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The Impact of Imperfect Information on the Transactions of Contaminated Properties

Jeffrey Zabel

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The well documented existence of hundreds of thousands of contaminated properties is a major environmental problem in the United States. Recently, there has been a lot of discussion in the academic literature and political arena about the benefits of the redevelopment of contaminated sites. Given that there may be positive net benefits, why is it that these sites have not been clean up and redeveloped? The focus of this paper is analyzing how incomplete information can deter the transactions of contaminated sites. First, a model of contaminated property transactions is developed. Second, the concept of incomplete information is defined and applied to this model. It is then shown how incomplete information can deter socially optimal transactions of contaminated properties. Third, a framework for empirically estimating the impact of incomplete information on property transactions is developed. Fourth, a framework for measuring the associated welfare loss from the reduced rate of property transactions is established. Fifth, recommendations about how to proceed in this relatively new area of research are provided, particularly with respect to estimating the empirical model.

Key words: land cleanup, reuse, brownfields, asymmetric information, market for lemons
Subject Area Classifications: Hazardous Waste, Land Use, Benefit-Cost Analysis

The Impact of Imperfect Information on the Transactions of Contaminated Properties

Jeffrey Zabel[1]

1. Introduction

The well documented existence of hundreds of thousands of contaminated properties is a major environmental problem in the United States. Simons (1998) estimated that there were 384,000 listed brownfield sites in the U.S in 1996. The U.S. EPA estimates that there are currently more than 450,000 brownfield sites (U.S. EPA 2006a). Contamination is particularly pervasive in the industrial sector.[2] Recently, there has been a lot of discussion in the academic literature about the benefits of the redevelopment of hazardous waste sites in the context of major policy issues like curtailing urban sprawl (Greenberg et al 2001a) , sustainable development of urban areas (Nijkamp et al 2002), affordable housing (Greenberg et al 2001b), and open space (DeSousa 2004). In the political arena, President Bush has made brownfields redevelopment one of his top environmental priorities by signing the Small Business Liability Relief and Brownfields Revitalization Act in 2002. Former EPA Head Christie Whitman said that redeveloping brownfield sites "can create jobs in areas where they are very much needed and also will improve the tax base of many communities" (U.S. EPA 2002).

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[1] Jeffrey Zabel is an Associate Professor in the Department of Economics at Tufts University. The author would like to thank Elizabeth Kopits, Robin Jenkins, and David Simpson for very useful comments. The results in this paper reflect the views of the author and do not necessarily reflect the views of the U.S. Environmental Protection Agency.

[2] Based on historical land use, Noonan and Vidich (1992) estimated the probability of contamination for specific commercial and industrial categories. These probabilities include 0.99 for coal gas plants, 0.95 for plastics manufacture, 0.92 for oil storage, 0.88 for power plants, and 0.80 for refuse recycling facilities.

The above references appear to indicate that many contaminated properties are under-utilized and that significant benefits may well be obtained from their remediation and redevelopment. Given that there *may be* positive net benefits, why is it that these sites have not been cleaned up and redeveloped? The goal of this paper is to investigate one possible answer; imperfect information. Three cases are considered; the seller has more information about the level of contamination than the buyer, both the buyer and seller have equal but only partial information about the contamination level, and the buyer has more information than the lender.

Researchers have focused on the role that liability plays in the under-development of contaminated properties. Under the 1980 Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), liability related to contamination is strict, joint and several, and retroactive. Strict liability means that responsible parties can be held liable for any contamination even if there was no negligence involved in the handling of the hazardous materials. Joint and several liability means that a single party can be held responsible for all damages even if that party's contribution to the damages is minimal. Retroactive liability means that responsible parties can be held liable for contamination that occurred prior to the promulgation of CERCLA in 1980.

Anecdotal evidence indicates that developers can be deterred from making a transaction because of CERCLA liability. Sigman (2005) cites a survey conducted by the U.S. Conference of Mayors that finds that after the lack of funding for cleanup, liability is the biggest problem facing the redevelopment of contaminated sites. What developers appear to want is certification that they are not liable for costs associated with on-site contamination; either the contamination has been cleaned up and hence is no longer a problem or that they are not liable for any future contamination costs. Such certification can come in the form of No Further Action (NFA) letters, certificates of cleanup completion, or covenants not to sue (Alberini et al. 2005, Wernstedt et al. 2006a, 2006b). This could be the result of having made all appropriate inquires to qualify developers for the "innocent landowner" provision (Boyd et al 1996). Sigman and Chang (2005) discuss ways in which joint and several liability can affect transactions since the extent of the buyer's liability is affected by the existence of other responsible parties.

The deterrence effect of liability appears to contradict economic theory that indicates that a properly functioning property market should capitalize the costs associated with liability into the selling price and hence should not affect the likelihood of a transaction. This should be the case as long at both the buyer and the seller have full information about the contamination level. Only if the contamination costs are not fully capitalized into the real estate market should liability impact property transaction rates. There is limited evidence that this appears to be the case. Sigman (2005) uses city-level data for 1990-2000 to show that liability laws have a significantly negative effect on redevelopment of old industrial sites.

There are a number of other factors that might affect transactions of contaminated properties. These include

- Uncertainty involving liability
- Differences in buyer and seller risk aversion

- Differences in buyer and seller default rates
- Externalities
- Property characteristics
- Incomplete information about the level of contamination

Boyd, Harrington, and Macauley (1996, henceforth BHM) address the issue of whether or not CERCLA can deter the cleanup and redevelopment of brownfield sites and hence promote the use of greenfield sites. BHM start with the assumption that the price of contaminated sites should be discounted to cover the added costs of remediation and any other costs associated with the actual or potential site contamination (e.g. liability insurance and risk). Still, uncertainty can arise about (1) the existence and size of liabilities and (2) the allocation of liability costs between buyers and sellers. BHM investigate whether these uncertainties can impact the rate at which contaminated properties transact. To do so, BHM develop a model of property transactions that explicitly models the uncertainty of the existence of contamination and who is liable for the costs of contamination. They show that if the market is working correctly, these uncertainties should be capitalized into the market and hence should not deter efficient property transactions from being completed. BHM show that efficient transactions may not take place when the buyer and seller have different levels of risk aversion.

Segerson (1993) develops a model to examine the impact that liability transfers (from seller to buyer) have on property transactions. Segerson shows that if the buyer and seller are equally likely to default and if the likelihood of the seller defaulting does not depend on whether or not the property sells, the choice of liability transfer rule does not deter socially efficient transactions from taking place. When this condition does not hold, the buyer and seller will have different valuations of the liability (i.e., if the seller has a greater probability of not being able to pay the liability cost, he does not value these costs as highly as does the buyer) and efficient transactions may not take place.

Zabel (2003) shows that if external benefits are not internalized in the developer's decision process then socially optimal transactions may not occur. Externalities include health benefits to local residents when the contaminated site is remediated, property tax increases, additional jobs, and increased aesthetics when the site is redeveloped. Thus the net gain from these sources can turn the negative returns to the developer into positive gains to society.

