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Hedonic housing prices and the marginal willingness to pay for pollution abatement in Ontario, Canada

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The aim of this study is to utilize a revealed-preferences approach to estimate the marginal willingness to pay for pollution abatement based on the toxicity levels of pollutants listed under the National Pollutant Release Inventory in Ontario, Canada. The results from the spatial hedonic price model applied to the housing market reveal that the estimated price and income elasticities, and the marginal willingness to pay for pollution abatement accord well with expectation. Overall, the results indicate that in 2006 the cumulative marginal willingness to pay to abate a tonne of pollution in Ontario was $8.4 million for pollutants that are human carcinogen, $1.3 million for pollutants that are probable/possible human carcinogen, $2.1 million for pollutants that are not classifiable as human carcinogen, and $14 thousand for pollutants in none of these groups. While these results alone are not sufficient to determine the optimal levels of pollution abatement, they can be used in tandem with the estimation of firms marginal abatement costs to determine the optimal levels of pollution abatement in Ontario.

Keywords: Hedonic method, pollution releases, housing prices

Introduction

The health consequences of exposure to hazardous pollutants remains one of the main environmental concerns in many developed countries. This is despite the adoption of more stringent environmental regulations and improvement in the environmental quality over the past decades. For example, air pollution in Canada is reported to be the cause of many premature death, increased hospital admissions and emergency room visits, and lost work days (Government of Canada 2013). Ghazawi, et al. (2019) reported a higher levels of a deadly blood cancer clustered in Ontario's cities renowned for their manufacturing, and chemical industries. This, however, does not necessary mean that environmental regulations, or the level of pollution abatement are inadequate. The optimal level of pollution abatement depends on the trade-off between costs and benefits from an additional unit of abatement, which are measured by the marginal cost of, and marginal willingness to pay for pollution abatement (The Environmental Literacy Council 2015).

While the abatement costs can often be estimated using market transactions (*e.g.*, forgone revenues or additional costs associated with the installation and operation of pollution control technologies), the abatement benefits are usually more difficult to estimate because pollutants are not traded in a market. The main approaches to estimate the maximum price that individuals are willing to pay to abate one more unit of pollution are based on either stated-preferences which is based on a survey, or revealed-preferences which is based on actual decisions that individuals make. The aim of this study is to utilize a revealed-preferences approach to quantify individuals' marginal willingness to pay for pollution abatement in Ontario, Canada. Such estimates are important to determine if the benefits from the abatement of an additional unit of pollution outweigh their costs.

A hedonic price estimation model is commonly used to study differentiated products by decomposing the price of a commodity into separate components (hedonic) that determine the price (Rosen, 1974; Epple, 1987). In the housing market where properties are nonhomogeneous, a hedonic price model is the most widely used estimation technique. Moreover, housing markets can provide information about the marginal willingness to pay for commodities such as the quality of residential services, characteristics of surrounding neighborhoods, or environmental amenities for which no explicit market exists. This is because the price of a house is as much influenced by the quality of the bundle of residential services and surrounding neighborhoods as the other aspects of housing, such as the physical characteristics of the house in question (Kain and Quigley, 1970; Can, 1992; Small and Steimetz, 2012). In this way, the estimated marginal willingness to pay can be used to measure the benefits associated with the qualitative elements of the housing market that are not explicitly traded in the market.

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In a typical Rosen two-step hedonic price estimation model, a hedonic housing price equation will be estimated in the first stage, and the derivative of the hedonic price equation with respect to each housing characteristics will be used in the second stage to estimate the marginal willingness to pay for the qualitative elements of the housing market (Harrison and Rubinfeld, 1978; Nelson, 1978). There are, however, a number of well-known concerns in the second stage of the estimation (*i.e.*, beyond the usual identification problem caused by the interaction of the supply and demand curves) due to the endogenous relationship between the chosen level of qualities and prices (Bartick, 1987; Epple, 1987). These concerns have induced many researchers to recover estimates of the hedonic price function and valuing marginal changes in amenities from the first stage (Chay and Greenstone, 2005). Furthermore, the advances in spatial-econometric estimation techniques (Can, 1990; Dubin, 1992) enable researchers to investigate the cross-boundary impacts of neighborhood characteristics in a hedonic housing price estimation models (Kim et al., 2003).

