



**To Sell or Not To Sell: The Impacts of
Pollution on Home Transactions**

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Abstract:

Numerous nonmarket valuation studies have examined the impacts of environmental commodities on house prices, but little attention has been given to how shifts in these commodities affect the *occurrence* of home transactions, and the resulting welfare implications. Using a novel theoretical framework and an empirical analysis of homes impacted by petroleum releases from underground storage tanks, this paper demonstrates that changes in environmental quality can significantly impact a household's decision to sell their home, and that this change in behavior has important implications towards theoretical welfare measures and empirical estimates. A discrete time duration model is estimated using a panel of single-family homes from 2000 to 2007. The dependent variable is the annual occurrence of a sale at each individual home. I find that contamination and cleanup activities in close proximity significantly impact the probability that a home is sold. Most striking is that this probability is reduced by about 50% during ongoing cleanup. This finding is most pronounced among lower quality homes and where an exposure pathway is present.

JEL Classification: D63 (Externalities); I18 (Government Policy; Regulations; Public Health); Q51 (Valuation of Environmental Effects); Q53 (Air Pollution; Water Pollution; Noise; Hazardous Waste; Solid Waste; Recycling); R2 (Household Analysis)

Keywords: housing market, property transactions, discrete time duration model, hedonic analysis, leaking underground storage tanks, groundwater contamination

I. INTRODUCTION

Five to nine percent of home-owning households in the U.S. decide to move in a given year.¹ While there is a host of reasons why a household may decide to move (e.g., new job, changes in household size, etc.), in some cases the decision to sell one's home may be influenced by exogenous changes in local public amenities and disamenities. Whatever the case, a household's decision to sell or not sell their home has important implications for non-market valuation via hedonic property value methods.

While much theoretical and empirical research has examined how amenities and disamenities of interest are capitalized in property prices, there has been significantly less work on how changes in these commodities affect the *occurrence* of home transactions in the first place, and the resulting welfare implications. The objective of this paper is to demonstrate that the occurrence of home transactions is a crucial yet under-examined component of the impact of local amenities and disamenities in the housing market. A theoretical model of a household's decision to sell is developed to (i) demonstrate that a shift in the occurrence or rate of home transactions is evidence of a welfare impact, and to (ii) examine when the hedonic price function, by itself, is enough to infer non-marginal welfare estimates, or at least bound such effects. This novel extension of Rosen's (1974) seminal theory accounts for the fact that in most hedonic applications home sellers are not firms who endogenously choose all aspects of the housing bundle, but rather are households who currently live in the home to be sold and where some characteristics of the bundle (namely local public goods, such as environmental quality) are exogenous.

¹ Based on the US Census Bureau's 2001 to 2011 American Housing Surveys (<http://www.census.gov/housing/ahs/data/national.html>, accessed September 17, 2013).

From 2000 to 2011 homeownership rates in the US ranged from 66% to 69% (Callis and Kresin, 2013). Over this same period 25% to 30% of a homeowners household's wealth was in home equity (Gottschalck et al., 2013). The theoretical claims formalized in this paper extend on a non-marginal welfare argument going back to Lind (1973) and Bartik (1988). Households depend on their home as a financial asset to put towards purchasing a new home, and so when the value of this asset is adversely impacted, so is their ability to purchase a new home.

An empirical example is then presented where the occurrence of home transactions is in fact impacted by shifts in environmental quality. Focusing on homes in close proximity to petroleum releases from underground storage tanks (USTs), three main hypotheses are explored. First, are homeowners' decisions to sell their home impacted by petroleum contamination from underground storage tank (UST) sites in close proximity? Second, if so, does this impact vary depending on the presence of an exposure pathway (private groundwater wells) or actual contamination in a household's private well? Third, does the impact of contamination and cleanup activities impact the decision to sell differently across higher versus lower quality homes, and if so, what are the implications for self-selection bias in conventional hedonic analyses?

To answer these questions a discrete time duration model of the annual occurrence of a sale is estimated using a unique panel dataset of all residential parcels from 2000 to 2007 in three Maryland Counties. This approach is superior to looking at aggregate data on transaction rates within an area because it uses a more spatially refined house-level unit of observation. Plus individual house characteristics, in addition to characteristics of the neighborhood, can be used to explain sales activity.

The remainder of this paper proceeds as follows. Section II provides a brief overview of the literature. The theoretical model and empirical application are presented in Sections III and IV, respectively. The empirical results are discussed in Section V, followed by concluding remarks in Section VI.

II. LITERATURE REVIEW

II.A. Hedonic Property Value Studies

The earliest known application of the hedonic method can be traced back to a Masters thesis in 1922 by G.C. Haas, who analyzed the impact of city size and distance to city center on agricultural land prices (Colwell and Dilmore, 1999). A half a century later, Rosen (1974) laid the theoretical brickwork linking hedonics to welfare analysis by demonstrating that in equilibrium the marginal implicit price of an attribute equates to the buyer's marginal willingness to pay. This finding spurred a flurry of hedonic property value studies focusing on all types of public amenities and disamenities. Most studies only estimate the hedonic price function and use the estimated implicit prices to infer marginal welfare impacts.

To estimate non-marginal welfare changes the underlying demand functions must be estimated. However, this “second stage” procedure generally lacks proper identification (Epple, 1987; Bartik 1987), and is often not carried out due to the need to make arbitrary functional form assumptions on household preferences, or the need for data on multiple housing markets, household characteristics, and proper instruments.² In light of these difficulties, several studies have relied on “back of the envelope” calculations using non-marginal price changes in order to obtain some rough sense of non-marginal welfare impacts (e.g., Davis, 2004; Chay and

² For examples see Chattopadhyay (1999), Boyle et al. (1999), and Day et al. (2007).

Greenstone, 2005; Chattopadhyay et al., 2005; Linden and Rockoff, 2008; and Greenstone and Gallagher, 2008). Although such capitalization effects estimated from a first stage hedonic regression are useful to policymakers, they do not necessarily equal households' willingness to pay for non-marginal changes.³

In some contexts, particularly those where the policy or exogenous shift of interest is a localized event and does not shift the hedonic price function, the literature's focus on buyers willingness to pay is misplaced. Consider a localized exogenous shift in environmental quality, where house prices in a specific locale change, but the hedonic price schedule remains fixed. Households in their roles as homebuyers are free to choose their housing bundles along this fixed price schedule. If they choose a home with a degraded level of environmental quality at a lower price, it is because it is optimal for them to do so given their preferences and budget constraints. Under the standard hedonic assumptions of free mobility and a continuum of housing bundles, for such localized shifts households in their role as the homebuyer can be no worse off.

In contrast, this same localized shift in environmental quality is exogenously imposed on the current owners (and potential sellers) of the impacted homes. The crux of this paper is in the spirit of a non-marginal welfare argument going back to Lind (1973). The idea is that non-marginal welfare impacts from sufficiently local changes are simply windfall gains or losses to the property owners, and therefore can be estimated solely from a change along the same hedonic price schedule (Polinsky and Shavell, 1976; Freeman, 1979; Bartik, 1988). In addition to the assumptions of free mobility, a constant hedonic price schedule, and a continuum of homes, this non-marginal welfare argument depends on a theoretical abstraction that, according to Bockstael

³ See Kuminoff and Pope (2012) or Kuminoff et al. (forthcoming) for discussions of the necessary assumptions in making such welfare claims.

and McConnell (2006, pg 166), was first introduced by Lind (1973) and later refined by Bartik (1988), where households are isolated in two separate roles: one as a landlord and the other as a tenant. In the common case where households own their home it is argued that the household can be thought of as both the landlord and tenant.

As later demonstrated in section III.B, when households are linked in their roles as a landlord and tenant, and are truly treated as homeowners who rely on their home for both housing services and as a financial asset, then the validity of this non-marginal welfare argument depends on the household's intention to sell under the status quo or given some exogenous shift in environmental quality.

II.B. Impacts on Transaction Activity

Despite the potential welfare implications, there are few studies examining how a household's decision to sell or remain in their current home is impacted by shifts in local environmental commodities. In fact, no studies to date have estimated the welfare effects associated with a change in property transaction rates (US EPA, 2011). The few studies that have estimated how pollution impacts transaction activity have mainly focused on industrial and commercial properties, and in general find that transaction rates decline with increases in actual or suspected contamination (Sementelli and Simons, 1997; Simons and Sementelli, 1997; Simons et al., 1999), but this is not always the case (Howland, 2004).

In the residential real estate literature significant attention has been given to the home selling and transaction process, but few studies have focused on how environmental amenities and disamenities could impact this process (Knight, 2008). Most claims in the literature have been limited to speculation and anecdotal evidence. For example, Simons et al. (1999) voiced

concern that hedonics may understate welfare losses because it does not capture decreases attributable to the delay in selling a home. Stated preference studies and focus groups on pollution from leaking underground storage tanks (LUSTs) have revealed that respondents are less likely to place bids on hypothetical homes with degraded levels of environmental quality, and when put in the role of the seller respondents are reluctant to sell and are concerned with their ability to do so (Simons and Winson-Geideman, 2005; Alberini and Guignet, 2010). Residents near actual LUST sites expressed similar concerns of how nearby contamination can reduce their ability to sell their homes.⁴ There are several mechanisms that could lead to such concerns, including asymmetric information and risk perceptions, adverse selection, and a seller's general unwillingness or inability to accept a large discount in price.

To my knowledge there are only two studies that formally investigate how environmental commodities impact the occurrence of residential transactions. Focusing on highway noise, Huang and Palmquist (2001) jointly estimated the hedonic price function and an equation explaining the time a home is on the market. They found that highway noise negatively impacted home prices, but had no significant effect on market duration. They speculate that this may be due to two opposing forces. A seller may have a lower reservation value at higher levels of the disamenity, and is thus more likely to receive an acceptable bid for the home. On the other hand, buyers may be more reluctant to bid on such a home, and so it is less likely to be sold. Like much of the literature on the home transaction process (Knight, 2008), Huang and Palmquist (2001) focus only on homes that are eventually sold or are at least on the market to be sold. From a nonmarket valuation standpoint this focus is too narrow. The population of interest in welfare analysis is usually all households that are potentially impacted by the environmental commodity

⁴ For example, see Lenhart (15 Jun. 1998), Tamber (12 May 2006), and Leslie (20 Apr. 2007).

in question, regardless of their intent to sell or not. In this sense, a more critical question encompasses the occurrence of a sale among the population of all impacted households and homes.

Depro and Palmquist (2012) shed light on this broader question. Similar to the approach taken in this paper, they estimate a discrete-time binary choice model, and examine how characteristics of the home, the household, macroeconomic trends, and of particular interest, changes in local ozone levels, impact the probability that a household decides to sell their home and successfully does so in a given year. They find that the probability of a household moving and choosing a new housing bundle is 2.1% higher when ozone concentrations increase by 1 part-per-billion (ppb), relative to the levels at the time the home was first purchased. They conclude that households do exhibit ozone averting actions in deciding when to re-optimize and choose a new home. Depro and Palmquist also find that households are more likely to move when ozone levels improve, an effect that is slightly less (a 1 ppb decrease in ozone implies a 0.5% increase in the odds of moving).

This paper adds to these earlier works by examining how changes in a unique environmental disamenity, petroleum releases from underground storage tanks (USTs), impact the occurrence of home transactions. Furthermore, the empirical analysis here examines whether low or high quality homes are more or less likely to sell in the face of environmental contamination – a question that has not yet been formally examined in the literature, but could suggest self-selection biases in conventional hedonic studies.

