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Repairs under imperfect information ☆

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A B S T R A C T

We propose a theory of how repairs affect prices under imperfect information. Our model reveals that repairs may lower prices because, if repairs are not always successful, they may reveal negative information about product quality. We also show that the price effect of repairs is increasing in the share of defective products in the population. Under perfect information a repair cannot lower the price and the price effect does not depend on the defective unit share. Data on condominium transactions during Vancouver's leaky condominium crisis provide support for the model predictions.

1. Introduction

In the late 1990s, hundreds of stories appeared in the Vancouver BC news media about water leaks leading to rot and mold in condominiums. Over one third of the wood-frame condos built in the 1990s underwent building envelope repairs. The cost of repairs to individual unit owners averaged in excess of $50,000.[1] Condo buyers during this period faced the difficult choice of whether to buy a repaired or unrepaired condo. Since not all condo building repairs are completely successful, a repaired condo is "damaged goods" and of uncertain quality. However, an unrepaired condo was also of uncertain quality as it might have defects that had yet to be corrected.

In this paper, we model the price effect of a repair under perfect and imperfect information and test the theories using data on prices and sales of Vancouver condominiums. In the imperfect information model, buyers do not know the true quality of a unit but know whether it has been repaired. We establish that a repair lowers the price if the share of defective units in the population is low and raises the price when the share is high. This result contrasts with the effect of a repair under perfect information that we show cannot reduce a condo's price and is independent of the share of defective units.

The housing transaction data from the leaky condo crisis provide useful variation for testing the theories. First, variation in the length of time between a transaction and a subsequent repair helps distinguish between cases of perfect and imperfect information. For units that transact shortly before the repair, buyers are likely aware of the leak problem because the damage may be visible and they have access to strata council meeting minutes where the leak may be discussed. For transactions occurring well before the repair, it is more likely that buyers are not aware of the problem.

In addition, the data contain cross-sectional and temporal variation in the share of defective condo units. We establish that changes in building codes led to higher defect rates for units of a particular type and vintage. Over time the surge in media accounts of the problem led to increased buyer recognition of the leakage problem and a growing public perception of the high defect rate in the condo population. Therefore, as buyers learned of the problem through media accounts, they updated their priors about the likelihood that an unrepaired unit will be defective. These features of the data provide a unique setting to test the models.

Relying primarily on repeat sales estimation methods, we find that for units repaired soon after their initial purchase, repairs are associated with higher prices. We interpret this finding as indicating that the buyer knew the condo was defective at time of purchase. However, when repairs occurred more than a year

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[1] The repair incidence figure is based on our data and calculations (see Table 1). Boei (2008) reports that per-unit repair loans issued by the Homeowner Protection Office averaged $62,000 for wood-frame apartments and $72,000 for concrete buildings.

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subsequent to the initial purchase, we find both positive and negative effects of repairs. For unrepaired units purchased prior to widespread media reporting of the leaky condo crises, subsequent repairs are associated with lower prices when the units are resold. However, once the problems became well known, we find evidence that buyers discounted the prices of unrepaired condos of the type subject to the most defects—wood-frame condos built between 1989 and 1999—and subsequent repair of these units resulted in higher prices.

A feature of many second-hand markets is that the buyer often has information on whether the product has undergone a repair. While obtaining this information is useful, there often remains uncertainty about whether the repair is successful. We contribute to the literature on imperfect information by incorporating the repair decision into a model of equilibrium pricing with imperfect information. To our knowledge, this is the first paper to consider how information on repairs influences pricing.

Our analysis is closely related to the asymmetric information literature because buyers do not observe the true quality of goods. This literature predicts, in the extreme case, that bad units completely drive out good units from the resale market (Akerlof, 1970). In this case, all units trade for the same price equal to the quality of bad units and our price results would not obtain. We show that under plausible assumptions both good and bad units will be offered for resale even when sellers know the true quality of their units and strategically choose whether to repair defective units and offer them for sale. Thus, we contribute a general depiction of pricing of repaired and unprepared goods under imperfect information that extends to the case of asymmetric information.

The empirical literature on imperfect information in property markets has focussed on identifying information asymmetries. Levitt and Syverson (2008) find that real estate agents appear to take advantage of information asymmetries by persuading clients to accept offers more quickly and at lower prices than they are willing to accept for their own homes. Rutherford et al. (2007) demonstrate that these results also extend to the condominium market. Garmaise and Moskowitz (2004) investigate how differences in the quality of property tax assessments influence commercial real estate activity. They show that informationally disadvantaged agents limit their participation in real estate markets characterized by asymmetric information. Nanda and Ross (2009) find that state adoption of seller disclosure laws mitigate the lemons problem associated with asymmetric information in property markets and result in higher prices. We extend this literature by investigating the price effects of a common feature of housing markets—information available to buyers that a unit has undergone repair.

In the next section, we present our theory of the price effects of repairs under perfect and imperfect information and identify testable predictions. We explain how repeat sales information on condominium transactions can be used to test the theory. Section 3 contains the empirical analysis. It includes a description of the data, the econometric specification, and presentation and discussion of the results. In Section 4, we explain why the model predictions are robust to features of the leaky condo setting not explicitly captured in our general model of pricing of repaired goods. Section 5 summarizes our results.

2. Theory

This section presents theory that generates the key predictions we test in our empirical analysis. We derive the price impact of a repair under two hypotheses: perfect information and imperfect information. Unique implications that distinguish imperfect information from perfect information are that repairs can *lower* housing prices under imperfect information and that the price change due to a repair increases with the share of defective units in the population. In order to focus on the key ideas, this model assumes that repairs and sales occur randomly with exogenously given probabilities. We provide a full model which endogenize these decisions in Appendix A.

2.1. Description

There is one unit measure of condo units. Units differ in their quality $q \in \{G, D\}$ where G and D indicate the quality of good units and defective units respectively ($G > D$). A key parameter in the model is β that measures the share of the defective units in the population.

We assume an infinite number of risk neutral buyers with the following preferences

$$x + q \cdot I_O, \tag{1}$$

where x is the numeraire good, $q \in \{G, D\}$ is unit quality, and I_O is an indicator variable taking 1 if an individual owns a unit and 0 otherwise.

In stage 0, the nature randomly assigns each unit to either perfect information or imperfect information. Under perfect information, buyers can observe unit quality. Under imperfect information, buyers cannot observe quality. The probability of a unit being assigned to imperfect information is α.

In stage 1, randomly chosen $\phi \in (0,1)$ share of defective units get repaired. A repair has a stochastic outcome: a repaired defective unit becomes a good unit with probability $\rho \in (0,1)$ and remains a defective unit with probability $1 - \rho$. Repair outcomes are realized at the end of stage 1.

In stage 2, units are offered for sale. There are four types of condo units at the beginning of stage 2: RG (repaired good), RD (repaired defective), UG (unrepaired good), and UD (unrepaired defective). Different types can have different selling probabilities: type iq gets randomly sold with probability σ_q^i ($i = R$, U and $q = G$, D).

We are interested in how the price effect of a repair differs under perfect information and imperfect information. To make the distinction clear, we characterize the equilibrium separately for a sub-game representing each case. We will present the combined effect in Section 2.5.1 where we map our model to data.

2.2. Equilibrium under perfect information

Suppose that buyers can directly observe unit quality. Buyers' utility function given in (1) implies that each buyer is willing to pay G and D for a good unit and a defective unit, respectively. Since there are an infinite number of buyers, housing prices are determined as

$$\begin{cases} P_G = G \\ P_D = D. \end{cases}$$

Now we characterize how a repair affects the unit price. If a repair succeeds, housing price changes from D to G. If a repair does not succeed, the price remains at D. Thus, average price gain due to a repair is $\rho(G - D)$. A repair cannot lower price and the average price gain does not depend on the defective unit share β.

Proposition 1. *Suppose that buyers can observe the true quality of housing units.*

(a) *A repair either raises a unit's price or leaves it unchanged. On average, repairs have positive effects on prices.*
(b) *The average price change associated with repairs does not depend on the defective unit share β.*

Note that when we derive Proposition 1, we keep track of the same units before and after a repair, instead of comparing average repaired unit price with average unrepaired unit price in a cross-section. This has two important implications. First, it suggests that we should test the theory using repeat sales information on individual units. We elaborate on this point in Section 2.5.2. Second, Proposition 1 pertains to units that are transacted as defective units prior to being repaired. This information requirement is weaker than perfect information which assumes buyers can observe the true quality of all units including good ones that are not to be repaired. We will comment further on this issue in Section 3.2 where we discuss how we obtain α variation used in the empirical analysis.

2.3. Equilibrium under imperfect information

Suppose buyers do not observe true quality q but observe whether a unit has received a repair or not. Sellers may or may not observe the true quality of their units. The only unit characteristic buyers observe is whether a unit has been repaired or not. This implies that there will be two price levels in equilibrium—P^R for repaired units and P^U for unrepaired units. Given an infinite number of risk neutral buyers, demand is perfectly elastic and the price of each group is set equal to the expected quality in market:

$$P^i = E(q|i)$$

where $i = R, U$.