The objective of this study is to estimate the marginal willingness to pay for pollution abatement based on the toxicity levels of pollutants listed under the National Pollutant Release Inventory (NPRI) in Ontario, Canada. In contrast to studies that estimate the marginal willingness to pay for a single type of pollutant (*e.g.*, Chay and Greenstone, 2005; Ito and Zhang 20016; Freeman, et al. 2017), the marginal willingness to pay in this study is estimated for the aggregate level of pollutants where pollutants are grouped into categories in accordance with the weight of evidence classification for carcinogens and their toxicity levels using the guideline and data from the United States Environmental Protection Agency (United States Environmental Protection Agency, 1986, 2011). A spatial-econometric model using a panel data is utilized to estimate the marginal willingness to pay. The use of a panel rather than cross-sectional data requires the property and neighborhood data to be aggregated. The tradeoff is the loss of property-specific information for the gain of a better understanding of the collective marginal willingness to pay for pollution abatement. Nonetheless, if the structural and physical characteristics of the neighborhoods are relatively unchanged over the period of the study, the loss of using aggregated data will be negligible because the impacts of these characteristics will be captured by the fixed effects. While the estimated results from this study alone are not sufficient to determine the optimal levels of pollution abatement, they can be used in tandem with the estimation of firms marginal abatement costs to determine the optimal levels of pollution abatement in Ontario. Another novel contribution of this study is to estimate the cumulative benefits from the 2006 levels of pollution abatement for pollutants listed under the NPRI. Data for firms' pollutants were retrieved from the NPRI (Environment Canada, 2014) and data for housing and socioeconomic characteristics of neighborhoods were retrieved from the Canadian Census (Statistics Canada, 2014).

Model

A hedonic housing price equation is used to decompose the housing prices into three sets of components (*i.e.*, hedonic) based on housing, socioeconomic, and pollution characteristics of a neighborhood. The implicit functional form of the hedonic housing price equation can be written as:

$$P_{it} = P(K_{it}, S_{it}, E_{it}) \quad (1)$$

where P represents the average annual rent; and K, S and E represent the sets of housing, socioeconomic, and pollution characteristics in location i at time t, respectively. In the empirical application of the model, Equation (1) is assumed to take a log-linear form to allow the marginal effect of each independent variable to vary with the housing prices across neighborhoods. This is a necessary condition to estimate the marginal willingness to pay for the housing characteristics in the second stage estimation (Rosen, 1974). The empirical model can be written as:

$$ln(P_{it}) = K'_{it}\beta + S'_{it}\delta + E'_{it}\theta + \mu_i + \gamma_t + \epsilon_{it} \quad (2)$$

where β, δ, and θ represent parameter vectors for housing, socioeconomic and pollution characteristics of neighborhoods, respectively; μ_i represent neighborhood-specific fix-effects, γ_t represents time-specific effects, and ϵ_{it} is an error term. If pollutants were truly local in nature, it would be reasonable to assume that pollutants in a neighborhood would only affect the housing prices in that neighborhood. However, in the presence of cross-boundary pollution, pollutants in one neighborhood can affect the housing prices in the surrounding neighborhoods, and hence their influences should be captured using techniques such as spatial-econometric estimation. As a result, Equation (2) is adjusted to allow for spatial autoregressive in the model as follows:

$$ln(P_{it}) = \rho \sum_{j=1}^{n} W_{ij} ln(P_{jt}) + K'_{it}\beta + S'_{it}\delta + E'_{it}\theta + \mu_i + \gamma_t + \epsilon_{it} \quad (3)$$

where W represents an inverse-distance spatial-weighting matrix. Suppressing the fixed- and time-effects for brevity, the reduced form can be obtained as:

$$ln(P) = [I - \rho W]^{-1}[K, S, E]\begin{bmatrix}\beta \\ \delta \\ \theta\end{bmatrix} + [I - \rho W]^{-1}\epsilon \quad (4)$$

where all the terms are expressed in terms of vectors and matrices. The first term on the right hand side of Equation (4) measures the direct and indirect effects of the explanatory variables on the average annual rent in a neighborhood. The estimated coefficients from Equation (4) can be used to directly obtain the hedonic, or implicit, prices for the environmental variables in each neighborhood.[1] In addition, the demand or the marginal willingness to pay can also be estimated using an instrumental variable technique applied to the hedonic prices from the first stage (*i.e.*, Equation (3)). Given that there are a distribution of sellers and buyers, the coefficient of the marginal willingness to pay is estimated from:

$$dP_{it}/dE_{it} = \alpha_i + E'_{it}\alpha_1 + X'_{it}\alpha_2 + \upsilon_{it} \quad (5)$$

where dP_{it}/dE_{it} represents the hedonic prices of the environmental variables in location i at time t; E_{it} and X_{it} represent the environmental and buyers' (*i.e.*, renters') characteristics in location i at time t, respectively; and υ_{it} is an error term that represents unobserved determinants of tastes.

Data

Data for firms' pollutants were retrieved from the National Pollutant Release Inventory (Environment Canada, 2014), and data for housing and socioeconomic characteristics of neighborhoods were retrieved from the Canadian Census (Statistics Canada, 2014).

National Pollutant Release Inventory

National Pollutant Release Inventory is "Canada's legislated, publicly accessible inventory of pollutant releases to air, water and land, and disposals and transfers for recycling" (Environment Canada, 2014). Pollutants are grouped into four categories in accordance with the weight of evidence classification for carcinogens and their toxicity levels using the guideline and data from the United States Environmental Protection Agency (United States Environmental Protection Agency, 1986, 2011). These toxicity groups are: (A) human carcinogen, (B) probable/possible human carcinogen, (C) not classifiable as human carcinogen, and (D) none of the above.