II.C. Location Sorting Models

Although the focus is not on a household's decision to sell per se, locational sorting models examine a similar discrete choice. Following Tiebout's (1956) seminal piece, the basic idea is that preferences can be inferred from how households sort themselves across different communities that offer location-specific public goods, at different prices (as reflected in the cost of housing). Starting with Epple and Sieg (1999), this alternative non-market valuation approach has gained momentum, with applications to environmental commodities such as air pollution (Banzhaf and Walsh, 2008; Kuminoff, 2009; Sieg et al., 2004; Smith et al., 2004; Tra, 2010) and open space (Klaiber and Phaneuf, 2010; Walsh, 2007).⁵

Sorting models offer several advantages over first stage hedonic methods (and by extension the framework laid out in this paper), including the ability to account for widespread shifts that yield a new equilibrium, and to allow for feedback effects due to the sorting of different populations across neighborhoods. However, neither of these advantages apply in the context of localized changes, which is the focus of this paper.

One shortfall of the sorting literature is that households are largely treated as renters, and capital gains/losses that accrue to households in their roles as homeowners are disregarded. One exception is a recent working paper by Bayer et al. (2011), who modeled neighborhood choice in a dynamic setting. This allowed them to account for a household's expectation of how the value of their home as a financial asset will evolve over time. This is a key direction for future research because a large component of household wealth is in home equity, ranging from 25% to 30% during 2000 to 2011 (Gottschalck et al., 2013). The current paper further emphasizes the

⁵ See Kuminoff et al. (forthcoming) for a comprehensive review of the locational equilibrium sorting literature, and Klaiber and Kuminoff (forthcoming) for an excellent practical summary.

importance of capitalization effects to a homeownership household's wealth. As formally argued in the next section, exogenous changes to a household's current housing bundle affects their wealth, which in turn impacts that household's propensity to sell their home, as well as the set of new homes that fall within their budget set.

III. THEORETICAL MODEL

III.A. To sell or not to sell

In a given period a household is faced with the decision of whether to sell their current housing bundle and move to a new home. For notational ease, suppose a household's current home is composed of a single attribute \bar{q} , which denotes the level of environmental quality at the location of that home. If a household decides to sell, they are faced with the following utility maximization problem:

$$\max_{q,z} U(q, z); \quad \text{s.t.} \quad Y + P(\bar{q}) \geq P(q) + z + k \quad (1)$$

where q denotes the household's new housing bundle, which for simplicity is also composed of a single attribute, environmental quality. The budget constraint shows that the sum of an exogenous level of income (Y) and funds received from selling a household's current home ($P(\bar{q})$) must be greater than or equal to the price of the new home ($P(q)$) plus numeraire consumption (z) and a fixed moving cost (k). The prices of the current and new home follow the same hedonic price schedule $P(\cdot)$, but the actual prices differ since \bar{q} does not generally equal q . It is assumed that utility is strictly increasing with consumption ($\frac{\partial U}{\partial q} > 0, \frac{\partial U}{\partial z} > 0$) and that price is strictly increasing with quality ($\frac{\partial P}{\partial q} > 0$). Note that a seller can always sell their home if he is willing to lower the asking price to the highest bidder's bid, which is reflected in

the hedonic price function since this is the upper envelope of all buyers' bid functions (Rosen, 1974).

Although the household did previously choose their current home \bar{q} , this is considered exogenous in equation (1). Of course with respect to some attributes a household could incur costs to adjust their current housing bundle (e.g., adding a room or renovating a bathroom), and in some cases a household could even improve aspects of environmental quality. For example, they could replace lead pipes or install a better ventilation system. However, for the purposes of this analysis \bar{q} and q are aspects of environmental quality associated with the location of a home, and are therefore public in nature.

The utility maximizing solutions to (1) are:

$$z^* = Y + \bar{P} - P^* - k ; \text{ and } q^* = q(Y + \bar{P}) \quad (2)$$

where $\bar{P} = P(\bar{q})$ and $P^* = P(q^*)$. The utility maximizing new housing bundle q^* is a function of the exogenous level of income and the amount received from selling one's current home. Sometimes referred to as the "down-payment" effect, there is theoretical (Stein, 1995) and empirical (Chan, 2001) support that the price received for one's current home can impact their new optimal housing choice. Plugging these optimal levels into the utility function yields the maximized utility if a household sells their current home and moves to a new one:

$$U^* = U(q^*, z^*) \quad (3)$$

Thus far the problem has been conditional on the household selling their current home. However, as is often the case, a household could decide not to sell and continue to reside in their

current home. If a household does not sell, then they face the somewhat trivial utility maximization problem:

$$\max_z U(\bar{q}, z); \quad s.t. \quad Y \geq z \quad (4)$$

Since utility is strictly increasing with z , the optimal demand for the numeraire and the maximized level of utility obtained when the household remains in their current home are:

$$\bar{z}^* = Y; \text{ and } \bar{U} = U(\bar{q}, Y) \quad (5)$$

Whether a household decides to sell or not depends on the relative value of their optimal utility level from selling (U^*) versus their reservation utility level from not selling and remaining in their current home (\bar{U}). More formally, a household will sell their current home if:

$$U^* = U(q^*, z^*) > U(\bar{q}, Y) = \bar{U} \quad (6)$$

As shown in Appendix A, this decision rule can be depicted graphically by extending Rosen's (1974) theory of the bid and offer functions.

III.B. Impact of a Non-Marginal Localized Shift

The focus of this paper is ultimately on a household's decision of whether to sell their current home, and how this is impacted by an exogenous change in environmental quality. Suppose there is a localized exogenous decrease in environmental quality at a household's current home from \bar{q}_0 to \bar{q}_1 , where $\bar{q}_0 > \bar{q}_1$. A localized shift is one where sufficiently few homes are impacted as to not shift the housing market equilibrium, and so the hedonic price function remains constant (Bartik, 1988; Palmquist, 2005). It is unknown a priori how such a change would impact a household's decision to sell. A decrease in \bar{q} would result in a lower

price received for the current home, which in turn implies that less income would be available for housing and numeraire consumption, implying that $U_0^* > U_1^*$, where subscripts 0 and 1 denote before and after the shift in \bar{q} , respectively. On the other hand, a decrease in \bar{q} also implies a decrease in the household's reservation utility, $\bar{U}_0 > \bar{U}_1$. These counteracting forces make the impact of a change in environmental quality on a household's decision to sell or not sell ambiguous.

Nonetheless, an increase or decrease in transactions in response to a decrease (increase) in \bar{q} , all else constant, implies a decrease (increase) in welfare.⁶ For example, if a decrease in environmental quality switches the direction of the inequality in equation (6), then a household who was going to sell would now decide not to. In this case the loss in current housing services is not as bad as the loss in the value they would receive from selling their home at a discount, and thus the subsequent loss in utility from having to settle for a less desirable new home. Similarly, a household who was not planning to sell ($U_0^* < \bar{U}_0$) may now decide to sell because the loss in utility from remaining at a lower quality home is too great compared to moving ($U_1^* > \bar{U}_1$).⁷

As discussed in section II.A, most hedonic property value studies only examine price differentials estimated from hedonic regressions. Making non-marginal welfare inferences to home buyers solely from these implicit price estimates is generally invalid.⁸ However, under the

⁶ No change in transaction activity, however, does not necessarily imply that there is no impact on welfare; it just means that if there is an impact the relative changes were not large enough to flip the inequality in equation (6).

⁷ Although the model here is static in order to keep this theoretical illustration as tractable as possible, this concept could be expanded to a dynamic programming framework where a household's objective is to maximize the present value of the expected stream of utility over all subsequent periods. Such extensions are a useful direction for future research because they better capture how a change in environmental quality encourages or delays a sale.

⁸ Kuminoff and Pope (2012) lay out three necessary and sufficient conditions to interpreting price differentials as exact willingness to pay measures: (i) preferences, income, and technology must be fixed, (ii) utility must be

assumptions of free mobility, a continuum of homes, and a fixed hedonic price schedule, it has been argued that any non-marginal welfare impacts are simply windfall gains or losses to property owners (Polinsky and Shavell, 1976; Freeman, 1979; Bartik, 1988). These claims made early on in the hedonic literature rely on a theoretical abstraction that severs the link between a household in their role as a buyer of one home and seller of another.

This paper re-establishes this connection. When households are linked in their role as a seller of their current home and potential buyer of a new home, the estimated price differential may not necessarily equal a change in welfare, depending on a household's intention to sell.

To formally define measures of welfare, I first introduce the following expenditure minimization problems. If a household decides to sell and purchase a new home, their expenditure minimization problem is:

$$\min_{q,z} P(q) + z + k; \quad \text{s.t. } U(q, z) \geq u \quad (7)$$

A household minimizes their total expenditure, including the cost of their new home ($P(q)$), moving or transaction costs (k), and numeraire consumption (z); subject to obtaining a fixed level of utility (u). The minimizing arguments (or Hicksian demands) and the corresponding expenditure function, are shown below.⁹

$$q_h^* = q_h(u); \quad z_h^* = z_h(u); \quad \text{and} \quad e(u) = P(q_h^*) + z_h^* + k \quad (8)$$

separable in the public commodity of interest and the demand for this good must be perfectly elastic over the range of interest, and (iii) the second derivate of the hedonic price function with respect to the commodity of interest must equal zero.

⁹ Following conventional theory, these Hicksian demand and expenditure functions are functions of both utility and prices. However, prices are not represented in the right-hand side since the price schedule is not varied in this theoretical exercise. Additionally, such notation is complicated by the fact that unit prices are not constant exogenous parameters, but instead follow an exogenous price schedule.

If a household remains in their current home they face the following expenditure minimization problem:

$$\min_z z; \quad \text{s.t. } U(\bar{q}, z) \geq u \quad (9)$$

and the Hicksian numeraire demand and expenditure function are simply:

$$\bar{z}_h^* = \bar{z}_h(\bar{q}, u) = \bar{e}(\bar{q}, u) \quad (10)$$

In this theoretical framework, the choice of which expenditure function to use (equation 8 or 10) to define *Compensating Variation* (CV) and *Equivalent Variation* (EV) is important, and depends on whether a household optimally chooses to sell or not under the status quo or given some exogenous shift in quality from \bar{q}_0 to \bar{q}_1 . Consider a decrease in environmental quality ($\bar{q}_0 > \bar{q}_1$). A household could fall into one of four cases.

CASE 1: Sell / Sell: In this case a household is initially intending to sell their current home given \bar{q}_0 , and would still optimally decide to do so after a decrease in quality to \bar{q}_1 . Here compensating variation (CV_{SS}) is defined using the “sell” expenditure function (equation 8):

$$\begin{aligned} CV_{SS} &= e(U_1^*) - e(U_0^*) \\ &= P(q_{h1}^*) + z_{h1}^* + k - [P(q_{h0}^*) + z_{h0}^* + k] \end{aligned} \quad (11)$$

where U_j^* is the maximized utility when a household sells given \bar{q}_j (see equation 3), and q_{hj}^* and z_{hj}^* are the Hicksian demands (from equation 8) evaluated at U_j^* , for $j = 0, 1$. Exploiting the duality between the Marshallian and Hicksian demands when evaluated at U_j^* , the former can be substituted in for the latter, as shown:

$$CV_{SS} = P(q_1^*) + z_1^* + k - [P(q_0^*) + z_0^* + k]$$

$$\begin{aligned}
&= P_1^* + [Y + \bar{P}_1 - P_1^* - k] + k - \{P_0^* + [Y + \bar{P}_0 - P_0^* - k] + k\} \\
&= \bar{P}_1 - \bar{P}_0
\end{aligned} \tag{12}$$

where $P_j^* = P(q_j^*)$ and $\bar{P}_j = P(\bar{q}_j)$ for $j = 0, 1$. Some further simplification reveals that in this case where the household sells either way, CV does equal the change in price.¹⁰ The same result can be shown for equivalent variation (EV_{SS}) in this case, implying:

$$CV_{SS} = EV_{SS} = \bar{P}_1 - \bar{P}_0. \tag{13}$$

When a household optimally chooses to sell given \bar{q}_0 or \bar{q}_1 , the theoretically valid change in welfare does in fact equal the change in price along a fixed hedonic surface. This is in agreement with the non-marginal welfare claims previously made by Lind (1973), Bartik (1988), and others. In their analyses households were considered separately in their role as a landlord and tenant. In making this abstraction these households were forced to always participate in the market in order to consume housing services. Therefore, it is not surprising that this typical result holds in the current framework when the household endogenously chooses to participate (i.e., sell and buy a home). However, in cases where a household does not necessarily sell, the change in price may not equal the corresponding change in welfare.

