Disentangling Property Value Impacts of Environmental Contamination from Locally Undesirable Land Uses: Implications for Measuring Post-Cleanup Stigma

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Abstract
This research seeks to identify the impact of environmental contamination on residential housing prices separate from land use externalities associated with the contaminated sites. This is possible in an empirical model that considers the influence of uncontaminated commercial properties on home values concurrently with contaminated property influences. Our approach addresses an important source of omitted variable bias that has not been fully recognized in the literature, and it allows identification of stigma effects in a way not possible in past studies. We estimate difference-in-differences models that pool observations across a metro area and across time, as well as repeat sales models that rely on multiple transactions per home. Results indicate that environmental contamination more than doubles the negative influence commercial properties have on neighboring residential home values. Furthermore, we find little evidence of stigma effects once a contaminated site is remediated. The negative spillover effects associated with remediated contaminated sites are largely indistinguishable from the spillover effects from commercial properties with no known contamination.

1) Introduction

The US Environmental Protection Agency (EPA) administers the federal Superfund program to remediate commercial and industrial sites with severe environmental contamination. There are currently more than 1,600 sites on the National Priority List that are eligible for cleanup under the program, and federal expenditures on these sites are substantial. For example, as of 2009 the EPA had spent $3.1 billion in ongoing cleanup costs for 75 of the listed sites, with additional funding needs of $300 – $700 million per year projected through 2014 (US Government Accounting Office, 2010). Large though it is, the National Priority List (NPL) is only one part of the hazardous waste site issue in the US. Recent estimates suggest there are as many as 350,000 contaminated properties that require cleanup, with costs that could reach $250 billion (US EPA, 2004). Given the large ongoing and future cleanup costs it is critical to understand the benefits associated with hazardous waste site remediation. One source of benefits that has long been a topic of policy and academic debate is the increase in property values that may accompany the removal of proximate hazardous wastes (e.g., Greenstone and Gallagher, 2008; US EPA, 2009).

Hedonic property value models have been the dominant approach used by researchers to measure the impact of hazardous waste sites on residential home prices. Applications typically rely on a small number of contaminated sites to identify price gradients for the proximity of residential homes to the sites (e.g., Kiel, 1995; Kiel and Zabel, 2001). Often there is also a focus on understanding how the price gradient changes as contaminated sites are remediated. Generally this literature finds an economically significant price discount for homes located closer to a contaminated site (e.g. Gamper-Rabindran and Timmins, 2013), although individual studies have reported neutral (e.g. Greenstone and Gallagher, 2008) and in some cases even positive impacts (e.g. Kiel and Williams, 2007).

A near universal feature of the past literature is the absence of explicit consideration of *uncontaminated* commercial property influences on home values concurrently with *contaminated* property influences. This is true despite the fact that commercial properties agglomerate, meaning the distance to a contaminated site is likely to be correlated with the distance to uncontaminated sites. The potential for omitted variable bias arises because the influence of commercial development on home prices may be substantial, irrespective of the property's environmental status (Li and Brown, 1980; Mahan et al., 2000). The extent to which omitted commercial land uses have biased the estimates of hazardous waste site impacts on neighboring property values depends on the estimation strategy employed. Our review of the literature suggests that this challenge has been overcome with only varying degrees of success.

In this paper we depart from the past literature by focusing on land use externalities more generally, to isolate the impacts of environmental contamination on housing values. We explicitly recognize that hazardous waste sites are commercial or industrial properties (hereafter simply referred to as 'commercial properties') that may be undesirable neighbors, irrespective of their environmental status. We identify the universe of contaminated and uncontaminated commercial properties in a large but unified urban housing market – the Twin Cities of Minneapolis and Saint Paul – and explicitly model the concurrent influence of these properties on housing transactions prices. Our analysis uses observed sales of residential homes in five urban core counties of the Twin Cities, between 1990 and 2007, that lie within three miles of a hazardous waste site. Homes are linked spatially to 103 hazardous waste sites, 64 percent of which were remediated during our study period and at least one of these sites was delisted each year during our study period, with the exception of 1990 and 1992. Homes are also linked spatially 8,000 non-hazardous commercial/industrial properties.

Our main identification strategy relies on a difference-in-differences model within a cross-sectional framework pooling transactions across the metro area and over an 18 year period (Parmeter and Pope, 2011), combined with narrow spatial windows and numerous spatial and time fixed effects, to capture the external effects of commercial properties while minimizing the potential for omitted variables bias (Davis, 2011). We also estimate a repeat sales, house fixed effect specification (Mastromonaco, 2015). In both modeling approaches, we examine the impact of proximity to hazardous waste sites on housing transactions prices before and after cleanup in comparison to the impact of proximity to uncontaminated commercial properties across the same time periods. In this way we are able to identify the impact of environmental contamination separately from other land use externalities.

A key contribution of this research is our novel examination of stigma effects. Stigma refers to property value discounts that remain after cleanup of a proximate hazardous waste site has occurred (McCluskey and Rausser, 2003). In past studies, any residual negative impact of a remediated hazardous waste site was interpreted as stigma. However, absent an appropriate comparison group, it is not possible to separate stigma effects from other potential land use externalities. Our approach is unique in that it provides a benchmark against which we can compare any residual post-cleanup price impacts and thus determine if stigma exists.

Our cross sectional results indicate that proximity to clean commercial properties reduces neighboring home values by 2.5 percent, while proximity to a contaminated site reduces values by approximately 8 percent. For the latter, we find that remediation increases property values between 2.3 and 5 percent – a result that is also confirmed by the repeat sales analysis. Importantly, we find little evidence of stigma effects once a hazardous waste site is remediated: the price discount for proximity to a remediated contaminated site is largely indistinguishable from the price discount for proximity to a clean commercial site. This is true when considering an average price change over the entire delisting period, and also when we allow price effects to differ across the number of years post-remediation. Thus findings of stigma in earlier research may be the result of proximity to non-hazardous but still commercial land uses, rather than residual impacts of the past environmental contamination.

These findings arise from a comprehensive database of hazardous waste sites with the most carefully delineated spatial boundaries constructed to date for a single urban area. The geographic information system (GIS) data are verified with visual inspections of the boundaries of all contaminated sites, and our distance measures are refined to reflect differences between waste site boundaries and housing parcel centroids. Thus our application exploits more variability in the spatial landscape than comparable studies that typically focus on a small number of NPL sites, and it eliminates the measurement problems associated with using map points rather property boundaries. The high quality of our data and robustness of our results allow us to conclude that non-environmental land use externalities are critical for understanding the benefits of hazardous waste remediation, and in particular, the potential for stigma effects post-remediation.

2) Hedonic Estimates of Hazardous Waste Site Impacts

The hedonic literature exploring the impact of hazardous waste sites on property values began over thirty years ago, and it contains many individual studies and summaries of results. A recent meta-analysis by Braden et al. (2011) identifies at least 25 property value studies that focus on environmentally contaminated sites.[1] The objective of this literature is to isolate the effect on home values of proximity to these sites, and individual studies have approached this identification challenge in different ways. In this section we categorize the various studies based on the methods and data used, and contrast them with the strategy we follow.

We begin by noting that, with only one exception (discussed below) past studies do not explicitly consider uncontaminated commercial property influences on home values concurrently with contaminated property influences. This is true despite the fact that agglomeration of commercial properties means that the distance to a contaminated site is likely to be correlated with the distance to non-contaminated industrial activities. This introduces a potential confounding effect in that proximity to commercial land uses can affect residential property values regardless of the property's environmental status.[2] Thus any observed price discount

[1] Recent reviews and critiques of the literature are provided by Boyle and Kiel (2002), US EPA (2009); and Sigman and Stafford (2011).

[2] The literature examining the impact of commercial development on home values generally finds a discount for homes near commercial properties, though this is not robust across all studies since proximity to commercial development can also provide access to employment and retail opportunities (see Li and Brown, 1980; Grether and Mieszkowski, 1980; Crafts, 1998; Mahan, et al., 2000; Matthews and Turnbull, 2007). Zoning laws that have sought to separate residential properties from commercial activity since the 1940s suggest that the negative spillovers likely outweigh access benefits for households (Matthews and Turnbull, 2007).

could be attributable to local externalities from traffic, noise, and congestion as well as (or instead of) the presence of environmental contamination.