Figure 1: The average annual pollution generated, and released in Forward Sortation Areas in Ontario, Canada

[1] Assuming that the housing market is in equilibrium, the hedonic prices from the first stage estimation can be used to estimate the marginal willingness to pay for environmental variables as: $\theta \otimes i'[I - \rho W]^{-1}P/n$; and the elasticity of housing prices with respect to changes in environmental variables can be obtained by $\eta_E = \theta(1 - \rho)^{-1}\bar{E}$ where $\bar{E}$ is the mean value for the environmental variables (Kim et al., 2003).

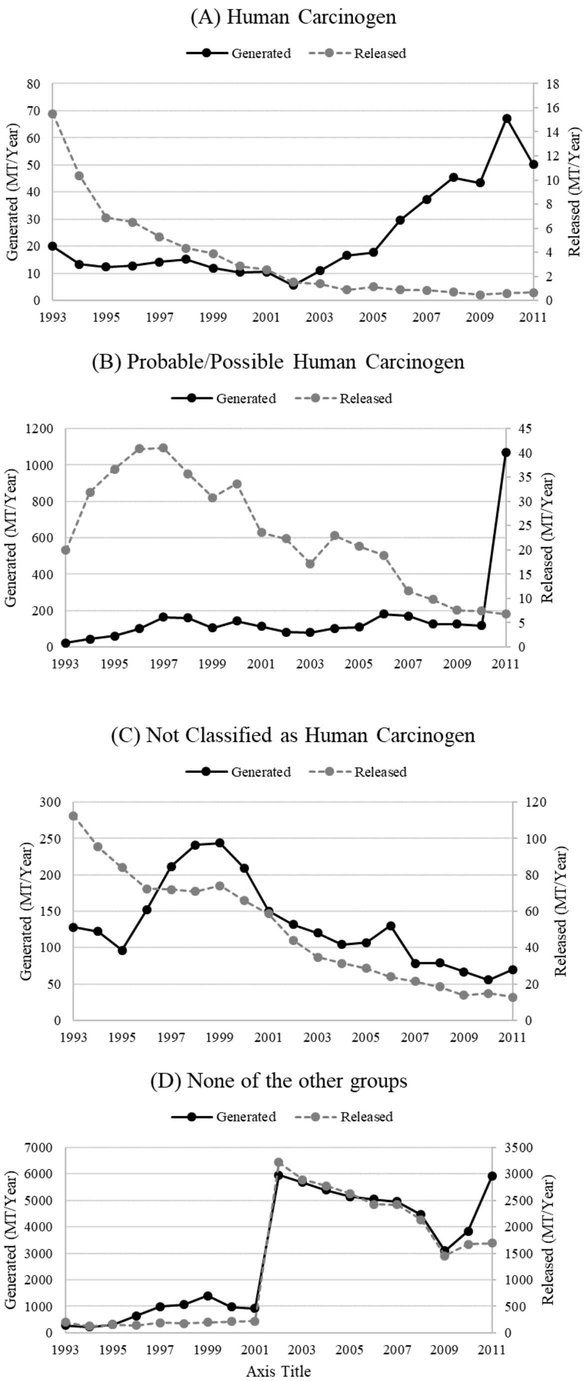

Figure 1 depicts the average annual pollution generated and released to all media (air, soil, and water) in Forward Sortation Areas (major geographic areas in which all postal codes start with the same three characters) in Ontario, Canada from the commencement of the NPRI program in 1993 to 2011. The difference between pollution generated and released is the amount of pollution abated in the form of disposals and transfers for recycling. Given the fact that the number of pollutants required to be reported under NPRI has increased over time (Environment Canada, 2014), the share of pollution abated in each toxicity group has substantially increased. This is partially due to more stringent environmental regulations, but it is also due to technological advances in production and pollution abatement technologies. However, it is not possible to separate the abatement that was due to environmental regulation versus the one from technological advances. The shares of pollution abated in the most toxic groups (*i.e.*, groups A and B) have increased from 24, and 17percent in 1993 to 99 percent in 2011, respectively. Similarly, the share of pollution abated in group C has increased from 12 percent to 82 percent over the same period of time. Overall, pollution releases in toxicity groups A, B, and C in 2011 were 96, 66, and 89 percent lower than their levels in 1993, respectively. Pollutants in group D should be considered separately because seven criteria air contaminants were included to the pollutants in this group in 2002.[2] The share of pollution abated in the last group increased from 28 percent in 1993 to 76 percent in 2001; however, due to the inclusion of new air pollutants, this share declined to 46 percent in 2002, and it has since increased to 71 percent in 2011.

Census

Data for the housing and socioeconomic characteristics of neighborhoods were retrieved from the Canadian Census where neighborhoods are defined based on urban Forward Sortation Areas (FSAs).[3] The summary statistics for a selective number of variables that represent the housing and socioeconomic characteristics of FSAs in Ontario based on the existence of a listed NPRI facility is provided in Table 1. Data reveal that 78 percent of FSAs in 2006 had a listed NPRI facility in their boundaries compared to 54 percent of FSAs in 1996.