CASE 2: Do not sell / Sell: Next consider the case where a household's optimal choice is initially not to sell and to continue living in their current home at \bar{q}_0 . However, given some exogenous decrease to \bar{q}_1 the household decides to sell. CV is again defined using the "sell" expenditure function (equation 8), since CV reflects the amount of compensation needed after the shift in

¹⁰ Note that this result would not necessarily hold if moving costs were not assumed to be constant.

quality. The difference here is that the second term is now evaluated at \bar{U}_0 because the household was not initially going to sell:

$$\begin{aligned} CV_{ns} &= e(U_1^*) - e(\bar{U}_0) \\ &= P(q_{h1}^*) + z_{h1}^* + k - \{P(q_h(\bar{U}_0)) + z_h(\bar{U}_0) + k\} \end{aligned} \quad (14)$$

When evaluated at U_1^* standard duality results apply and the Hicksian and Marshallian demands are equal, but such simplifications do not apply to the part of equation (14) that is inside the $\{\cdot\}$, and so:

$$\begin{aligned} CV_{ns} &= P(q_1^*) + z_1^* + k - \{P(q_h(\bar{U}_0)) + z_h(\bar{U}_0) + k\} \\ &= P_1^* + [Y + \bar{P}_1 - P_1^* - k] + k - \{P(q_h(\bar{U}_0)) + z_h(\bar{U}_0) + k\} \\ &= Y + \bar{P}_1 - \{P(q_h(\bar{U}_0)) + z_h(\bar{U}_0) + k\} \end{aligned} \quad (15)$$

The middle equality holds by plugging in the definition of z_1^* from equation (2).

Since CV is measured using the “sell” expenditure function in Case 2, it can be shown that the change in the hedonic price actually understates the welfare loss. By definition of Case 2, the household does not sell given \bar{q}_0 because $\bar{U}_0 > U_0^*$. It follows that $e(\bar{U}_0) > e(U_0^*)$, which in turn implies $CV_{ns} = e(U_1^*) - e(\bar{U}_0) < e(U_1^*) - e(U_0^*) < 0$. Plugging in the result from equations (11) and (12) implies: $CV_{ns} = e(U_1^*) - e(\bar{U}_0) < \bar{P}_1 - \bar{P}_0 < 0$. In this case, the change in price understates the total welfare loss because not only did the household lose the value of their home as a financial asset, but there is an additional welfare loss associated with forcing the household to the point of deciding to sell.

The corresponding measure of EV for Case 2 differs from CV because *equivalent variation* is measured prior to the shift in environmental quality, and so the “do not sell” expenditure function (from equation 10) is used:

$$\begin{aligned}
EV_{ns} &= \bar{e}(\bar{q}_0, \bar{U}_1) - \bar{e}(\bar{q}_0, U_0^*) \\
&= \bar{z}_h(\bar{q}_0, \bar{U}_1) - \bar{z}_h(\bar{q}_0, U_0^*)
\end{aligned} \tag{16}$$

CASE 3: Sell / Do not sell: Now suppose a household optimally chooses to sell given \bar{q}_0 , but under \bar{q}_1 they would decide to not sell and to continue living in their current home. In this case the appropriate measure of CV is evaluated using the “do not sell” expenditure function (equation 10):

$$\begin{aligned}
CV_{sn} &= \bar{e}(\bar{q}_1, \bar{U}_1) - \bar{e}(\bar{q}_1, U_0^*) \\
&= \bar{z}_h(\bar{q}_1, \bar{U}_1) - \bar{z}_h(\bar{q}_1, U_0^*) \\
&= Y - \bar{z}_h(\bar{q}_1, U_0^*)
\end{aligned} \tag{17}$$

The last equality holds due to the duality between the Marshallian and Hicksian numeraire demand functions, and the former’s definition in equation (5).

The corresponding EV measure for Case 3, is defined using the “sell” expenditure function (equation 8):

$$\begin{aligned}
EV_{ns} &= e(\bar{U}_1) - e(U_0^*) \\
&= P(q_h(\bar{U}_1)) + z_h(\bar{U}_1) + k - \{P(q_{h0}^*) + z_{h0}^* + k\}
\end{aligned} \tag{18}$$

Plugging in the Marshallian demands (equation 2), and some algebraic simplification yields:

$$\begin{aligned}
EV_{ns} &= P(q_h(\bar{U}_1)) + z_h(\bar{U}_1) + k - \{P(q_0^*) + z_0^* + k\} \\
&= P(q_h(\bar{U}_1)) + z_h(\bar{U}_1) + k - \{P_0^* + Y + \bar{P}_0 - P_0^* - k + k\} \\
&= P(q_h(\bar{U}_1)) + z_h(\bar{U}_1) + k - \{Y + \bar{P}_0\}
\end{aligned} \tag{19}$$

In this specific case, since EV_{ns} is measured using the “sell” expenditure function, it can be shown that the price differential actually overstates the welfare loss. If the household decides

not to sell given \bar{q}_1 , it follows that $\bar{U}_1 > U_1^*$, which implies $e(\bar{U}_1) > e(U_1^*)$. Subtracting $e(U_0^*)$ from both sides and plugging in the definitions from equations (11), (12), (18), and (19) yields: $\bar{P}_1 - \bar{P}_0 < EV_{ns} < 0$. In this case the change in price estimated from a hedonic regression would overstate the welfare loss. The intuition is that a household has the ability to remain in their current home and not participate in the market. By doing so they are not forced to realize the full loss in the value of their home as an asset, and therefore can minimize any welfare loss.

CASE 4: No Sell / No Sell: Now consider the final case where a household's optimal decision is not to sell given \bar{q}_0 or \bar{q}_1 . In this case CV is defined as:

$$\begin{aligned}
CV_{nn} &= \bar{e}(\bar{q}_1, \bar{U}_1) - \bar{e}(\bar{q}_1, \bar{U}_0) \\
&= \bar{z}_h(\bar{q}_1, \bar{U}_1) - \bar{z}_h(\bar{q}_1, \bar{U}_0) \\
&= Y - \bar{z}_h(\bar{q}_1, \bar{U}_0)
\end{aligned} \tag{20}$$

and the corresponding measure of EV is:

$$\begin{aligned}
EV_{nn} &= \bar{e}(\bar{q}_0, \bar{U}_1) - \bar{e}(\bar{q}_0, \bar{U}_0) \\
&= \bar{z}_h(\bar{q}_0, \bar{U}_1) - \bar{z}_h(\bar{q}_0, \bar{U}_0) \\
&= \bar{z}_h(\bar{q}_0, \bar{U}_1) - Y
\end{aligned} \tag{21}$$

It is ambiguous whether the price differential would under or overstate the welfare impacts in this case.

As seen in the four cases above, a change in house price may not necessarily equal the change in household welfare. This framework extends on the theoretical work of Bartik (1988) by modeling households as homeowners who simultaneously derive housing services from their current home and also depend on it as a financial asset. Establishing this link between homeownership households in their role as both the landlord and tenant shows that the change in

price will equal the change in welfare, as Bartik (1988) and others argued, but only in situations where the household would optimally decide to sell under the status quo and given some exogenous shift (Case 1). If a household was not originally intending to sell but this decrease in environmental quality encouraged them to do so, then (depending on the welfare measure of interest) the change in price underestimates the loss in welfare (Case 2). If this shift induced a household not to sell, but they would have done so otherwise, then the decrease in price estimated from a conventional hedonic regression analysis would overstate the loss in welfare (Case 3).

Empirically estimating such welfare effects would be difficult. A key appeal of hedonics is that it only requires data on housing characteristics and transactions, which are readily available for many locations. Estimating CV and EV based on the above framework requires knowledge of household demographics, preferences, and income; not to mention the need to estimate the expectation of which of the four Cases a household would fall under. Data limitations prevent estimating such welfare measures in this paper, and I leave this for future research. The empirical application in the next section motivates and takes a first step in that direction by providing an example where shifts in local environmental quality do in fact affect households' decisions to sell or not sell their home.

IV. EMPIRICAL APPLICATION

A household's decision of whether to sell their home in a given year is empirically estimated. The analysis focuses on residential parcels in close proximity to petroleum releases from underground storage tanks (USTs), such as those commonly found at gas stations. Three main hypotheses are examined. First, are home transactions impacted by contamination and

cleanup events at leaking UST sites in close proximity? Second, if so, does this impact vary depending on the presence of an exposure pathway (private groundwater wells) or actual contamination in a household's private well? Third, does this impact on transaction activity systematically differ across higher versus lower quality homes?

IV.A. Background on Leaking Underground Storage Tanks

Occasionally USTs leak as a result of corrosion, cracks, defective piping, or spills during refilling and maintenance. Leaking contaminants can seep into the soil and groundwater, and sometimes migrate to surrounding water bodies, ecological systems, and even drinking water sources. Human exposure to these contaminants occurs primarily through consumption of contaminated groundwater (but potentially also through vapor migration). Petroleum by-products such as benzene, toluene, ethyl benzene, and xylenes (BTEX) pose human health risks, including cancer and adverse effects on the kidneys, liver, and nervous system (US EPA, 2012a). Petroleum products can also contain harmful additives, such as Methyl tertiary butyl ether (MTBE), a former gasoline additive and suspected carcinogen (Toccalino, 2005).

Those most at risk are nearby households who rely on private groundwater wells, which draw water directly from the groundwater beneath their property. If a leak occurs at an UST in close proximity, the local aquifer is potentially susceptible to contamination. In contrast, homes connected to the public water system often get their drinking water from sources farther away, and so the residing households may not be exposed to contaminated water should a release occur near their home. Furthermore, unlike public water sources, private wells are not regulated by the Safe Drinking Water Act (US EPA, 2012b), and so households depending on private wells may

face even greater risks since their water is not required to undergo routine testing, monitoring, and treatment.

Whether actual health risks are present or not, responses in the housing market are driven by buyers' and sellers' perceptions, which in turn depend on public information and awareness. Although nearby residents and potential buyers are likely aware of a gas station or other UST facilities in close proximity, they may not necessarily be aware of a leak should one occur. These tanks are underground and there are not always obvious cues of contamination. Frequently, media attention is minimal and notification requirements by regulators are often limited to parties who are directly affected by the contamination (Zabel and Guignet, 2012; Guignet, 2013).

Cleanup activities, on the other hand, can be fairly invasive and yield visual cues making buyers and sellers aware of the disamenity. Clean-up can include removal of the tanks, excavation of contaminated soil, pump-and-treat and vacuuming of contaminated groundwater, bioremediation (i.e., adding oxygen and enzymes to the groundwater), soil vapor extraction, digging pollution recovery trenches, building concrete caps and containment walls, and on-going testing and monitoring of surrounding wells. These activities can last anywhere from a few days to many years.

IV.B. Empirical Model

Following equation 6, household h will sell their current home i in a given year t ($sold_{ith} = 1$) if the maximized utility they get from selling is greater than their reservation utility level; and will not sell otherwise ($sold_{ith} = 0$). More formally:

$$sold_{ith} = \begin{cases} 1, & \text{if } U^*(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, \mathbf{M}_t, Y_h) > \bar{U}(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, Y_h) \\ 0, & \text{if } U^*(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, \mathbf{M}_t, Y_h) \leq \bar{U}(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, Y_h) \end{cases} \quad (22)$$

where Y_h is household h 's income, and \mathbf{M}_t is a vector of annual time dummies to account for temporal fluctuation in the housing market. The current housing bundle (previously denoted as \bar{q} in the theoretical model) is now a vector of attributes of the house and its location (\mathbf{x}_{it}), as well as environmental attributes ($\mathbf{UST}_{it}, \mathbf{LUST}_{it}$).