Let π_q^i ($i = R, U$ and $q = G, D$) denote the number of units in each type at the beginning of stage 2. For group $i \in \{R,U\}$, there are $\pi_G^i\sigma_G^i$ good units and $\pi_D^i\sigma_D^i$ defective units offered for sale. Thus, we can characterize group i's price as

$$P^i = E(q|i) = \frac{\pi_G^i\sigma_G^i G + \pi_D^i\sigma_D^i D}{\pi_G^i\sigma_G^i + \pi_D^i\sigma_D^i} = \frac{G + (\pi_D^i/\pi_G^i)(\sigma_D^i/\sigma_G^i)D}{1 + (\pi_D^i/\pi_G^i)(\sigma_D^i/\sigma_G^i)}. \quad (2)$$

Eq. (2) shows that a group i's price, P^i, is determined by the share ratio π_D^i/π_G^i and the selling probability ratio σ_D^i/σ_G^i. Since σ_D^i/σ_G^i is exogenously given, we just need to characterize π_D^i/π_G^i to pin down price P^i.

For unrepaired units, π_D^U/π_G^U is determined by initial defective unit share β and repair probability ϕ,

$$\frac{\pi_D^U}{\pi_G^U} = \frac{(1-\phi)\beta}{(1-\beta)}.$$

This yields

$$P^U = \frac{(1-\beta)G + (1-\phi)\beta(\sigma_D^U/\sigma_G^U)D}{(1-\beta) + (1-\phi)\beta(\sigma_D^U/\sigma_G^U)}. \quad (3)$$

For repaired units, π_D^R/π_G^R is determined solely by repair success probability ρ because only defective units get repaired.

$$\frac{\pi_D^R}{\pi_G^R} = \frac{(1-\rho)\phi\beta}{\rho\phi\beta} = \frac{1-\rho}{\rho}.$$

This yields

$$P^R = \frac{\rho G + (1-\rho)(\sigma_D^R/\sigma_G^R)D}{\rho + (1-\rho)(\sigma_D^R/\sigma_G^R)}. \quad (4)$$

Since buyers cannot observe true quality, a repair would change price from P^U to P^R. We characterize this price effect of a repair as a function of the defective unit share β. Fig. 1 shows how P^U and P^R in equations (3) and (4) change as β changes. First, P^R does not depend on β and is strictly between D and G for $\rho \in (0,1)$. Second, P^U is decreasing in β.[2] As β converges to 0, P^U converges to G. As β converges to 1, P^U converges to D. Third, as a corollary, there is $\hat{\beta}$ such

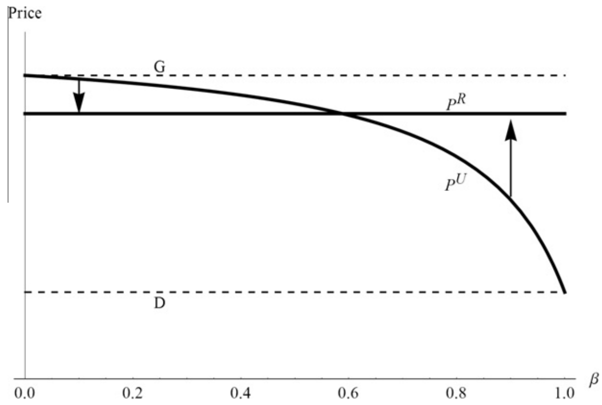

Fig. 1. Prices for different shares of defects in the population (β).

that repair lowers price (i.e., $P^R < P^U$) for $\beta < \hat{\beta}$ and raises price for $\beta > \hat{\beta}$. The unique predictions under asymmetric information is that repair can lower a unit's price and that the price effect of a repair increases with β.

Proposition 2. *Suppose that buyers cannot observe true unit quality but observe whether a unit received a repair or not.*

(a) *A repair lowers the price if the defective unit share $\beta > 0$ is sufficiently low relative to the repair success probability and raises the price if the defective unit share $\beta < 1$ is sufficiently high. (There exists a $\hat{\beta}$ such that $P^R < P^U$ if $\beta < \hat{\beta}$ and $P^R > P^U$ if $\beta > \hat{\beta}$.)*
(b) *The price effect of a repair increases with β,*

$$\frac{\partial P^R/P^U}{\partial \beta} > 0.$$

2.4. Strategic seller behavior: the full model

The model presented above assumes that sellers do not make decisions: Repairs and sales occur randomly with exogenously given probabilities ϕ and $\sigma_q^i (i = R, U$ and $q = G, D)$. This raises the concern that our result may not hold if sellers observe the true quality of their units and make repair and selling decisions strategically as in the information asymmetry literature. For example, in the classical information asymmetry model, owners do not sell good units and buyers correctly infer that all units in the market, whether repaired or not, are defective. This results in market prices of D. Given these market prices, owners may not repair their units at all since it will not raise price.

In Appendix A we provide the full model that allows the repair and selling decisions to be endogenous and shows that our results are robust even with information asymmetry. The full model makes three key additional assumptions. First, unit owners receive selling shocks and even good unit owners may sell their units if their selling shocks are large enough. This prevents the market price from collapsing to D. The selling shocks represent many factors that induce moving such as a new job or household member changes. Second, we allow heterogeneity in repair costs among owners. This implies that owners do not all make the same repair decision and prevents an equilibrium where all defective units get repaired and all remaining unrepaired units are good units. Repair costs may vary among owners because they have different opportunity cost of their time. Third, unit owners get consumption value from their homes if they do not sell their units. This allows an equilibrium where owners do repairs even if the repairs lower market price. As in the simple model, prices are determined by expected unit quality but now buyers anticipate the repair and sales decisions of owners. In the

[2] $\frac{\partial P^U}{\partial \beta} = -\frac{(G-D)(1-\phi)\sigma_D^U\sigma_G^U}{(\beta(1-\phi)\sigma_D^U + (1-\beta)\sigma_G^U)^2} < 0.$

appendix, we establish that the predictions of the simple model extend to this more realistic depiction of owner behavior.

2.5. Testing the theory

In the data, there will be transactions for which the unit quality is known and other transactions for which unit quality is unknown. Therefore, we do not expect to observe outcomes that perfectly correspond to either the perfect information and imperfect model predictions. This section derives the model implications under this mixed case that we test in our empirical analysis. In addition, we explain why cross-sectional information is ill suited to testing the predictions of the perfect information model.

2.5.1. The copresence of perfect information and imperfect information

Recall that in stage 0 of the model, nature randomly assigns each housing unit to imperfect information with probability α. Buyers cannot observe quality for α share of units but do observe quality for $1-\alpha$ share of units. The *average* price effect of a repair that an econometrician would observe is a weighted average of price effects arising from transactions with perfect and imperfect information.

Proposition 1 states that the price effect of a repair under perfect information is positive. Proposition 2 shows that the price effect under imperfect information can be positive or negative depending on β. When both types of units are present, the average repair effect is a linear combination of the two effects where the imperfect information prediction receives a weight of α. It is positive for α sufficiently close to 0 where the perfect information case dominates. If β is sufficiently small to generate negative repair effects under imperfect information, the average repair effect is negative for high α and positive for low α.

The copresence of perfect and imperfect information ($0 < \alpha < 1$) does not change the prediction in Proposition 2 that the repair effect is increasing in the share of defective units in the population, β. Under perfect information, the effect of a repair is independent of β. Therefore, in the mixed case, the price effect of a repair with respect to changes in β has the same sign as the one under imperfect information but with an α times magnitude.

Proposition 3. *Suppose that buyers do not observe the quality for α share of condo units but do observe the quality of remaining $1-\alpha$ share of housing units.*

(a) *For sufficiently low α the price effect of a repair is positive.*
(b) *If β is sufficiently small, the price effect is negative for high α but positive for low α.*
(c) *Suppose $\alpha > 0$. The price effect of a repair increases with β.*

Our empirical analysis will focus on testing Proposition 3. One caveat is that our empirical analysis will partly treat β as the *perceived* defective unit share among buyers. The perceived defective unit share can be affected by various signals as well as the actual defective unit share in the population. For example, we can expect perceived β to rise with media reporting of the leaky condo crisis, even when the actual defect share does not change.

Another parameter affecting the price effect of a repair is the repair success probability ρ. Higher ρ raises the price effect of a repair under both perfect and imperfect information. We do not establish a separate proposition for this relationship because we cannot test it. We mention it as a possible confounding factor when we discuss the differences in the price effect of a repair across buildings with different structural characteristics.

2.5.2. Identification: cross-sectional vs. time-series information

To estimate the price effect of a repair, we can compare the prices of repaired and unrepaired condos at a point in time (cross-sectional information) or examine the price of an individual condo before and after a repair (time-series information). We show that the cross-sectional comparison cannot correctly identify the price effect of a repair under perfect information.

Recall in Section 2.2 we derive the repair effect in the case of perfect information by comparing the prices of a unit before and after a repair. A repair increases the unit price from D to G with success probability ρ and leaves the price unchanged at D with probability $1-\rho$. Thus, a repair cannot lower price and, on average, raises price by $\rho(G-D)$.

