity problem, IC < 30.

TABLE III
RESULTS OF THE LINEAR MODEL HEDONIC REGRESSION

Variables	TSP		SO_2		CO		NO_x		Hydrocarbons	
	β	t	β	t	β	t	β	t	β	t
(Constante)	**-92,506**	-14,567	**-93,334**	-14,764	**-82,591**	-12,979	**-96,145**	-15,182	**-87,899**	-13,855
AREA_TOT	**5,428**	129,933	**5,422**	130,359	**5,421**	130,098	**5,412**	130,039	**5,428**	130,096
Ground_floor	**-15,785**	-8,042	**-16,251**	-8,313	**-16,208**	-8,277	**-15,712**	-8,037	**-16,035**	-8,177
Brick	**15,792**	9,439	**15,596**	9,365	**15,748**	9,441	**16,620**	9,979	**15,562**	9,310
panel	**-8,447**	-5,900	**-8,542**	-5,996	**-8,565**	-6,002	**-9,354**	-6,563	**-8,385**	-5,866
jacuzzi_sauna	**54,095**	6,565	**53,905**	6,570	**53,744**	6,539	**54,694**	6,664	**53,973**	6,558
Guard	**77,384**	13,187	**77,113**	13,197	**77,441**	13,231	**78,186**	13,376	**77,128**	13,159
furniture	**13,145**	6,477	**13,173**	6,519	**13,218**	6,530	**13,115**	6,488	**13,184**	6,505
video_surv	**16,756**	3,290	**17,033**	3,359	**16,940**	3,335	**16,151**	3,184	**16,927**	3,328
reception	**12,757**	5,966	**12,868**	6,047	**12,619**	5,921	**10,977**	5,155	**13,180**	6,169
Dist_H_centro	**-5,336**	-37,812	**-5,382**	-38,304	**-5,382**	-38,236	**-5,195**	-36,846	**-5,461**	-38,646
D_Kinderg	**,353**	4,552	**,435**	5,725	**,413**	5,397	**,269**	3,622	**,372**	4,855
AO_SchoolPriv	**1,409**	9,885	**1,819**	13,902	**1,296**	9,386	**3,692**	20,018	**1,219**	8,431
AO_UnivPubl	**2,235**	30,953	**1,999**	26,954	**2,001**	26,341	**1,608**	18,272	**2,331**	33,333
AO_hazards	**-,490**	-10,698	**-,536**	-14,956	**-,345**	-7,565	**-,631**	-18,562	**-,633**	-18,203
N_bathroom	**72,541**	14,385	**73,504**	14,636	**73,979**	14,702	**73,428**	14,616	**72,617**	14,417
AREA_KITCH	**5,419**	18,223	**5,484**	18,521	**5,420**	18,281	**5,326**	17,990	**5,469**	18,406
lake_river	**12,315**	2,968	**11,893**	2,879	**12,492**	3,018	**11,236**	2,718	**12,133**	2,928
garage	**11,775**	2,865	**11,137**	2,721	**11,843**	2,889	**11,574**	2,827	**11,504**	2,802
Emis_TSP	**-,046**	-7,761								
Emis_SO2			**-,004**	-14,720						
Emis_CO					**-,043**	-12,438				
Emis_NOx							**-,005**	-14,280		
Emis_HxCx									**-,005**	-10,185
Adjusted R^2		*0,722*		*0,724*		*0,723*		*0,724*		*0,722*

Interpretation of Results: As expected, the variable "Total area" is of utmost importance or explanatory power (t = 130). For every meter of the total area of the flat the price increases \$5.4 thousand. A flat on the ground floor costs about \$16 thousand less. A brick construction of the building is valued \$15-16 thousand and, conversely, a panel construction depreciates a flat by \$8.4-9.4 thousand.

Among the attributes of luxury, the greatest value is given to guards in the building (\$77-78 thousand), Jacuzzi or sauna adds \$53-54 thousand, and extra bathroom increases the price by \$72-73 thousand. The highest explanatory power after the total area belongs to the distance to the centre (t-ratio = -37.812). With each kilometre away from downtown the price diminishes by \$5.3 thousand.