Existing studies have addressed this issue only in indirect ways. For example, a measure of the percentage of land in owner occupied residential use around a home is often used as a control variable for land use. More recent studies also include proximity to amenities, employment opportunities, and transportation networks. The extent to which these measures address the problem of correlated land use depends on other aspects of the studies. Cross sectional studies (e.g., Kohlhase, 1991; Kiel, 1995; Gayer et al., 2000; Kiel and Zabel, 2001) rely on variation in prices and distances to contaminated sites to estimate the impact of contamination on property values. The gradient of price with respect to distance is used to measure the external cost of contamination. However, if the net external effect of proximity to commercial properties is negative and the distance to contaminated and uncontaminated commercial sites is positively correlated, this gradient may provide an upwardly biased estimate of the external cost of contamination.[3]

Three estimation strategies can help alleviate the omitted variables problem: the use of spatial fixed effects, cross sectional difference-in-differences models, and/or repeat sales models. High resolution spatial fixed effects can address omitted land uses if contaminated and conventional commercial site externalities operate at different spatial scales. However, if the spatial externalities operate on the same scale then inclusion of fixed effects that adequately

[3] This is the conclusion reached by Deaton and Hoehn (2004), the only study we are aware of that explicitly considers contaminated and uncontaminated commercial property impacts on home values concurrently. Specifically, in a study of two NPL sites, the authors estimate models in which price depends on the distance to the nearest of the contaminated sites. They examine specifications that exclude and include a variable measuring the distance to the nearest area zoned 'highly industrial' by the city. Exclusion of the variable leads to a positive and significant price gradient for homes located further from the contaminated sites. Inclusion of the variable causes the gradient estimate to drop by 60 percent and become statistically insignificant.

control for exposure to conventional commercial properties will simultaneously soak up the variation in distance to the contaminated sites that is needed to estimate the gradient of interest. Assuming different spatial scales is one way to avoid this, but the localized nature of most land use spillovers suggests it is unlikely to be valid in the majority of cases. In practice, most past studies have included spatially coarse fixed effects that are unlikely to have addressed the omitted variable bias we are concerned with here.[4] Even census tract fixed effects may not be spatially resolute enough, given that external effects operating at the less than one mile range are smaller than township limits, school districts, and census tracts in all but the densest urban cores.

A difference-in-differences modeling approach can alleviate omitted variables concerns by controlling for time-invariant unobservables. Applications typically use cross-section sales data pooled across important milestones in a hazardous waste site history, such as before and after cleanup (Kohlhase, 1991; Dale et al., 1999; Kiel and Williams, 2007), or a panel of mean or median home values in a census tract (Noonan et al., 2007; Greenstone and Gallagher, 2008; Gamper-Rabindran and Timmins, 2013). Studies that estimate the distance-to-hazardous-waste-site gradient using sales occurring before and after a site cleanup will not be biased, if the omitted surrounding commercial land uses are time invariant. The trouble occurs, however, when one wishes to attribute any price difference to removal of the contamination. Even if we are convinced the distance gradient is identified, we cannot measure the benefits of cleanup because stigma effects cannot be distinguished from the residual land use effects.

The existence and magnitude of stigma is important from a policy perspective as it can have important consequences for the benefit-cost analysis of hazardous waste site remediation programs. The empirical evidence is quite varied with findings of no post-cleanup stigma

[4] Examples include studies that pool data from several municipalities (Gayer et al., 2000), and those that use school district fixed effects within a single jurisdiction (Dale et al., 1999; McCluskey and Rausser, 2003).

(Kohlhase, 1991; Dale, et al., 1999, Messer et al., 2006) to significant stigma effects post-cleanup (McCluskey and Rauser, 2002). For NPL sites that have negative distance gradients while contaminated, Kiel and Williams (2007) find both positive and negative gradients post-cleanup. Regardless of the direction, without an estimate of the distance gradient for uncontaminated commercial properties for comparison, it is not possible to use the price change for contaminated sites as the measure of realized benefits from cleanup activities. In the following sections we describe the data and estimation approaches we use to address this point.

3) Data

Our empirical analysis focuses on the Minneapolis-Saint Paul metropolitan statistical area (MSA), which is also referred to as the Twin Cities region. The area is representative of northern cities that had industrial economies in the last century, which left a legacy of environmentally contaminated properties throughout the urban core. The MSA is comprised of 13 counties and has a population of 3.3 million people. Our data cover five counties lying in the urban core of the MSA.[5] They cover approximately 2,000 square miles, with a 2010 population of 2.48 million people residing in more than one million housing units. The latter represents 77 percent of the housing units in the MSA (all MSA figures are drawn from the 2010 census).

Hazardous waste and clean commercial sites

Data on every environmentally contaminated parcel listed on a state or federal registry were obtained from the Minnesota Pollution Control Agency (MPCA). The federal registry is the Comprehensive Environmental Response, Compensation and Liability Information System

[5] These include Anoka, Dakota, Hennepin, Ramsey and Washington counties. A small number of observations are also drawn from Carver County.

(CERCLIS), which reports information on hazardous waste sites that are under inspection, known to be contaminated, or in the process of being remediated, including federal Superfund (NPL) sites. Minnesota also maintains an inventory of hazardous waste sites, referred to as the Permanent List of Priorities (PLP) or State Superfund sites. These sites may or may not appear on the CERCLIS or NPL registries, depending on the source of funds available for cleanup.[6] Our analysis includes all unique federal CERCLIS/NPL and state PLP sites within the five-county region. We refer to each site as a 'hazardous waste site' (HWS) or simply as a contaminated site for ease of exposition. In addition, we refer to all other, non-listed commercial and industrial properties as 'clean commercial' properties, with the understanding that both commercial and industrial facilities are represented. We recognize that there may be contaminated parcels within the group we identify as clean commercial that are not yet discovered by authorities. If this is the case, any differences in the estimated impacts for contaminated and clean commercial properties will underestimate of the true effects if market participants are aware of contamination prior to discovery by authorities.

There are 103 hazardous waste sites in our final data set, including industrial facilities such as chemical manufacturing and commercial enterprises such as drycleaners. Of these, 23 (22 percent) are on the federal CERCLIS. Overall, 66 sites (64 percent) were remediated and delisted during the study period. A delisting of at least one HWS occurs in every year from 1986 through 2008, a period that encompasses our sales data, with the exception of 1990 and 1992. The MPCA provided latitude/longitude coordinates for all sites, as well as street addresses, narrative descriptions of the location, and narrative descriptions of the site in its current and past

[6] Empirical results suggest no significant difference in the externality effects between NPL or non-NPL sites. This is true for both the listed period and the period after delisting. As such, we aggregate all sites in the empirical models.

use. Sites were matched to county tax parcel boundary maps provided by MetroGIS, a regional planning organization that collects, maintains and analyzes a wide array of spatially explicit data in a geographic information systems database for the metropolitan area.[7] Sites were first matched to the parcel boundary maps based on the latitude and longitude coordinates reported for the sites by MPCA. After this initial match, the address recorded in the parcel map was compared to the address recorded for the hazardous waste site. Sites were then visually inspected using Google maps aerial photography to confirm site boundaries. Finally, the visual boundaries were compared to parcel maps to determine the set of parcels that comprised each site.

The case by case inspection process that we undertook to determine each site's boundary is critical given the small spatial scale at which we expect the externality effects to operate. The majority of commercial and industrial properties comprise more than one legally defined tax parcel. Even single-unit facilities, such as a warehouse or a manufacturing building, can comprise six or more individually defined tax parcels. Thus, matching latitude/longitude coordinates to a single parcel erroneously decreases the size of the site relative to its true boundaries, and often substantially so.

Figure 1 displays a map of the seven inner counties in the Twin Cities. Census tracts are outlined in black and the cities of Minneapolis and Saint Paul are shown in grey. The centroids of the 103 contaminated sites in the final data are marked as dots, and are enlarged substantially for visibility. The figure shows that the contaminated sites are concentrated in the western portion of the urban area, near the urban core.

To determine the land use of each contaminated site, property tax records were matched

[7] Information about the organization and its data products are available at: http://www.metrogis.org/index.shtml.

to the MetroGIS parcel map through each property's unique identifier. Our ability to determine specific land uses is limited by inconsistent reporting of codes across jurisdictions, and land-use descriptions that are not informative about the actual activity occurring on the property (e.g., "mixed use"). Nonetheless, using informed judgment including visual inspection of satellite images of each property, we categorize sites into two aggregate categories: commercial or industrial. Fifty-nine of the 103 hazardous waste sites are categorized as industrial, and the remainder are commercial. In the home sales data, each transaction is assigned to its nearest hazardous waste site. Forty-one percent of homes have their closest hazardous waste site categorized as an industrial land use.

In addition to locating the hazardous waste site, we used the MetroGIS parcel map to geo-locate over 8,000 clean commercial properties in our five county study area. Following the same process as with the hazardous sites, we are able to coarsely categorize locations as being either commercial or industrial. Similar to above, each transaction in the sales data is assigned to its closest clean commercial property. Thirty-four percent of these are categorized as an industrial land use. Because of the ad-hoc nature in the coding of land use discussed earlier, our main analyses explores the average impact of all contaminated sites, vis-à-vis all non-contaminated commercial/industrial sites. This approach follows the existing literature in that it abstracts from the specific land uses of the contaminated site as a potential determinant of external impacts.

Transactions data

Residential single family home sales data were obtained from Plat System Services, a private vendor, for each of the counties in the study area (see also Anderson and West, 2006 and

Klaiber and Phaneuf, 2010).[8] Data on sales prices, sales dates, and housing characteristics were matched to the MetroGIS parcel boundary map using each parcel's unique parcel identification number. The most recent sales transaction for each single-family detached residential home that sold in the five-county study area is available for the period 1990 to 2007. There are over 250,000 sales of this type during the study period. Transactions with missing data were excluded from the analysis, as were transactions with unusually low sale prices (less than $20,000) as these likely do not represent arm's length transactions. In addition, observations with unusually large features (e.g., more than 13 bathrooms) or infeasible small features (e.g., no bedrooms) were excluded. The data also contain information on prior sales, although this information is somewhat less reliable due to inconsistency in the tax assessors' records from which Platt System Services gathers it data (e.g., in some counties earlier transactions prices/dates appear to be missing). We observe approximately 95,000 homes transacting more than once during the study period, creating over 220,000 different transactions records.