Suppose that an econometrician estimates the repair effect by comparing cross-sections of repaired and unrepaired units. The average prices that the econometrician will observe will reflect a mixture of good and defective units. We can write the expected value of prices, which depend on repair rates, ϕ, and selling probabilities, σ_q^i ($i = R$, U and $q = G$, D), as follows

$$E(P|U) = \frac{(1-\beta)G + (1-\phi)\beta\left(\sigma_D^U/\sigma_G^U\right)D}{(1-\beta) + (1-\phi)\beta\left(\sigma_D^U/\sigma_G^U\right)} \tag{5}$$

$$E(P|R) = \frac{\rho G + (1-\rho)\left(\sigma_D^R/\sigma_G^R\right)D}{\rho + (1-\rho)\left(\sigma_D^R/\sigma_G^R\right)}. \tag{6}$$

The price difference between $E(P|R)$ and $E(P|U)$ is different from the expected price gain $\rho(G-D)$ established in Section 2.2.[3] Moreover, the average repaired unit price $E(P|R)$ can be even lower than average unrepaired unit price $E(P|U)$ if β is sufficiently close to 0 because $E(P|U)$ approaches G as β goes to zero. Thus, the cross-sectional comparison does not correctly identify $\rho(G-D)$ in general.

This reasoning indicates that a cross-sectional comparison of prices is not suited to testing the predictions of the perfect information model. Neither is it suited to testing the mixed case (Proposition 3) which builds on the results under perfect information. The price effect of a repair under perfect information, however, can be measured by following a unit over time. The prediction that a repair cannot lower price is conditional on the unit initially being defective. When we estimate the repair effect by following the same unit before and after a repair, we know the unit was initially defective and a repair will increase the price on average.

3. Empirical analysis

We use condo transaction data during the leaky condo crisis to test our theory. Our empirical analysis proceeds as follows. We begin by describing the data and explaining the sources of variation in α and β we use to test Proposition 3. Then we show our regression specifications and present and interpret the empirical results.

3.1. Data

We utilize the complete universe of residential transactions in Vancouver from 1983 to the second quarter of 2005 (2005:Q2).[4] The data are provided by Landcor from the British Columbia Assessment Authority (BCAA) records of transactions. The data include transaction date, selling price, the primary structure characteristics, age, address, and neighborhood identifiers.[5]

Since there is no complete publicly available database that identifies which buildings have repaired envelopes, we constructed

[3] Note that Eqs. (5) and (6) are identical to Eqs. (3) and (4). This is not a coincidence. The econometrician can only observe expected prices which correspond to the priors of buyers under imperfect information.

[4] We exclude pre-sold, new condo transactions because their prices are set as many as two years in advance of the date of completion and do not reflect market conditions at the time of the registration of the transaction.

[5] The neighborhoods are determined by the British Columbia Assessment Authority with the goal of creating a balanced workload for their assessors while retaining a degree of neighborhood homogeneity. In total, there are 88 neighborhoods in the Vancouver metropolitan area with condo transactions over our period of study.

the repair data by hand. We use two different sources. The first is a set of buildings in which at least one unit owner has received repair loans from the Homeowner Protection Office (HPO). There is a means test for receiving support, so the HPO will likely exclude buildings with higher income or wealthier owners. The second source is information on buildings that received a building permit for repair to the building envelope. When a permit identified that the work was done for an envelope repair, we treat it as a repair. These data were obtained through a hand search of permit data done back to 1984 for each municipality in the Vancouver metropolitan area.[6] The dates of repair correspond to the date of the first application for funding for the HPO data and issuance dates for the permit data. Since an envelope repair applies to all the units in the building, if a building is repaired, all units within it are considered to be repaired. In the regression analysis, we cluster standard errors by building because we expect unobserved shocks to condo prices to be correlated for units in the same building.

3.2. Variation in α and β

The timing of a leaky condo repairs and selling dates provides information that we can use to infer the share of units whose quality are unknown to buyers, α. The repair dates reflect the culmination of a lengthy process where (1) the leak is noticed, (2) the strata council discusses the problem and authorizes repair, and (3) the permit is applied for and issued or the loan application is made. Since buyers have access to strata council meeting minutes, the buyer will become informed of the defect during a period shortly before the repair date permit.[7] Therefore, condos that transact shortly before a repair are likely to correspond to low α (i.e., close to the perfect information case) whereas those for which the interval is longer imply high α. Inspections and strata minutes may reveal that a unit is defective but cannot identify a good unit with certainty. Perfect information about the presence of defects is precisely the information we need to test Proposition 1 which is conditional on the unit being known to be defective prior to the repair.

The leaky condo crisis provides two kinds of variation in the share of defective units, β. First, the defective unit share varies depending on structure type and construction year. The building envelope separates the indoors from the outdoors and includes the exterior walls, foundation, roof, windows and doors. Rot and mold arise when rain penetrates the exterior walls and creates moisture. Wood frame buildings built between 1989 and 1999 are more susceptible to the leaking problem due to changes in building codes. Starting in the 1970s, developers in Vancouver began imitating California architecture styles. California has a much dryer climate than Vancouver and following this architecture style resulted in leaks in poorly constructed buildings. This leakage, however, did not cause major rot and mold problems until the government started requiring air tight building systems in 1989. This regulation prevented any water that penetrated the exterior walls from evaporating. In response to the serious problems that ensued, in 1999 the BC government began requiring builders to implement technologies to deal with the moisture problems such as rain screens.

Media attention to the problem also led to variation in perceived β over time. News stories about leaky condos exploded in the late 1990s. Thus, condo buyers prior to the media coverage were unlikely to be aware of potential leakage problems but were fully aware after the stories were all over the news. This suggests that β, as perceived by buyers, increased over time.

Table 1
Repairs across different condo types.

	Buildings			Units		
	Total	Repair	Share	Total	Repair	Share
Concrete, pre 1989	260	26	0.10	13,149	1231	0.09
Concrete, 1989–1999	551	58	0.11	26,936	3741	0.14
Wood frame, pre 1989	1729	206	0.12	26,309	4899	0.19
Wood frame, 1989–1999	1306	397	0.30	33,658	13,843	0.41

Share is the proportion of units/buildings that underwent envelope repairs.

Table 1 reports the share of repaired units by structure type. We divide structures into four groups based on whether they were concrete frame or wood frame and whether they were built before 1989 or between 1989 and 1999. We ignore units built starting in 2000 as none were subject to envelope repair through the end of our time period. We also omit townhouses as they were hardly ever repaired (less than 1% of the time). We report repairs for buildings and units.

The table clearly reveals that the leak problem is most pronounced for wood-frame structures built in the 1989–1999 period. We refer to these condos as wood90s condos hereafter. Thirty percent of these building types were repaired. We also observe that repaired buildings were on average larger than unrepaired buildings as repairs comprised 41% of wood90s condo *units*. The repair percentage of wood90s condos is about three times higher than those of other types: the incidence of repairs is 10% of concrete-frame high rise condos built before 1989, 11% for concrete-frame condos built between 1989 and 1999, and 12% for pre-1989 wood-frame condo buildings (referred to hereafter as woodpre89 condos). Because the repair frequency is similar for concrete-frame condos across the two vintages, we will consider them as a single type (concrete condos) in ensuing analysis. The table provides clear evidence that the share of defective units in the population of condos, β, was highest for wood90 condos.

Fig. 2 portrays how news about the leak problem and repairs evolved over time. It displays the number of news stories about leaky condos and the number of repairs by condo type from 1990 to 2004. We measure the former as the number of articles in local papers that include key words related to the leaky condo crisis.[8] As is clear from this figure, this problem did not explode into the greater public consciousness until 1998, coinciding with the rapid increase in repairs. After 2003 repairs drop off though articles do not taper off as much, in part because of remaining court cases.

3.3. Specification

Suppose the price of condo i in period t is a function of unit characteristics, repair status, and unobserved neighborhood and quarterly effects according to the following semilog functional form:

$$\ln P_{it} = \alpha_i \mathbf{X}_i + \gamma R_{it} + \beta_t Q_t + \phi N_n + e_{it} \qquad (7)$$

where $\mathbf{X}_i$ are unit characteristics, Q_t and N_n are dummies for quarter t and neighborhood n, respectively, and R_{it} implies condo i's building has been repaired.

Eq. (7) is a hedonic specification where a unit's price is a function of unit and neighborhood characteristics and, unless unit fixed effects are added, the parameters are identified largely off cross-

[6] We likely undercount the incidence of repairs. If a building permit did not give a reason for the permits we do not consider it to be an envelope repair. HPO undercounts as well because eligibility is based on income.

[7] There may be lengthy and contentious deliberations among owners concerning the extent of the leak problem and the necessary repairs. Indeed, Boei (2006) provides an account of dissident owners attempting to get court orders to force the strata council to undertake building envelope repairs. While we do not know the time to obtain a envelope repair permit in the 1990s, the current wait time is 5–6 weeks according to the City of Vancouver.

[8] The article search used the Canadian Newsstand, ABI/INFORM Archive Complete,and ABI/INFORM Global databases. The search used various combinations of words such as condo, water, leak, damage, and strata.