Our variable of interest is air pollution emissions. In all equations the effect is negative and significant. Specifically, for every ton of TSP house prices down \$46. If we introduce the CO equation, the effect is \$43. For SO_2 the effect is \$4, and for HC and NO_x is \$5. These values represent the implicit price or the marginal willingness to pay for air quality.

B. Logarithmic Model

The dependent variable is the neperian logarithm of the price. The results of the regressions are presented in Table IV. The quality of fit (R^2) is 0.89, a good result compared to other hedonic studies (0.70 on average).

As mentioned, the interpretation of the coefficients of the logarithmic model is based on elasticity. If the variable is transformed, 1% change in this variable causes a change of β% in house price. However, if the variable is not transformed (dummies, N bathrooms), the change in 1 unit of the variable causes a change in (β * 100)% of the price.

1) Interpreting Results: Variables without Transforming

The coefficient for a number of bathrooms is 0.087, which means that for an additional bathroom a flat price increases a 8.7%. A ground floor discounts 7.3%. A brick building adds to the value 2.3% and a panel construction lowers it 3.6%. An apartment with a Jacuzzi or sauna would cost 11.1% more. Guards remain leaders in the added value on the price among the specific qualities of the flat, accounting for 13.6%.

Regarding neighbourhood social variables, its impact is significant, although very small. For example, each kindergarten in the district increases the flat price by 0.1%. The same impact is caused by public universities. In contrast, private schools elevate the price by 0.8%.

Two variables related to the environment (apart from industry emissions) are hazards and lake-river. Both are significant and with expected sign. For each hazard more in the area the flat value loss is 0.2%. However, the proximity to a lake or river is appreciated by 4.2% of the total price of the apartment.

2) Interpreting Transformed Variables

The total area preserves the largest explanatory power (t = 201), with 1% larger total area the price rises by 0.923%. Also, with 1% bigger kitchen area the price ascends by 0.156%. As expected, the effect of distance to city centre and the metro is negative. Distancing from the centre 1% represents a loss of flat value of 0.257%. Similarly, while moving away from the metro area 1% of the distance, the price of a flat drops by 0.043%.

TABLE IV
RESULTS OF THE LOG LOG MODEL HEDONIC REGRESSION

Variables	TSP		SO_2		CO		NO_x		Hydrocarbons	
	B	t	B	t	B	t	B	t	B	t
(Constante)	**2,173**	104,344	**2,156**	105,957	**2,367**	79,556	**2,412**	94,847	**2,111**	105,323
LN_Tot_AREA	**,923**	201,874	**,922**	201,121	**,923**	201,782	**,922**	202,785	**,923**	202,607
Ln_Kitch_AREA	**,156**	26,848	**,154**	26,454	**,156**	26,692	**,154**	26,572	**,157**	27,032
N_bathroom	**,087**	13,401	**,087**	13,431	**,088**	13,496	**,087**	13,537	**,088**	13,683
Ground_floor	**-,073**	-15,941	**-,073**	-16,068	**-,073**	-16,010	**-,073**	-16,150	**-,073**	-16,188
brick	**,023**	6,208	**,023**	6,302	**,023**	6,316	**,024**	6,562	**,023**	6,222
panel	**-,036**	-11,507	**-,040**	-12,489	**-,038**	-11,868	**-,040**	-12,543	**-,037**	-11,846
jacuzzi_sauna	**,111**	8,319	**,112**	8,368	**,111**	8,261	**,113**	8,505	**,111**	8,317
guardia	**,136**	13,653	**,137**	13,767	**,136**	13,701	**,137**	13,817	**,136**	13,735
Furniture	**,061**	13,755	**,062**	14,016	**,061**	13,852	**,061**	14,017	**,061**	13,925
video_surv	**,050**	5,103	**,050**	5,046	**,050**	5,074	**,049**	5,000	**,051**	5,190
reception	**,052**	11,436	**,053**	11,624	**,052**	11,530	**,050**	11,265	**,053**	11,850
LN_dist_Centre	**-,257**	-67,079	**-,249**	-63,236	**-,254**	-65,563	**-,255**	-66,855	**-,255**	-66,821
LN_dist_Metro	**-,043**	-27,350	**-,043**	-26,762	**-,043**	-27,119	**-,043**	-27,355	**-,042**	-26,481
D_Kinderg	**,001**	8,277	**,001**	7,572	**,001**	7,739	**,001**	7,649	**,001**	8,653
AO_SchoolPriv	**,008**	28,425	**,011**	35,918	**,009**	30,172	**,013**	37,576	**,007**	20,536
AO_UnivPubl	**,001**	4,575	**-,001**	-2,563	**,000**	2,455	**,000**	-2,377	**,001**	5,802
AO_hazards	**-,002**	-17,473	**-,004**	-48,631	**-,003**	-23,861	**-,004**	-49,684	**-,002**	-23,380
Lake-river	**,042**	4,600	**,039**	4,326	**,040**	4,437	**,039**	4,323	**,041**	4,496
garage	**,056**	7,889	**,053**	7,491	**,056**	7,863	**,054**	7,646	**,055**	7,780
LN_EmisTSP	**-,030**	-12,251								
LN_EmisSO2			**-,014**	-17,777						
LN_EmisCO					**-,053**	-11,866				
LN_EmisNOx							**-,045**	-19,405		
LN_EmisHC									**-,016**	-17,125
Adjusted R^2	*0,887*		*0,888*		*0,887*		*0,889*		*0,888*	