The core sample includes only homes that are within three miles of a hazardous waste site, resulting in 152,592 homes available for analysis. We use the most recent sale of each home in a cross-sectional analysis, and the repeated transactions are employed in a repeat sales analysis. Table 1 presents key summary statistics for the cross-sectional data, and Table 2 presents the repeat sales data. For the former, the mean sales price (in 2008 dollars) is $236,055. The average home has approximately three bedrooms and two baths, and its age at the time of sale was 41.78 years. The age statistic reflects the older, urban nature of the neighborhoods surrounding contaminated sites, which is also evidenced by the fact that 91 percent are located in

[8] Information on the company and its data products is available at www.platsystems.com.

densely populated urbanized areas (Table 1, second panel).[9]

The third panel in Table 1 summarizes homes according to their proximity to contaminated sites or clean commercial properties. Three discrete categories are created labeled HWS, COM, and NONE. The variable *HWS* is equal one for homes that are within 0.5 miles of a hazardous waste site; this occurs for 11.34 percent of homes in the sample. The variable *COM* is equal to one when the home is within 0.3 miles of a clean commercial property, but more than 0.5 miles from a contaminated site.[10] A large majority of homes (75.5 percent) fall into this category. The *NONE* category includes homes that are more than 0.5 miles from a HWS and 0.3 miles from a clean commercial property.

Each home is also categorized by whether its sale occurred while the nearest hazardous waste site is listed on the federal or state registries, or after the site is remediated and delisted. In aggregate, nearly 68 percent of sales occurred while the nearest hazardous waste site was listed as contaminated, and 32.26 percent occurred after the nearest site was delisted (*Delist*=1). The final two rows of Table 1 summarize the interaction between the delisted indicator, and proximity to a HWS or clean commercial property. Of the 17,308 parcels that are within 0.5 miles of a hazardous site, 4,751 sold after the site was delisted. This is 3.11 percent of the entire sample and 27.4 percent of the transactions with *HWS*=1. Similarly, of the 115,193 parcels sold in proximity to a clean commercial site, 38,325 sold after its nearest hazardous waste site was delisted. This is nearly 25.11 percent of the sample, and 33 percent of parcels for which *COM*=1.

[9] According to the US Census Bureau, an urbanized area consists of contiguous census block groups that hold 1,000 people per square mile, and together encompass a population of at least 50,000 people.

[10] As discussed in Section 4, we chose proximity indicators of 0.5 miles for an HWS and 0.3 miles for a clean commercial property based on exploratory models that indicate external effects of these types of properties are likely to have their greatest impact within these distances, and are likely to decline substantially thereafter.

Table 2 presents summary statistics for the repeat sales portion of the data. Comparing the first panel of Table 2 to the summary statistics in Table 1, we see that the average characteristics of the repeat sales data are generally similar to the cross-sectional data. Mean sales price is somewhat lower in the repeat sales data, as is the mean lot size. The average age at the time of sale for the repeat sales data is approximately four years older than in the cross sectional data, which is not surprising, since new home sales in the later part of our study period would not be included in the repeat sales data. Table 2 also indicates that the percentage of transactions with *HWS*=1 and *COM*=1 (and their respective delist interactions) are similar to the cross-sectional data.

4) Empirical Strategy and Results

In our main analysis we use a difference-in-differences model in a cross-sectional context. We examine the impact of 'treatment' with undesirable nearby land uses (hazardous or clean commercial sites) across two distinct time periods defined by the remediation status of the nearest hazardous waste site (currently listed or remediated and delisted). These impacts are identified relative to homes that are comparatively far away from both contaminated and clean commercial properties (*NONE*=1 in Table 1). To define treatment status, we employ narrow spatial windows and specify a buffer around each hazardous waste site or clean commercial property, and allow the externality effect to be constant within the buffer. This approach to measuring the impact of locally undesirable land uses has been employed by Pope (2008) and Linden and Rockoff (2008) to determine the price impact of proximity to a registered sex offender, Zabel and Guignet (2012) to examine the price effect of proximity to leaking underground storage tanks, and Davis (2011) for the external effects of being near a power plant.

To operationalize this strategy, a decision is needed on the maximum distance a home can be from the externality and still experience its effects. To investigate this, we estimate the following two models:

$$\ln price_{itnh} = \alpha + \sum_{b=1}^{B} \nu_b H_{it}^b + \eta X_{it} + \delta_h + \theta_n + \tau_t + \varepsilon_{it}, \quad (1)$$

and

$$\ln price_{itnc} = \alpha + \sum_{b=1}^{B} \chi_b C_{it}^b + \eta X_{it} + \delta_h + \theta_n + \tau_t + \varepsilon_{it}, \quad (2)$$

where $price_{itnh}$ denotes the sale price of house *i* that sold in year *t*, in neighborhood *n*, and whose nearest hazardous waste site is denoted *h*. The variable $price_{itnc}$ is similarly defined for homes whose nearest clean commercial site is denoted *c*. In equation (1), $H_{it}^b = 1$ if home *i* sold at time *t* has distance to its nearest hazardous waste site in the interval bin denoted *b*. To construct our bins, we use 0.2 mile increments starting at a distance of 0.1 miles. Thus *b*=1 corresponds to the distance bin (0, 0.1], *b*=2 corresponds to (0.1, 0.3], *b*=3 corresponds to (0.3, 0.5], and so forth. We define the last bin as distance interval (1.7, 2.0], so the ν_b coefficients measure price differences relative to homes that are between two and three miles from the nearest hazardous waste site.

Similarly for equation (2), $C_{it}^b = 1$ if home *i* sold at time *t* has distance to its nearest clean commercial property in interval bin *b*. The bins for equation (2) are the same as for (1), though the last bin is distance interval (1.9, 1.1], so the χ_b coefficients measure price differences relative to homes that are between 1.1 and three miles from the nearest clean commercial property. Furthermore, to avoid confounding clean commercial externality impacts with hazardous waste sites, equation (2) is estimated with a sample that excludes homes located within one mile of a hazardous waste site. Among the remaining variables in equations (1) and (2), the vector X_{it}

contains the housing and location characteristics that were presented in the first two panels of Table 1, including a quadratic term for each continuous variable and quarter of sale dummy variables. The term δ_h is a hazardous waste site spatial fixed effect that captures common unmeasured effects for all homes whose nearest hazardous waste site is h. Similarly, θ_n is a neighborhood fixed effect for each of 47 school districts and 18 townships, which captures common jurisdictional effects such as school quality, property tax rates, and public services. Finally, τ_t denotes year of sale fixed effects, and ε_{it} is the disturbance term.

Estimation results for these models are shown in Table 3. The results in column 1 indicate that homes up to 0.7 miles from a site have a price discount between 7 and 9 percent relative to homes located two miles or more from the nearest hazardous waste site (the base category). Between 0.7 and 1.7 miles the price discount is statistically significant, but it falls in magnitude to less than 2 percent for the more distant bins. These estimates suggest that statistically significant external effects continue out to about 1.5 miles from the contaminated site, but that the economically large external effects are more localized. The external effect of proximity to clean commercial properties is even more localized. The coefficient estimates in column 2 show that the negative price impact of proximity to a clean commercial property disappears between 0.3 and 0.5 miles distance from the property, which is consistent with the findings of Matthews and Turnbull (2007).[11]

[11] We also explored continuous distance models. For example, we estimated regressions with distance and distance squared to the undesirable land use included in the specification. These models were estimated separately for homes whose nearest neighbor is a hazardous waste site, and for homes whose nearest neighbor is a clean commercial property. The models were estimated using only sales that occurred while the nearest hazardous waste site was listed, and with the full sample in which an interaction term is included between distance and distance squared with a dummy variable indicating whether the nearest site was delisted or not. Results indicate that the marginal effect of distance from an undesirable land use is zero at a distance of 2.5 miles for hazardous waste sites

Using this preliminary evidence, a home is defined as treated by a hazardous waste site (*HWS*=1) if the distance to the nearest site is less than 0.5 miles. A home is considered treated by a clean commercial property (*COM*=1) if the distance to the nearest site is less than 0.3 miles *and* the distance to the nearest hazardous waste site is more than 0.5 miles. These definitions (summarized in Tables 1 and 2) were chosen to isolate an effect that is economically important, and to facilitate a comparison between the two land use treatments. However, we recognize from the results in Table 3 that the external effects of contaminated sites are likely to extend beyond 0.5 miles. To minimize the impact of 'partially' HWS treated sales – e.g. a home (say) 0.75 miles from the nearest contaminated site that is also within 0.3 miles of a clean commercial property – we restrict the estimation sample and exclude all homes that are between 0.5 and 1.5 miles of a contaminated site. Thus, the estimation sample includes all homes within 0.5 miles of a contaminated site (*HWS*=1 in Table 1) and all homes within 1.5 and 3.0 miles of a contaminated site. Homes that lie between 1.5 and 3.0 miles of a hazardous waste site are classified as treated by either a clean commercial site if the home is within 0.3 miles of a clean commercial property (*COM*=1), or treated by neither a contaminated or a clean commercial property if the home is further than 0.3 miles from a clean commercial property (*NONE*=1). By excluding homes between 0.5 miles and 1.5 miles of a HWS, the estimation sample is reduced to 82,908 homes. Appendix Table A1 presents summary statistics for this subsample, and indicates that the average characteristics for the subsample are similar to the full sample that was summarized in Table 1.