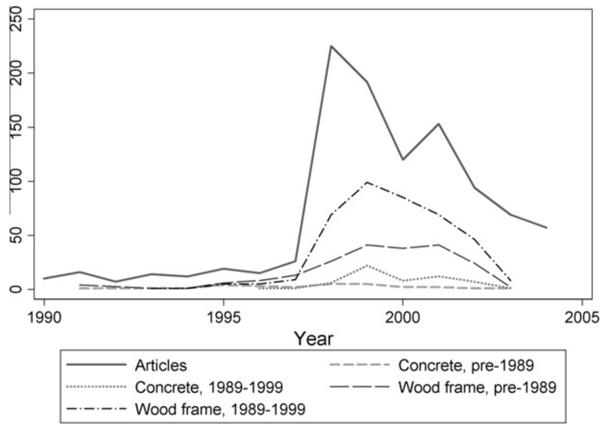

Fig. 2. Repairs and news stories.

sectional variation. As argued in Section 2.5.2, our theoretical result does not hold under cross-sectional comparison and thus we convert Eq. (7) into a repeat sales specification by taking the difference between condo i's price in period $t+j$ and t to obtain:

$$\ln P_{i,t+j} - \ln P_{it} = \gamma(R_{i,t+j} - R_{it}) + \beta_{t+j}Q_{t+j} - \beta_t Q_t + \epsilon_{i,t+j}. \quad (8)$$

where $\epsilon_{i,t+j} = e_{i,t+j} - e_{it}$. Note that each repeat sales observation contains a first (period t) and a second ($t+j$) transaction and that $(R_{i,t+j} - R_{it})$ captures whether a repair occurred between the two transactions.[9] Repeat sales estimates are identified by times-series variation in the data. The quarterly time dummy variables capture general price changes and can be used to construct a price index. Since the repair variable identifies units that have undergone repair, the price index reflects prices of unrepaired units.

The repeat sales specification has the virtue of removing non-time varying unobservables that may cause bias. However, it does not eliminate time-varying unobservables that could cause bias. For example, unit quality may degrade over time in response to to a repair if the repair financially constrains owners. This correlation would lead to bias in both the hedonic and the repeat sales specifications.[10]

3.4. Results

The first four columns of Table 2 display results for the hedonic specification and the last column shows results for the repeat sales specification. We include hedonic specifications for comparison and will employ only the repeat sales specification in subsequent analysis. Column (1) uses all condo observations and, for comparability with the repeat sales specification, column (2) limits the sample to units with at least two transactions. Column (3) and (4) introduce neighborhood and condo unit fixed effects. We provide results for all condos and subsets based on type: concrete, woodpre89, and wood90s. The hedonic regressions in columns (1–3) include (log) floor area; age and age squared; whether the unit has a prime, good, or fair view; whether it underwent a major renovation; the number of half and full bathroom; and the number of stories in the building.[11] The coefficients on these variables are significant and enter with the expected signs and we do not report them for the sake of brevity.

Table 2 reveals that the estimated repair coefficients tend to be negative. When we consider all observations, the estimates are not sensitive to the specification and indicate a repair lowers price by 1.0–1.4%.[12] A comparison of the hedonic estimates without fixed effects shown in columns (1) and (2) and estimates based on time series variation shown in the remaining columns reveal differences, although these differences are not statistically significant. We observe indications of negative bias in the estimates that use cross-sectional variation for concrete and wood90s condos: The repair estimates are lower in the first two columns than the specifications that incorporate building or unit fixed effects or first differences (repeat sales).[13] This could indicate repaired units have low quality that is not observed. However, the hedonic estimates for woodpre89 appear to have the opposite bias—repaired units seem to have high

Table 2
Hedonic and repeat sales specifications.

	Hedonic				Repeat sales
	All	Repeats	Bldg FE	Unit FE	
All					
Repair Effect	−0.012	−0.010	−0.013[c]	−0.011	−0.014[b]
	(0.009)	(0.009)	(0.008)	(0.008)	(0.007)
N	157,904	121,049	121,096	121,096	74,248
R^2	0.865	0.865	0.485	0.767	0.727
rmse	0.179	0.177	0.191	0.090	0.150
Concrete					
Repair Effect	−0.042[c]	−0.035	−0.030	−0.020	−0.021
	(0.023)	(0.023)	(0.022)	(0.022)	(0.022)
N	56,271	40,377	40,388	40,388	24,105
R^2	0.862	0.866	0.381	0.765	0.730
rmse	0.191	0.188	0.226	0.087	0.149
Wood, pre-1989					
Repair Effect	0.020	0.015	−0.003	−0.005	−0.001
	(0.013)	(0.012)	(0.013)	(0.013)	(0.012)
N	56,469	49,556	49,577	49,577	32,174
R^2	0.862	0.862	0.622	0.802	0.762
rmse	0.162	0.162	0.177	0.100	0.157
Wood, 1989–1999					
Repair Effect	−0.026[a]	−0.029[a]	−0.013	−0.012	−0.020[b]
	(0.010)	(0.010)	(0.008)	(0.009)	(0.008)
N	45,164	31,116	31,131	31,131	17,969
R^2	0.795	0.801	0.285	0.552	0.572
rmse	0.145	0.143	0.158	0.076	0.138

Standard errors are clustered by building and shown in parentheses with [a], [b] and [c] respectively denoting significance at the 1%, 5% and 10% levels. The hedonic regressions include log (area), age and age squared, whether the unit has a prime, good, or fair view, whether it underwent a major renovation, number of half and full bathrooms, number of stories in the building, neighborhood effects and type-specific quarterly time effects. Repeat sales specifications include type-specific prices indexes.

[9] An issue with repeat sales data is that measured structure characteristics do not vary over time even though in practice units undergo renovations. This problem should be less acute for condos as the ability to make major alterations to the structure is limited. Even so, the BCAA data includes a variable for "effective year" that indicates their assessment of a building's interior's vintage, which tracks major renovation date. Usually the effective year is same as the year of construction, but if there was a major renovation, the effective year will be the year of renovation. We use this to control for major structural changes by designating transactions prior to this date as belonging to a "different" unit.

[10] Both the hedonic and repeat sales specifications assume the implicit prices of condo attributes are constant (the coefficients are time invariant). If these implicit prices vary over time, the quarter dummies may not fully capture all of the changes, and there exists the possibility of components in the error term that could potentially confound the analysis, even for the repeat sales specification. For example, suppose the price appreciation is higher for condos with three bathrooms than condos with one bathroom. The coefficient on the repair variable would be biased if the likelihood of repair depends on the number of bathrooms. However, we could think of no theoretical reason why this should be the case.

[11] We include type-specific quarterly effects in all specifications.

[12] The estimated repair coefficients closely approximate the percentage change in price associated with repair since the estimates are close to zero.

[13] The results with building fixed effects (column 3) are very similar to those with condo fixed effects (column 4) because whenever a building is repaired, all condos in the building are considered to be repaired.

Table 3
Repairs effects by time from sale to repair by condo type.

	All	Concrete	Wood frame		All
			Pre-1989	1989–1999	
0–6 months	0.062[a]	−0.002	0.107[a]	0.049[b]	0.049[a]
	(0.019)	(0.033)	(0.019)	(0.023)	(0.019)
7–12 months	0.039[a]	0.014	0.041[c]	0.047[a]	0.029[b]
	(0.011)	(0.025)	(0.021)	(0.016)	(0.011)
1–2 years	0.001	−0.030	0.024[c]	0.003	−0.008
	(0.009)	(0.019)	(0.015)	(0.012)	(0.009)
2–3 years	−0.006	−0.050	0.023	−0.002	−0.012
	(0.012)	(0.032)	(0.018)	(0.014)	(0.012)
3+ years	−0.027[a]	−0.016	−0.017	−0.037[a]	−0.020[b]
	(0.008)	(0.023)	(0.014)	(0.009)	(0.008)
Sales interval					0.005[a]
					(0.000)
N	74,248	24,105	32,174	17,969	74,248
R^2	0.727	0.730	0.763	0.575	0.730
rmse	0.150	0.149	0.156	0.137	0.149

Standard errors are clustered by building and shown in parentheses with [a], [b] and [c] respectively denoting significance at the 1%, 5% and 10% levels. Column (1) regressions include type-specific price indexes.

unobserved quality. A comparison of columns (4) and (5) reveals that employing condo unit fixed effects generates similar estimates to the repeat sales specification. This is not surprising since both estimates are based on within-condo price variation.[14] The mainly negative estimates of the price effect of a repair in the repeat sales specification suggest imperfect information since repairs cannot lower prices under perfect information.

3.4.1. Perfect information vs. imperfect information – α

Proposition 3 states that the average price effect of a repair is positive when there is a preponderance of units transacted under perfect information (α is sufficiently low). When transactions corresponding to imperfect information dominate (α is high), the average repair effect may be positive or negative depending on the share of defective units in the population. We test the proposition by using the variation in the likelihood that a buyer was aware of the leak problem when the unit transacted as an unrepaired unit.

We allow the repair effect to vary according to the time between the first sale (in a paired, repeat sales observation) and the repair date. Specifically, we replace γ in Eq. (8) with $\sum_k \gamma_k W_k$ where W_k is a dummy variable indicating that the first sale belongs to window k and γ_k captures the price effect of a repair in window k.[15] For transactions corresponding to short windows, since water damage may be visible or strata council information available, we expect α to be low and the repair effect should be positive. In the case of longer windows where imperfect information may predominate, the repair effect may be positive or negative.

In estimates reported in Table 3, we employ sale-to-repair windows of 0–6 months, 7–12 months, 1–2 years, 2–3 years, and 3+ years. We report results for all condos and the three types—concrete, woodpre89, and wood90s. The results reveal mostly positive and significant repair effects for the shorter windows and mostly negative effects for longer windows. For example, column (1) reveals that across all condos, a repair increased price by about 6.2 percent if the the repair occurred within 6 months of the sale, but a repair lowered price by 2.7 percent if the repair was done more than three years after the sale. The shorter window results are consistent with perfect information where buyers knew of the defect when they purchased and then the unit increased in value after it was repaired.