Another deterrent to property transactions is that contaminated sites are often too small for effective redevelopment and can be poorly situated to highways and/or roads. Simons (1998) notes that, in Cleveland, the average size of industrial sites that are brownfields is one to one-and-one-half acres. Further, in Milwaukee, the average size of tax delinquent contaminated non-residential properties is four-tenths of an acre. Simons claims that, today, industrial sites typically require three to five acres. He also points out the successful commercial properties require, at a minimum, to be located near the intersection of a major and a minor street. Thus older industrial or commercial sites that are now likely to be contaminated and may have been reasonably located in the past have become, in Simon's words, "functionally obsolete" (pg 9).

Finally, it is often the case that all the parties involved in transactions (buyer, seller, and lender) are not fully informed about the contamination level of the property.

The focus of this paper is on the impact that such incomplete information has on deterring socially optimal transactions from taking place. One case is asymmetric information whereby one party has more information than another. Here, it is assumed that the seller knows the true level of contamination and the buyer does not. This is similar to the scenario that Akerloff (1970) describes in the used car market. It is shown that Ackerloff's result (the market for "lemons") follows in the case of contaminated properties; the market is dominated by the sale of properties with relatively high levels of contamination. Another example of incomplete information is the scenario where both the buyer and the seller have the same information about the level of contamination but it is less than the actual level of contamination (it is also possible that the buyer and the seller perceive that the contamination level is higher than actual). This is referred to as "partial" information. It is shown that buyers will refuse to sell their properties if they believe that the costs they would incur from the additional contamination that would be revealed at a site inspection are greater than the benefits from the sale. This condition is known as "mothballing."

Another important case involves asymmetric information between the buyer and the lender. That is, similar to Stiglitz and Weiss (1981), it is assumed that the buyer knows the contamination level and the lender only knows the distribution of possible contamination levels. It is shown that situations can arise where the equilibrium outcome is that only buyers of properties with high contamination levels will take out loans. There is evidence that lenders will not provide loans involving highly contaminated properties (Patchin 1988). This outcome can arise in this model if the probability of default for the high contamination properties is high enough to make a transaction infeasible. In this case, no transactions will occur.

This paper is structured as follows. In Section 2, a model of transactions of contaminated properties is developed. In Section 3, the concept of incomplete information is defined and applied to the model developed in Section 2. It is shown how incomplete information can deter the sale of contaminated properties and result in a loss of welfare. Building on the model that is established in Sections 2 and 3, a framework for empirically estimating the impact of incomplete information on property transactions is developed in Section 4. The related empirical literature is surveyed in this section. Given that incomplete information does deter property transactions, it is important to measure the associated welfare loss. This is discussed in Section 5. Section 6 concludes with recommendations for areas of future research.

2. A Model of Transactions of Contaminated Properties

In this section, a model of transactions of contaminated properties is developed.[3] This will allow for the impact of different forms of incomplete information on the transaction rates of contaminated properties to be analyzed. Assume that there is a potential buyer and seller of a property with actual contamination level C. Let C be measured as the cost of cleanup of the on-site contamination. Assume that this cost is an increasing function of the level of contamination.

Assume, initially, that the buyer and seller have full knowledge of the contamination level C. Define $P_B(C)$ to be the buyer's reservation price given contamination level C This reservation price is the present discounted value of the stream of rents emanating from the property. If P is the sales price of the property, the buyer will buy the property if $P \leq P_B(C)$. It is assumed that the buyer will clean up the site upon purchase so that the value of the clean site to the buyer is at least as great as the value of the contaminated site plus the cleanup costs. Here, for simplicity, we assume equality

$$P_B(C) = P_B(0) - C \qquad (1)$$

where $P_B(0)$ is the value of the site to the buyer once it is clean, i.e. the rents the buyer can receive from the site.[4] Assume that $P_B(C) > 0$ (or $P_B(0) > C$); the property has positive economic value after being cleaned up and redeveloped. Otherwise the buyer will not be willing to pay a positive price for the site and no transaction will take place.

Define $P_S(C)$ to be the seller's reservation price given contamination level C. The seller will sell the property if $P \geq P_S(C)$. One can view $P_S(C)$ as the (present value) of the rents that the owner is currently receiving for the site. It is assumed that the seller's value of the property once cleaned up is less than or equal to the value when contaminated plus the remediation costs or the seller would have cleaned up the site. To simplify matters, assume this is an equality.[5] That is, $P_S(0) = P_S(C) + C$. A transaction is considered to be efficient (or feasible) if $P_B(0) > P_S(0)$ (note this can also be stated as $P_B(C) > P_S(C)$). Hence the selling price will fall between the seller's and buyer's reservation prices; $P_B(C) > P > P_S(C)$.

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3 This is motivated by the models in BHM and Segerson (1993).

4 It is not necessary to assume that the buyer will fully clean up the site since one can just normalize to "zero" the optimal post-cleanup level of contamination.

5 Assuming an inequality means that one would need to define a function $f(C) \leq C$ such that

Assume that all benefits that arise from cleaning up and remediating the site are internalized into $P_B(C)$. Then the net benefits to society from the transaction are[6]

$$NB = P_B(C) - P_S(C) = P_B(0) - P_S(0). \quad (2)$$

3. Incomplete Information and its Effect on Transactions of Contaminated Properties

The focus of this section is on the impact of incomplete information about the contamination level of the site on the likelihood that a property transaction will take place.[7] Let C_S and C_B be the buyer's and seller's knowledge of the level of contamination. The definition of complete or perfect information is

$$C_B = C_S = C. \quad (3)$$

A more general definition of complete information would be that $f(C_S) = f(C_B)$; the seller's and buyer's distributions of the contamination are equal. One can view C_S and C_B as either the seller's and buyer's expected contamination levels or the special case where $f(C_S)$ and $f(C_B)$ are degenerate distributions with single outcomes. The focus here is on these scalars rather than the distributions to simplify matters. Using the distributions will not change the basic results.

The definition of incomplete information is that the condition of complete information does not hold. Three special cases are considered.

$P_S(0) = P_S(C) + f(C) < P_S(C) + C$.

[6] Technically, net benefits should be $P_B(0) - P_S(C) - C$ but since $P_B(C) = P_B(0) - C$ and $P_S(0) = P_S(C) + C$, both equalities in equation (2) entail.

[7] See Varian (1984) or MasCollell, Whinston, and Green (1995) for detailed analyses of incomplete information.

Case 1: Asymmetric Information: $C_B \neq C_S = C$. Under asymmetric information, the buyer has full information but the seller has only partial knowledge about the level of contamination. Note, it could be the case that $C_B > C$ or $C_B < C$. The latter case will be considered here.