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and 0.8 miles for clean commercial sites. While the continuous distance models suggest the impacts of a hazardous waste site are larger than the more flexible specifications in equations (1) and (2), the results are likely driven by the functional form assumption.

Main specification

Our main analysis examines home sales during the period when the nearest contaminated site is listed or delisted. We use a difference-in-differences framework based on the following specification:

$$\begin{aligned}\ln price_{itnh} &= \alpha + \gamma_1 Delist_{ith} + \beta_1 HWS_{it} \times \mathrm{I}(Delist_{ith} = 0) + \beta_2 \times HWS_{it} \times \mathrm{I}(Delist_{ith} = 1) + \\ &\varphi_1 COM_{it} \times \mathrm{I}(Delist_{ith} = 0) + \varphi_2 COM_{it} \times \mathrm{I}(Delist_{ith} = 1) + \eta X_{it} + \delta_h + \theta_n + \tau_t + \varepsilon_{it},\end{aligned} \tag{3}$$

where the definitions for X_{it} and the various fixed effects follow from equations (1) and (2), and HWS_{it} and COM_{it} are the treatment dummy variables as defined in Table 1. The dummy variable $Delist_{ith}$ equals one if the sale occurred after the nearest hazardous waste site was delisted, and zero otherwise, and $\mathrm{I}(Delist_{ith}=j)$ is an indicator variable equal to one if the expression is true. The econometric specification in equation (3) implies that all price impacts from commercial properties, contaminated or not, are relative to the left-out category of untreated homes (*NONE*=1 in Table 1). Finally, it bears repeating that the sample used to estimate equation (3) includes homes within three miles of a HWS, but excludes those between 0.5 and 1.5 miles of an HWS, in order to avoid falsely categorizing homes as treated by clean commercial properties (*COM*=1), when they are also partially treated by a HWS.

Given the specification in equation (3), interpretations for key coefficients are as follows. First, the price effect of being treated by a listed contaminated site is β_1, and the effect of being treated by a contaminated site after remediation and delisting is β_2.[12] Second, φ_1 is the price effect of treatment with a clean commercial site during the period when the closest contaminated site is listed on a registry, and φ_2 is the effect of treatment with a clean commercial property,

[12] Given our model specification, the exact measure of the percentage impact of our treatment variables is a nonlinear transformation of the parameters (see Halvorsen and Palmquist, 1980). In practice, the transformation has a very modest impact on our results and so we do not use it here for ease of exposition.

after the nearest contaminated site has been remediated and delisted. These interpretations motivate two hypothesis tests. The first is H_0: $\beta_1=\varphi_1$, which examines whether the price effect of proximity to a listed HWS is the same as proximity to a clean commercial property, during the same listing period. The second is H_0: $\beta_2=\varphi_2$, which tests if a remediated and delisted contaminated site has the same price effect as a clean commercial property. Said another way, given estimates of β_2 and φ_2, we can determine if the average effect of formerly contaminated sites, post-remediation, is equivalent to the average effect of never-contaminated commercial properties. Past studies have estimated β_1 and β_2, usually in a continuous distance framework, and used a test of $\beta_2=0$ to examine the issue of stigma. However, as noted earlier, stigma is untestable without information on the average impacts of clean commercial properties within a market.

The coefficient estimates of interest for equation (3) are presented in columns 1 and 2 of Table 4. As a robustness check, column 2 expands the estimation sample by defining homes as treated by a contaminated site (*HWS*=1) if the home is within 0.7 miles of a contaminated site. This treatment definition increases the number of homes for which *HWS*=1 by over 12,000 (thus also increasing the total sample size by the same amount), while staying consistent with our findings from Table 3 that suggest economically significant impacts are likely to extend this far out from a HWS. The full set of coefficient estimates for both models are available in appendix Table A2.

The estimates indicate that treatment with a contaminated or clean commercial site, while the nearest contaminated site is listed, decreases property values relative to untreated homes. Specifically, proximity to a listed hazardous waste site reduces property values nearly 8 percent, relative to homes that are not treated by either an HWS or a clean commercial property.

Proximity to a clean commercial property (while the nearest contaminated site is listed) reduces property values approximately 2.5 percent relative to the same comparison group. Table 5 presents F-tests and p-values that confirm that these price effects are statistically different for both columns: we strongly reject the equality of price effects for listed hazardous waste sites and clean commercial properties.

Post-delisting of a HWS, both models indicate that prices increase for properties in close proximity to the HWS, but they differ in magnitude. Column 1 of Table 4 indicates that homes within 0.5 miles of a HWS increase in value by an average of 5 percentage points post-delisting; this increase is statistically significant at the 1 percent level. Importantly, the persistent discount that remains for homes surrounding a delisted HWS (-2.92 percent) is not statistically different than the discount for homes surrounding clean commercial properties during the delisting period (-2.96 percent). This is a key finding, and our first evidence that the persistent negative influence of proximity to a formerly hazardous waste site may be the result of commercial land use externalities unrelated to past contamination.

When considering a larger spatial definition for treatment by a HWS ($dHWS$<0.7 miles) shown in Column 2 of Table 4, we note that there remains a statistically significant difference (at the 5 percent level) between the discount for properties near a remediated HWS (-5.18 percent) and those near clean commercial properties for this model (-3.52 percent). While statistically significant, the effect is economically small at approximately 1.5 percentage points. More importantly, this result is not robust across model specifications. For example, as reported in Appendix Table A3, if we include township-specific time-trends in the models, there are no significant differences between the proximity to a HWS and a clean commercial property post-delisting of the HWS (see columns 1 and 2 in Table A3).[13] In addition, as discussed next, we generally do not find a significant difference between proximity to a delisted HWS and a clean commercial property when we consider how the external effects of these sites evolve over time.

A closer look at stigma

The specification in equation (3) informs us about the average effect of delisting on properties in proximity to hazardous waste sites. In doing so, however, it ignores any impact that the timing of delisting relative to the time of sale may have on prices. This could have consequences for our stigma analysis if the post-delisting price appreciation shown in Table 4 is the result of effects that appear several years after the actual remediation. To investigate this type of heterogeneity we generalize our cross sectional specification as follows:

$$\begin{aligned} \ln price_{itnh} = \alpha + \sum\nolimits_{j=1}^{J} \gamma_1^j Delist_{ith}^j + \beta_1 HWS_{it} \times \mathrm{I}(Delist_{ith} = 0) + \\ \sum\nolimits_{j=1}^{J} \beta_2^j \times HWS_{it} \times \mathrm{I}(Delist_{ith}^j = 1) + \varphi_1 COM_{it} \times \mathrm{I}(Delist_{ith} = 0) + \\ \sum\nolimits_{j=1}^{J} \varphi_2^j COM_{it} \times \mathrm{I}(Delist_{ith}^j = 1) + \eta X_{it} + \delta_h + \theta_n + \tau_t + \varepsilon_{it}, \end{aligned} \tag{4}$$

where t once again indexes the year of sale, and j now indexes the number of years prior to the sale. With this, the delisting dummy variables take time-specific interpretations. Specifically, $Delist_{ith} = 0$ indicates that the closest hazardous waste site to property i was listed on a registry at the time of sale, while $Delist_{ith}^j = 1$ indicates that the closest hazardous waste site had a delist year that was j years before the sale in time t. Under this generalization, the interpretations for β_1 and φ_1 are unchanged – they reflect the price discount from treatment by a hazardous waste site and clean commercial property, respectively, while the nearest contaminated site is listed.

[13] The F-statistic (p-value) for the hypothesis test H_0: $\beta_2=\varphi_2$ is 1.88 (0.1706) and 1.40 (0.2366) for the models presented in columns (1) and (2) of Appendix Table A3, respectively.

However, the interpretation for β_2^j is now time specific. It measures the price effect of treatment by a HWS, *j* years after the nearest hazardous waste site was delisted. Similarly, φ_2^j measures the price effect of treatment by a clean commercial site, *j* years after the nearest hazardous waste site was delisted.

With equation (4) our tests for stigma are year specific. For example, $\beta_2^j = \varphi_2^j$ implies that the price effects of proximity to clean commercial and remediated/delisted hazardous waste sites are the same *j* years after delisting, implying the absence of stigma. In contrast, $\beta_2^j < \varphi_2^j$ (more negative) is evidence of stigma *j* years after delisting, since it implies the price discount for delisted HWS-treated homes is larger than for otherwise similar, COM-treated homes. We are interested in the extent to which the relationship between β_2^j and φ_2^j changes for different values of *j*.

The parameter estimates from equation (4) are shown in columns 3 and 4 in Table 4, and hypothesis tests are presented in Table 5. The two models again vary by the contaminated site treatment definition (*HWS*=1) of 0.5 miles or 0.7 miles from a HWS. If we only look at the estimates for the β_2^j parameters, the models indicate that prices are appreciating slowly post-remediation. However, these need to be compared to the estimates for the φ_2^j parameters, which show that there are also larger price discounts for proximity to clean commercial properties in several post-delist years. As indicated by the hypothesis tests in Table 5, the price discounts for homes in proximity to a HWS are not significantly different from the price discounts for homes in proximity to a clean commercial property in all but one year post-delisting. The exception is year 2 post-delist for both models, in which the coefficient estimate for proximity to a clean commercial property is statistically insignificant.[14] Thus even though price appreciation is relatively modest in the year following remediation, it is important to note that there is little evidence that the lack of greater appreciation is due to stigma – i.e. the year one post-remediation spillover effect for the HWS mirrors that of clean commercial properties.