As can be seen in Table 1, the summary statistics for variables that represent the housing characteristics of neighborhoods reveal that FSAs with NPRI facilities had a lower percentage of row houses in 1996, a higher percentage of less than five story apartment buildings in 1996 and 2001, and a higher percentage of duplex houses, but there were no significant differences between the percentage of detached houses, semi-detached houses, and more than five story apartment buildings between both areas. Data also reveal no differences between the percentage of rented units and the average number of rooms and bedrooms between both areas. While FSAs with NPRI facilities had a higher percentage of minor or major repairs, a smaller percentage of houses in these areas had a regular maintenance. The percentages of renters and owners that spend 30 or more percent of their incomes on dwelling were not significantly different between both areas; however, the value of dwelling, gross rent, and owners gross payment for dwelling were significantly lower in FSAs with NPRI facilities.

In addition, the summary statistics for variables that represent the socioeconomic characteristics of neighborhoods reveal that FSAs with NPRI facilities were not only more populous, but they also had a higher percentage of population born in Ontario. While the percentage of individuals with aboriginal background seemed to be higher in these areas, the difference was significant only in 1996. Furthermore, FSAs with NPRI facilities experienced a higher unemployment rate in 1996 and 2001, and a higher incident of low-

[2] These are: carbon monoxide, oxides of nitrogen, sulphur dioxide, total particulate matter, particulate matter less than or equal to 2.5 Microns, particulate matter less than or equal to 10 Microns, and volatile organic compounds.

[3] The 2011 Census is excluded from the analysis because of the concerns with regard to the data compatibility with the previous census years. The elimination of the mandatory-long form census and its replacement with the voluntary National Household Survey in 2011 initiated an ongoing debate about the reliability of the data collected. In particular, studies show that there are systematic differences between the non-respondents and respondents in similar voluntary surveys (Green and Milligan 2010; Brochu, Morin and Billette 2014), where people at the extremes of the socioeconomic scale are unlikely to fill out voluntary surveys (Collier 2010). Consequently, there are major concerns about the representativeness of the 2011 because of the selection bias inherent in the voluntary survey (Green and Milligan 2010).

income families in 2001 and 2006. They had significantly higher percentages of households that were separated, divorced, or widowed, but they had the same percentages of single and married households, with the exception of the percentage of married household in 2006 which appeared to be lower. Consequently, households in these areas seemed to have fewer children on average, but the difference was significant only in 1996. While the percentage of immigrants seemed to be lower, the difference is insignificant. The percentage of individuals with a university degree as well as median family income were significantly lower in FSAs with NPRI facilities. In addition, households in these areas were significantly less mobile in the long-run, but not in the short-run.

Results

The results for the hedonic housing price equation from the first stage estimation (*i.e.*, Equations 2 and 3) are reported in Table 2. The results for a fixed-effect panel model is reported in the second column, and the results for a fixed-effect spatial autoregressive model is reported in the third column.[4] The estimated direct, indirect, and total marginal effects for the spatial model are reported in the remaining columns. As can be seen in Table 2, the estimated coefficients for the simple-panel model and the spatial-panel model are fairly similar. These results are consistent with earlier studies

[4] The diagnostic test favors the autoregressive model over the spatial error model (*i.e.*, the Wald test suggests that that the coefficient of spatial error term is not statistically different than zero).

Table 1: Summary statistics for variables that represent the housing and socioeconomic characteristics of Forward Sortation Areas in Ontario, Canada (in 2006 dollars)