Case 2: Partial Information: $C_B = C_S \neq C$. Under partial information, the buyer and seller have the same information (so there is no asymmetric information in Case 2) but this information is not complete. The version of Case 2 that is most relevant is where the buyer and seller believe that the level of contamination is less than the true level of contamination. That is, $C_B = C_S < C$. While the other case is not uncommon (i.e., $C_B = C_S > C$), what deters transactions is the buyer's belief that the actual level of contamination is greater than what is currently known.[8]

Case 3: Asymmetric and Partial Information: $C_B \neq C_S \neq C$. This combines Case 1 and Case 2 so that both asymmetric and partial information exist.

An important contribution to the analysis of asymmetric information is the market for lemons as first developed by Akerloff (1970). Akerloff analyzed the used car market where sellers have full knowledge of the quality of their cars but prospective buyers do not. This is the situation considered under Case 1. An important issue in the context of property markets is the extent to which asymmetric information exists. States can set their own laws that require different levels of disclosure about the quality of the property. Clearly, if such laws require the owner to disclose any knowledge of the contamination

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8 As of July 2006, of 6,767 properties assessed as part of the EPA's brownfields pilot program, 2,218 did not need to be cleaned up. One caveat is that information about the pilot programs is self-reported so under-reporting can bias this result (U.S. EPA 2006b).

level of the property, then the likelihood of asymmetric information is reduced. In this case, the extent of asymmetric information will depend on the effectiveness of these full disclosure laws. Pancak et al (1996) indicate that 36 states had residential property disclosure laws in 1996. It is not clear, though, which of these states include contamination levels as items that must be disclosed. Further, it is not clear if similar laws pertain to commercial and industrial properties. This is an area of future research. Nanda (2005) estimates a duration model of the time until a state adopts a property condition disclosure law. The number of disciplinary actions relative to the number of complaints against real estate brokers and the extent of broker supervision of real estate salespersons are found to have a significant impact on the likelihood of adoption.

Another feature of a market with asymmetric information is the concept of signaling. This refers to the buyer's or seller's attempt to gain information about the quality of the good. In the property market, the signal can come in the form of a site inspection (though often the buyer is required to do a site inspection).

Case 1: Asymmetric Information.

In this case, $C_B < C_S = C$. Assume there are two types of properties with high and low levels of contamination; C_H and C_L respectively, where $C_H > C_L \geq 0$. To simplify matters, set $C_L = 0$; assuming this extreme case does not affect the substance of the argument but simplifies the analysis. Assume that the transactions of both types of properties are feasible; i.e., $NB > 0$. Let the proportion of high contamination properties be p where $0 < p < 1$. Assume that the seller has perfect information about the property so that $C_S = C_H$ or 0 depending on whether the property has a high or low level of contamination. The buyer only knows p, the probability that the property has the high level of contamination, and the contamination levels of the two property types. Then the expected cost (level of contamination) to the buyer is $C_B = pC_H$. The buyer will pay no more than $P_B(C_B)$ for the property. Note that $C_B < C_H$ since $p < 1$.

If the property has the high level of contamination then a transaction will take place since

$$\begin{aligned} P_B(C_B) - P_S(C_S) &= P_B(C_B) - P_S(C_H) \\ &= (P_B(0) - pC_H) - (P_S(0) - C_H) \\ &= NB + (1-p)C_H > 0. \end{aligned} \tag{4}$$

This follows since net benefits, NB, are assumed to be greater than zero.

If the property has the low level of contamination then a transaction will NOT take place if

$$\begin{aligned} P_B(C_B) - P_S(C_S) &= P_B(C_B) - P_S(C_L) \\ &= (P_B(0) - pC_H) - P_S(0) \\ &= NB - pC_H < 0. \end{aligned} \tag{5}$$

Thus a transaction will NOT occur if pC_H is bigger than NB; the buyer's expected remediation costs are greater than net benefits. If this situation holds then no transactions of the relatively clean sites will take place since the seller will always be unwilling to sell these sites. Since the buyer realizes this, the reservation price will fall to $P_B(C_H)$. Thus there are sites with relatively low levels of contamination that do not sell even though the transaction is efficient. This is the conventional "market-for-lemons" welfare loss.

Case 2: Partial Information

In this case, $C_B = C_S < C$. One can view this as a situation where the buyer and seller have the same knowledge of some but not all of the contamination or that they share a common probability distribution of contamination levels f(C) where the expected value is $C_B = C_S$. As Boyd et al (1996) point out, while CERCLA requires that contaminated sites be reported, this does not mean that such sites will be cleaned up. Assume that C will be revealed at the sale given a site inspection. Assume that without the site inspection the transaction is feasible (NB > 0). Further assume that, as a result of the site inspection, the seller has to pay any additional cleanup costs or that the price the buyer is willing to pay is reduced by these cleanup costs (i.e. the effective sales price is lower by $C - C_S$). Then a transaction will NOT take place if

$$\begin{aligned} P_B(C_B) - P_S(C_S) &= (P_B(C_S) - (C - C_S)) - P_S(C_S) \\ &= P_B(C) - P_S(C_S) \\ &= (P_B(0) - C) - (P_S(0) - C_S) \\ &= NB - (C - C_S) < 0. \qquad (6) \end{aligned}$$

Thus, no transaction will occur if the increase in the level of contamination that is revealed at the site inspection, $C - C_S$, is greater than NB. Put another way, no transaction will take place if the value of the property to the seller prior to the site inspection, $P_S(C_S)$, is greater than the maximum the buyer will pay after the site inspection, $P_B(C)$. Thus under partial information, efficient transactions may not take place. This situation, where the owner refuses to sell under-utilized contaminated or potentially contaminated properties, is known as “mothballing.” Another cost of the discovery of additional contamination is the bad publicity this engenders. This is why large companies, that might be particularly susceptible to bad publicity, would be even more likely to mothball properties. It should be noted that the buyer will not know C prior to the site inspection (and hence the added costs of site inspection; $C - C_S$) but one can assume that the buyer has a distribution of values of the true contamination level where C might represent the mean value of this distribution.

Case 3: Partial and Asymmetric Information

In this case, partial and asymmetric information are combined. The scenario is similar to case 1 where there are two types of properties with high and low levels of contamination. This case is fully developed in Appendix 1. The results show that only partial information can deter the sales of high contamination properties. On the other hand, for properties with low contamination, asymmetric and partial information act in an additive sense; the likelihood of a transaction is less than if only one of these types of incomplete information is present.

Given the likelihood of a site inspection and hence the actual level of contamination will be revealed to both the buyer and the seller, one might question the relevance of asymmetric information in deterring transactions of contaminated properties. But experienced developers do not necessarily require a full site assessment prior to a purchase. Rather, they may rely on their past experiences with contaminated properties to make their own judgments about the profitability of the site and the price they are willing to pay. Their knowledge of the full costs of dealing with contamination can lead these developers to offer a low price that incorporates these costs. Further, their experience with the state and local governments and knowledge of existing tax credits will allow for a greater chance of turning a profit than would be the case for less experienced developers. An area of future research is the impact of developer experience on the probability of transaction of contaminated properties. Specifically, it would be worthwhile investigating how developer experience affects the impact of incomplete information on such transactions.