The last column of Table 3 add the variable "Sales interval" that measures the logged number of days between the first and second sale in a repeat sales observation. It captures survivorship bias influencing the differences in the estimates across the repair windows. The variable enters positively and significantly and slightly pushes the estimates towards zero. Adding the new variable, however, does not change the results that estimates are positive for short repair windows and negative for long windows and the significance of the estimates are largely preserved.

The repair estimates for individual condo types associated with the longer windows are insignificant except for the 3+ year window for wood90s units. Repairs to units of this condo type and window are associated with a 3.7% decline in value (column 4). Since repairs cannot lower price under perfect information, these results suggest imperfect information. This is the insight gleaned from the results in Table 2 but the negative repair effect is larger once we focus on the observations with longer windows.

3.4.2. Defective unit share – β

Proposition 3c states that, when there are uninformed buyers present in the data ($\alpha > 0$), the repair effect increases with β, the share of defective units in the population. We measure variation in β in two dimensions: (1) across unit type because different types differed in their rates of repair, and (2) perceived β increased over time as media stories brought attention to the problem.

Since wood90s condos had the highest incidence of repairs, we infer they were the most defective population of condos and should have the highest repair effects. The results for the longer repair windows in Table 3 indicate that the repair effect to be lowest for this condo type. Therefore, the cross-type comparison of repair effects are not consistent with our model predictions. Our theory, however, presumes all parameters are the same across condo types aside from β, the proportion of defective units in the population. Variation in other parameters such as the repair success probability and the relative value of good and defective units may confound the predicted cross-type effect of repairs.

We consider temporal variation in β by evaluating how the repair effect changed as the public became aware of the leaky condo crises. Until 1998, there was limited public knowledge of the leaky condo crisis and buyers likely considered β to be low. A low β implies that the initial transaction price in period t will be relatively high and the price change in $t + j$ subsequent to the unit being repaired will be low, even negative given $\rho < 1$ chance of the repair being successful. Once news of the leak problem became well known starting in 1998, a unit transacting as an unrepaired unit will have a depressed price because perceived β has become high. The repair effect for these units may be positive as a result of the high β when it initially transacted. Thus, we expect the repair effect to rise as the year of the first sale in the repeat sales observation increases.[16]

Accordingly, for each type of condo, we estimate repair effects separately by the year of first sale in the repeat sales observations. The estimated γ for each year would capture the price effect of a repair associated with perceived β for the year. In order to focus on cases where imperfect information is likely to predominate (high α) and results related to changes in the defective population share are likely to be most pronounced, we consider first sale-to-

[14] The repeat sales specification is a first difference equation. First differenced and fixed effects specifications yield identical results when there are two observations for each cross-sectional unit. They are not identical here because many units transact more than twice.

[15] We need not worry about the α corresponding to the transaction following a repair because the repaired unit price $E(P|R)$ does not depend on α: $E(P|R) = \rho G + (1 - \rho)D$ under both perfect information and imperfect information.

[16] β may differ between at the time of the first transaction and the subsequent one, but the post-repair value does not matter because theory predicts that repaired unit price does not depend on β both under perfect information and imperfect information.

repair windows of greater than one year and exclude observations with shorter windows in subsequent analysis. We begin with observations where the first sale occurred in 1995 or earlier because there was very little media information about the problem during those years. We end with observations where the first sale occurred in year 2000 because there are very few repeat sales observations with initial transactions subsequent to 2000 in our data set.

Table 4 reports the repair coefficient for the three condo types and for different years of the first sale in a repeat sales observation. When estimating the repair effect for a particular year, we eliminate all repaired condo observations where the first sale occurred in any other year other than the year in question. However, we keep all repeat sales observations that do not involve a repair because we would like as much information as possible to accurately measure the quarterly time effects.[17]

The table reports the number of repaired units for each first sale year and each of the condo type. We also provide results where we combine woodpre89 and wood90s (wood, all). The number of repaired units that we use to identify the repair effect is considerably smaller than the number of repaired units reported in Table 1 primarily because our repeat sales analysis requires a transaction both before and after a repair. Wood90s condos are repaired the most frequently and we typically have hundreds of repair observations for individual years (e.g., 746 in 1996) to estimate the repair effect. The repair numbers decline as we move later in time (dropping to 30 in 2000 for wood90s condos). Concrete and woodpre89 condos have over 100 repair observations in the earlier years and less than half that amount later on. The table also displays the number of unique buildings that are repaired as that is the variable that we use to cluster standard errors.

The repair effects and their 95% confidence intervals are shown in Fig. 3. Based on the theory and information on the leaky condo crises, we expect the repair effect to be highest for wood90s condos once the problem was observed and the effect will rise over time with increased public awareness. The results for wood90s condos, shown in the right panel, strongly support the theory. When these condos transacted in 1995 or earlier and 1996 as unrepaired units, buyers likely perceived β to be low and purchased at relatively high prices. Subsequent repairs that may or may not have been successful resulted in relative price decreases when these units were resold. However, later in time, unrepaired units were sold at discounts given concerns they might be defective. Repairs to these units resulted in price increases when they were subsequently sold. The repair effect goes from negative to positive as β increased. We observe that repairs on wood90s condos first transacting in 2000 resulted in about a 10% increase in price.

For the woodpre89 condos type, we also observe some evidence of increasing repair effects over time but most estimates are insignificant. Woodpre89 condos had relatively low defect rates but, apparently, buyers assessed these units in a similar fashion to wood90 condos. Combining the two types (all wood), we observe that the repair effect increases over time, with effects being negative and significant in the early period and positive and significant in the last year. The effect for concrete is smaller than for wood-frame units which is consistent with them having a lower β and there is no obvious trend in the repair effect over time for this group. The idea that buyers viewed concrete and wood-frame condos as having different defect rates is supported by the statement appearing in the Canada Mortgage and Housing Corporation (2002) study that "Some [buyers of resale leaky condos] believed that concrete buildings or townhouses were not subject to the leaky condo syndrome".

To formally test the relationship between public awareness of leakage problems and the repair effect, we interact the repair effect with the cumulative number of media reports of the issue.[18] We merge the media report variable so that it corresponds to the first sale year in the repeat sales transaction. The results are reported in Table 5. We observe a negative base effect across condo types and positive and significant interaction for all wood, woodpre89, and wood90s condos. The interaction is insignificant in the case of concrete condos. These results support the hypothesis that the repair effects are influenced by public knowledge of the leaky condo crises.

3.4.3. Relative prices movements

Fig. 4 shows price indexes for the three types of condos from 1991 to 2005:Q2. These are recovered from the quarterly dummy variables. Since the repair dummy variable captures the differential price change for repaired units, the price indexes reflect price changes of unrepaired condos. The repair coefficient in the repeat sales regressions measures the difference between price changes of repaired units relative to price changes of unrepaired units. Recall from the theory that the value of a repaired unit is $\rho G + (1 - \rho)D$ and does not vary across condo types. According to the theory, the relative increase in the repair effect for wood90s condos should reflect the decreased relative prices of unrepaired condos of this type. The figure shows that unrepaired, wood90s condos did appreciate more slowly than other condo unit types. This is consistent with buyers discounting unrepaired wood90s condos because they feared that they were likely to be defective.

4. Discussion

In Section 2 we provide a general model that applies to any market where repaired and unrepaired goods are traded. This section discusses the following leaky condo specific settings that our model does not capture directly: collective strata decision-making, warranty programs, and building inspectors.

The owners of units in a condominium building are members of the strata corporation and own a proportionate interest in the common property. The building envelope is part of common property and all owners are responsible for its repair and maintenance no matter where the leaks are located in the building (see Homeowner Protection Office, 2011). The governance and maintenance of a condo building is conducted by an elected strata council. Large expenditures such as a building envelope repair requiring special levies are approved by owners in an annual or special general meeting.

The repair decision for a leaky condo building is an outcome of a collective decision-making process. Our simple model above is agnostic on who makes the repair decision by assuming that repairs are done with an exogenously given probability. The full model provided in Appendix A assumes that individual owners make repair decisions. We show in Section A.4 that the individual owners in the full model can be interpreted as the strata corporation making a repair decision to maximize its members' expected utilities.

The risk of costly envelope repairs largely were born by the owners. The builder-financed New Home Warranty Program went bankrupt in 1998 because of claims related to leaky condos. In response to the crises, British Columbia established the Homeowner Protection Office (HPO) and now requires mandatory warranty insurance that covers newly built and repaired building envelopes for five years. However, Canada Mortgage and Housing Corporation

[17] Our data starts in 1983. A unit that transacts in 1983 and again in 1998 provides information in computing the 1998 price effect.

[18] We rescale the cumulative number of media reports by dividing by 100.

Table 4
Results by condo type and year of first sale.