The variables that proxy perceived and actual levels of environmental quality are \mathbf{UST}_{it} and \mathbf{LUST}_{it} . The former is a vector denoting the presence and number of UST facilities in close proximity to home i . \mathbf{LUST}_{it} is a vector of dummy variables denoting the presence of a leaking underground storage tank (LUST) within a given distance of home i in period t in each of three stages of the contamination and cleanup process. Briefly, if a leak is (i) *discovered* then an investigation is undertaken by the environmental regulators to assess the situation and determine the appropriate actions. The regulator may require that (ii) *cleanup* actions be taken, but not all LUSTs undergo active cleanup because petroleum products can naturally degrade over time. If there is no public or environmental threat then ongoing monitoring and natural attenuation are sometimes deemed the best course of action (US EPA, 2004; Khan et al., 2004). If cleanup is undertaken, it is complete by the time the leak investigation enters the final stage, (iii) *closure* of the investigation, which is reached when the regulatory agency no longer considers the LUST a threat.¹¹

¹¹ Similar interaction terms between distance to a pollution source and discrete contamination/cleanup events are a common identification strategy in hedonic property value studies (Boyle and Kiel, 2001; Farber, 1998).

The probability or expectation that home i is sold in period t can be modeled as,

$$\begin{aligned} E(\text{sold}_{it}) &= Pr\{U^*(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, \mathbf{M}_t, Y_h) > \bar{U}(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, Y_h)\} \\ &= Pr\{U^*(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, \mathbf{M}_t, Y_h) - \bar{U}(\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, Y_h) > 0\} \end{aligned} \quad (23)$$

Unfortunately, in this application there are no observed data on the households themselves, including income, preferences, and socio-economic characteristics. Therefore, the following reduced form model is estimated omitting these variables:

$$E(\text{sold}_{it}) = G\{\mathbf{x}_{it}, \mathbf{UST}_{it}, \mathbf{LUST}_{it}, \mathbf{M}_t\} \quad (24)$$

The probability of a sale follows the cumulative distribution function $G\{\cdot\}$, which is later assumed to be either Normal or Type II Extreme Value.

IV.C Home and Underground Storage Tank Data

The empirical analysis focuses on Maryland because I could physically access the necessary UST release investigation files at the Maryland Department of Environment (MDE), and a comprehensive dataset of homes and transactions was available. Focus was drawn to three Counties (Baltimore, Frederick, and Baltimore City), which were selected because together they provide a good mix of homes served by public water versus private groundwater wells. I construct a panel of 212,068 single-family homes each year from 2000 to 2007, yielding a total of $n=1,696,544$ observations.¹² About 29% of homes sold at least once during this period. All homes in Baltimore City are connected to the public water system, whereas about 18% and 51%

¹² This sample consists of all single-family homes where the same parcel tax identification number remained from 2000-2007, and the same house remained on the parcel. This is a relatively constant stock of homes. It is not always clear why a parcel's tax identification number changes, but sometimes this occurs because a parcel is put into a new land use, a new structure is built, or it is split into several lots or merged with neighboring parcels.

of homes in Baltimore and Frederick Counties, respectively, are in areas served by private groundwater wells.

Descriptive statistics as of 2007 are presented in table 1. The average home has an interior size of about 1,750 square feet, is 1.67 stories, is about 50 years in age, and is located about 14 kilometers from the nearest central business district. Figure 1 shows the annual transaction rate for each county from 2000 to 2007. As one may expect, there is a higher rate of transactions in the urban county of Baltimore City compared to that of the suburban/rural counties of Baltimore and Frederick. Nonetheless, there is a similar time trend across all counties, including the market downturn after 2006. As of 2007, about half of all single-family homes in this sample were within 500 meters of a registered underground storage tank (UST), and 14,567 (6.87%) of homes were within 500 meters of a leaking tank.

The MDE provided data on all USTs registered with the State. Attention is restricted to the 3,516 registered UST facilities in Baltimore (1495), Baltimore City (1562), and Frederick (459) Counties.¹³ The majority of facilities are in areas connected to the public water system (88%), but there are 426 UST sites in areas where households rely on private groundwater wells. Among the UST facilities where the MDE inspector noted the site use, most are classified as gas stations (574), 305 are listed just as commercial, and 421 as industrial.¹⁴ The average UST facility has three tanks and a total capacity of 17,363 gallons.

¹³ This set of UST facilities disregards those that are classified as farms, residences, and government facilities, relatively small tanks that are not regulated by MDE, and those missing a valid street address.

¹⁴ The site use was not listed at 2,216 of the UST facilities.

From 1996 to 2007, petroleum releases were discovered at 138 (3.92%) of these facilities.¹⁵ About 25% of these leaks occurred in areas where surrounding homes rely on private wells. At 27 of these LUST sites there was evidence confirming that contamination migrated to neighboring properties. As of the end of 2007, active cleanup efforts had been undertaken at 61 sites (44.2%). Considering the 84 leak investigations that were closed by the end of 2008, the average was open for 1.8 years (median 1.25 years), the shortest was a day, and the longest was 10.5 years.

V. EMPIRICAL RESULTS

V.A Impact of Petroleum Releases on Home Transactions

Several variants of equation (24) are estimated. Only the coefficient estimates of interest are presented, but all the attributes from table 1, as well as annual time dummies and county specific intercepts, are included in the regressions. Although not shown here, the majority of home structure, parcel, and location characteristics are statistically significant. The year dummies are also often significant, and reflect the trends in Figure 1.¹⁶

In table 2, Model 2.A is a probit regression of the annual occurrence of a sale, and includes homes in all three counties. The estimated average marginal effects are shown. The

¹⁵MDE's Oil Control Program provided data on 42,100 oil "cases" in Maryland, which included routine compliance checks, the opening and closing of USTs, and leak investigation and remediation cases. Out of these cases, 284 pertain to investigations for vapor intrusion, or soil and groundwater contamination in the study area, and were opened between 1996 and 2007. Lesser cases where contamination was not found or the events were trivial were disregarded, leaving 255 cases. I exclude cases that were not linked to a UST facility with a valid address, leaving 219 cases. To ensure a relatively homogeneous set of LUSTs and better control for pre-leak conditions, I focus on the 138 leak investigations that were undertaken at a UST facility registered with MDE. Leaks at non-registered facilities are the result of past land uses and could currently be used for a variety of activities, and so there is no clear counterfactual. In contrast, the obvious counterfactual to leaks at registered tanks is non-leaking registered tanks.

¹⁶The full results for selected specifications are presented in Appendix B, including separate models for each county.

number of UST facilities within 500 meters of a home (whether a leak has occurred or not) has a statistically insignificant association with the annual occurrence (or probability) of a sale. There is also a statistically insignificant relationship between the annual probability of a sale and dummy variables denoting the presence of a non-leaking UST facility within 500m and a leaking UST facility within 500 meters (*LUST within 500m*). The latter denotes the presence of a LUST at any stage of the leak investigation and cleanup process, including if a leak has not yet been discovered. The coefficients on *# of USTs within 0-500m*, *non-leaking UST within 500m* and *LUST within 500m* cannot necessarily be interpreted as causal. These variables are merely meant to control for differences between baseline propensities of a sale.

In a quasi-experimental framework, *non-leaking UST within 500m* denotes the “control” group of homes, and *LUST within 500m* indicates the “treated” group (including observations prior to treatment). The “treatment” in this case is the discovery of a leak (*leak discovered*), initiation of cleanup activities (*cleanup*), and completion of cleanup and closure of a leak investigation (*post-closure*). The estimated average marginal effects corresponding to these dummy variables can be interpreted as causal average treatment effects. These are the average effects of the leak investigation and cleanup activities on the annual propensity of a sale for homes within 500 meters of a LUST, relative to before the leak was discovered.¹⁷

Consider the average home across these three counties. Before a leak is discovered the probability that a home within 500 meters of a LUST is sold in a given year is 4.81%. According to model 2.A the discovery of a leak increases the annual probability of a sale 0.46 percentage

¹⁷A 500 meter buffer was chosen based on the extent of price impacts found in past hedonic studies of these data (Zabel and Guignet, 2012; Guignet, 2013). The point estimates are similar when using a 200 meter buffer, but the results are not always statistically significant. This is likely due to the much smaller number of homes within 200 meters of a LUST. For example, in 2007 there were 2,355 homes within 200 meters of a leak, whereas there were over 14,416 homes within 500 meters.

points, from 4.81% to 5.27%. During cleanup, however, it seems the annual probability of a sale decreases to 4.27% ($=4.81-0.54$). After closure of the leak investigation and completion of cleanup, the annual probability of a sale seems to increase again to 5.29% ($=4.81+0.48$), which is above the transaction rate prior to the discovery of the leak. Although the effects of the leak and cleanup are seemingly small, the percent changes in the annual probability of a sale range from negative 11% to positive 10.0%.¹⁸ As argued in the theoretical model, these systematic changes in behavior are evidence of welfare effects on surrounding homeowners.

V.B. Impacts by Water Source: Private Wells versus Public Water

The remainder of the empirical analysis focuses on Baltimore and Frederick Counties, where a significant portion of homes rely on private groundwater wells. All homes in Baltimore City are connected to the public water system, and so this county is disregarded in order to facilitate a cleaner comparison across public water and private well homes.

The next two columns in table 2 correspond to Model 2.B, which includes interaction terms allowing the coefficients on nearby USTs and LUSTs, and the impact of leak and cleanup activities, to vary across public water and private well homes.¹⁹ In the public water column, the positive and statistically significant coefficients on *leak discovered* and *post-closure* suggest that the opening and closure of a leak investigation lead to an increase in transactions relative to before the leak was discovered. Most striking, however, is that for homes on private wells cleanup activities reduce the probability of a sale by 1.90 percentage points. The probability that

¹⁸These findings are robust to the inclusion of several neighborhood attributes, as measured by tract level characteristics from the 2000 US Census, namely: percent of population that is non-white, that possess a college degree, median household income, and percent of housing units that are owner occupied.

¹⁹A likelihood ratio test rejects the null hypothesis that these coefficients are equal, lending support to the inclusion of these interaction terms (chi-sq=9.92, p-value=0.0304).

a home with a private well is sold in a given year is 3.59%, on average, implying that cleanup leads to a 53% reduction in the probability that a home is sold.^{20, 21}

Cleanup may entail fairly intrusive activities, including removal of the underground tanks, excavation of contaminated soil, pumping of contaminated groundwater, and on-going testing and monitoring. It is unclear whether this 53% reduction in the annual probability of a sale is evidence of an increase or decrease in welfare. Actual contamination levels and the associated risks are likely decreasing during cleanup, but individual perceptions of these risks may not necessarily follow objective levels (Messer et al, 2006). Cleanup activities may serve as visual cues that make buyers and sellers aware of contamination issues for the first time, or cause them to perceive the risks as more severe (Dale et al., 1999; Messer et al, 2006). Residents may also find cleanup efforts bothersome and aesthetically displeasing (Weber et al., 2001). These visual cues could also lead to public stigma (Gregory and Scatterfield, 2002), deterring buyers from looking at homes in the neighborhood, and/or discouraging sellers from entering the market until the situation is resolved.

Model 2.C is similar to the previous model, but is estimated using Chamberlain's (1980) Fixed Effect (FE) logit specification, where all time invariant characteristics of a housing bundle and its location are conditioned out, thus reducing the potential for omitted variable bias.²² Mean marginal effects cannot be calculated for FE logit models because the home-specific fixed effects are unobserved. Instead, the estimated coefficients are displayed. There is no intuitive

²⁰ These results are robust to the inclusion of the census tract variables cited in footnote 18.

²¹ Comparing across public water and private well homes, Wald tests confirm that the impacts of *leak discovered* and *cleanup* are statistically different at the p=0.05 level. The coefficients corresponding to *post-closure* are not statistically different.