	1996			2001			2006		
Variables	NPRI	None NPRI	Diff. (%)	NPRI	None NPRI	Diff. (%)	NPRI	None NPRI	Diff. (%)
Population	24241.7	18876.3	28%***	25364.1	19743.8	28%***	25753.9	19645.7	31%***
Number of kids	1.27	1.32	-4%**	1.16	1.18	-1%	1.13	1.15	-2%
Single (%)	29.52	30.36	-3%	30.71	31.43	-2%	32.51	32.48	0%
Married (%)	53.40	54.34	-2%	51.93	53.43	-3%	50.05	52.15	-4%*
Separated (%)	3.53	3.24	9%***	3.60	3.18	13%***	3.66	3.18	15%***
Divorced (%)	6.66	6.18	8%**	6.92	6.33	9%***	7.24	6.60	10%***
Widowed (%)	6.89	5.87	17%***	6.84	5.62	22%***	6.54	5.59	17%***
Detached (%)	56.03	55.45	1%	55.84	57.04	-2%	53.32	54.75	-3%
Semi-detached (%)	6.24	5.91	6%	6.73	6.00	12%	5.90	5.95	-1%
Row (%)	6.56	8.38	-22%**	7.53	8.33	-10%	8.18	8.24	-1%
Duplex (%)	3.22	2.51	29%***	2.46	1.82	35%***	3.80	2.77	37%***
Apartment ≥ 5 stories (%)	15.69	17.23	-9%	16.16	17.31	-7%	16.46	17.62	-7%
Apartment < 5 stories (%)	11.71	9.91	18%**	10.75	9.02	19%**	11.86	10.30	15%
Other attached (%)	0.30	0.28	6%	0.31	0.22	44%***	0.25	0.17	46%**
Movable (%)	0.26	0.33	-22%	0.22	0.26	-12%	0.23	0.20	16%
Number of rooms	6.26	6.40	-2%	6.36	6.53	-3%*	6.52	6.72	-3%
Number of bedrooms	2.64	2.68	-2%	2.67	2.72	-2%	2.70	2.77	-2%
Rented (%)	35.71	35.50	1%	33.21	31.53	5%	30.68	29.10	5%
Banned (%)	0.02	0.00	315%	0.03	0.01	261%	0.03	0.00	0%**
Regular maintenance (%)	67.41	69.02	-2%**	67.88	69.87	-3%**	68.30	70.42	-3%**
Minor repairs (%)	24.95	24.12	3%	24.86	23.75	5%**	25.29	23.83	6%**
Major repairs (%)	7.62	6.86	11%***	7.23	6.38	13%***	6.38	5.75	11%**
Value dwelling	210756.3	254670.6	-17%***	214438.8	264201.5	-19%***	284389.2	385478.1	-26%***
Gross rent	839.4	909.4	-8%***	836.7	908.5	-8%***	840.4	917.8	-8%***
Tenants spend ≥ 30% income on rent (%)	15.77	15.15	4%	14.12	12.76	11%	13.68	12.59	9%
Owner payment	1066.1	1201.9	-11%***	1047.2	1184.6	-12%***	1140.7	1306.7	-13%***
Owners spend ≥ 30% income on housing (%)	11.73	12.02	-2%	11.33	11.19	1%	13.93	13.60	2%
Immigrants (%)	25.12	25.96	-3%	26.05	26.84	-3%	26.75	29.04	-8%
Recent immigrants (%)	4.86	5.44	-11%	4.49	4.76	-6%	4.63	4.78	-3%
Born in province (%)	65.01	62.43	4%*	64.43	61.62	5%*	63.14	59.67	6%**
Aboriginals (%)	1.21	0.89	36%*	1.54	1.29	19%	1.87	1.56	20%
University degree (%)	23.32	29.97	-22%***	24.86	33.10	-25%***	29.98	39.14	-23%***
Unemployment rate	9.38	8.51	10%***	6.43	6.00	7%**	6.63	6.35	5%
Movers 1 year ago (%)	15.37	15.66	-2%	14.39	14.59	-1%	14.10	13.61	4%
Movers 5 years ago (%)	43.85	46.43	-6%***	43.22	45.51	-5%**	41.92	42.85	-2%
Median family income	56891.1	62948.2	-10%***	60110.0	69115.7	-13%***	60941.6	71015.6	-14%***
Incidence of low income	15.22	14.45	5%	12.50	11.11	13%*	12.46	11.03	13%*
N	222	189		248	163		320	91	

* indicates 10%, ** indicates 5%, *** indicates 1% significance levels; NPRI: National Pollutant Release Inventory; Diff (%): percentage difference between neighborhoods with at least one listed NPRI facilities and those without one.

such as Kim, et al. (2003), where the authors reported that Ordinary Least Squares (OLS) is sufficient in estimating the combined direct and indirect marginal effects from a spatial model. This, however, does not mean that the spatial model conveys the same information as the panel model. The spatial model decomposes the total marginal effects into direct and indirect components, which in fact can be very informative for welfare and policy analyses.

The results for the variables that represent the housing characteristics of neighborhoods suggest that, all other things being equal, the average annual rent in a FSA is positively correlated with the average value of dwelling not only in that area, but also in the neighboring FSAs. The same is also true for a regular maintenance where the average annual rent is positively associated with a regular maintenance in a FSA and the neighboring FSAs. In contrast, major repairs only positively affect the average annual rent in a FSA. Controlling for the other factors, the average annual rent in a FSA has a negative correlation with the age of housing structures in that area (*i.e.*, the Wald joint significance test rejects the hypothesis that the direct effects are jointly zero). While the estimated indirect effects suggest the same relationship between the average annual rent in a FSA and the age of housing structures in the neighboring FSAs, the results are insignificant. In addition, the coefficients of the average number of bedrooms has the expected sign, but controlling for other factors the result is insignificant. It is important to point out that this does not mean that the number of bedrooms does not have any effect on the annual rent, but rather if, for example, the number of bedrooms does not change across census years, the effect will be captured by the FSAs' fixed-effects; and hence controlling for the fixed-effects, the estimated coefficient for the number of bedrooms will be insignificant.