	⩽1995	1996	1997	1998	1999	2000
Concrete						
Repair	−0.015	−0.046	−0.049[c]	−0.021	−0.000	−0.043
Effect	(0.025)	(0.038)	(0.027)	(0.024)	(0.020)	(0.039)
Number units	714	159	156	57	43	23
Number bldg	205	58	45	34	19	12
N	23,558	23,003	23,000	22,901	22,887	22,867
R^2	0.733	0.738	0.738	0.739	0.740	0.739
rmse	0.149	0.147	0.147	0.147	0.147	0.147
Wood, all						
Repair	−0.044a	−0.051[a]	−0.027[b]	−0.021	0.029[b]	0.096[a]
Effect	(0.009)	(0.012)	(0.012)	(0.016)	(0.015)	(0.031)
Number units	3195	890	720	277	157	39
Number bldg	1269	317	296	162	94	33
N	47,638	45,333	45,163	44,720	44,600	44,482
R^2	0.727	0.736	0.738	0.740	0.741	0.741
rmse	0.150	0.147	0.147	0.147	0.147	0.147
Wood, pre-1989						
Repair	−0.019	0.016	0.037[a]	−0.019	0.029	0.089[b]
Effect	(0.015)	(0.016)	(0.013)	(0.023)	(0.026)	(0.042)
Number units	1215	144	137	67	46	9
Number bldg	679	92	77	53	29	8
N	31,611	30,540	30,533	30,463	30,442	30,405
R^2	0.764	0.772	0.772	0.772	0.772	0.772
rmse	0.157	0.153	0.153	0.153	0.153	0.153
Wood, 1989–1999						
Repair	−0.036[a]	−0.034[b]	−0.014	0.002	0.042[b]	0.110[a]
Effect	(0.010)	(0.015)	(0.014)	(0.020)	(0.018)	(0.039)
Number units	1980	746	583	210	111	30
Number bldg	591	226	219	109	65	25
N	16,027	14,793	14,630	14,257	14,158	14,077
R^2	0.579	0.583	0.585	0.590	0.594	0.593
rmse	0.132	0.130	0.129	0.127	0.127	0.127

Standard errors are clustered by building and shown in parentheses with [a], [b] and [c] respectively denoting significance at the 1%, 5% and 10% levels.

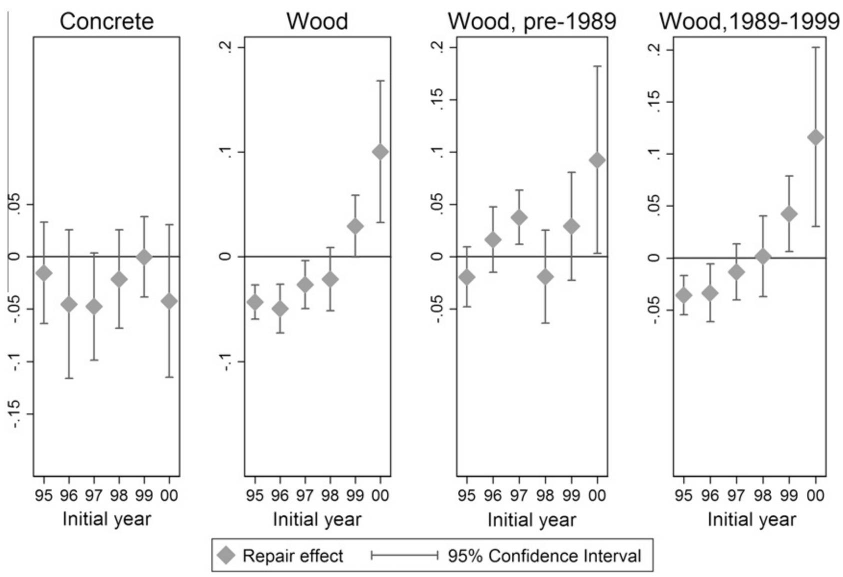

Fig. 3. Effects of repairs by year of first sale.

(2002) reports that prior to the government mandated insurance, "only a small percentage of problems were resolved by the warranty provider." The HPO issued interest-free loans to provide financing for envelope repairs. Repairs were no guarantee that problems had been been remedied: Canada Mortgage and Housing Corporation (2002) surveyed buyers of resale leaky condos and reports, "Some buyers were told a problem had been fixed. Most home buyers are not aware of the high rate of failure of fixes." Overall, the leaky condo crises generated considerable risk associated with the purchase of both repaired and unrepaired condos.

Table 5
Repair effects interacted with media articles.

	Concrete	All	Wood Frame	
			Pre-1989	1989–1999
Repair	−0.022	−0.055[a]	−0.026[c]	−0.048[a]
	(0.026)	(0.009)	(0.016)	(0.010)
Repair × Media	−0.001	0.015[a]	0.019[a]	0.017[a]
	(0.006)	(0.003)	(0.006)	(0.004)
N	24,002	49,735	32,017	17,718
R^2	0.730	0.721	0.763	0.573
rmse	0.149	0.151	0.156	0.137

Standard errors are clustered by building and shown in parentheses with [a], [b] and [c] respectively denoting significance at the 1%, 5% and 10% levels.

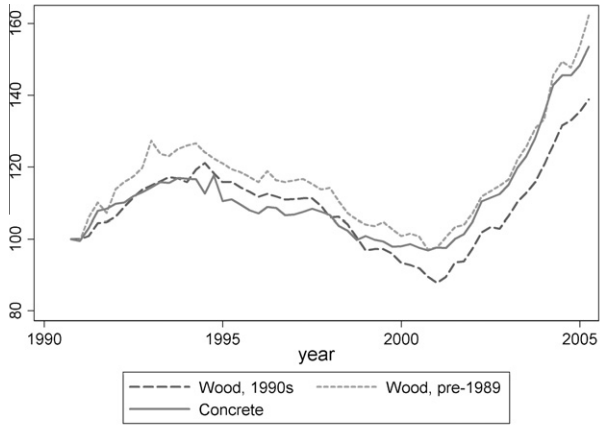

Fig. 4. Prices indexes for unrepaired units by type.

Media stories in the period were rife with stories of personal hardship caused by the repairs.[19]

Our model abstracts from the presence of building inspectors. These agents could conceivably detect the true quality of the units and we would obtain the predictions of the perfect information model. However, there is evidence that building inspectors were not often used: The Canada Mortgage and Housing Corporation (2002) survey of 40 buyers of resale leaky condos found that 29 of them did not have their units inspected by a professional prior to purchase. Even when inspectors are consulted, they may not be able to detect defects because their access is limited to the selling unit, not the entire building. Even if inspectors provide useful but imperfect information about unit quality, we expect Proposition 2 to hold. While the information provided by inspectors may influence the locus of P^R and P^U shown in Fig. 1, it will not change the result that there is a critical β such that a repair either raises or lowers the price of a condo unit.

We think the models developed in the paper are general and can apply to a variety of situations involving repaired goods transactions. While we abstract from features of the leaky condo crisis, the main predictions of the theory—repairs raise prices under perfect information but, depending on the defective unit share in the population, may raise or lower with imperfect information—obtain in this market.

[19] Canada Mortgage and Housing Corporation (2002) states, "The impact on people's lives has been enormous, even horrendous in some cases. Some people have lost much or all of their life savings, even their homes. Family life, home-based businesses and health have suffered due to disruption and the mess during repairs, and the strain of it all."

5. Conclusion

We model how consumers value goods of uncertain quality in the presence of imperfect information. Because both good and defective units are offered for sale and not all repairs are successful, buyers do not know the true quality of repaired and unrepaired goods. We show that repairs may reduce or increase prices depending on the share of defective products in the population. We contrast these predictions to those under perfect information where repairs are expected to raise prices and the price effect of repairs is independent of the defect rate.

Vancouver's leaky condo crisis provides a suitable setting to test model predictions. Different types of condos had different defect rates and information about the problems evolved over time. We find that the effects of repairs on prices depends on the timing of the repair. When repairs occurred soon after the first sale in a repeat sales observation, repairs raised prices, a result consistent with perfect information. When we evaluate repairs that occur at least one year after the first sale, we observe different repair effects across time. Repairs lowered the price of the condos most subject to leaks (wood-frame condos built between 1989 and 1999) during a period where there was limited public knowledge about the leaky condo crisis but raised their price later when media coverage of the crises mushroomed. We also show that the reason why the relative price of these repaired condos rose was because the price of unrepaired units became discounted. These results are consistent with our imperfect information model.

The paper contributes to the imperfect information literature by modeling a market where buyers observe whether or not a good has been repaired. The analysis applies to situations where a population is prone to some deficiency and repair is not always successful. This can be the case for defective building construction or other consumer durables. Under imperfect information, while a repair raises the expected consumption value of a product, our analysis reveals that it may or may not increase the price.

Appendix A. Full model

A.1. Model description

The model presented in Section 2 assumes that selling and repairing occur exogenously. This section provides the full model where owners are aware of their unit quality and make repair and selling decisions strategically. We show that the theoretical predictions are robust to an asymmetric information setting.

Repairs are made in stage 1. A repair has a stochastic outcome where defective units of quality D become good units of quality G with success probability ρ. A repair does not have any effect on good units—good units remain good. The owners of units of a particular quality do not all make the same repair decision because repair costs, c, vary across individuals. We assume the cost follows an i.i.d. cumulative distribution function $C[\underline{c}, \infty]$ where $\underline{c} > 0$. We also assume for simplicity that the repair cost distribution is identical across different quality groups G and D.[20] The repair cost can be interpreted as owners' *opportunity cost* as well as their pecuniary cost. For example, owners may have to spend time to plan a repair and owners may have different opportunity costs of their time.

In stage 2, owners receive selling shock s and decide whether to sell their units or not. The selling shock follows an i.i.d. cumulative distribution function $S[-\infty, \infty]$. This selling shock captures various reasons for selling including job change or marriage.