²² Estimation of the fixed effect logit model requires variation in the dependent variable within each cross-section, and therefore only includes the 49,312 homes that were sold at least once during the study period.

interpretation for the coefficients, but the sign and statistical significance can be interpreted the same as in the previous models. The results are similar, and most notably the impact of cleanup in public water areas is not statistically different from zero, whereas this effect among homes on private groundwater wells remains negative and significant.²³ This confirms that ongoing cleanup activities are a strong deterrent of transactions among homes with private wells.

V.C. Transaction Effects among Homes Most at Risk

Table 3 further focuses on homes where the residents are most at risk – those where an exposure pathway (private wells) and a potential contamination source (a UST within 500 meters) are present. As seen in model 3.A, among these homes the only statistically significant effect is a 1.59 percentage point reduction in the probability that a home is sold during cleanup, again suggesting that the probability of a sale is cut almost in half (a 44.29% reduction). This result is robust (in sign and significance) even after controlling for all observed and unobserved time invariant home and parcel specific effects using a FE logit model (3.B). The statistically insignificant coefficients corresponding to *post-closure* suggest that sales activity rebounds back to the pre-leak levels once the perceptual reminders associated with cleanup cease, and the LUST is deemed safe by environmental regulators. Thus there appears to be no post-cleanup stigma, at least in terms of quantity of sales.

Given the importance of households' awareness of the disamenity and the information aiding in their formation of perceived risks, I re-estimate the above specifications with additional dummy variables indicating whether the private well at a home was previously tested for

²³ A Wald test suggests that this impact of cleanup is statistically different from the corresponding effect on homes in public water areas (chi-sq=4.27; p-value=0.0389).

contamination, and whether these test results revealed contamination levels above zero, or above the regulatory thresholds in Maryland. In an earlier hedonic study of these data, Guignet (2013) found that transaction prices were 11% lower among homes where the private well was tested. These were the homes where households were most at risk to exposure, and where they were formally notified of a nearby release and of actual or suspected contamination in their private well.

The results are not reported here, but in short, I find no statistically significant effect of notification or private well testing on the annual occurrence of a sale. This result holds no matter if a test took place within the last 1, 2, or 3 years, or any time prior. The results of such tests (i.e., BTEX or MTBE levels above zero, or above the regulatory thresholds) also do not seem to have a significant impact on the occurrence of a sale. This finding is robust across a variety of specifications, including probit and FE logit models, and whether the dummy variables *leak discovered*, *cleanup*, and *post-closure* were included or not. The previously discussed findings from tables 2 and 3, however, are robust to the inclusion of these well test variables.

V.D. Low versus High Quality Homes

Table 4 examines whether high versus lower quality homes are more or less likely to sell during LUST events. Again focus is drawn to homes where potential health risks are highest, those in private well areas and that are within 500 meters of an UST. Higher and lower quality homes are defined by observed characteristics, namely construction quality ratings by assessors or where a home falls in the distribution of assessed values in a given year. Interaction terms are included in models 4.A through 4.D to allow the effects of LUSTs on transactions to differ for lower- and higher-grade homes.

The only statistically significant result is the negative coefficients corresponding to the interaction term *cleanup* × *low*. Comparison to the coefficients on *cleanup* × *high* suggests that lower-end homes are far less likely to sell during cleanup activities. The average “low” quality home in model 4.A has a 3.61% probability of being sold in a given year, prior to the discovery of a leak. When a LUST in close proximity undergoes cleanup, the annual probability of a sale drops to half that, 1.82% (=3.61-1.79). In contrast, the average “high” quality home has a 3.33% probability of selling in a given year, and this is reduced by only 0.29 percentage points during cleanup, a statistically insignificant 9% reduction. As shown in models 4.B through 4.D, this pattern in the point estimates is robust to FE logit specifications and various definitions of low and high quality homes (although these differences are not statistically significant).²⁴

These results provide some evidence reflecting Simons et al.’s (1999) sentiment that hedonics may underestimate the effects of LUSTs because more desirable homes are more likely to sell in the face of pollution. Perhaps buyers in the market are more accepting of a nearby release if they are receiving a higher quality home at a discount. It is also possible that less wealthy selling households, who likely live in lower-grade homes, have less financial resources to move and purchase a new housing bundle, even if they wanted to (Hird, 1994, pg 192; Chan, 2001). In contrast, wealthier households have more financial resources and are less dependent on the proceeds from selling their current home when purchasing a new one. This suggests that relatively wealthy household have an increased ability to move, if desired.

Such influences suggest the possibility for higher-grade homes to “self-select” into the sample of sales used to estimate hedonic price regressions. If such aspects of home quality are

²⁴ Wald tests fail to reject the null that the impacts of cleanup are statistically equal across low and high-end homes.

not properly controlled for in the hedonic regressions, then property value impacts may be understated. Despite this, virtually none of the hedonic studies on environmental amenities or disamenities recognize this potential bias (Knight, 2008). This is at least partially due to the practical difficulties in trying to correct for it.

In theory it is possible to control for such selection bias with a Heckman (1979) two-step or propensity score matching approach (Wooldridge, 2002). Either involves first estimating the probability a parcel is sold and then estimating the hedonic price regression. One could also estimate this system of equations simultaneously (Huang and Palmquist, 2001). Either way, statistical identification requires a proper exclusion restriction, and it is difficult to find an exogenous variable that influences the occurrence of a sale but not the transaction price. Huang and Palmquist (2001) impose the necessary restrictions, but they do not offer any explanation behind the theoretical validity of their exclusions. Hallstrom and Smith (2005) take an alternative approach and model home sale occurrence as a function of dummies denoting the year a home is built. They argue that this “non-parametric treatment of the year built distinguishes selection from age and other attributes of a conventional hedonic price function,” but the validity of this assumption remains unclear.

Under standard hedonic assumptions, characteristics of the selling household or exogenous shocks to that household (such as a new job or child) do not enter the hedonic price function, and therefore could serve as identifying variables. However, household characteristics are not observed in most hedonic applications. A researcher also faces the difficult task of arguing that these characteristics are uncorrelated with unobserved attributes of the housing bundle, and the negotiation process and accepted transaction price. Nonetheless, building on these earlier works is a valuable direction for future research.

VI. CONCLUSION

There is a significant body of literature examining how property prices are impacted by environmental amenities and disamenities, but few studies have looked at how exogenous shifts in these commodities affect the *occurrence* of home transactions in the first place, and the resulting welfare implications. Using a theoretical model that extends on Rosen's (1974) seminal framework, and an empirical illustration of homes impacted by petroleum releases from underground storage tanks, it was shown that localized changes in environmental quality can significantly impact households' decisions of whether or not to sell their home. An increase or decrease in transactions in response to a decrease in environmental quality is evidence of a welfare loss to surrounding residents. Conversely, a welfare gain can be inferred from a change in transaction occurrences in response to an increase in quality. In the absence of a monetary welfare estimate, simply observing a change in transactions (all else constant) allows economists to at least argue the existence, and perhaps sign of a welfare impact.

In line with previous claims in the literature (Lind, 1973; Bartik, 1988; Polinsky and Shavell, 1976; Freeman, 1979), it was shown that the change in the price of a home may in fact be the appropriate welfare measure for *localized* changes in public amenities and disamenities. However, one contribution of this paper was in demonstrating that for homeowners this holds only in cases where the household would optimally decide to sell both with and without the exogenous shift in the commodity of interest. Cases where the price differential reflects an over- or underestimate of a welfare impact were established. If a household would not sell absent the exogenous shift, in its presence, or both, then estimating an exact welfare measure is much more complicated, and would require data on household characteristics, income, and preferences. Due

to these practical complications such welfare measures were not estimated here, but this is a fruitful path for future research.

As a first step, I empirically examined an environmental disamenity where there does in fact seem to be an impact on residential transactions. Focusing on homes in close proximity to petroleum releases at underground storage tank (UST) facilities, I find that the discovery of a leak, cleanup activities, and closure of a leak investigation, can significantly impact the propensity of a sale. Most striking is that the probability a home is sold is reduced by about 50% during ongoing cleanup efforts, an effect that is most prominent among homes that rely on private groundwater wells, and hence where an exposure pathway is present. Perhaps the visual cues associated with cleanup lead to revisions in risk perceptions (Dale et al., 1999; Messer et al, 2006), and may even foster a temporary public stigma (Gregory and Scatterfield, 2002), deterring buyers from looking at homes in the neighborhood, and/or discouraging sellers from entering the market. This deterrence was found to be strongest among lower-quality homes, suggesting a potential for self-selection bias in traditional hedonic results (at least in this specific application to leaking USTs).

Depro and Palmquist (2012) recently found that shifts in atmospheric ozone levels increase the probability of a sale by 0.5% to 2.1%. This paper contributes to these findings by examining how transaction occurrences are impacted by a unique environmental disamenity. I find larger, and most notably negative, impacts on the occurrence of residential transactions. Such differences seem reasonable. Compared to air pollution, UST releases have a more direct (actual or perceived) effect on surrounding properties, and the contamination and cleanup events are relatively distinct shifts in environmental quality, and are therefore perhaps more perceivable to buyers and sellers in the market. Further research should investigate how other environmental

amenities and disamenities impact housing transactions, as well as how to estimate these welfare impacts and ultimately unite the relationship between transaction price and occurrence that has largely been overlooked in the non-market valuation literature.

WORKS CITED

- Alberini, Anna and Dennis Guignet (2010), "Preliminary Stated-Preference Research on the Impact of LUST Sites on Property Values: Focus Group Results," US EPA NCEE Working Paper, 10-09, Washington, D.C., August.
- Banzhaf, H. Spencer and Randall P. Walsh (2008), "Do People Vote with Their Feet? An Empirical Test of Tiebout's Mechanism," *American Economic Review*, 98(3), 843-863.
- Bartik, Timothy J. (1987), "The Estimation of Demand Parameters in Hedonic Price Models," *Journal of Political Economy*, 64(2), 172-183.
- Bartik, Timothy J. (1988), "Measuring the Benefits of Amenity Improvements in Hedonic Price Models," *Land Economics*, 64(2), 172-183.
- Bayer, Patrick, Robert McMillan, Alvin Murphy, and Christopher Timmins (2011), "A Dynamic Model of Demand for Houses and Neighborhoods," NBER Working Paper, 17250, Cambridge, MA, July.
- Bockstael, Nancy and Kenneth McConnell (2006), Environmental and Resource Valuation with Revealed Preferences. Dordrecht, Holland: Springer Publishing.
- Boyle, K. J., P. J. Poor and L. O. Taylor (1999). "Estimating the Demand for Protecting Freshwater Lakes from Eutrophication." American Journal of Agricultural Economics **81**(5): 1118-1122.
- Boyle, Melissa, and Katherine Kiel (2001), "A Survey of House Price Hedonic Studies of the Impact of Environmental Externalities," *Journal of Real Estate Literature*, 9(2), 117-144.
- Callis, Robert R., and Melissa Kresin (2013), U.S. Census Bureau News, November 5, 2013, <http://www.census.gov/housing/hvs/files/currenthvspress.pdf>, accessed December 31, 2013.
- Chamberlain, Gary (1980), "Analysis of Covariance with Qualitative Data," *Review of Economic Studies*, 47, 225-238.
- Chan, Sewin (2001), "Spatial Lock-in: Do Falling House Prices Constrain Residential Mobility?," *Journal of Urban Economics*, 49, 567-586.
- Chattopadhyay, Sudip (1999), "Estimating the Demand for Air Quality: new Evidence Based on the Chicago Housing Market," *Land Economics*, 25(1), 22-38.
- Chattopadhyay, Sudip, John B. Braden, and Arianto Patunru (2005), "Benefits of Hazardous Waste Cleanup: New Evidence From Survey – And Market – Based Property Value Approaches," *Contemporary Economic Policy*, 23(3), 357-375.