The results for the variables that represent socioeconomic characteristics of neighborhoods suggest that the average annual rent in a FSA is positively correlated with the size of population in that area, and the neighboring FSAs. While the average annual rent seems to have a positive relationship with the number of residents born in Ontario and a negative relationship with the percentages of immigrants and aboriginal population, controlling for the other factors, these results appear to be insignificant. The average annual rent in a FSA is positively correlated with the percentage of external migrants in the area, where external migrants are defined as those Canadians who lived outside Canada at the earlier reference date; but it has an insignificant correlation with the percentage of external migrants in the neighboring FSAs. Controlling for the other factors, the relationship between the average annual rent and the unemployment rate, and the percentage of individuals with a university degree appear to be insignificant. Furthermore, the average annual rent has a positive correlation with the median family income in a FSA, but its correlation with the median family income in the neighboring FSAs is insignificant.

The results for the variables that represent pollution generation and abatement in communities suggest that the average annual rent in a FSA is negatively correlated with pollution generation, and positively correlated with pollution abatement in the area and the neighboring FSAs for all toxicity groups. Furthermore, the Wald joint significance test rejects the hypothesis that the direct, indirect, or total effects are jointly zero.

The results from the second stage estimation for households' marginal willingness to pay for pollution abatement based on different toxicity groups are reported in Table 3. In order to estimate the equations of the marginal willingness to pay, an instrumental variable technique is applied to the hedonic or implicit prices for pollution abatement (*i.e.*, Equation 4), where the hedonic prices are calculated using the results from the first stage estimation (*i.e.*, the last column of Table 2). As expected, households' marginal willingness to pay increases with a decrease in the level of abatement (*i.e.*, the higher the level of pollution, the higher the marginal willingness to pay to abate an additional unit of pollution), and increases with households' income (*i.e.*, the higher the income, the higher the marginal willingness to pay to abate an additional unit of pollution). As can be seen in Table 3, these effects are also separated into direct, indirect, and total effects, where for all the toxicity groups, the cumulative indirect effects on the marginal willingness to pay for pollution abatement are greater than the direct effects.

Using the estimation results from the first and second stage estimation, the estimated price and income elasticities of pollution abatement; a typical household's marginal willingness to pay for, and its benefits from the 2006 levels of pollution abatement; and the cumulative marginal willingness to pay for, and the cumulative benefits from the 2006 levels of pollution abatement in Ontario, Canada are reported in Table 4. The price elasticity of pollution abatement indicates that a 10 percent reduction in abatement (or increase in pollution) increases the marginal willingness to pay for pollution abatement by 0.224, 0.097, 0.252, and 0.0502 percent for pollutants in toxicity groups A, B, C, and D, respectively. Additionally, the income elasticity indicates that a 10 percent increase in income increases the marginal willingness to pay for pollution abatement by 5.25, 4.04, 2.87, and 3.3 percent for pollutants in toxicity groups A, B, C, and D, respectively.

Overall, a typical household's marginal willingness to pay to abate a tonne of pollution in Ontario is estimated to be $2.85, $0.53, $0.89, and $0.0084 (in 2006 dollars) for pollutants in toxicity groups A, B, C, and D, respectively. Given the 2006 levels of pollution abatement in Ontario, a typical household's benefits from pollution abatement is estimated to be $572.29, $128.58, $151.79, and $12.52 for pollutants in toxicity groups A, B, C, and D, respectively. However, because pollution is non-rivalrous, it is very difficult to form a meaningful opinion about the magnitude of the marginal wiliness to pay, or the benefits when the results are expressed in per household basis. It is more informative to express the results in terms of the cumulative marginal willingness to pay for, or the cumulative benefits from pollution abatement in Ontario rather than for a typical household. In this way the cumulative marginal willingness to pay to abate a tonne of pollution is estimated to be $8.4 million, $1.3 million, and $2.1 million for pollutants in toxicity groups A, B, and C, respectively; and $14 thousand for pollutants in toxicity group D (in 2006 dollars). Given the 2006 levels of pollution abatement in Ontario, the abatement of pollutants listed under the NPRI are associated with $1,690 million, $322 million, $352 million, and $21.8 million (in 2006 dollars) restored direct and induced cumulative benefits from pollution abatement in toxicity groups A, B, C, and D, respectively.

Conclusions

The aim of this study is to utilize a revealed-preferences approach to estimate the marginal willingness to pay for pollution abatement based on the toxicity levels of pollutants listed under the NPRI in Ontario, Canada. The marginal willingness to pay for pollution abatement is estimated by applying a spatial hedonic price model to a Rosen two-step method. In the first stage estimation, a log-linear regression model is used to regress the average gross rent on the housing, socioeconomic, and pollution characteristics of neighborhoods. Using the results from the first stage estimation, the hedonic or implicit abatement prices for each neighborhood are recovered, and the marginal willingness to pay for pollution abatement is estimated in the second stage estimation. Data for firms' pollutants were retrieved from the NPRI (Environment Canada, 2014). Pollutants are grouped into four categories in accordance with the weight of evidence classification for carcinogens and their toxicity levels using the guideline and data from the United States Environmental Protection Agency (United States Environmental Protection Agency, 1986, 2011). Finally, data for housing and socioeconomic characteristics of neighborhoods were retrieved from the Canadian Census (Statistics Canada, 2014).