These results show that asymmetric and partial information can deter efficient transactions of contaminated properties from taking place. A possible solution would be some form of contract between the buyer and seller. An indemnity contract that requires the seller to incur any future costs of existing contamination would seem to solve the problem. The drawback with such a contract is that it may not be enforceable given that the seller may go bankrupt at some future date and hence be unable to pay these costs. Patchin (1988) claims that the only viable indemnity contracts are underwritten by large insurance or bonding companies but that such contracts are not available for sites with even mild levels of contamination. He notes that existing indemnity contracts are almost always issued by large governmental organizations.

Another possible solution is liability insurance that can be purchased by the buyer. Such a market does exist but appears to be underutilized. The problem is that this insurance is quite complicated and without full information, developers can over-pay. While the advent of liability insurance was initially hailed as a brownfields success story, many developers of brownfield sites do not carry liability insurance since the benefits are not perceived to outweigh the costs (Meyer et al 2002). One possible solution for the incomplete information problem would be to offer liability insurance to potential sellers that would cover liability and cleanup costs related to any prior contamination discovered at site inspection. Potential adverse selection and moral hazard issues would need to be addressed. This is an area of future research.

3.3 The Impact of Asymmetric Information on the Likelihood of Debt Financing

Another reason why transactions of contaminated sites might not occur is that banks are often unwilling to make loans for such properties since they can be liable for damages if the developer defaults on the loan. CERCLA was amended in 1992 to reduce the likelihood of liability by banks (Segerson 1993). Still, since there is more risk involved with the remediation and redevelopment of contaminated sites, there is a higher risk of default compared to loans for greenfield properties. When banks do make loans, they may require a larger down-payment for contaminated sites to compensate for the higher risk of default. This reduces the returns to buyers of contaminated sites which can turn what was a profitable deal into a deal buster. Patchin (1988) claims that that likelihood of obtaining debt financing for highly contaminated sites is very small. He also states that limited opportunities exist for obtaining financing for even mildly contaminated properties.

Assuming that debt financing is possible, can asymmetric information affect the likelihood of debt financing? To answer this question, first consider the case where there is perfect information. Let there be two states of nature; a good one (high value) in which the buyer turns a profit and a bad one (low value) in which he defaults. Let the probability of default by the buyer be p_d. Then with probability $(1-p_d)$ the value of land is

$P_{BH}(0)$ and with probability p_d the value of the land is $P_{BL}(0)$ where $P_{BH}(0) > P_{BL}(0)$.[9] From now on, the "(0)" and the subscript "B" will be suppressed unless needed.

The expected value of the property to the buyer is

$$E[P_B] = (1-p_d)P_H + p_d P_L \,. \tag{7}$$

Recall that the value of the property to the seller is $P_S(0)$ To simplify the analysis, assume that the buyer gets all the surplus so that the price is $P = P_S(0)$. The buyer will pay for the site by taking out a loan. Denote the lending rate as r. If the bad state of nature occurs, the buyer defaults and the value of this outcome to him is zero. Then the expected net benefits to the buyer are

$$ENB[P, P_H, p_d, r] = (1-p_d)(P_H - (1+r)P). \tag{8}$$

If $ENB[P, P_H, p_d, r] > 0$, the buyer will take out a loan and the transaction will take place. Note that the buyer's decision depends only on whether or not net benefits in the good state of nature are positive. That is, he ignores the risk of the bad state of nature.

The lender will make a loan if the benefits from doing so outweigh the costs. Denote the lender's return on the next best investment as s where $r > s$ and s is assumed to be exogenous. If the bad state of nature arises, the property is worth P_L and the buyer defaults. Thus the lender takes ownership of the property worth P_L but loses the value of the loan, P, and the opportunity cost of the loan, $s \cdot P$. It is likely that the value of the property to the lender is less than P_L; the lender does not possess the expertise that the buyer has to realize the full potential of the property. Further, if the lender was to sell the property, the sales price would likely be less than P_L. Let the discount in the value of the

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[9] Note that the buyer's value of the site is evaluated at contamination level 0 since this implicitly includes the cost of cleanup of the site which is assumed to be part of the amount the buyer needs to finance.

property to the lender be X. If the good state of nature arises, the property is worth P_H and the buyer repays the loan. Thus the lender makes a profit of (r–s)·P. The lender's decision is to make a loan if expected profits are non-negative (assume
$P_L < P < P_H$)

$$E[\pi] = p_d \cdot [(P_L - X) - (1+s) \cdot P] + (1-p_d) \cdot [(r-s) \cdot P] \geq 0. \tag{9}$$

Following Segerson (1993), assume that the lending industry is competitive so the bank earns zero profits. Hence the rate charged to the borrower is the value that sets the left-hand-side of equation (9) to zero. Then solving for r gives

$$r = \frac{(1+s) \cdot P - p_d (P_L - X)}{(1-p_d) \cdot P} - 1. \tag{10}$$

Taking the derivative with respect to p_d gives (holding other factors constant)

$$\frac{\partial r}{\partial p_d} = \frac{(1+s) \cdot P - (P_L - X)}{(1-p_d)^2 \cdot P} > 0. \tag{11}$$

Thus the interest rate charged by the lender is an increasing function of p_d, the probability of default. Substituting equation (10) into equation (8), the buyer's net benefits can be expressed as

$$ENB[P, P_H, p_d, r(P, P_L, p_d)] = E[P_B] - (1+s) \cdot P - p_d X. \tag{12}$$

Three things are different here from (11) above. First, the buyer must consider expected benefits rather than just benefits under the good outcome. Second, the lender recoups the value of the loan and the opportunity cost of these funds (competition drives the profits to zero). Third, the buyer is force to take up the discount of the property value to the lender in the bad state of nature. As Segerson (1993) states "Thus, through the interest rate, the lender is able to shift to the buyer … the opportunity cost of its funds and the reduced value of the property in the foreclosure state" (page S-60).

Now consider the scenario where there are two types of properties with high and low levels of contamination; $C_H > C_L \geq 0$. The probability of the site having the high level of contamination is p. Assume that the highly contaminated sites have a higher risk and higher return. To make things simple, assume that the value of the site in the bad state of nature is the same for both types of properties. Further assume that the value to the seller after cleanup is the same for both types of properties and hence the sales price (including the cost of cleanup) is the same. Thus the following scenario holds

$p_{dL} < p_{dH}$, $P_{LL} = P_{HL}$, and $P_{LH} < P_{HH}$,

where p_{dL} and p_{dH} are the probabilities of default for the properties with low and high levels of contamination, P_{LL} and P_{HL} are the values of the sites with low and high levels of contamination in the low value state, P_{LH} and P_{HH} are the same in the high value state (note that the first subscript refers to the contamination level and the second refers to the high or low value state of nature). Hence, the expected value of the properties with low and high levels of contamination can be expressed as

$$E[P_L] = p_{dL} \cdot P_{LL} + (1-p_{dL}) \cdot P_{LH} < E[P_H] = p_{dH} \cdot P_{HL} + (1-p_{dH}) \cdot P_{HH}.$$