- Chay, Kenneth Y., and Michael Greenstone (2005), "Does Air Quality Matter? Evidence from the Housing Market," *Journal of Political Economy*, 113(2), 376-424.
- Colwell, Peter F., and Gene Dillmore (1999), "Who Was First? An Examination of an Early Hedonic Study," *Land Economics*, 75(4), 620-626.
- Dale, Larry, James C. Murdoch, Mark A. Thayer, & Paul A. Waddell (1999), "Do Property Values Rebound from Environmental Stigmas? Evidence from Dallas," *Land Economics*, 75(2), 311-326.
- Davis, Lucas W. (2004), "The Effect of Health Risk on Housing Values: Evidence from a Cancer Cluster," *The American Economic Review*, 94(5), 1693-1704.
- Day, Brett, Ian Bateman, and Iain Lake (2007), "Beyond implicit prices: recovering theoretically consistent and transferable values for noise avoidance from a hedonic property price model," *Environmental Resource Economics*, 37, 211-232.
- Depro, Brooks, and Raymond B. Palmquist (2012), "How Do Ozone Levels Influence the Timing of Residential Moves?," *Land Economics*, 88(1), 43-57.
- Epple, Dennis (1987), "Hedonic Prices and Implicit Markets: Estimating Demand and Supply Functions for Differentiated Products," *The Journal of Political Economy*, 95(1), 59-80.
- Epple, Dennis and Holger Sieg (1999), "Estimating Equilibrium Models of Local Jurisdiction," *Journal of Political Economy*, 107(4), 645-681.
- Farber, Stephen (1998), "Undesirable facilities and property values: a summary of empirical studies," *Ecological Economics*, 24, 1-14.
- Freeman, A. Myrick III (1979), *The Benefits of Environmental Improvement*, John Hopkins Press, Baltimore.
- Gottschalck, Alfred, Marina Vornovytskyy, and Adam Smith (2013), "Household Wealth in the U.S.: 2000 to 2011," U.S. Census Bureau, <http://www.census.gov/people/wealth/>, accessed November 7, 2013.
- Greenstone, Michael, and Justin Gallagher (2008), "Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program," *The Quarterly Journal of Economics*, August, 951-1003.
- Gregory, Robin S., and Theresa A. Scatterfield (2002), "Beyond Perception: The Experience of Risk and Stigma in Community Contexts," *Risk Analysis*, 22(2), 347-977.
- Guignet, Dennis (2013), "What Do Property Values Really Tell Us? A Hedonic Study of Pollution from Underground Storage Tanks," *Land Economics*, 89(2), 211-226.

- Haas, G. C. (1922), "A Statistical Analysis of Farm Sales in Blue Earth County, Minnesota, as a Basis for Farm Land Appraisal," Masters Thesis, University of Minnesota.
- Hallstrom, Daniel G. and V. Kerry Smith (2005), "Market responses to hurricanes," *Journal of Environmental Economics and Management*, 50, 541-561.
- Heckman, James J. (1979), "Sample Selection Bias as a Specification Error," *Econometrica*, 47(1), 153-161.
- Hird, John A. (1994), Superfund: The Political Economy of Environmental Risk, Baltimore, MD: The John Hopkins University Press.
- Howland, Marie (2004), "The Role of Contamination in Central City Industrial Decline," *Economic Development Quarterly*, 18, 207-219.
- Huang, Ju-Chin and Raymond B. Palmquist (2001), "Environmental Conditions, Reservation Prices, and Time on the Market for Housing," *Journal of Real Estate Finance and Economics*, 22(2), 203-219.
- Khan, Faisal I., Tahir Husain, Ramzi Hejazi (2004), "An overview and analysis of site remediation technologies," *Journal of Environmental Management*, 71, 95-122.
- Klaiber, H. Allen and Nicolai V. Kuminoff (forthcoming), "Equilibrium Sorting Models of Land Use and Residential choice," in: Joshua Duke and Junjie Wu (Eds.), Oxford Handbook of Land Economics. Oxford University Press.
- Klaiber, Allen and Daniel Phaneuf (2010), "Valuing Open Space in a Residential Sorting Model of the Twin cities," *Journal of Environmental Economics and Management*, 60(2), 57-77.
- Knight, John R. (2008), "Hedonic Modeling of the Home Selling Process," in: Andrea Baranzini, Jose Ramirez, Caroline Schaerer, Philippe Thalmann (Eds.), Hedonic Methods in Housing Markets: Pricing Environmental Amenities and Segregation. Springer Science+Business Media, New York, New York, pp. 39-54.
- Kuminoff, Nicolai V. (2009), "Decomposing the Structural Identification of Nonmarket Values," *Journal of Environmental Economics and Management*, 57(2), 123-139.
- Kuminoff, N. V. and J. C. Pope (2012). Do "Capitalization Effects" for Public Goods Reveal the Public's Willingness to Pay? Tempe, Arizona State University.
- Kuminoff, Nicolai V., V. Kerry Smith, and Christopher Timmins (forthcoming), "The New Economics of Equilibrium Sorting and Policy Evaluation Using Housing Markets," Forthcoming in *Journal of Economic Literature*.

- Lenhart, Jennifer. "Troubled Waters in Hills of Va.; Loudoun Towns Cope With Pollutants Seeping Into Wells." The Washington Post: Pg C08. 15 Jun. 1998.
- Leslie, Katie. "Gas leak contaminates more homes." The Frederick News-Post Online. 20 Apr. 2007, www.fredericknewspost.com, accessed 5 June 2008.
- Lind, Robert C. (1973), "Spatial Equilibrium, the Theory of Rents, and the Measurement of Benefits from Public Programs," *Quarterly Journal of Economics*, 87(2), 188-207.
- Linden, Leigh, and Jonah E. Rockoff (2008), "Estimates of the Impact of Crime Risk on Property Values from Megan's Law," *The American Economic Review*, 98(3), 1103-1127.
- Messer, Kent D., William D. Schulze, Katherine F. Hackett, Trudy A. Cameron, & Gary H. McClelland (2006), "Can Stigma Explain Large Property Value Losses? The Psychology and Economics of Superfund," *Environmental and Resource Economics*, 33, 299-324.
- Palmquist, R.B.(2005), "Property value models," in: G. Mäler, J.R. Vincent (Eds.), Handbook of Environmental Economics, vol. 2, North-Holland, Amsterdam, pp. 763–819.
- Polinsky, A. Mitchell, and Steven Shavell (1976), "Amenities and Property Values in a Model of an Urban Area," *Journal of Public Economics*, 5, 119-129.
- Rosen, Sherwin (1974), "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," *The Journal of Political Economy*, 82(1), 34-55.
- Sementelli, Arthur, and Robert A. Simons (1997), "Regulation of Leaking Underground Storage Tanks: Policy Enforcement and Unintended Consequences," *Economic Development Quarterly*, 11, 236-248.
- Sieg, Holger V., Kerry Smith, Spencer Banzhaf, and Randy Walsh (2004), "Estimating the General Equilibrium Benefits of Large Changes in Spatially Delineated Public Goods," *International Economic Review*, 45(4), 1047-1077.
- Simons, Robert A., and Arthur Sementelli (1997), "Liquidity Loss and Delayed Transactions with Leaking Underground Storage Tanks," *The Appraisal Journal*, 65(3): 255–60.
- Simons, Robert A., William Bowen, Arthur Sementelli (1999), "The Price and Liquidity Effects of UST Leaks from Gas Stations on Adjacent Contaminated Property," *The Appraisal Journal*, 67, 186-194.
- Simons, Robert A. and Kimberly Winson-Geideman (2005), "Determining Market Perceptions on Contamination of Residential Property Buyers Using Contingent Valuation Surveys," *Journal of Real Estate Research*, 27(2), 193-220.

- Smith, V. Kerry, Holger Sieg, H. Spencer Banzhaf, and Randy Walsh (2004), "General Equilibrium Benefits for Environmental Improvements: Projected Ozone Reductions under EPA's Prospective Analysis for the Los Angeles Air Basin," *Journal of Environmental Economics and Management*, 47(3), 559-584.
- Stein, Jeremy C. (1995), "Prices and Trading Volume in the Housing Market: A Model with Down-Payment Effects," *The Quarterly Journal of Economics*, May, 379-406.
- Tamber, Caryn. "Families seek more than \$1B for Exxon Mobil leak in Jacksonville." The Daily Record. 12 May 2006.
- Tiebout, Charles (1956), "A Pure Theory of Local Expenditures," *Journal of Political Economy*, 64(5), 416-424.
- Toccalino, Patty (2005), "Human-Health Effects of MTBE: A Literature Summary," United States Geological Survey, http://sd.water.usgs.gov/nawqa/vocns/mtbe_hh_summary.html, accessed September 8, 2009.
- Tra, Constant I. (2010), "A Discrete Choice Equilibrium Approach to Valuing Large Environmental changes," *Journal of Public Economics*, 94(1-2), 183-196.
- US EPA (2004), United States Environmental Protection Agency, "How to Evaluate Alternative Cleanup technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers," EPA 510-R-04-002, www.epa.gov/oust/pubs/tums.htm, accessed April 1, 2013.
- US EPA (2011), United States Environmental Protection Agency, "Handbook on the Benefits, Costs, and Impacts of Land Cleanup and Reuse," EPA-20-R-11-001.
- US EPA (2012a), United States Environmental Protection Agency, "Drinking Water Contaminants," June 5, 2012, Web, <http://www.epa.gov/safewater/contaminants/index.html#listmcl>, accessed Feb. 18, 2013.
- US EPA (2012b), United States Environmental Protection Agency, "Private Drinking Water Wells," Mar. 4, 2012, Web, <http://water.epa.gov/drink/info/well/>, accessed Feb. 18, 2013.
- Walsh, Randall L. (2007), "Endogenous Open Space Amenities in a Locational Equilibrium," *Journal of Urban Economics*, 61(2), 319-344.
- Weber, Olaf, Roland Scholz, Renate Buhlmann, and Dirk Grasmuck (2001), "Risk Perception of Heavy Metal Soil Contamination and Attitudes toward Decontamination Strategies," *Risk Analysis*, 21(5), 967-977.
- Wooldridge, Jeffrey M. (2002), Econometric Analysis of Cross Section and Panel Data, Cambridge, MA: The MIT Press.

Zabel, Jeffrey and Dennis Guignet (2012), "A Hedonic Analysis of the Impact of LUST Sites on House Prices," *Resource and Energy Economics*, 34(4), 549-564.

FIGURES AND TABLES

Figure 1. Sales Rate Trends by County.

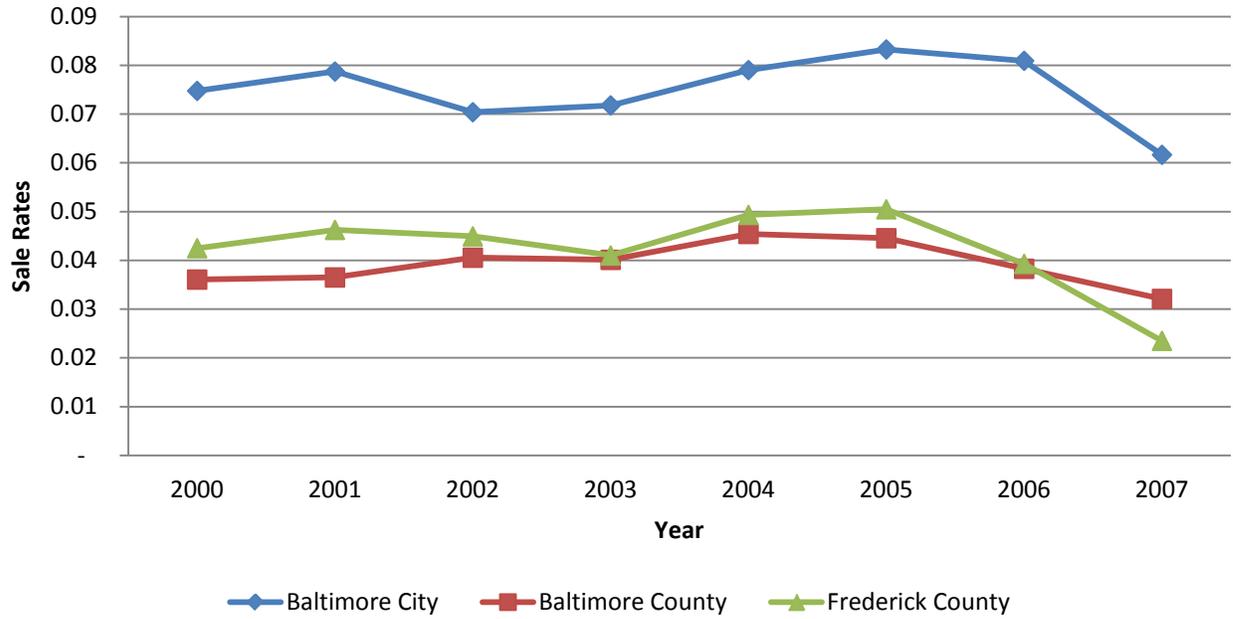


Table 1. Attributes of Single Family Homes in Baltimore City, Frederick, and Baltimore Counties (2007).