As a robustness check, we note that there are no significant price differences between homes near a HWS and homes near a clean commercial property post-delisting of the HWS for models that include township-specific time-trends (see Table A3, columns 3 and 4). The one exception is a significant difference in the price discounts in years 4+ for the model in column 3.[15] However, the effect is opposite of stigma and indicates that clean commercial properties have a significant negative impact, while remediated HWS have no significant effect on property values.

Similar patterns suggesting an absence of stigma are found when we consider alternative disaggregation of time periods post-delisting. For example, we examined models that include year-specific price impacts for years one through five post-delisting, and an aggregate term for six years and greater. We also estimated models that include year-specific effects out to nine years, and an aggregate term for ten years and greater. These two models are estimated using specifications that match equation 4, and with specifications that include township-specific time trends parallel to the models reported in Table A3. Across all of these models we find: (a) large,

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[14] The finding of a negative, but statistically insignificant coefficient for proximity to commercial a clean property in year 2 post-delisting is robust across models estimated. While we do not have a direct explanation for this finding, it is likely an artifact of the sparse number of sales for some treatment categories that result from breaking the sample into year-specific sales. Specifically, there are approximately 300 observations (sales) in each year for two categories: homes classified as not treated by an HWS or a clean commercial property (*NONE*=1, the base category) and homes classified as treated by an HWS when *dHWS*<0.5 miles.

[15] The F-statistic (p-value) for the hypothesis test H_0: $\beta_2^4 = \varphi_2^4$ is 3.30 (0.0692).

statistically significant discounts for proximity to a HWS, relative to a clean commercial property, while the site is listed; (b) the discount for proximity to a HWS is smaller in the post-delisting period, relative to the listed period, and declines over time; and (c) the large majority of coefficient estimates for proximity to a HWS post-delisting are statistically equal to the discount for proximity to a clean commercial property in the same post-delist year. This latter point provides evidence in favor of the absence of post-remediation stigma.[16]

Repeat sales analysis

As a complement to our cross sectional analysis we also examine a set of repeat sales models. We focus only on homes that are treated HWS or COM, since Table 2 shows that *NONE*-treated homes are not well-represented in the subset of homes selling multiple times.[17] Similar to the cross sectional analysis, we examine an average effect model of the form

$$\ln price_{it} = \alpha_i + \gamma_1 Delist_{ith} + \beta_2 \times HWS_{it} \times \mathrm{I}(Delist_{ith} = 1) + \eta X_{it} + \tau_{t',t} + \varepsilon_{it}, \tag{5}$$

and a disaggregate model given by

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[16] The four models estimated imply 64 tests of $\beta_2^j = \varphi_2^j$, where *j* is the number of years post-delisting that a sale occurs. We find a significant difference in the coefficient estimates for *HWS*=1 and *COM*=1 that implies possible stigma for a delisted HWS in 9 of 64 tests. In seven of those nine instances, the coefficient estimate for proximity to a clean commercial property in that year was small and statistically insignificant, although surrounding years were negative and significant (and insignificantly different from proximity to a HWS).

[17] We focus on homes that are treated HWS or COM due to the sparseness of our repeat sales sample in the category NONE. Using the 0.5 mile HWS treatment definition, 8.54 percent of our repeat sales transactions (5,472 transactions) have *NONE*=1. This is in contrast to 63 and 23.5 percent for *COM*=1 and *HWS*=1, respectively. As we discuss below, our analysis uses fixed effects that interact the year sold with the last year sold so as to make comparisons between similar time intervals. This introduces approximately 170 interval categories to the models, resulting in sparse coverage for many time intervals within the NONE category. For example, nearly 50 percent of the time intervals have fifteen or fewer transactions for homes categorized as NONE, while similar figures for HWS and COM-treated transactions are 14 and 10 percent, respectively.

$$\ln price_{it} = \alpha_i + \sum\nolimits_{j=1}^{J} \gamma_1^j Delist_{ith}^j + \sum\nolimits_{j=1}^{J} \beta_2^j \times HWS_{it} \times \mathrm{I}(Delist_{ith}^j = 1) + \eta X_{it} + \tau_{t',t} + \varepsilon_{it}. \qquad (6)$$

In these equations, α_i is a house-specific intercept (fixed effect) that absorbs the time-constant characteristics of the property, including neighborhood/school district effects as well as its status as an *HWS* or *COM*-treated property. The other variables follow from the previous subsections, with two exceptions. First, X_{it} now only contains characteristics of the property that change over time; for our specific regressions we include age of the structure and the quarter of sale dummy variables.[18] Second, we use a richer set of time fixed effects, whereby $\tau_{t',t}$ denotes a year sold by year of previous sale interaction. This means our price change comparisons are between properties selling in the same time interval – i.e. coefficients are identified by comparisons between properties that have the same year sold *and* year of previous sale indicators. In addition, to account for potentially different time trends between neighborhoods with ultimately-remediated and never-remediated closest hazardous waste sites, we interact $\tau_{t',t}$ with a dummy variable indicating whether the nearest hazardous waste site remained listed throughout the study period.

The repeat sales models, by construction, cannot inform us about any level differences between COM and HWS-treated homes, but we can estimate their differential response to delisting events. Table 6 contains the results from four specifications that follow those presented in Table 4. The first two columns confirm our results from the cross-sectional models. The insignificant estimate for γ_1 confirms that there is no price impact on COM-treated homes when the nearest hazardous waste site is delisted. In contrast, the positive and significant estimate for β_2 shows that homes in proximity to a hazardous waste site appreciate 2.3 percent on average

[18] The data only contain information on current property characteristics such as number of bedrooms.

following a delisting. Columns 3 and 4 in Table 6 are generally consistent with the cross-sectional results, though they indicate price appreciation that is concentrated in the early years (column 3) or relatively constant across years (column 4), whereas the cross-sectional results tend to suggest price appreciation grows over time.

In general, the repeat sales models replicate the important qualitative findings from our cross sectional analysis. We see that HWS and COM treated homes are intuitively different in their response to remediation, and the well-controlled environment of the repeat sales model confirms that delisting causes statistically significant appreciation for properties in proximity to the remediated hazardous waste site. While the model cannot show if there are residual price discounts beyond non-contaminated commercial land uses (the test for stigma used in the cross sectional analysis), we can say that appreciation effects are not delayed as might be the case if there were stigma effects present in the market.

5) Conclusions

Our research highlights the heretofore overlooked point that we cannot identify stigma effects associated with past environmental contamination without understanding how locally undesirable, but non-contaminated, land uses impact housing prices. Residual negative spillover effects of a formerly contaminated site may be unrelated to former contamination, but instead a reflection of the undesirable nature of the current land use if the parcel remains commercial or industrial. Findings of stigma in earlier research (e.g., McCluskey and Rauser, 2002) may therefore be the result of proximity to non-hazardous, but still commercial land uses, rather than residual impacts of former environmental contamination.

By examining hazardous waste sites and uncontaminated, undesirable land use externalities simultaneously, we are able to draw several conclusions. We find that commercial properties with no known environmental contamination reduce neighboring residential home values by an average of 2.5 percent. Environmental contamination augments this negative external impact, so that the overall effect is approximately 8 percent. Thus, environmental contamination causes external effects that are more than twice as large as the land use spillovers associated with commercial land use – a substantial amount that is similar to what is found in many other studies. For example, based on the mean prices of the original studies, negative spillover effects of contaminated sites are typically found to be in the range of 7 to 12 percent (McClelland et al., 1990; Mendelsohn et al., 1992; Kiel and Zabel, 2001), though discounts of 16 percent and more have been estimated for NPL sites (e.g., Kiel and Williams, 2007; Gamper-Rabindran and Timmins, 2013).[19]

Importantly, in contrast to past studies, we can interpret the post-delisting price effects of (formerly) contaminated sites cleanly via a properly specified comparison group. This allows us to compare the residual effect of a remediated hazardous waste site to the average commercial properties in our study area. We find little evidence that contaminated sites suffer from stigma once contamination is removed: remediated contaminated sites have residual external effects that are generally no larger than the average uncontaminated commercial site in the region. We do not suggest that our results are unequivocal and apply to all hazardous waste sites and all markets. However, future work should clearly compare the spillover effects of remediated commercial and industrial properties with their local (never-contaminated) counterparts to determine the existence and magnitude of stigma.

[19] A few studies report estimates as low as 3 percent (Kiel, 1995 and Gayer et al., 2002).