If the lender knows the contamination level of the property, he will charge a higher interest rate to the property with the higher level of contamination (this follows from equations (10) and (11) above); $r_H > r_L$.[10] Assume that the transactions of both the properties with low and high contamination are feasible at these interest rates, that is

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[10] As in Stiglitz and Weiss (1982), it is possible to assume that the lender requires the buyer to put up collateral in order to receive the loan. Further, the amount of collateral could vary by the risk of the loan.

$$E[P_L] - (1+s)P - p_{dL}X > 0 \text{ and } E[P_H] - (1+s)P - p_{dH}X > 0. \qquad (13)$$

Now consider the case of asymmetric information. It is assumed that the lender does not know the contamination level of the site but knows the risks of each type of site whereas the buyer knows the true contamination level (as in Stiglitz and Weiss (1981)). As before, the lender will charge an interest rate that sets expected profits to zero. One can show that this interest rate, r_{HL}, is between r_H and r_L (see Appendix 2). The transaction of the property with the high level of contamination is feasible at this rate since $r_{HL} < r_H$. But it is possible that the transaction of the low contamination property is not feasible at this higher interest rate since $r_{HL} > r_L$. In this situation, only properties with the high level of contamination are financed. In the long run, the lender realizes this and sets the interest rate to r_H. Thus there can be a result where both low and high contamination properties are feasible under full information but only the high contamination properties are feasible under asymmetric information.

Now assume a scenario where the probability of default for the property with the high level of contamination is large enough so that the feasibility condition in (13) does not hold

$$E[P_L] - (1+s)P - p_{dL}X > 0 \text{ and } E[P_H] - (1+s)P - p_{dH}X < 0 \qquad (14)$$

where it is assumed the low contamination property is still feasible. If the lender had full information, he would lend to the low contaminated properties at the rate r_L. In the presence of asymmetric information, the lender would charge the interest rate of r_{HL}. Given that $r_{HL} > r_L$, it is possible that this makes the project infeasible for the low

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Adding this factor here only complicates the analysis and does not change, in any fundamental way, the results.

contaminated properties. Since $r_{HL} < r_H$, it is possible that the high contamination properties are now feasible. But note that, in the long-run, the lender will realize that no buyers of low contamination properties are taking loans and he will increase the interest rate to r_H. Hence, no loans will be made. Thus there can be a result where only the low contamination properties are feasible under full information but neither the low nor the high contamination properties are feasible under asymmetric information and hence no loans are made.

3.4 A Comparable Contamination Problem with Incomplete Information: Lead Paint

A similar case to the contaminated property problem is the example of lead paint. The asymmetric information scenario where the seller knows information about the existence of lead paint in the house and the potential buyer does not is a common occurrence. So too is the case of partial information where both parties are not fully informed about the existence of lead paint in the house. Lead paint was banned in 1978 so these issues of imperfect information apply to units built prior to 1978. Miceli et al. (1996) develop a framework in order to conduct an economic analysis of the efficiency of laws designed to reduce lead paint risk. They show that in the case of asymmetric information, the efficient outcome may not be achieved (i.e. removing the lead paint when net benefits are greater than zero) in the absence of a "duty to notify" law that is imposed on the seller. In the partial information case, the decision is whether or not to test for lead. This is similar to the decision of whether or not to carry out a site inspection of a (potentially) contaminated property (Segerson (1993) addresses this issue). Miceli et al. show that, given full capitalization of costs, the efficient outcome is realized and there is no need for a mandatory testing law. Ford and Gilligan (1988) estimate a hedonic property value model that includes a measure of the risk of lead paint. They find that the associated costs of lead paint were capitalized into prices using transaction data from Baltimore, Maryland in 1984.

4. An Empirical Framework for Estimating the Impact of Incomplete Information on Property Transactions

In this section, a framework is developed for empirically estimating the extent to which factors related to contamination affect property transaction rates. In particular, the impact of incomplete information on the likelihood of a transaction is modeled. The basis of the empirical framework is the transaction model of contaminated properties that was developed in Sections 2 and 3. With this model in mind, the literature on the sales of contaminated properties is surveyed. Empirical evidence on the impact of contamination on property transaction rates is slim. There appears to be no empirical study that looks at the impact of incomplete information on property transaction rates.

4.1 Empirical Model

Following Fisher, Gatzlaff, Geltner, and Haurin (2004; hereafter FGGH), the seller's reservation price, $P_S(C_S)$, is specified to be a function of market (M), property (R), and owner (O) characteristics for property i in period t. This is extended to include the seller's knowledge of the contamination level, C_S

$$P_{it}^{S} = \beta_0^{S} + M_{it}\beta_1^{S} + R_{it}\beta_2^{S} + O_{it}\beta_3^{S} + C_{it}^{S}\beta_4^{S} + u_{it}^{S} \qquad (15)$$

where u^S is an unobserved stochastic error term. The buyer's reservation price, $P_B(C_B)$, is specified as

$$P_{it}^{B} = \beta_0^{B} + M_{it}\beta_1^{B} + R_{it}\beta_2^{B} + O_{it}\beta_3^{B} + C_{it}^{B}\beta_4^{B} + u_{it}^{B} \qquad (16)$$

A transaction will take place if

$$\begin{aligned} TR_{it}^{*} &= P_{it}^{B} - P_{it}^{S} \\ &= \beta_0 + M_{it}\beta_1 + R_{it}\beta_2 + O_{it}\beta_3 + I_{it}\beta_4 + CMC_{it}^{S}\beta_5 + C_{it}\beta_6 + u_{it} \geq 0 \end{aligned} \qquad (17)$$

where $\beta_j = \beta_j^{B} - \beta_j^{S}, i = 0,1,2,3, I_{it} = C_{it}^{B} - C_{it}^{S}, CMC_{it}^{S} = C_{it} - C_{it}^{S}$, and $u_{it} = u_{it}^{B} - u_{it}^{S}$.

Note that C_{it}^{B} and C_{it}^{S} are zero for greenfield sites; i.e. sites where there is no actual or perceived contamination. I_{it} is zero when C_{it}^{B} and C_{it}^{S} are equal and nonzero when C_{it}^{B} and C_{it}^{S} are not equal; the case of asymmetric information. CMC_{it}^{S} is zero when C_{it}^{S} equals C_{it}, the actual level of contamination, and is nonzero when C_{it}^{S} and C_{it} are not equal; the case of partial information.

TR_{it}^{*} is unobserved but TR_{it} is observed where

$$TR_{it} = \begin{cases} 1 & \text{if } TR_{it}^{*} \geq 0 \\ 0 & \text{if } TR_{it}^{*} < 0 \end{cases}$$

That is, what is observed is whether or not a transaction has occurred. Consider the class of models of the form

$$P(TR = 1 \mid X) = G(\beta_0 + X\beta)$$

where $X = (M,R,O,I,CMC^S,C)$ is a vector of the factors that affect transaction rates and G is defined to be a function that lies between 0 and 1:

$0 < G(z) < 1$ for all real numbers z.