Variable	Obs	Mean	Std. Dev.	Min	Max
interior square footage	212067	1752.694	805.806	256	19389
lot size (acres)	211941	0.693	43.500	0	382.690
number full baths	212068	1.676	0.743	0	32
number half baths	212068	0.479	0.555	0	10
porch size (sqft)	189418	332.516	249.629	1	4352
number of fireplaces	105309	1.171	0.492	1	12
basement (dummy)	212068	0.763	0.425	0	1
number of stories	212068	1.565	0.472	1	4
attached garage (dummy)	212068	0.351	0.477	0	1
low quality construction ^a	212035	0.006	0.078	0	1
average quality construction ^a	212035	0.851	0.356	0	1
good quality construction ^a	212035	0.137	0.344	0	1
high quality construction ^a	212035	0.006	0.075	0	1
age of home (years)	211976	50.502	26.800	1	285
in private groundwater well area (dummy)	212068	0.223	0.416	0	1
distance to central business district (kilometers) ^b	212068	14.217	7.188	0	50
meters to nearest public open space (meters)	212068	774.618	1042.523	0	10747
distance to nearest commercial zone (meters)	212068	719.305	826.613	0	9697
distance to nearest major road (meters)	212068	1040.282	1177.656	0	10582

a. Dummy variables based on classification by tax assessors.

b. Central business district defined as Baltimore's inner harbor for Baltimore City and County, and the City of Frederick for Frederick County.

Table 2. Base Regression Results of Annual Probability of a Home Transaction.
(Dependent variable *sold* = 1 if home sold that year, 0 otherwise).

VARIABLES ^a	All counties	Baltimore and Frederick			
	Probit ^b (2.A)	Probit ^b (2.B)		FE Logit ^b (2.C)	
		Public Water	Private Water	Public Water	Private Water
# of USTs within 0-500 m	0.0001 (0.000)	0.0001 (0.000)	0.0001 (0.001)	0.0201 (0.102)	0.3187 (0.467)
Non-leaking UST within 500m	0.0002 (0.000)	-0.0001 (0.000)	0.0004 (0.001)	0.0149 (0.380)	0.8461 (0.999)
LUST within 500m	0.0001 (0.001)	-0.0010 (0.001)	-0.0004 (0.004)	-0.2871 (0.528)	0.0289 (1.443)
× leak discovered	0.0046*** (0.002)	0.0076*** (0.002)	-0.0032 (0.004)	0.1025* (0.059)	-0.1488 (0.175)
× cleanup	-0.0054** (0.002)	-0.0024 (0.002)	-0.0190*** (0.006)	-0.0823 (0.101)	-0.9727** (0.419)
× post-closure	0.0048*** (0.001)	0.0035** (0.002)	-0.0021 (0.005)	0.1714** (0.074)	0.1945 (0.229)
Observations	1,696,544	1,456,624		394,496 (49,312 homes)	
Log Likelihood	-305974.9606	-242163.0715		-111545.0888	

*** p<0.01, ** p<0.05, * p<0.1

Note: Std errors are in parentheses. In the probit models errors are clustered by parcel.

a. All variables are binary indicator dummies unless otherwise noted.

b. Average marginal effects displayed for Probits, but the raw coefficient estimates are presented for Fixed Effect Logit.

Table 3. Regression Results of Annual Probability of a Home Transaction: Homes Most at Risk.
(Dependent variable *sold* = 1 if home sold that year, 0 otherwise).

VARIABLES ^a	Private Well Area & within 500 m of UST	
	Probit ^b (3.A)	FE Logit ^b (3.B)
# of USTs within 0-500 m	0.0002 (0.001)	0.3952 (0.475)
LUST within 500m	0.0010 (0.003)	-1.6709 (1.558)
× leak discovered	-0.0020 (0.004)	-0.1513 (0.179)
× cleanup	-0.0159*** (0.005)	-0.9545** (0.419)
× post-closure	-0.0015 (0.004)	0.1701 (0.236)
Observations	76,618	17,590 (2,199 homes)
Log Likelihood	-10990.0874	-4896.3228

*** p<0.01, ** p<0.05, * p<0.1

Note: Std errors are in parentheses. In the probit models errors are clustered by parcel.

a. All variables are binary indicator dummies unless otherwise noted.

b. Average marginal effects displayed for Probits, but the raw coefficient estimates are presented for Fixed Effect Logit.

Table 4. Regression Results of Annual Probability of a Home Transaction: Low versus High-end Homes. (Dependent variable *sold* = 1 if home sold that year, 0 otherwise).

VARIABLES ^a	Private Well Area & within 500 m of UST			
	Probit ^{†, b} (4.A)	FE Logit ^{†, b} (4.B)	FE Logit ^{†, c} (4.C)	FE Logit ^{†, d} (4.D)
# of USTs within 0-500 m	0.0002 (0.001)	0.4024 (0.475)	0.4067 (0.475)	0.3974 (0.476)
LUST within 500m (dummy)	0.0012 (0.003)	-1.6530 (1.581)	-1.8365 (1.667)	-1.5930 (1.535)
× leak discovered × low	-0.0012 (0.004)	-0.1520 (0.190)	-0.1862 (0.191)	-0.1332 (0.218)
× cleanup × low	-0.0179*** (0.005)	-1.3064** (0.540)	-1.2331** (0.623)	-1.4120** (0.682)
× post-closure × low	-0.0017 (0.004)	0.1693 (0.236)	0.1395 (0.238)	0.1979 (0.248)
× leak discovered × high	-0.0101 (0.008)	-0.2690 (0.500)	-0.0407 (0.400)	-0.2169 (0.243)
× cleanup × high	-0.0029 (0.017)	-0.0932 (0.728)	-0.7351 (0.606)	-0.6587 (0.497)
× post-closure × high	0.0037 (0.019)	0.0972 (1.078)	0.7324 (0.764)	-0.0036 (0.566)
Observations	76,618	17,590	17,590	17,590
Log Likelihood	-10989.3014	-4895.4584	-4895.7385	-4895.7559
Number of homes		2,199	2,199	2,199

*** p<0.01, ** p<0.05, * p<0.1

Note: Std errors are in parentheses. In the probit models errors are clustered by parcel.

† Average marginal effects displayed for Probit model, but raw coefficient estimates are presented for the Fixed Effect Logit models.

a. All variables are binary indicator dummies unless otherwise noted.

b. Low end homes defined by home quality rated as "low" or "average" by tax assessors, and higher end homes are those rated "good" or "high."

c. Low end homes defined as lower 75% of assessed values for that year, and high end homes defined as highest 25%.

d. Low end homes defined as lower 50% of assessed values for that year, and high end homes defined as highest 50%.

APPENDIX A. Relating Theory to Rosen's Bid and Offer Functions.

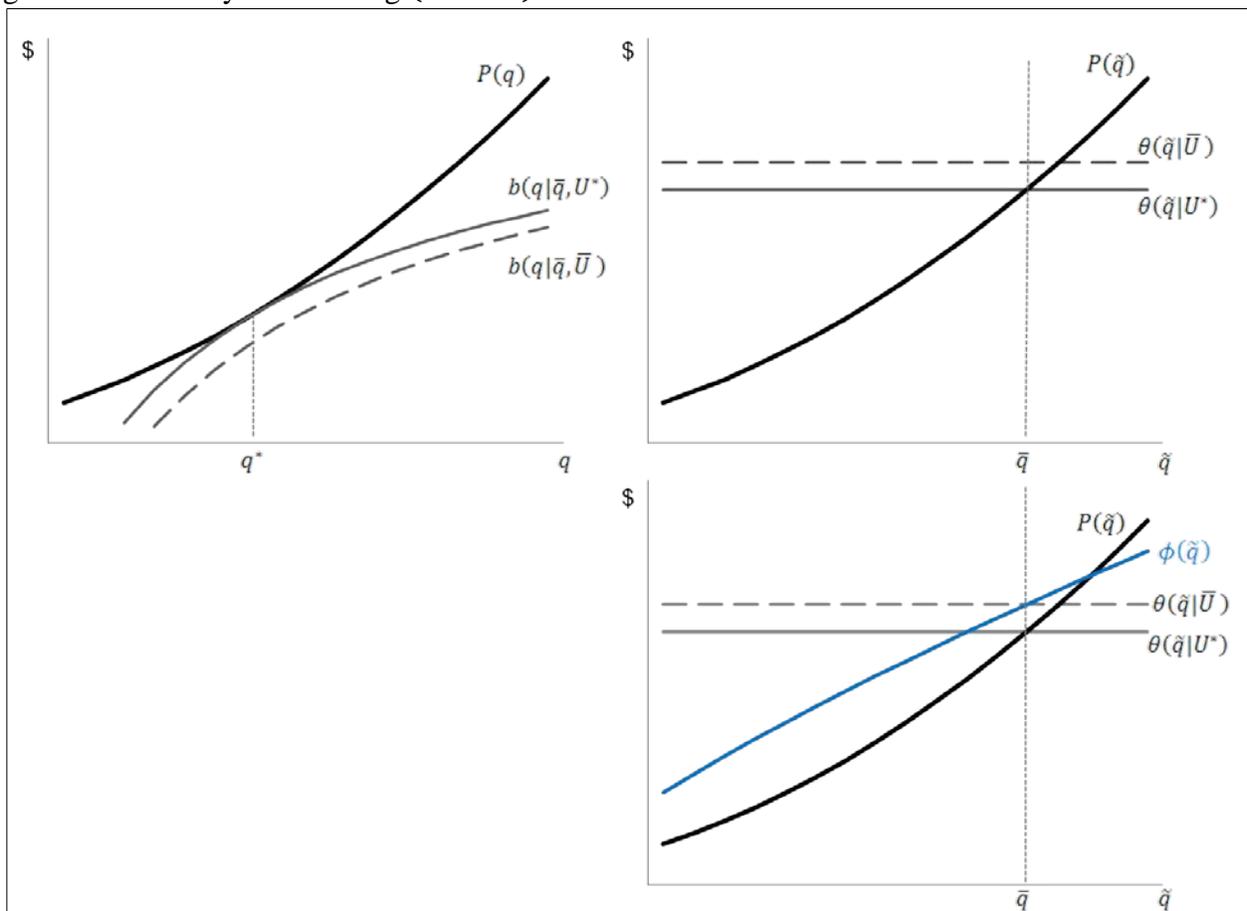
The Bid Function. Rosen's (1974) bid function defines the maximum amount a buyer will pay for their new home (q) in order to obtain a certain level of utility (u). Similarly, in the current framework a household's bid function for a new housing bundle $b = b(q|\bar{q}, u)$ is implicitly defined as: $U\{q, Y + \bar{P} - k - b\} = u$. The bid function is an indifference curve where the buyer trades off housing cost versus quality. The slope of the bid function equals the buyer's marginal willingness to pay (MWTP) for a change in q . Rosen (1974) demonstrated that in equilibrium the bid and hedonic price function are tangent, and so the slope of the price function equals MWTP. As shown in Figure A.1 (top, left panel), if a household decides to sell their current home and purchase a new one, then their new optimal housing choice (q^*) is obtained at the tangency point between the bid and hedonic price functions.