[20] Allowing defective units to incur higher repair cost does not affect our qualitative results.

Owners may maintain ownership of their home and enjoy the consumption value equal to its quality, G or D. Alternatively, they may sell the property and realize the selling shock and the market price of the unit. When they sell their property, they have to pay moving cost $m > 0$ assumed to be constant across owners. Owners have the following risk neutral preferences expressed as

$$x + q \cdot I_O + (s - m)(1 - I_O) \tag{9}$$

where x is a numeraire good, $q = G, D$ and I_O is a dummy variable taking 1 if they own a unit and 0 otherwise.

A.2. Equilibrium under perfect information

Suppose that both buyers and owners can observe the true quality of housing units. In this case, housing unit price depends directly on unit quality.

$$\begin{cases} P_G = G \\ P_D = D \end{cases}$$

When owners sell their housing units, they gain selling price P^i and selling shock s but have to pay moving cost m. They also lose housing utility q. Thus, the owners of type (i,q) housing unit sell their units if and only if

$$P^i + s > q + m \tag{10}$$

where $i = R, U$ and $q = G, D$.

Since the selling price and the unit quality are the same in this perfect information case, the selling price and unit quality cancel out and owners sell their units if the selling shock s is greater than the moving cost m. Thus, the selling probability σ is equal to $1 - S(m)$ across all types.

An owner repairs if the expected benefits exceed the costs. Good unit owners do not repair their units because it would not change the unit quality and thus price. For defective units, a successful repair increases both unit quality and price, by $G - D$. Thus, whether an owner sells his unit or not, the expected benefit from a repair is $\rho(G - D)$. An owner repairs his unit if this benefit is greater than his repair cost:

$$\rho(G - D) > c.$$

Now we characterize the price effect of a repair. A successful repair raises price by $G - D$. An unsuccessful repair does not change unit price. The expected price gain due to a repair is $\rho(G - D)$. We obtain same predictions about the effect of repairs on prices under perfect information that were generated in the simple model.

Proposition 4. *Suppose that buyers as well as owners can observe the true quality of housing units.*

(a) *A repair either raises a unit's price or leaves it unchanged. On average, repairs have positive effects on prices.*
(b) *The average price change associated with repairs does not depend on the defective unit share β.*

A.3. Equilibrium under asymmetric information

Suppose that buyers cannot observe the quality of a unit but do observe whether a unit is repaired or not. We characterize owners' equilibrium behavior backward from stage 2.

A.3.1. Stage 2

At the beginning of stage 2 there are four types of condos—repaired good units, repaired defective units, unrepaired good units, and unrepaired defective units. Owners receive selling shock s and make selling decisions.

Owners make selling decisions by comparing the benefits of the sale, $P^i + s$, to the costs of the sale, $q + m$ (see Eq. (10)). Note that higher price will make owners more likely to sell their units. Also, defective unit owners are more likely to sell their units than good unit owners when facing the same price. This is a typical feature of lemons market models. Since there is no upper bound of the selling shock, s, at least some of each condo type are supplied on the market.

Let $\hat{s}_q^i$ denote the selling shock cut off for owner type (i,q) such that

$$\hat{s}_q^i = q - P^i + m. \tag{11}$$

Type (i,q) unit owners sell their units if and only if their selling shock s is greater than the cut off $\hat{s}_q^i$. The selling probability σ_q^i for group (i,q) is

$$\sigma_q^i = 1 - S\left(\hat{s}_q^i\right). \tag{12}$$

Now let π_q^i ($i = R, U$ and $q = G, D$) denote the number of units in each group at the beginning of stage 2. The expected number of type (i,q) units supplied on the market is $\pi_q^i \sigma_q^i$. Given that prices are equal to expected quality, we can express P^i as the weighted average of G and D:

$$P^i = \frac{\pi_G^i \sigma_G^i G + \pi_D^i \sigma_D^i D}{\pi_G^i \sigma_G^i + \pi_D^i \sigma_D^i} = \frac{G + \left(\pi_D^i/\pi_G^i\right)\left(\sigma_D^i/\sigma_G^i\right)D}{1 + \left(\pi_D^i/\pi_G^i\right)\left(\sigma_D^i/\sigma_G^i\right)} \tag{13}$$

where $i = U, R$. Note that price is always between G and D.

Eqs. (11)–(13) implicitly define selling shock cut offs $(\hat{s}_G^i, \hat{s}_D^i)$, selling probabilities (σ_G^i, σ_D^i) and price P^i for each group $i = R, U$ as functions of π_D^i/π_G^i. The ratio of defective units to good units in group i, π_D^i/π_G^i, is the state variable that determines all the endogenous variables in stage 2 for group i. Note that the repaired group and unrepaired groups do not interact with each other in stage 2 and are solved independently.

A.3.2. Stage 1

In stage 1, owners make repair decisions given expected net utility in stage 2. Let V_q^i denote expected net utility from stage 2 for group (i,q)

$$\begin{aligned} V_q^i &= \int_{-\infty}^{\hat{s}_q^i} q\,dS + \int_{\hat{s}_q^i}^{\infty} (P^i + s - m)dS \\ &= \left(1 - \sigma_q^i\right)q + \int_{\hat{s}_q^i}^{\infty} (P^i + s - m)dS \end{aligned} \tag{14}$$

where $i = R, U$ and $q = G, D$. Note that V_q^i is a function of π_D^i/π_G^i since $\hat{s}_q^i$, σ_q^i and P^i are the functions of π_D^i/π_G^i. Given these net utiliies $\left\{V_G^R, V_G^R, V_D^U, V_D^U\right\}$ from stage 2, owners in stage 1 decide whether to repair or not.

A repair on defective units has stochastic outcome with success probability ρ. A repair to a good units does not change its quality. Let $\hat{c}_D$ and $\hat{c}_G$ denote the cut off repair costs that makes owners indifferent to repairing or not repairing.

$$\left\{\rho V_G^R + (1 - \rho)V_D^R\right\} - V_D^U = \hat{c}_D \tag{15}$$

$$V_G^R - V_G^U = \hat{c}_G \tag{16}$$

where the left hand sides of Eqs. (15) and (16) are the expected gains from repairs.

Quality q unit owners do repairs if and only if their repair costs are lower than the cut offs $\hat{c}_q (q = G, D)$. We express the repair probability ϕ_q for quality q units as

$$\phi_q = C(\hat{c}_q) \tag{17}$$

where $q = G, D$.

Now we can characterize the stage 2 quality distribution $(\pi_G^R, \pi_D^R, \pi_G^U, \pi_D^U)$

$$\pi_G^R = \phi_G(1-\beta) + \phi_D\rho\beta \quad (18)$$

$$\pi_D^R = \phi_D(1-\rho)\beta \quad (19)$$

$$\pi_G^U = (1-\phi_G)(1-\beta) \quad (20)$$

$$\pi_D^U = (1-\phi_D)\beta \quad (21)$$

where, for example, the number of repaired good units π_G^R consists of units that were initially good and subsequently repaired $\phi_G(1-\beta)$ and units that were initially defective and successfully repaired $\phi_D\rho\beta$.

Expressing the stage 2 state variables as ratios, $(\pi_D^R/\pi_G^R, \pi_D^U/\pi_G^U)$, gives

$$\frac{\pi_D^R}{\pi_G^R} = \frac{\phi_D(1-\rho)\beta}{\phi_G(1-\beta)+\phi_D\rho\beta}$$

$$\frac{\pi_D^U}{\pi_G^U} = \frac{(1-\phi_D)\beta}{(1-\phi_G)(1-\beta)}.$$

Note that these ratios depend on the stage 2 net utility functions $\left(V_G^R, V_D^R, V_G^U, V_D^U\right)$.

Given the state variables $(\pi_D^R/\pi_G^R, \pi_D^U/\pi_G^U)$ determined in stage 1, we can solve Eqs. (11)–(13) to obtain the stage 2 endogenous variables: prices (P^R, P^U), selling probabilities, $(\sigma_G^R, \sigma_D^R, \sigma_G^U, \sigma_D^U)$, and selling cut offs $(\hat{s}_G^R, \hat{s}_D^R, \hat{s}_G^U, \hat{s}_D^U)$. These values generate net utility $\left(V_G^R, V_D^R, V_G^U, V_D^U\right)$. Give stage 2 net utility, we obtain the stage 1 repair probabilities (ϕ_G, ϕ_D) and repair cost cutoffs $(\hat{c}_G, \hat{c}_D)$ from Eqs. (16) and (17). These values determine the state variables $(\pi_D^R/\pi_G^R, \pi_D^U/\pi_G^U)$. Equilibrium obtains when the state variables obtained in stage 1 equal the state variables used to solve for the stage 2 variables. More generally, the equilibrium is the solution of equations (11)–(21) for the 22 unknowns listed above.

A.3.3. Implications

This section derives theoretical implications. We begin by characterizing who repairs. Defective unit owners repair for two reasons. First, they get an expected consumption utility gain equal to $\rho(G-D)$ if they end up not selling their units. Second, they benefit if repairs raise selling prices and they sell their units. In contrast, good unit owners do not get any service utility gain. This makes good unit owners relatively less likely to repair than defective unit owners.