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Table 1. Select summary statistics (N=152,592).[a]

Housing Characteristics	Mean	Std. Dev.
Sales price (2008$)	$236,055	$115,702
Sales year	2000	4.69
Number bedrooms	3.13	0.87
Number bathrooms	1.81	0.77
Lot size (in acres)	0.37	0.62
Age of dwelling (in years)	41.78	28.14
Location Characteristics[b]		
Distance to nearest water body (miles to the boundary)	0.45	0.35
Distance to the nearest urban center (miles)	4.47	6.15
Distance to the nearest urbanized area (miles)	0.27	1.60
Urban =1 if parcel is within urban center boundary	0.26	--
Urbanized Area =1 if within urbanized area boundary	0.91	--

Proximity to HWS and Other Commercial Properties	Percent	# parcels = 1
HWS = 1 if parcel is within 0.5 miles of a hazardous waste site	11.34	17,308
COM = 1 if parcel is within 0.3 miles of a clean commercial property and at least 0.5 from an HWS	75.49	115,193
NONE =1 if parcel is >0.5 miles from a HWS and >0.3 miles from a clean commercial property	13.17	20,091
Delist =1 if parcel sale date is after nearest HWS is delisted	32.26	49,228
HWS × Delist = 1 if parcel is within 0.5 miles of an HWS and sale occurs after the HWS is delisted.	3.11	4,751
COM × Delist = 1 if parcel is within 0.3 miles of a clean commercial property and sale occurs while the nearest HWS is delisted.	25.11	38,325

[a] All homes in the sample are within 3 miles of a HWS.

[b] Each home is also spatially linked to 47 school districts, 18 townships, and 103 hazardous waste sites.

Table 2. Select summary statistics for repeat sales sample (N=123,116 for 53,497 unique properties).[a]

Housing Characteristics		
	Mean	Std. Dev.
Sales price (2008 dollars)	\$205,246	\$107,097
Sales year	1999	4.74
Number bedrooms	3.04	0.86
Number bathrooms	1.73	0.71
Lot size	0.28	0.43
Age of dwelling (years)	45.90	28.77
Location Characteristics and Proximity to HWS and Clean Commercial Properties		
	Percent	# parcels = 1
Urban =1 if parcel is within urban center boundary	36.05	19,259
HWS = 1 if parcel is within 0.5 miles of a hazardous waste site	12.21	6,420
COM = 1 if parcel is within 0.3 miles of a clean commercial property and at least 0.5 from an HWS	80.77	43,333
NONE =1 if parcel is >0.5 miles from a HWS and >0.3 miles from a clean commercial property	7.01	8,632
Delist =1 if parcel sale date is after nearest HWS is delisted	28.75	15,514
HWS × Delist = 1 if parcel is within 0.5 miles of an HWS and sale occurs after the HWS is delisted.	3.09	1,605
COM × Delist = 1 if parcel is within 0.3 miles of a clean commercial property and sale occurs while the nearest HWS is delisted.	23.77	12,839

[a] All homes in the sample are within 3 miles of a HWS.

Table 3. Selected parameter estimates from equations (1) and (2).[a]

Distance to site[b]	(1) Proximity to a listed HWS (Equation 1)	(2) Proximity to a clean commercial property (Equation 2)
(0, 0.1] miles	-0.0901***	-0.0815***
	(0.010)	(0.018)
(0.1, 0.3] miles	-0.0729***	-0.0467***
	(0.006)	(0.018)
(0.3, 0.5] miles	-0.0755***	-0.0130
	(0.005)	(0.018)
(0.5, 0.7] miles	-0.0759***	-0.0023
	(0.005)	(0.018)
(0.7, 0.9] miles	-0.0597***	0.0255
	(0.004)	(0.019)
(0.9, 1.1] miles	-0.0442***	-0.0265
	(0.004)	(0.022)
(1.1, 1.3] miles	-0.0336***	
	(0.005)	
(1.3, 1.5] miles	-0.0188***	
	(0.005)	
(1.5, 1.7] miles	-0.0164***	
	(0.005)	
(1.7, 2.0] miles	0.0077*	
	(0.004)	
Observations	103,364	100,113

[a] The dependent variable is the natural log of sales price for homes transacting between 1990 and 2007 that are no further than 3 miles from an HWS. We observe the delisting of at least one HWS in each year between 1986 and 2008, with the exception of 1990 and 1992. Column 1 examines the impact of distance to a listed hazardous waste site. Column 2 examines the impact of distance to a clean commercial property. The sample in column 1 includes homes within three miles of a hazardous waste site that sold while the nearest HWS was listed. The sample in column 2 includes homes that are between one and three miles of a hazardous waste site. Both specifications include the full set of covariates listed for the regressions described in equations (1) and (2), including house, lot and location characteristics of the property, year and quarter of sale dummy variables, and fixed effects for 47 school districts, 18 townships, and 103 nearest hazardous waste sites. Finally, robust standard errors in parentheses, where *** p<0.01, ** p<0.05, * p<0.1.

[b] Dummy variables for the distance bins are relative to homes more than 2.0 miles for column 1, and more than 1.1 miles for column 2.

Table 4. Selected parameter estimates from equations (3) and (4).[a]

		(1)	(2)	(3)	(4)
Model Reference		Equation (3)	Equation (3)	Equation (4)	Equation (4)
Treatment Definition for HWS=1[b]		HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi	HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi
Variables	Coef.[c]				
HWS×I(*Delist*=0)	β_1	-0.0794*** (0.0054)	-0.0768*** (0.0042)	-0.0802*** (0.0054)	-0.0773*** (0.0042)
HWS× I(*Delist*=1)	β_2	-0.0292*** (0.0066)	-0.0518*** (0.0050)		
HWS×I($Delist^1$ =1)	β_2^1			-0.0563*** (0.0179)	-0.0658*** (0.0134)
HWS×I($Delist^2$ =1)	β_2^2			-0.0573*** (0.0177)	-0.0702*** (0.0126)
HWS×I($Delist^3$ =1)	β_2^3			-0.0571*** (0.0143)	-0.0719*** (0.0118)
HWS×I($Delist^{4+}$=1)	β_2^4			-0.0171** (0.0074)	-0.0434*** (0.0056)
COM× I (*Delist*=0)[d]	φ_1	-0.0237*** (0.0043)	-0.0252*** (0.0040)	-0.0238*** (0.0043)	-0.0253*** (0.0040)
COM× I(*Delist*=1)	φ_2	-0.0296*** (0.0060)	-0.0352*** (0.0056)		
COM×I($Delist^1$ =1)	φ_2^1			-0.0443** (0.0205)	-0.0410** (0.0193)
COM×I($Delist^2$ =1)	φ_2^2			-0.0233 (0.0183)	-0.0266 (0.0171)
COM×I($Delist^3$ =1)	φ_2^3			-0.0502*** (0.0156)	-0.0525*** (0.0145)
COM×I($Delist^{4+}$=1)	φ_2^4			-0.0247*** (0.0071)	-0.0320*** (0.0066)
R^2		0.6579	0.6625	0.6580	0.6625
Observations		82,908	95,194	82,908	95,194

[a]Appendix Table A2 presents the full set of coefficient results. The dependent variable is the natural log of sales price for homes transacting between 1990 and 2007 that are no further than 3 miles from an HWS. We observe the delisting of at least one HWS during the study period, with the exception of 1990 and 1992. All models include the full set of covariates describing the property as listed in appendix Table

A2, as well as year and quarter of sale dummy variables, and fixed effects for 47 school districts, 18 townships, and 103 nearest hazardous waste sites. Homes are excluded from the estimation sample if they are between 0.5 and 1.5 miles of an HWS for the models in Columns 1 and 3, and excluded if they are between 0.7 and 1.5 miles of an HWS for the models in Columns 2 and 4. Robust standard errors are in parentheses, where *** indicates p<0.01, ** indicates p<0.05, and * indicates p<0.1.

[b] The models in columns 1 and 3 define a home to be treated by a HWS if distance to the HWS (*dHWS*) is less than or equal to 0.5 miles. Similarly, the models in columns 2 and 4 define a home to be treated by a HWS if distance to the HWS is less than or equal to 0.7 miles. Increasing the distance by which a home can be considered treated by an HWS also increases the sample size.

[c] Coefficient references are given that coincide with equations (3) and (4).

Table 5. Hypothesis tests for equations (3) and (4).

	(1)	(2)	(3)	(4)
Model Reference	Equation (3)	Equation (3)	Equation (4)	Equation (4)
Treatment Definition for HWS=1[a]	HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi	HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi
Hypothesis test[b]				
H_0: $\beta_1=\varphi_1$	86.38 (<0.0001)	96.24 (<0.0001)	88.23 (<0.0001)	97.73 (<0.0001)
H_0: $\beta_2=\varphi_2$	<0.01 (0.9953)	5.79 (0.0161)		
H_0: $\beta_2^1=\varphi_2^1$			0.27 (0.6010)	1.24 (0.2653)
H_0: $\beta_2^2=\varphi_2^2$			2.82 (0.0934)	5.08 (0.0242)
H_0: $\beta_2^3=\varphi_2^3$			0.16 (0.6936)	1.33 (0.2487)
H_0: $\beta_2^4=\varphi_2^4$			0.73 (0.3923)	2.07 (0.1500)

[a] See Table 4 for definitions of treatment.

[b]Tests are based on parameters estimates in Table 4. Failure to reject the hypothesis $\beta_2^j=\varphi_2^j$ implies there is no price difference between properties treated *HWS*=1 whose sale occurred *j* years after their nearest hazardous waste site was delisted and properties treated *COM*=1 whose sale occurred *j* years after the nearest hazardous waste site was delisted.