This class of models is known as Binary Response Models (see Wooldridge (2002) for a detailed analysis). Note that G will have to be nonlinear to ensure that $0 < G(z) < 1$. One function that satisfies this restriction is the cumulative probability function (CDF). Two special cases are the logit and probit models. These two models arise if it is assumed that G is the CDF for a logistic or a normal random variable, respectively.

FGGH estimate a probit model of property transactions using the National Council of Real Estate Investment Fiduciaries (NCREIF) data set. This includes 3,311 properties as of the 4th quarter of 2001 and consists of office, industrial, apartment, and retail sites. These sites tend to be larger and more highly valued than the typical site. The data include 18,432 annual observations from 1985 to 2001; 1,556 of the observations represent sales and for 16,876 of the observations there was no sale (note that there are multiple observations for properties that appear in the data in two or more years). Variables that affect transaction rates must differentially affect the reservation prices of buyers and sellers. This follows since the coefficients in the transaction equation (17) are the differences in the coefficients in the buyers' and sellers' reservation price equations (15 and 16). FGGH note that transaction frequencies are typically pro-cyclical and hence are likely to be positively correlated with relatively high growth in the economy in general and in the real estate market in specific. This implies that these economic factors will cause the buyer's reservation price to increase by more than the seller's reservation price. These factors are measured using the percentage change in employment in the previous two years in the MSA and the change in the NCREIF property index (NPI). FGGH further note that transaction frequencies are likely to be affected by both the "flow of funds" and the "cost of funds." Funds will typically flow to the assets with the highest returns. Hence the likelihood of a real estate transaction will be inversely related to the returns to stocks and bonds. FGGH measure these latter returns using the percentage change in the S&P 500, the average annual yield of the 10-year Treasury note, and the average annual difference in the commercial mortgage rate and the 10-year Treasury note. Government policy can also affect transactions. FGGH include an indicator of the Tax Reform Act of 1986 which reduced the tax benefits of investment property and hence had a negative impact on transaction rates.

FGGH also point to ownership characteristics as significant determinants of a property transaction. They mention two sales strategies; "opportunistic sale" and "sell winners." The first strategy is based on the idea that owners will be less likely to sell at prices below appraised value. Hence, FGGH include the ratio of the hedonic estimate of the property value to the appraised value in their model. The "sell winners" strategy implies that owners will be more likely to sell if their property is making excess returns so that they can capture these gains. FGGH include the excess return on a property since its purchase (relative to the NPI index). Organizational characteristics that might affect sales include whether the property is held in an open-ended fund, is held by a joint venture, or is held without debt. FGGH also surmise that the longer a property is held the more likely it will sell; this is indicative that properties "have reached their useful holding period, and strategic improvements to the property have been completed" (pg 250).

Property characteristics that might affect transactions include age, size, and location. Properties with higher occupancy rates are expected to be more likely to transact since the buyer will incur fewer costs related to the unoccupied space. In addition, higher occupancy rates may be correlated with higher levels of unobserved property quality. FGGH find that all three factors; market, ownership, and property characteristics, are significant and approximately equivalent determinants of the probability of a transaction.

The variables I, CMC^S, and C are included in the property transaction model (equation 17) to capture the impact of contamination on the probability of transaction. The variable I will be non-zero when the buyer's and seller's knowledge of the contamination differ. Thus, this variable will capture the effect of asymmetric information on transaction rates. A proxy variable is needed since this difference is not actually observed. One possibility is a measure of the existence and extent of full disclosure laws in each state. The endogeneity of this variable will be an issue. One solution is to use state dummies in the transaction model but then the identification of the impact of asymmetric information will be based on changes in the full disclosure law within states. Other possible instruments include the ones that Nanda (2005) found to significantly affect state adoption of property disclosure laws; these may proxy for the effectiveness of these laws (the number of disciplinary actions relative to the number of complaints against real estate brokers and the extent of broker supervision of real estate salespersons).

The variable CMC^S will be nonzero when the seller's knowledge differs from the actual level of contamination. Thus, the impact of this variable will capture the effect of partial information on transaction rates. Recall that an important reason that partial information can have a negative impact on transaction rates is the certainty of a site inspection being part of the transaction process. Another factor that plays a role is the imperfect detection of contamination prior to a transaction. Proxies for these factors would relate to the cost and frequency of site inspections in the state (since rules governing site inspections are usually set at the state level).

Including C in the transaction equation (17) will capture whether the costs of contamination are fully capitalized into prices; that is, the coefficient should be zero if this is the case and should be negative if these costs are under-capitalized (or over-capitalized) into prices. It would be useful to account for the types of contamination and end-uses to see if these site characteristics result in different impacts of contamination on transactions.

4.2 Literature Survey on the Impact of Contamination on Property Transaction Rates

There is plenty of evidence that hazardous waste sites affect the prices of nearby residences. There is also a small literature on the impact of contamination on the value of the contaminated property, itself (Jackson (2002), McGrath (2000)). But empirical evidence on the impact of contamination on property transaction rates is limited. There appears to be no empirical study that looks at the impact of incomplete information on property transaction rates.

Two studies consider the impact of disclosure about contamination on property transaction rates. Jenkins-Smith et al. (2002) conduct a contingent valuation survey in Corpus Christi, Texas to investigate the impact of the disclosure of information on property contamination on the willingness to pay (WTP) for the property. They use a split-sample approach where the control group received information about a typical house and the treatment group was given additional information about soil contamination. In particular, the treatment group was told that Texas state law requires the seller to disclose information about conditions that may affect the use of the home or the occupants' health. In this case, it was reported that concentrations of lead, cadmium, and zinc were found in the soil of nearby homes. The likely source of the contamination was a nearby smelter that had been shut down. Further, the contaminated properties had twelve inches of top soil removed and the Texas Natural Resources and Conservation Commission revealed that the contamination no longer posed a health problem. A contingent valuation telephone survey was conducted and a response rate of approximately 50% produced a sample of 1,036. The authors find that 53% of the treatment group responded that their WTP for the house was zero. Thus, for a large portion of potential buyers, the impact of the information disclosure is to drop out of the market. This will clearly have a negative impact on the likelihood that these properties will sell.

Berrens et al. (2003) use the same methodology as Jenkins-Smith et al. (2002). In this study, the additional information reported to the treatment group concerned dust and air pollution emanating from a local concrete products facility. The authors find that 35% of the treatment group responded that their WTP for the house was zero. Again, this should adversely impact the probability that a property would sell.