Table 2: The first stage estimation for the hedonic housing price function

	Fixed-Eff.	Spatial	Marginal Effect		
			Direct.	Indirect	Total
2001	-0.0159	-0.0176*	-0.0183*	-0.039	-0.0573*
2006	-0.0661***	-0.0499***	-0.0511***	-0.105**	-0.156***
Ln(value of dwelling)	0.156***	0.115***	0.117***	0.241**	0.358***
Number of bedrooms	-0.0311	-0.0227	-0.0231	-0.0475	-0.0706
Regular maintenance (%)	0.00437***	0.00476***	0.00468***	0.0101*	0.0148**
Major repair (%)	0.00431	0.00471*	0.00470*	0.00976	0.0145
Construction period 40s (%)	-0.00155	-0.0018	-0.0019	-0.00381	-0.00571
Construction period 50s (%)	-0.00245	-0.00232	-0.00237	-0.00501	-0.00738
Construction period 60s (%)	-0.00232**	-0.00216**	-0.00224**	-0.0048	-0.00704*
Construction period 70s (%)	0.000469	0.000485	0.000471	0.00127	0.00174
Construction period 80s (%)	0.00116	0.00121	0.00119	0.00233	0.00352
Dwellings rented (%)	-0.00128	-0.00103	-0.000995	-0.00233	-0.00333
Population	0.00000187**	0.00000172**	0.00000174**	0.00000359*	0.00000533**
Number of kids	-0.00624	-0.00943	-0.00857	-0.0204	-0.0289
Immigrants (%)	-0.000167	-0.0000142	0.0000533	0.000511	0.000564
Aboriginal (%)	-0.00243	-0.00138	-0.00147	-0.00325	-0.00472
Born in province (%)	0.00154	0.00176	0.00183	0.00485	0.00667
Intra-province migrants 1 year (%)	0.00223	0.00256	0.00227	0.00478	0.00705
Inter-province migrants 1 year (%)	-0.00924	-0.00624	-0.00687	-0.0152	-0.0221
External migrants 1 year (%)	0.0101*	0.00876*	0.00903*	0.0188	0.0278*
Intra-province migrants 5 year (%)	-0.000882	-0.000804	-0.000719	-0.00118	-0.0019
Inter-province migrants 5 year (%)	-0.00193	-0.00173	-0.00165	-0.00256	-0.00421
External migrants 5 year (%)	0.00211***	0.00146**	0.00142**	0.00299	0.00441*
University degree (%)	-0.000419	-0.000201	-0.000193	-0.00038	-0.000573
Unemployment rate	0.00165	0.00134	0.00144	0.0032	0.00465
Median family income	0.00000254**	0.00000191*	0.00000192*	0.0000042	0.00000611
Incident rate of low income families	-0.0025	-0.00202	-0.00209	-0.00449	-0.00658
Number of NPRI Firms	-0.000013	-0.0000045	-0.0000205	-0.0000711	-0.0000916
Number of Employees	-0.000000141	-0.000000169	-0.000000163	-0.000000373	-0.000000536
Total pollution generated A	-0.0000226	-0.0000746	-0.0000763	-0.000184	-0.00026
Total pollution generated B	-0.0000126	-0.0000146	-0.0000148	-0.0000338	-0.0000486
Total pollution generated C	-0.0000314**	-0.0000318**	-0.0000325**	-0.0000724	-0.000105*
Total pollution generated D	0.00000067	-0.000000182	-0.00000017	-0.000000359	-0.000000529
Total pollution abated A	0.0000334	0.0000856	0.0000875	0.000212	0.0003
Total pollution abated B	0.0000138	0.0000163	0.0000165	0.0000374	0.0000539
Total pollution abated C	0.0000262*	0.0000275**	0.0000281**	0.0000634	0.0000916
Total pollution abated D	-0.00000133	0.00000028	0.000000271	0.000000578	0.000000849
R^2	0.47	0.4	$\rho = 0.666$ ***		
N	1389	1389	$\sigma_e^2 = 0.00187$ ***		

* indicates 10%, ** indicates 5%, *** indicates 1% significance levels; NPRI: National Pollutant Release Inventory; Eff: Effect; Toxicity groups are: (A) human carcinogen, (B) probable/possible human carcinogen, (C) not classifiable as human carcinogen, and (D) none of the above.

Table 3: The second stage estimation for the marginal willingness to pay functions for pollution abatement in different toxicity groups

	Group A	Group B	Group C	Group D
Direct Effect.				
Constant	0.385	0.0952***	0.201***	0.00178***
Abatement	-0.000100*	-0.00000671***	-0.0000432**	-9.28e-09***
Median family income	0.00000757	0.00000110***	0.00000133***	1.47e-08***
Indirect Effect				
Constant	0.933	0.216***	0.453***	0.00381***
Abatement	-0.000243*	-0.0000152***	-0.0000973**	-1.98e-08***
Median family income	0.00000249***	0.000226**	3.14e-08***	2.59E-05
Total Effect				
Constant	1.318	0.312***	0.654***	0.00559***
Abatement	-0.000343*	-0.0000220***	-0.000140**	-2.91e-08***
Median family income	0.0000259	0.00000359***	0.00000433***	4.61e-08***
R^2	0.541	0.356	0.143	0.432
N	70	391	478	827

* indicates 10%, ** indicates 5%, *** indicates 1% significance levels; Toxicity groups are: (A) human carcinogen, (B) probable/possible human carcinogen, (C) not classifiable as human carcinogen, and (D) none of the above.