Table 6. Selected repeat sales model parameter estimates (equations 5 and 6).[a]

		(1)	(2)	(3)	(4)
Model Reference		Equation (5)	Equation (5)	Equation (6)	Equation (6)
Treatment Definition for HWS=1[b]		HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi	HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi
Variables	Coef.[c]				
Delist=1	γ_1	-0.0132 (0.0122)	-0.0171 (0.0107)		
Delist[1]=1	γ_1^1			-0.0187 (0.0140)	-0.0200 (0.0127)
Delist[2]=1	γ_1^2			-0.0232 (0.0144)	-0.0252* (0.0131)
Delist[3]=1	γ_1^3			-0.00179 (0.0151)	-0.00595 (0.0138)
Delist[4+]=1	γ_1^4			0.00436 (0.0138)	-0.00193 (0.0122)
HWS× I(*Delist*=1)	β_2	0.0226** (0.00958)	0.0248*** ((0.00741)		
HWS×I(*Delist*[1] =1)	β_2^1			0.0517*** (0.0188)	0.0310** (0.0145)
HWS×I(*Delist*[2] =1)	β_2^2			0.0422** (0.0190)	0.0376** (0.0149)
HWS×I(*Delist*[3] =1)	β_2^3			-0.00857 (0.0194)	-0.00319 (0.0154)
HWS×I(*Delist*[4+]=1)	β_2^4			0.0191 (0.0118)	0.0300*** (0.00916)
R^2		0.763	0.763	0.772	0.772
Unique properties		24,485	30,097	24,485	30,097
Observations		58,591	69,262	58,591	69,262

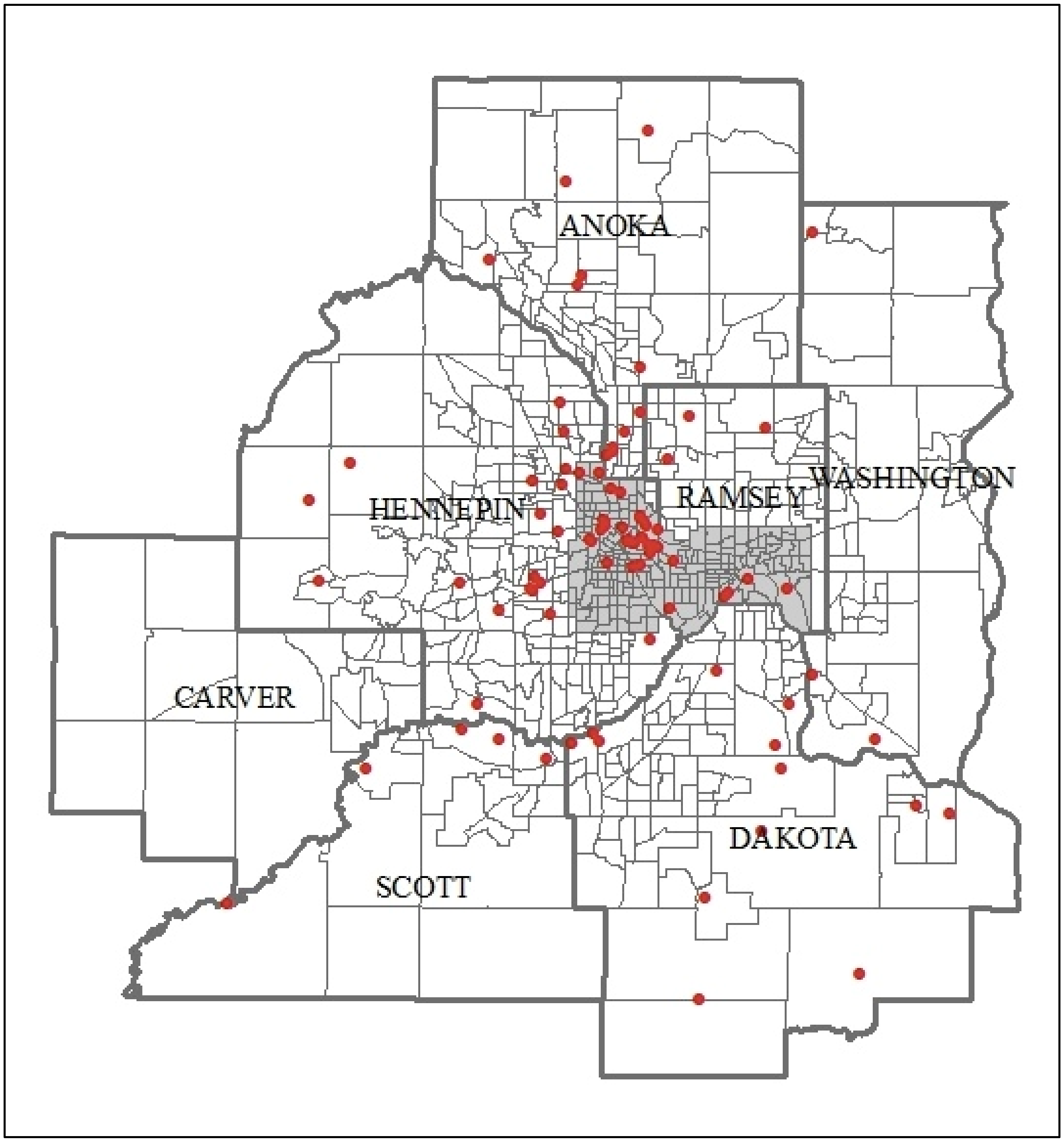
[a]The dependent variable is the natural log of sales price for homes transacting between 1990 and 2007 that are no further than 3 miles from an HWS. We observe the delisting of at least one HWS during the study period, with the exception of 1990 and 1992. All models include age and quarter of sale indicators, as well as year sold/year of last sale interval pair fixed effects. The time intervals are interacted with an indicator variable for properties whose nearest hazardous waste site remains listed throughout the study period. Homes are excluded from the estimation sample if they are between 0.5 and 1.5 miles of an HWS for the models in Columns 1 and 3, and excluded if they are between 0.7 and 1.5 miles of an HWS for the models in Columns 2 and 4. Standard errors are in parentheses, where *** indicates p<0.01, ** indicates p<0.05, and * indicates p<0.1.

[b] The models in columns 1 and 3 define a home to be treated by a HWS if distance to the HWS (*dHWS*) is less than or equal to 0.5 miles. Similarly, the models in columns 2 and 4 define a home to be

treated by a HWS if distance to the HWS is less than or equal to 0.7 miles. Increasing the distance by which a home can be considered treated by an HWS also increases the sample size.

[c] Coefficient references are given that coincide with equations (5) and (6).

Figure 1. Study area and distribution of hazardous waste sites.



Notes: Hazardous waste site centroids are highlighted in red and are enlarged substaintially for visibility. County and census tract bondaries are outlined, and the city boundaries of Minneapolis and St. Paul are highlighted in grey.

Appendix Table A1. Summary statistics for alternative samples[a]

Treatment Definition for HWS=1[b]	Sample (1) HWS=1 if dHWS < 0.5 mi		Sample (2) HWS=1 if dHWS < 0.7 mi	
Number of observations	82,908		95,194	
Housing Characteristics				
	Mean	Std. Dev.	Mean	Std. Dev.
Sales price (2008$)	$244,849	$116,961	$240,921	$115,738
Sales year	2001	4.69	2000	4.68
Number bedrooms	3.18	0.86	3.15	0.87
Number bathrooms	1.86	0.77	1.84	0.77
Lot size (in acres)	0.42	0.71	0.40	0.68
Age of dwelling (in years)	37.75	26.84	38.98	27.21
Location Characteristics[c]				
Distance to nearest water body (miles to the boundary)	0.42	0.32	0.43	0.32
Distance to the nearest urban center (miles)	5.20	5.22	4.98	5.20
Distance to the nearest urbanized area (miles)	0.25	1.05	0.26	1.08
Urban =1 if parcel is within urban center boundary	0.19	--	0.21	--
Urbanized Area =1 if within urbanized area boundary	0.90	--	0.91	--
Proximity to HWS and Other Commercial Properties				
	Percent	# parcels = 1	Percent	# parcels = 1
HWS = 1 if parcel is within 0.5 miles of a hazardous waste site (Sample 1) or 0.7 miles of a hazardous waste site (Sample 2)	20.88	17,308	31.09	29,594
COM = 1 if parcel is within 0.3 miles of a clean commercial property and at least 1.5 miles from an HWS	63.80	52,892	55.56	52,892
NONE =1 if parcel is >0.5 miles from a HWS and >0.3 miles from a clean commercial property	15.33	12,708	13.35	12,708
Delist =1 if parcel sale date is after nearest HWS is delisted	29.26	24,257	29.87	28,434
HWS × Delist = 1 if HWS=1 and sale occurs after the HWS is delisted.	5.73	4,751	9.38	8,928
COM × Delist = 1 if parcel is within 0.3 miles of a clean commercial property and sale occurs while the nearest HWS is delisted.	19.17	15,894	16.70	15,894

[a] All homes in the sample are within 3 miles of a HWS. Properties between 0.5 and 1.5 miles of an HWS are excluded from Sample (1) and properties between 0.7 and 1.5 miles of a HWS are excluded from Sample (2).

[b] Sample 1 excludes properties whose distance to a HWS (*dHWS*) is between 0.5 and 1.5 miles and the samples 2 excludes properties whose distance to a HWS is between 0.7 and 1.5 miles.