TABLE V
MARGINAL WILLINGNESS TO PAY FOR AIR QUALITY, $$

Pollution variables Emissions of:	*M WTP per 1 unit change*	*M WTP per 1% change*
	Linear model	Log-log model
TSP	46	114,6
CO	43	53,48
SO_2	4	202,46
NO_x	5	171,90
HC	5	61,12

Further the results of pollution variables are interpreted. An increase of 1% in emissions of TSP carries a negative effect on the price of 0.03%. Knowing that the average price of an apartment is $382 thousand, the marginal willingness to pay to reduce the level of emissions of TSP in 1% equals $114.6. The results of other equations are the following: marginal WTP to reduce SO_2 emissions in 1% equals $53.48, for CO is $202.46, and for NO_x and hydrocarbons are $171.9 and $61.12 respectively.

In Table V the results of the linear and logarithmic models are summarized and the willingness to pay for marginal changes in air quality is presented.

These results are comparable with other studies. Chattopadhyay [18] estimated that the marginal WTP for PM_{10} is between $268 and $363, and according to [10] it is between $60-70 per 1 mcg/m^3. Smith & Huang **Error! Reference source not found.** presented the list of results marginal WTP of hedonic studies between 1967 and 1988, where the range is between $0.4 and $366 (1982-84). Some of the estimates are between $159 and $234 **Error! Reference source not found.**, $17 to $33 **Error! Reference source not found.**, from $116 to $138 **Error! Reference source not found.**, from $0.4 to $174 **Error! Reference source not found.**, $366 **Error! Reference source not found.**, from $159 to $191 **Error! Reference source not found.**, and $141 to $191 **Error! Reference source not found.**.

VI. CONCLUSIONS

In this study the hedonic pricing method is applied to the housing market of Moscow in order to find and quantify the effect of air pollution on housing prices. A comprehensive database of 20 thousand flats was used, where physical characteristics of apartments, neighbourhood data, and multiple pollutants emissions data were joined. The sample is representative and covers all areas of the city.

The results confirm the assumption that individuals perceive the level of contamination and take it into account when choosing a home. This way an indirect market of the environmental quality is created, generating implicit prices for cleaner air. The results of regressions suggest that the effect on price is small but significant. According to the linear model estimates, the marginal WTP to emissions reduction in a ton ranges from $5 ($NO_x$, HC) to $43-46 (TSP, CO).

The limitations of this study are the following:

Firstly, the prices represent apartment supply, not transactions data. Secondly, a lack of some important variables such as the age of buildings, noise & crime levels, which hindered including them in the regressions.

Implications for economists, ecologists, real estate agencies and city authorities could be cited. As for real estate agencies, the hedonic method is a complex tool that facilitates the estimation of housing prices by multiple characteristics. As for the city authorities, the results of this study could be taken into account in a cost-benefit analysis to evaluate possible reduction costs of air pollution in the city.

Future studies will be necessary to apply spatial statistics and flexible functional forms such as the Box-Cox transformation. With the sample enlarged, the second stage of the hedonic model can be implemented and benefits for non-marginal reductions in pollution can be calculated.

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