The current framework extends Rosen's model by allowing households to "opt-out" of participating in the market by continuing to live in their current home, if it is optimal for them to do so ($\bar{U} > U^*$). If the bid function corresponding to \bar{U} is at a higher isocline, as shown in Figure A.1, then a household's bid is always below the hedonic price function, and therefore below all sellers' offers – since the hedonic price function is the lower envelope of all sellers' offer functions (Rosen, 1974). In this case the household would optimally decide not to sell and to remain in their current home.

Dissecting Rosen's Offer Function. In the current framework, a household is both a buyer and seller, and so the exact same problem can be represented from a households' point of view as a seller. Rosen (1974) defined the "offer function" as an indifference curve denoting the minimum amount a seller will offer to sell a housing bundle for in order to achieve a fixed level of profit, or in this case utility. In Rosen's original framework seller's were profit maximizing

firms that endogenously choose the location of where to “produce” a housing bundle, and therefore also choose the corresponding level of environmental quality associated with that location. Rosen envisioned the offer function as an indifference curve where developers trade off higher production costs for higher revenues.

Figure A.1. Household’s Bid Function for New Home (top, left), and Offer Indifference Curve (top, right) and Offer Schedule (bottom, right) for Current Home: When reservation utility is greater than utility from selling ($\bar{U} > U^*$).



In contrast, here sellers are households who live in their current home. Although such households can endogenously influence some aspects of their current housing bundle (e.g., add a bathroom, renovate the kitchen, install an air filter, plant trees, etc.), they cannot alter the location of their current home. Therefore, levels of public amenities and disamenities associated

with that location, including aspects of environmental quality, are exogenous to the seller. In this context Rosen's concept of the offer function no longer holds and must instead be represented as two separate notions.

The Offer Indifference Curve. The first component is what I call the *offer indifference curve*, which is denoted as $\theta = \theta(\tilde{q}|u)$, and where \tilde{q} denotes an exogenous level of environmental quality at the current home. For a fixed level of utility u , the offer indifference curve is implicitly defined as: $U(q', Y + \theta - P(q') - k) = u$, where $q' = q(Y + \theta)$ is the Marshallian demand for environmental quality at the new housing bundle (from equation 2) evaluated at $Y + \theta$. As with Rosen's offer function, the offer indifference curve denotes the minimum amount a household will offer to sell their current home for in order to achieve u .

In contrast to Rosen's offer function, notice here that \tilde{q} does not enter the offer indifference curve. In the current context \tilde{q} only varies under some exogenous perturbation, and so the amount a seller can offer their current home for in order to achieve a fixed level of utility is constant. The location of one's current home is fixed, and so the seller cannot tradeoff costs of "producing" a housing bundle with higher levels of \tilde{q} against the corresponding increases in revenue from selling. As depicted in Figure A.1 (top, right panel), the offer indifference curve is flat, implying that no matter the exogenous level of \tilde{q} the seller will still offer to sell for the same fixed amount $\theta(\tilde{q}|u)$, holding u constant. That said, the market value of the home would still increase or decrease according to $P(\tilde{q})$.

Now if the level of environmental quality at the current home is at $\tilde{q} = \bar{q}$, the household will sell at the point where the offer indifference curve $\theta(\tilde{q}|U^*)$ intersects the hedonic price schedule $P(\bar{q})$. However, if it is optimal for a household to remain in their current home

($\bar{U} > U^*$), then as depicted in Figure A.1 by the higher isocline $\theta(\bar{q}|\bar{U})$, the lowest the household is willing to offer for \bar{q} is higher than the highest a buyer is willing to bid ($\theta(\bar{q}|\bar{U}) > P(\bar{q})$). In this case the selling household would “opt out” of the market and continue to live in their current housing bundle.

The Offer Schedule. The second component of Rosen’s offer function is what I call the *offer schedule*.²⁵ Similar to Rosen’s offer function, this offer schedule is upward sloping – as quality at one’s current home exogenously increases, the price a seller will offer to sell it for also increases. In contrast to Rosen’s model, however, the offer schedule here is not an indifference curve. The upward sloping offer schedule here is not the result of trading off between higher “production” costs with increased revenue, as was the case in Rosen’s model. In the current context \tilde{q} is exogenous, and the upward slope is due to the fact that as quality at one’s current home exogenously increases, the selling household’s reservation utility also increases, and so a higher price would be required to entice the household into selling.

In short, the offer schedule denotes the points of indifference between selling and not selling ($U^* = \bar{U}$) at different levels of environmental quality. It is these points of indifference that mark the minimum amount a seller is willing to sell their current housing bundle for. The offer schedule $\phi = \phi(\tilde{q})$ is depicted in the in the bottom, right panel of Figure A.1, and is implicitly defined as: $U(q'', Y + \phi - P(q') - k) = \bar{U}$, where $\bar{U} = U(\tilde{q}, Y)$, and $q'' = q(Y + \phi)$ is the Marshallian demand for quality (from equation 2) evaluated at $Y + \phi$.

²⁵ I thank Nick Kuminoff for clarifying the distinction between these two components of Rosen’s initial concept of the offer function. Any errors of course are solely my own.

For a given \tilde{q} , at any price below the offer schedule the seller would be better-off not selling and continuing to live in their current home, and for any price above they would be better off selling. For $\tilde{q} = \bar{q}$, it is clear that $\phi(\bar{q}) > P(\bar{q})$, implying that the minimum amount needed to entice the household to sell in this case is greater than the buyers' highest bid.

APPENDIX B. Supplementary Regression Results

Table B1. Full Probit Regression Results of Annual Probability of a Home Transaction: Base Model and by County. Estimated Average Marginal Effects. (Dependent variable *sold* = 1 if home sold that year, 0 otherwise).

VARIABLES	All counties (2.A)	Baltimore City (B1.A)	Baltimore Co. (B1.B)	Frederick Co. (B1.C)
ln(interior square footage)	-0.0187*** (0.001)	-0.0291*** (0.003)	-0.0174*** (0.001)	-0.0165*** (0.002)
ln(acres)	-0.0059*** (0.000)	-0.0040*** (0.001)	-0.0057*** (0.000)	-0.0064*** (0.001)
# full baths	0.0055*** (0.000)	0.0083*** (0.001)	0.0048*** (0.000)	0.0048*** (0.001)
# half baths	0.0016*** (0.000)	-0.0015 (0.001)	0.0027*** (0.000)	0.0021** (0.001)
basement (dummy)	-0.0009** (0.000)	0.0005 (0.003)	-0.0011** (0.000)	-0.0029*** (0.001)
# of stories	0.0093*** (0.000)	0.0126*** (0.002)	0.0076*** (0.001)	0.0093*** (0.001)
# of fireplaces	0.0016*** (0.000)	-0.0024* (0.001)	0.0025*** (0.000)	0.0016** (0.001)
fireplaces_missing	0.0039*** (0.001)	0.0072*** (0.002)	0.0030*** (0.001)	0.0031** (0.001)
porch size (sqft)	0.0000 (0.000)	-0.0000 (0.000)	-0.0000*** (0.000)	0.0000*** (0.000)
porch_missing	0.0006 (0.001)	-0.0011 (0.002)	0.0015* (0.001)	-0.0004 (0.002)
attached garage (dummy)	0.0026*** (0.000)	0.0019 (0.002)	0.0024*** (0.000)	-0.0018** (0.001)
low quality construction	-0.0160*** (0.002)	0.0500 (0.031)	-0.0151*** (0.002)	-0.0121*** (0.003)
good quality construction	0.0062*** (0.001)	0.0032 (0.002)	0.0078*** (0.001)	0.0022** (0.001)
high quality construction	0.0088*** (0.003)	0.0029 (0.008)	0.0143*** (0.004)	-0.0064 (0.009)
quality missing	0.0457*** (0.013)	0.0347 (0.103)	0.0420*** (0.012)	
age of home (years)	-0.0001*** (0.000)	0.0005*** (0.000)	0.0000 (0.000)	-0.0003*** (0.000)
age^2	0.0000*** (0.000)	-0.0000** (0.000)	0.0000 (0.000)	0.0000*** (0.000)

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VARIABLES	All counties (2.A)	Baltimore City (B1.A)	Baltimore Co. (B1.B)	Frederick Co. (B1.C)
age_missing	-0.0044 (0.006)	0.0270 (0.044)	-0.0048 (0.006)	0.0082 (0.013)
private well area	-0.0027*** (0.001)		0.0022*** (0.001)	-0.0079*** (0.001)
meters to open space	0.0000*** (0.000)	0.0000*** (0.000)	0.0000*** (0.000)	0.0000* (0.000)
meters to commercial zone	-0.0000 (0.000)	-0.0000*** (0.000)	0.0000** (0.000)	-0.0000 (0.000)
meters to major road	-0.0000*** (0.000)	-0.0000** (0.000)	-0.0000*** (0.000)	0.0000 (0.000)
inverse distance to CBD	2.9949** (1.401)	4.8504 (13.473)	-4.8648 (9.409)	3.9561** (1.598)
Frederick (dummy)	0.0050*** (0.001)			
Baltimore City (dummy)	0.0293*** (0.001)			
2001 dummy	0.0015** (0.001)	0.0033 (0.002)	0.0004 (0.001)	0.0037*** (0.001)
2002 dummy	0.0028*** (0.001)	-0.0050** (0.002)	0.0044*** (0.001)	0.0026* (0.001)
2003 dummy	-0.0002 (0.001)	-0.0084*** (0.002)	0.0021** (0.001)	-0.0020 (0.001)
2004 dummy	0.0057*** (0.001)	-0.0017 (0.002)	0.0073*** (0.001)	0.0060*** (0.001)
2005 dummy	0.0057*** (0.001)	0.0019 (0.003)	0.0062*** (0.001)	0.0071*** (0.002)
2006 dummy	-0.0009 (0.001)	-0.0008 (0.003)	-0.0002 (0.001)	-0.0030** (0.001)
2007 dummy	-0.0107*** (0.001)	-0.0192*** (0.002)	-0.0066*** (0.001)	-0.0189*** (0.001)

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VARIABLES	All counties (2.A)	Baltimore City (B1.A)	Baltimore Co. (B1.B)	Frederick Co. (B1.C)
# of USTs within 0-500 m	0.0001 (0.000)	-0.0004** (0.000)	0.0003** (0.000)	-0.0001 (0.000)
Non-leaking UST within 500m (dummy)	0.0002 (0.000)	0.0020 (0.002)	-0.0003 (0.001)	-0.0005 (0.001)
LUST within 500m (dummy)	0.0001 (0.001)	0.0041 (0.004)	-0.0023** (0.001)	0.0045* (0.003)
× leak discovered (dummy)	0.0046*** (0.002)	-0.0008 (0.005)	0.0071*** (0.002)	-0.0010 (0.003)
× cleanup (dummy)	-0.0054** (0.002)	-0.0357*** (0.013)	-0.0026 (0.003)	-0.0097*** (0.004)
× post-closure (dummy)	0.0048*** (0.001)	0.0081* (0.004)	0.0028* (0.002)	0.0010 (0.004)
Observations	1,696,544	239,920	1,117,856	338,768
Log Likelihood	-	305974.9606	-63589.0275	-183828.0434
		-58055.9735		

*** p<0.01, ** p<0.05, * p<0.1

Note: Clustered std errors (by parcel) are in parentheses.