[c] Each home is also spatially linked to 47 school districts, 18 townships, and 103 hazardous waste sites.

Appendix Table A2. Full results for base models presented in Table 4.[a]

	(1)	(2)	(3)	(4)
Model Reference	Equation (3)	Equation (3)	Equation (4)	Equation (4)
Treatment Definition for HWS=1[b, c]	HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi	HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi
Variables:				
Delist=1	0.0066	0.0093		
	(0.0085)	(0.0080)		
Delist[1]=1			0.0091	0.0064
			(0.0209)	(0.0199)
Delist[2]=1			0.0062	0.0088
			(0.0191)	(0.0181)
Delist[3]=1			0.0293*	0.0298*
			(0.0165)	(0.0156)
Delist[4+]=1			0.0054	0.0084
			(0.0095)	(0.0090)
HWS×I(*Delist*=0)	-0.0794***	-0.0768***	-0.0802***	-0.0773***
	(0.0054)	(0.0042)	(0.0054)	(0.0042)
HWS× I(*Delist*=1)	-0.0292***	-0.0518***		
	(0.0066)	(0.0050)		
HWS×I(*Delist*[1] =1)			-0.0563***	-0.0658***
			(0.0179)	(0.0134)
HWS×I(*Delist*[2] =1)			-0.0573***	-0.0702***
			(0.0177)	(0.0126)
HWS×I(*Delist*[3] =1)			-0.0571***	-0.0719***
			(0.0143)	(0.0118)
HWS×I(*Delist*[4+]=1)			-0.0171**	-0.0434***
			(0.0074)	(0.0056)
COM× I (*Delist*=0)	-0.0237***	-0.0252***	-0.0238***	-0.0253***
	(0.0043)	(0.0040)	(0.0043)	(0.0040)
COM× I(*Delist*=1)	-0.0296***	-0.0352***		
	(0.0060)	(0.0056)		
COM×I(*Delist*[1] =1)			-0.0443**	-0.0410**
			(0.0205)	(0.0193)
COM×I(*Delist*[2] =1)			-0.0233	-0.0266
			(0.0183)	(0.0171)
COM×I(*Delist*[3] =1)			-0.0502***	-0.0525***
			(0.0156)	(0.0145)
COM×I(*Delist*[4+]=1)			-0.0247***	-0.0320***
			(0.0071)	(0.0066)
Bedrooms	0.1414***	0.1380***	0.1412***	0.1379***
	(0.0074)	(0.0069)	(0.0074)	(0.0069)
$(Bedrooms)^2$	-0.0108***	-0.0102***	-0.0108***	-0.0102***
	(0.0011)	(0.0010)	(0.0011)	(0.0010)
Baths	0.1338***	0.1372***	0.1336***	0.1372***
	(0.0102)	(0.0097)	(0.0102)	(0.0097)
$(Baths)^2$	<0.0001	0.0002	0.0001	0.0002

	(0.0024)	(0.0023)	(0.0024)	(0.0023)
Acres	0.1541***	0.1560***	0.1542***	0.1561***
	(0.0081)	(0.0078)	(0.0081)	(0.0078)
(Acres)^2	-0.0181***	-0.0183***	-0.0182***	-0.0183***
	(0.0014)	(0.0014)	(0.0014)	(0.0014)
Age	-0.0012**	-0.0014***	-0.0011**	-0.0014***
	(0.0006)	(0.0005)	(0.0006)	(0.0005)
(Age)^2	-0.0001***	-0.0001***	-0.0001***	-0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
(Age)^3	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Miles to water	-0.1997***	-0.1958***	-0.2001***	-0.1965***
	(0.0123)	(0.0110)	(0.0123)	(0.0110)
(Miles to water)^2	0.0692***	0.0667***	0.0696***	0.0673***
	(0.0098)	(0.0084)	(0.0098)	(0.0084)
In Urban Center (=1)	0.0659	0.0716	0.0672	0.0750
	(0.0593)	(0.0486)	(0.0592)	(0.0487)
Miles to urban center	0.0220***	0.0225***	0.0216***	0.0221***
	(0.0033)	(0.0030)	(0.0033)	(0.0030)
(Miles to urban center)^2	-0.0008***	-0.0009***	-0.0008***	-0.0009***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
In Urbanized Area (=1)	-0.0653***	-0.0498***	-0.0653***	-0.0498***
	(0.0110)	(0.0108)	(0.0110)	(0.0108)
Miles to urbanized area	0.0054	0.0106	0.0058	0.0109
	(0.0124)	(0.0118)	(0.0124)	(0.0118)
(Miles to urbanized area)^2	0.0004	-0.0004	0.0003	-0.0004
	(0.0017)	(0.0016)	(0.0017)	(0.0016)
Fixed Effects Included:	Year and Quarter of Sale; Nearest HWS (103) total; Township (18 total); School District (47 total)			
R-squared	0.6579	0.6625	0.6580	0.6625
Observations	82,908	95,194	82,908	95,194

[a]The dependent variable is the natural log of sales price for homes transacting between 1990 and 2007 that are no further than 3 miles from an HWS. We observe the delisting of at least one HWS during the study period, with the exception of 1990 and 1992. Homes are excluded from the estimation sample if they are between 0.5 and 1.5 miles of an HWS for the models in Columns 1 and 3, and excluded if they are between 0.7 and 1.5 miles of an HWS for the models in Columns 2 and 4. Robust standard errors are in parentheses, where *** indicates p<0.01, ** indicates p<0.05, and * indicates p<0.1.

[b] The models in columns 1 and 3 define a home to be treated by a HWS if distance to the HWS (*dHWS*) is less than or equal to 0.5 miles. Similarly, the models in columns 2 and 4 define a home to be treated by a HWS if distance to the HWS is less than or equal to 0.7 miles. Increasing the distance by which a home can be considered treated by an HWS also increases the sample size.

Appendix Table A3. Selected parameter estimates from equations (3) and (4) including township-specific time-trends.[a]

		(1)	(2)	(3)	(4)
Model Reference		Equation (3)	Equation (3)	Equation (4)	Equation (4)
Treatment Definition for HWS=1[b]		HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi	HWS=1 if dHWS<0.5mi	HWS=1 if dHWS<0.7mi
Variables	Coef.[c]				
HWS×I(*Delist*=0)	β_1	-0.0809*** (0.0055)	-0.0780*** (0.0042)	-0.0815*** (0.0055)	-0.0784*** (0.0042)
HWS× I(*Delist*=1)	β_2	-0.0179*** (0.0068)	-0.0426*** (0.0052)		
HWS×I($Delist^1$=1)	β_2^1			-0.0473** (0.0185)	-0.0565*** (0.0139)
HWS×I($Delist^2$=1)	β_2^2			-0.0405** (0.0186)	-0.0545*** (0.0132)
HWS×I($Delist^3$=1)	β_2^3			-0.0515*** (0.0149)	-0.0647*** (0.0123)
HWS×I($Delist^{4+}$=1)	β_2^4			-0.0060 (0.0076)	-0.0351*** (0.0058)
COM× I (*Delist*=0)	φ_1	-0.0248*** (0.0043)	-0.0261*** (0.0040)	-0.0249*** (0.0043)	-0.0261*** (0.0040)
COM× I(*Delist*=1)	φ_2	-0.0288*** (0.0060)	-0.0343*** (0.0055)		
COM×I($Delist^1$=1)	φ_2^1			-0.0493** (0.0202)	-0.0463** (0.0190)
COM×I($Delist^2$=1)	φ_2^2			-0.0215 (0.0183)	-0.0241 (0.0169)
COM×I($Delist^3$=1)	φ_2^3			-0.0551*** (0.0162)	-0.0575*** (0.0152)
COM×I($Delist^{4+}$=1)	φ_2^4			-0.0221*** (0.0070)	-0.0296*** (0.0065)
Fixed Effects Included:[d]		Quarter of Sale; Nearest HWS (103 total); Township x Year (324 total); School District (47 total)			
R^2		0.6529	0.6670	0.6629	0.6670
Observations		82,908	95,194	82,908	95,194

[a] The dependent variable is the natural log of sales price for homes transacting between 1990 and

2007 that are no further than 3 miles from an HWS. We observe the delisting of at least one HWS during the study period, with the exception of 1990 and 1992. All models include the full set of covariates describing the property as listed in appendix Table A2, as well as quarter of sale dummy variables, fixed effects for 47 school districts and 103 nearest hazardous waste sites, and fixed effects for year-sold interacted with18 township dummy variables to allow for township-specific time trends. Homes are excluded from the estimation sample if they are between 0.5 and 1.5 miles of an HWS for the models in Columns 1 and 3, and excluded if they are between 0.7 and 1.5 miles of an HWS for the models in Columns 2 and 4. Robust standard errors are in parentheses, where *** indicates p<0.01, ** indicates p<0.05, and * indicates p<0.1.

[b] The models in columns 1 and 3 define a home to be treated by a HWS if distance to the HWS (*dHWS*) is less than or equal to 0.5 miles. Similarly, the models in columns 2 and 4 define a home to be treated by a HWS if distance to the HWS is less than or equal to 0.7 miles. Increasing the distance by which a home can be considered treated by an HWS also increases the sample size.

[c] Coefficient references are given that coincide with equations (3) and (4).

[d] There are 18 townships and 18 years interacted to form 324 dummy variables for the interaction of these two variables.