Two studies provide simple comparisons of the transaction rates of contaminated and non-contaminated properties. Simons, Bowen and Sementelli (1999; henceforth SBS) analyze commercial properties in Cuyahoga County, Ohio (this includes the city of Cleveland). They identified 122 private properties with leaking underground storage tanks (LUSTs). These properties sold at an annual rate of 2.7% whereas the annual transaction rate for over 32,000 uncontaminated properties was 4.0%. Hence, the transaction rate for the LUST sites was 33% lower than for those sites without contamination. This result is suggestive at best since it is based on a very small sample of contaminated properties and it is likely that the difference in transaction rates between and uncontaminated properties is not statistically different from zero. Further, this analysis does not control for the characteristics of the sites so it is unclear if this difference is solely driven by differences in contamination levels. Finally, this analysis is limited to sites in a single county and a particular type of contamination (LUSTs) and it is unclear if this result would generalize to other parts of the country and to other types of contamination. SBS also find that for the 20 LUST sites that did sell, 30% obtained seller financing while 20% obtained bank financing. For all commercial properties sold between 1988 and 1997, 13% obtained seller financing while 27% obtained bank financing. They conclude that this evidence "substantiates the notion that owners of contaminated properties have difficulty accessing their equity in the property, and suffer from a type of liquidity loss that further compounds property value loss.” (pg 192) Again, these results should, at best, be taken as suggestive given the very small sample sizes of contaminated properties. Using a similar dataset, Sementelli and Simons (1997) find that a No Further Action (NFA) letter has no impact on the transaction rates of LUST sites.

Three studies focus on the impact of contamination on the redevelopment of such properties. Clearly this is strongly linked to sales. The problem of asymmetric information would not apply (since there is no buyer) but that of partial information could deter redevelopment. The study that is most similar in approach to the empirical framework established in Section 4.1 is Sigman (2006). She estimates the impact of CERCLA liability laws on the redevelopment rates of industrial sites in the U.S. The data are annual city-level observations from 1990 to 2000. The data are from surveys of realtors and are not transaction data. The dependent variable is the vacancy rate of industrial space. Sigman uses fixed effects to capture unobserved city-specific factors that can affect vacancy rates. The presence of joint and several liability laws implies a 40% increase in vacancy rates in city centers. There is suggestive evidence that joint and several liability has a bigger impact in cities with a higher risk of contamination. Strict liability does not significantly affect vacancy rates. The impact of joint and several liability on vacancy rates in suburban areas is negative but not significant. Sigman notes that this is indicative of the substitution of suburban for urban land when the latter faces higher liability costs. Sigman tests for the endogeneity of the liability variables using the number of mining establishments in the state, the frequency of accidental spills, and the number of lawyers as instruments. The results do not provide strong evidence against the exogeneity of the liability variables. Sigman also finds similar results using a data set of brownfield sites; the presence of joint and several liability in a city is associated with 67% more brownfield sites. These results as not as strong as the previous ones since the data are cross-sectional and hence it is not possible to use fixed effects to capture unobserved city-level factors that are correlated with liability laws and because the definition of a brownfield is not standardized across cities.

McGrath (2000) analyzes the impact of contamination on the likelihood of redevelopment for 195 industrial properties in Chicago that sold between August 1983 and November 1993; 95 of which were redeveloped. Individual property contamination levels are not known so McGrath uses a list of contamination probabilities for 25 industrial and commercial land-uses developed by Noonan and Vidich (1992). McGrath estimates a probit model where the dependent variable is whether or not a property that sold is redeveloped. Explanatory variables include the parcel and building area, the age and condition of the building, location variables, the percent of African-Americans residing in the census tract, the ratio of the building floor area to parcel area (used as a proxy for demolition costs) and the probability of contamination variable, PROBCON. The estimated coefficient for PROBCON is negative but not significant. Hence, there is no evidence that redevelopment of a purchased site is affected by the presence of contamination. It is important to note that these properties have already sold so this result does not imply that the presence of contamination will have no effect on transaction rates.

Lange and MacNeil (2004) estimate a logit model where the dependent variable is whether or not the redevelopment of a brownfield site was “successful” or “not-so-successful” (the authors do not state was it means for redevelopment to be successful). The data on 26 successful and 26 not-so-successful sites were obtained from surveys sent to 228 representatives of EPA brownfield assessment pilots (the response rate was 24%). Four factors were found to significantly affect successful redevelopment; an index of political support (financial incentives and limitations on developer liability) and the willingness of the lending institution to cooperate on project financing, adequacy of infrastructure, the fraction of the site redeveloped as office or commercial use, and the fraction of greenspace in the end-use plan.

5. Calculating the Welfare Loss Due To Incomplete Information

Recall from Section 2 that the net benefits to society from a property transaction are

$$NB = P_B(C) - P_S(C) = P_B(0) - P_B(0). \qquad (18)$$

The welfare loss from transactions that do not take place due to imperfect information is thus the loss of the net benefits. The net benefits are the difference in the use-value of the property in the buyer’s and seller’s hands. Thus one needs to determine the value of the property under both scenarios. The use-value to the buyer reflects the returns from the property after it is redeveloped in its highest end-use. Developers will calculate these returns to determine if the site is worth purchasing and redeveloping. This can include a market analysis that evaluates the supply and demand for a particular end-use of the site to determine the value of the property, the rents that can be charged once the redevelopment is complete, and the likelihood of vacancies. The bottom line to the developer is the after-tax cash flow (ATCF) of the project.[11] Also, see Simons (1998) for an example of calculating returns on brownfields versus greenfields for retail, industrial, and housing development projects.

Typically, the developer will only consider factors that will affect his ATCF. From society's standpoint, there are also external benefits from cleanup to consider. For nearby residents, these come in the form of increased health (or a lower risk of ill-health). Additional benefits can also derive from an increase in aesthetics and improvement of the town's image. These benefits are also associated with the redevelopment of the property. Wernstedt (2004) provides a thorough review of studies that attempt to calculate the benefits from the reuse of contaminated properties. While these studies provide measures of the increase in jobs, income, property values, and taxes that result from redevelopment, they do not calculate the net benefits to society that are appropriate for a complete welfare analysis. In particular, these studies do not include the opportunity costs of the resources used in redeveloping contaminated sites.

6. Conclusions

This paper has focused on a particular reason for the inefficient level of transactions of contaminated sites; incomplete information. A model of property transactions was developed and an analysis of the impact of incomplete information on transaction rates was undertaken. It was shown, from a theoretical standpoint, that both asymmetric and partial information can deter efficient transactions from taking place. An

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11 For more details on the developer's evaluation process see Sirmans and Jaffe (1981) and Zabel (2003).

empirical model was developed for estimating the extent of this impact. There are a small number of studies that focus on transaction rates of properties and very few that focus on transactions of contaminated properties. Thus there is a need for more empirical analysis in this area. This will involve the collection of data on individual properties, their characteristics, and contamination levels. It will also be important to obtain proxy variables for the existence of asymmetric and partial information. The proxies for asymmetric information include the extent and effectiveness of state-level disclosure laws that pertain to the release of property contamination information. The proxies for partial information include the cost and frequency of site inspections in each U.S. state. Two other areas of future research are the role of developer experience in the transactions of contaminated properties and the potential market for seller's liability insurance

One group of players that has been ignored, for the most part, in this study is the federal, state, and local government institutions. In particular, government programs that provide financial incentives for remediation and redevelopment (i.e. the Small Business Liability Relief and Brownfields Revitalization Act) can significantly affect the likelihood that contaminated properties will transact. Further, existing zoning laws and their end-use restrictions and the ability for buyers to have properties rezoned will play an important role in whether or not contaminated properties will sell. This analysis is outside the scope of this paper and is left for further research.