Table 4: The price and income elasticities of pollution abatement; marginal willingness to pay for, and benefits from the 2006 levels of pollution abatement in Ontario, Canada (in 2006 dollars)

	Group A	Group B	Group C	Group D
Price and income elasticity to abate pollution				
Price elasticity	-0.0224	-0.0097	-0.0252	-0.00502
Income elasticity	0.5253	0.4043	0.2871	0.33
A typical household's Marginal Willingness to Pay (MWTP) for, and its benefits from the 2006 levels of pollution abatement in Ontario, Canada				
Direct MWTP for pollution abatement (tonne/year)	$0.83	$0.16	$0.27	$0.0027
Indirect MWTP for pollution abatement (tonne/year)	$2.02	$0.37	$0.62	$0.0057
Total MWTP for pollution abatement (tonne/year)	$2.85	$0.53	$0.89	$0.0084
Direct benefits from pollution abatement/year	$167.21	$39.30	$46.64	$3.99
Indirect benefits from pollution abatement/year	$405.87	$89.08	$105.14	$8.53
Total benefits from pollution abatement/year	$572.22	$128.58	$151.79	$12.52
Cumulative Marginal Willingness to Pay (MWTP) for, and cumulative benefits from the 2006 levels of pollution abatement based on the number of occupied dwelling in FSAs with and without NPRI facilities in Ontario, Canada				
Number of dwellings in FSAs with NPRI facilities	451,145	1,451,755	1,945,095	3,521,270
Number of dwellings in FSAs without NPRI facilities	3,979,380	2,978,770	2,485,430	909,255
Direct cumulative MWTP for pollution abatement (tonne/year)	$375,472	$234,389	$536,574	$9,413
Indirect cumulative MWTP for pollution abatement (tonne/year)	$8,038,978	$1,090,135	$1,545,642	$5,199
Total cumulative MWTP for pollution abatement (tonne/year)	$8,414,450	$1,324,542	$2,082,216	$14,612
Direct cumulative benefits from pollution abatement/year	$75,435,492	$57,050,532	$90,721,514	$14,049,158
Indirect cumulative benefits from pollution abatement/year	$1,615,117,157	$265,367,074	$261,327,204	$7,759,671
Total cumulative benefits from pollution abatement/year	$1,690,552,649	$322,423,607	$352,048,718	$21,808,829

NPRI: National Pollutant Release Inventory; FSA: Forward Sortation Area; MWTP: Marginal willingness to pay; Toxicity groups are: (A) human carcinogen, (B) probable/possible human carcinogen, (C) not classifiable as human carcinogen, and (D) none of the above. Numbers are rounded for brevity.

The results from the first and second stage estimation, the estimated price and income elasticities, and the marginal willingness to pay for pollution abatement accord well with expectation. The results from the first stage estimation indicate that controlling for other factors, the average annual rent in a FSA is positively correlated with the value of dwelling and regular maintenance in that area and the neighboring FSAs; and with major repairs and contemporariness of the area. Moreover, the average annual rent has a positive correlation with the size of population in a FSA and the neighboring FSAs, and with the percentage of external migrants and the median family income in the area. While the average annual rent seems to have the expected relationship with the percentage of residents born in Ontario, the percentages of immigrants and aboriginal population; controlling for the other factors, the results appear to be insignificant. The results for the variables that represent pollution generation and abatement in FSAs suggest that the average annual rent in a FSA is negatively correlated with pollution generation and positively correlated with pollution abatement in the area and the neighboring FSAs for all toxicity groups. The results from the second stage estimation are used to calculate the marginal willingness to pay to abate a tonne of pollution in Ontario. The cumulative marginal willingness to pay to abate a tonne of pollution in Ontario is estimated to be $8.4 million, $1.3 million, $2.1 million for pollutants in toxicity groups A, B, and C, respectively; and $14 thousand for pollutants in toxicity group D (in 2006 dollars). As mentioned earlier the optimal level of pollution abatement occurs at the level where for an additional unit of abatement the marginal benefits is equal to the marginal costs. While the estimated results from this study alone are not sufficient to determine the optimal levels of pollution abatement, they can be used in tandem with the estimation of firms marginal abatement costs to determine the optimal levels of pollution abatement in Ontario. Finally, given the 2006 levels of pollution abatement in Ontario, the abatement of pollutants listed under the NPRI are associated with $1,690 million, $322 million, $352 million, and $21.8 million (in 2006 dollars) restored direct and induced cumulative benefits from pollution abatement in toxicity groups A, B, C, and D, respectively.

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