Lemma 5. *Defective units are more likely to get repaired than good units.*

Good unit owners may repair even though repair does not change their unit quality. This is a pure signaling behavior that can happen when the selling probability is sufficiently high and the repaired unit price is substantially higher than the unrepaired unit price. Although this is theoretically possible and interesting, we believe that repairs of good units are rarely observed in reality. We rule out this possibility by restricting the distribution of the selling shock.

Assumption 1. $S(D-G+m)$ is sufficiently high.

If the selling shock is smaller than $D-G+m$, it follows from Eq. (11) that the owner would not sell.[21] Assumption 1 restricts $S(D-G+m)$ sufficiently to make the selling probability small enough that the expected price benefit of repair is less than the minimum repair cost $\underline{c}$. Thus, no owners repair solely for the purpose of potential price benefits.

However, we need at least some defective units to be repaired in order for the price and selling probability of repaired units to be well defined. The following assumption implies that expected service utility gain is greater than the minimum repair cost $\underline{c}$. Combined with the previous assumption, this ensures that there are always some defective unit owners who repair in order to increase the consumption value of the unit.

Assumption 2. $\rho(G-D) > \underline{c}$

Lemma 6. *Suppose Assumptions 1 and 2 hold. (1) Good units do not get repaired. (2) Some defective units get repaired.*

Since all repaired units are initially defective units, the defective unit to good unit ratio for repaired units π_D^R/π_G^R depends only on repair success probability and is therefore constant at $(1-\rho)/\rho$. Since π_D^R/π_G^R is the stage 2 state variable determining the price and selling probability of repaired units, both these variables also depend only on the repair success probability.

Proposition 7. *Suppose Assumptions 1 and 2 hold. The price and selling probability of repaired units depend only on the repair success probability ρ.*

Now we show that a repair may increase or decrease a unit's price depending on the share of defective units in the population β. First, a repair lowers the price if $\beta$is sufficiently small. The price of repaired units stays constant when βchanges due to Proposition 7 and this constant price is strictly less than G because some repairs are not successful. On the other hand, the price of unrepaired units converges to G as β converges to 0. Thus, for sufficiently small $\beta > 0$, the repaired unit price is strictly lower than the unrepaired unit price.

Second, a repair raises the price if the defective unit share β is sufficiently large. The price of repaired units is strictly greater than D because some units get repaired successfully. On the other hand, the price of unrepaired units converges to D as β converges to 1. Thus, the price of repaired units is higher than that of unrepaired units for sufficiently large β.

Third, the relative price of repaired to unrepaired units increases monotonically as βincreases. Proposition 7 establishes that the price of repaired units is independent of β. If P^U falls monotonically with β, then the relative price of repaired units strictly increases with β. We establish that P^U is decreasing in β in two steps. First, we evaluate the stage 1 repair decision and show that π_D^U/π_G^U, the ratio of unrepaired defective units to unrepaired good units, increases with β. This step employs Assumption 1. Second, we establish that as π_D^U/π_G^U increases, the price of unrepaired units P^U decreases. This second step requires the additional assumption that the change in π_D^U/π_G^U has a small effect on the selling probabilities of good and defective unrepaired units:

Assumption 3. $S'(s)$ is sufficiently small for $s \in (D-G+m, G-D+m)$.

Our full asymmetric information model and Assumptions 1–3 yield the primary predictions generated by the simple model:

Proposition 8. *Suppose that buyers cannot observe true unit quality but observe whether a unit received a repair or not. Let Assumptions 1 and 2 hold.*

(a) *A repair lowers the price if the defective unit share $\beta > 0$ is sufficiently low and raises the price if the defective unit share $\beta < 1$ is sufficiently high.(There exists a $\hat{\beta}$ such that $P^R < P^U$ if $\beta < \hat{\beta}$ and $P^R > P^U$ if $\beta > \hat{\beta}$.)*
(b) *Let Assumption 3 hold. The price effect of a repair increases with β,*

[21] This is because $s < D-G+m \leqslant q-P+m$ for any $q \in \{G, D\}$ and $P \in [G, D]$.

$$\frac{\partial P^R/P^U}{\partial \beta} > 0.$$

Proof. (1) and (2) are proven in the text. To establish (3), we must prove that P^U falls monotonically with β. The proof takes advantage of the fact that the relative number of defective to good units, π_D^U/π_G^U, is the stage 2 state variable that, along with the selling shock, determines P^U. We first evaluate the stage 1 repair decision and establish that higher β increases π_D^U/π_G^U. Then we express the conditions under which an increase in π_D^U/π_G^U lowers P^U.

Step 1: The ratio of defective and good units among the repaired is given in Eq. (22) as

$$\frac{\pi_D^U}{\pi_G^U} = \frac{(1-\phi_D)\beta}{(1-\phi_G)(1-\beta)}.$$

Assumption 1 implies that no good units get repaired, $\phi_G = 0$. Making this substitution and then taking the derivative with respect to β gives

$$\frac{d}{d\beta}\frac{\pi_D^U}{\pi_G^U} = \frac{(1-\phi_D) - \beta(1-\beta)\frac{d\phi^D}{d\beta}}{(1-\beta)^2}$$

This expression is positive when

$$\frac{d\phi^D}{d\beta} < \frac{1-\phi_D}{\beta(1-\beta)} \tag{22}$$

$\frac{d\phi^D}{d\beta}$ measures the change in the repair probability when β increases. As stated previously, defective unit owners repair to (1) gain service utility and (2) realize potential price benefits if they sell their units and repair increases the price. An increase in βwill not affect (1) but may affect (2). However (2), the potential price benefit, is small when the selling probability is low as assumed in Assumption 1. Thus, Assumption 1 implies that $\frac{d\phi^D}{d\beta}$ is sufficiently small to make inequality (22) hold. [22]

Step 2. P^U is decreasing in π_D^U/π_G^U.

By combining Eqs. (11)–(13) we obtain the following expression for P^U:

$$P^U = \frac{D(\pi_D^U/\pi_G^U)(1-S(D+m-P^U)) + G(1-S(G+m-P^U))}{1+(\pi_D^U/\pi_G^U)(1-S(D+m-P^U)) - S(G+m-P^U)}.$$

Taking total derivatives and solving yields

$$\frac{dP^U}{d(\pi_D^U/\pi_G^U)} = \frac{-(P^U-D)(1-S(D+m-P^U))}{A+B}$$

where

$$A = (\pi_D^U/\pi_G^U)\left\{1-S(D+m-P^U) + (P^U-D)S'(D+m-P^U)\right\} + 1 - S(G+m-P^U),$$

and $B = -(G-P^U)S'(G+m-P^U)$.

Since $P^U > D$, the numerator is negative and we have $\frac{dP^U}{d(\pi_D^U/\pi_G^U)} < 0$ if the denominator is positive. All the terms comprising B are positive. Term B is negative. If B is sufficiently small as assumed in Assumption 3, we obtain $\frac{dP^U}{d(\pi_D^U/\pi_G^U)} < 0$. □

[22] Indeed, $\frac{d\phi^D}{d\beta} = 0$ in the limiting case where the selling probability is zero. In that case, we obtain the following from Eqs. (14)–(16).

$$\hat{c}_D \approx \rho(G-D)$$
$$\hat{c}_G \approx 0$$

Since the repair cut offs for good units and defective units approximately equal constants, $\frac{d\phi^D}{d\beta} = 0$.

A.4. The model with strata corporations

Suppose that the members of a strata corporation consist of a set B of individual unit owners. The goal of the strata corporation is to maximize expected aggregate utility of its members.[23]

Individual unit owners differ in selling shock s and repair costs c. The selling shock s follows c.d.f. S as defined in the full model. Repair costs c consist of a per unit building component c_B and an individual component ε: $c = c^B + \varepsilon$. The building component c_B follows the c.d.f. C as defined in the full model. The individual component ε follows c.d.f. F where we normalize ε so that $E(\varepsilon) = 0$. We assume that leak problem is building wide and thus individual unit quality is same as building quality. In actuality, units within a building with an envelope leak suffer different degrees of damage at a given point in time. Our justification for abstracting from these differences are twofold: (1) in the long run, all units in buildings with defective units will be compromised and (2) differences in damage across units may be partly captured by random variable ϵ.

We show that strata corporation's repair decision problem is identical to the repair decisions of individual owners in the full model and thus we can interpret individual owners in the full model as strata councils.

First, under perfect information case, all the equilibrium conditions in Section A.2 hold. For example, the expected benefit of repair is $\rho\ (G-D)$ and the expected cost of repair is c^B because $E(c) = c^B$ and c^B follows the c.d.f. C that was used for repair cost for individual unit in the full model.

Second, under asymmetric information case, the equilibrium is pinned down by Eqs. (11)–(18). All equations still hold with the strata council set up. For example, repair Eqs. (12) and (13) can be written as

$$\left\{\rho V_G^R + (1-\rho)V_D^R\right\} - V_D^U = E(\hat{c}_D) = \hat{c}_D^B$$
$$V_G^R - V_G^U = E(\hat{c}_G) = \hat{c}_G^B.$$

Since $\hat{c}_B$ follows the c.d.f. C as defined in Appendix A, we can write Eq. (14) as

$$\phi_q = C\left(\hat{c}_q^B\right).$$

Note that Eqs. (12)–(14) are same as the equations above. The only change is that we replace symbol $\hat{c}_D$ and $\hat{c}_G$ with $\hat{c}_D^B$ and $\hat{c}_G^B$. Thus, we obtain the same equilibrium and equilibrium properties.

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