Appendix 1
The Case of Asymmetric and Partial Information

In this appendix, Case 3: Asymmetric and Partial Information is evaluated. The results show that only partial information will deter the sales of high contamination properties. On the other hand, for properties with low contamination, asymmetric and partial information act in an additive sense; the likelihood of a transaction is less than if only one of these types of incomplete information is present.

As in Case 1, assume there are two types of properties with high and low levels of contamination; C_H and C_L respectively, where $C_H > C_L = 0$. Let the proportion of high contamination properties be p where $0 < p < 1$. Assume that the seller knows whether the site has high or low contamination but only has partial information about the actual level of contamination so that $C_S = C_{SH} < C_H$ if the property is highly contaminated or $C_S = C_{SL} < C_L = 0$ if the property contains the lower level of contamination (also assume $C_{SH} > C_{SL}$; the seller believes that the level of contamination is greater for the high level versus the low level contamination site). Also assume that the transactions of both types of properties are feasible; the net benefits are positive in both cases. The buyer only knows p and the partial information about the levels of contamination of the two types of properties. The buyer's expected cost (level of contamination) is $C_B = pC_{SH} + (1– p)C_{SL}$. Hence, the buyer will pay no more than $P_B(C_B)$ for the property. Note that $C_B < C_{SH}$ since $p < 1$ and $C_{SL} < C_{SH}$.

As in Case 2, assume that the actual level of contamination is not revealed until the site inspection. This means that the initial scenario (prior to the site inspection) is the same as

Case 1. Thus, the two types of incomplete information are considered sequentially; asymmetric information first and partial information second. The result of Case 1 is that, under asymmetric information, properties with high levels of contamination will always sell. For properties with the low level of contamination, a transaction will take place if

$$\begin{aligned} P_B(C_B) - P_S(C_S) &= (P_B(0) - (pC_{SH} - (1-p)C_{SL})) - (P_S(0) - C_{SL}) \\ &= NB - p(C_{SH} - C_{SL}) > 0 \qquad \text{(A1.1)} \end{aligned}$$

Call this Condition 1. If Condition 1 does NOT hold, then $p(C_{SH} - C_{SL})$ is bigger than NB and no transaction will occur (note that this is the same as equation (4) under Case 1 with $C_{SL} = 0$). That is, the difference between the buyer's expected remediation costs, C_B, and the seller's (partial) knowledge of these costs, C_{SL}, is greater than net benefits. If Condition 1 does not hold, the owners of low contamination properties will be unwilling to sell these sites. Since the buyer realizes this, his reservation price will fall from $P_B(C_B)$ to $P_B(C_{SH})$.

At this point, a transaction will take place if the site is highly contaminated or if the site contains the lower level of contamination and Condition 1 holds. Now assume that C (either C_H or C_L) is revealed at the sale given a site inspection and the seller has to pay any additional cleanup costs (i.e. the effective sales price is lower by $C - C_S$). A transaction of a high contamination site will take place if

$$\begin{aligned} P_B(C_B) - P_S(C_S) &= (P_B(C_{SH}) - (C_H - C_{SH})) - P_S(C_{SH}) \\ &= P_B(C_H) - P_S(C_{SH}) \\ &= (P_B(0) - C_H) - (P_S(0) - C_{SH}) \end{aligned}$$

$$= NB - (C_H - C_{SH}) > 0 \tag{A1.2}$$

Call this Condition 2. Then no transaction of a highly contaminated site will occur if Condition 2 does NOT hold. That is, there will not be a sale if the difference in the revealed level of contamination compared to the seller's knowledge of that contamination, $(C_H - C_{SH})$, is greater than NB (this is similar to equation (6) under Case 2). Thus, under asymmetric and partial information, efficient transactions of the high contamination properties may not take place. But note that this is only due to the presence of partial information and is not due to the presence of asymmetric information.

For a low level contamination site to sell, Condition 1 must hold. Further

$$\begin{aligned} P_B(C_B) - P_S(C_S) &= (P_B(C_{SL}) - (C_L - C_{SL})) - P_S(C_{SL}) \\ &= P_B(C_L) - P_S(C_{SL}) \\ &= (P_B(0) - C_L) - (P_S(0) - C_{SL}) \\ &= NB - (C_H - C_{SL}) > 0 \end{aligned} \tag{A1.3}$$

Call this Condition 3. Thus both Conditions 1 and 3 must hold for a low level site to sell. Note that these two conditions are different in nature and one does not imply the other. Condition 1 depends on NB being larger than the difference in the buyer's and seller's knowledge of the contamination levels (due to asymmetric information). Condition 3 depends on NB being larger than the difference in the actual contamination level and the seller's partial information of that contamination level. Hence, the existence of both asymmetric and partial information implies that the probability of low level contamination sites transacting is lower than if only one of these two forms of incomplete information holds.

Appendix 2
The Interest Rate under Asymmetric Information

In this appendix, the interest rate charged under asymmetric information between the lender and buyer is calculated. It is shown that this interest rate, r_{HL}, is between r_H and r_L; the interest rates charged to the high and low contamination properties under perfect information. The expected profits, $E[\pi_{HL}]$, to the lender are

$$E[\pi_{HL}] = (1\text{-}p)\,E[\pi_L] + p\,E[\pi_H] \tag{A2.1}$$

where p is the probability the site has the high level of contamination and $E[\pi_L]$ and $E[\pi_H]$ are the expected profits to the lender under the high and low contamination alternatives:

$$E[\pi_L] = p_{dL}\cdot[P_{LL} - (1+s)\cdot P] + (1-p_{dL})\cdot[(r_L-s)P]$$

and

$$E[\pi_H] = p_{dH}\cdot[P_{HL} - (1+s)\cdot P] + (1-p_{dH})\cdot[(r_H-s)P].$$

where p_{dL} and p_{dH} are the probabilities of default for the properties with low and high levels of contamination, P_{LL} and P_{HL} are the values of the site in the low value state with low and high levels of contamination, and P is the sales price of the property.

It follows that (recall that $P_{LL} = P_{HL}$)

$$E[\pi_{HL}] = p_{dHL}\cdot[P_{LL} - (1+s)\cdot P] + (1-p_{dHL})\cdot[(r_{HL}-s)P] \tag{A2.2}$$

where $p_{dHL} = p\cdot p_{dH} + (1\text{-}p)\cdot p_{dL}$ (A2.3)

and $$r_{HL} = \frac{(1-p)(1-p_{dL})r_L + p(1-p_{dH})r_H}{1-p_{dHL}}. \tag{A2.4}$$

It is easy to see that $p_{dL} < p_{dHL} < p_{dH}$ and $r_L < r_{HL} < r_H$. This shows that the interest rate charged will lie in between r_L and r_H.

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