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WHAT LIES BENEATH:
PIPELINE AWARENESS AND AVERSION

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ABSTRACT

Stated safety concerns are a major impediment to making necessary expansions to the natural gas pipeline network. While revealed willingness to pay to avoid existing natural gas pipelines appears small, it is difficult to know if this reflects true ambivalence or a lack of salience and awareness. In this paper, we test this latter hypothesis by studying how house prices responded to a deadly 2010 pipeline explosion in San Bruno, CA, which shocked both attention and information. Using multiple identification strategies, we fail to find any evidence of a meaningful shift in the hedonic price gradient around pipelines following these events. We conclude with a discussion of how this result relates to latent, fully informed preferences, as well as the implications for future pipeline expansions.

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1 Introduction

Due to advances in drilling technology, the economically recoverable supply of natural gas in the United States nearly doubled between between 2005 and 2014.[1] In order to capture the full benefits of this unexpected resource boom, significant increases in and improvements to the existing pipeline network are required. Despite this, according to the regulatory body which oversees these changes, the Federal Energy Regulatory Commission (FERC), new pipelines "are facing unprecedented opposition from local and national groups".[2] A major source of this opposition, particularly in densely populated areas, is concern about pipeline safety (Parfomak, 2013, 2016).

At first glance, it is easy to dismiss these concerns. Natural gas pipelines are extremely safe: over the past two decades, transmission incidents have resulted in an average of only 2.3 deaths per year. However, the psychology and behavioral economics literatures are rife with reasons why the disamenity associated with this particular risk might exceed that captured by a more typical VSL estimate. Consumers exhibit projection and availability bias, even when making large investments in housing and automobiles.[3] More generally, people overestimate the likelihood of risks that are uncontrollable, catastrophic, and inequitably distributed (Slovic, 1987), and exhibit probability neglect regarding fearsome risks (Sunstein and Zeckhauser, 2011).

A second reason to be skeptical of safety concerns is that this vocal opposition to new pipelines stands in stark contrast with apparent opinion towards existing pipelines. The U.S. has over 300,000 miles of high pressure natural gas transmission pipelines linking domestic supply and demand centers. Despite a handful of high profile events, this network is seemingly uncontroversial.[4] Recent studies using cross-sectional regression or appraiser opinion have failed to find any effect of pipeline proximity on home values (INGAA, 2016; Fruits, 2008). Citing these studies and, sometimes, its own commissioned appraisals, FERC routinely dismisses concerns that pipelines may reduce nearby property values when approving new pipeline routes.[5]

What explains this disconnect between loud stated fears about new pipelines and revealed ambivalence towards existing pipelines? One possible explanation is that new pipelines are much more salient than existing pipelines. FERC requires a lengthy public comment period before a new pipeline is approved, during which local news coverage and protests often draw attention to the most concerning parts of a project. Conversely, existing pipelines are hidden underground

[1]Source: https://www.eia.gov/naturalgas/crudeoilreserves/.

[2]FERC Commissioner Cheryl LaFleur (1/27/2015), https://www.ferc.gov/media/videos/lafleur/2015/012715-lafleur.pdf.

[3]For instance, Busse et al. (2012) show that swimming pools and central air have higher hedonic prices for homes sold during the summer than during the winter.

[4]Over the 20-year period of 1995–2014, local distribution system accidents accounted for 279 fatalities and more than 1,000 injuries, while transmission systems accounted for 42 fatalities and 174 injuries, or about one-seventh of the total. Over the 4-year period of 2011–2014, there has only been one single transmission-related fatality. (United States Department of Energy, 2015, pp NG-54)

[5]For example, see the recent FERC Environmental Impact Statements for the Constitution Pipeline and Algonquin Incremental Market. In the former, FERC describes contacting several appraisers in the area to ask whether they think the pipeline will reduce property values. In each case the response was that there is no evidence to suggest that (FERC EIS 0249F (2014) , pp 4-153).

and not well marked. Even if home-buyers are concerned about pipeline safety, finding a detailed map of pipeline locations was made intentionally burdensome after the terrorist attacks of 9/11. As a consequence, when one study asked homeowners known to live near pipelines how close they thought they were, 55% flatly denied living near one (Hansen et al., 2006). If people are not mindful of or even able to locate existing pipelines, it will be very difficult to infer their true aversion to this disamenity from house price data.

In this paper, we look for evidence of this wedge between true preferences and observed prices in the fallout from one of the deadliest pipeline incidents in U.S. history. On September 9th, 2010, a 30-inch transmission pipeline owned by Pacific Gas and Electric (PG&E) exploded in a densely populated suburb of San Francisco, killing eight people. The event generated prolonged media coverage, particularly in the state of California, bringing the issue of pipelines to the forefront of people's minds. In the weeks that followed, outrage swelled over the lack of pipeline location information. It was revealed that, incredibly, even the local fire chief was unaware of the high pressure pipeline's presence before it exploded. The following spring, in response to this outrage, PG&E sent letters out to all households living within 2000 feet of a pipeline alerting them to their proximity.

To test whether this shock to pipeline awareness and location information affected people's revealed preferences for living near pipelines, we look for changes in the hedonic price gradient following these events. We combine data on the universe of housing transactions in California with a proprietary map containing a snapshot of all natural gas transmission pipelines in the state. Our main approach is a difference-in-difference strategy that compares housing transactions within 1000 or 1000-2000 feet from a pipeline to those between 2000 and 4000 feet away. Leveraging the size our sample to finely control for differential trends in narrow geographic housing markets, we compare the price gradient after the explosion and informational letter to the pre-explosion equilibrium.

Using a variety of different temporal and spatial controls, we find little evidence that either the explosion or the letter was capitalized into house prices. This null result is robust to zooming in to just the counties surrounding San Bruno, and to triple-difference comparisons against other properties near pipelines in southern California. Using a regression discontinuity design, we also fail to find evidence of a spatial break in the hedonic price gradient at the 2000-foot cutoff for receiving the informational letter.

Given the nature of the variation generated by San Bruno and the reduced-form estimation strategy used, we are not able to recover (or even bound) fully informed, attentive willingness to pay (WTP) to avoid living near a natural gas pipeline. However, borrowing notation from the energy efficiency gap literature (Allcott and Greenstone (2012), we show that the coefficient on our DD estimator is equal to the product of the change in pipeline awareness and the true, fully informed, price relationship. After providing evidence that households were uninformed before the explosion, and that the aftermath events meaningfully increased attention and awareness, we conclude that the second term in that product must be small to generate our estimates. In the conclusion, we consider the policy implications of this interpretation.

Our findings contribute to two literatures. First, there are a limited set of papers that examine the housing market impacts of pipeline infrastructure. The study that most closely resembles our own is Hansen et al. (2006). This paper examines housing prices in the aftermath of a gasoline pipeline explosion in Bellingham, WA in 1999, which killed three people. The paper finds that houses closer to the pipeline sold at a discount after the explosion, but not before. However, there is no formal test of the difference between these coefficients. In addition, areas near the pipeline may have been adversely affected due to the loss of nearby parkland to the ensuing fire. In our context, we consider the impact on houses in the "shadow" of pipelines much further away that could not have been affected by the direct dis-amenity of the San Bruno explosion. Fruits (2008) directly estimates the impact of a new natural gas pipeline in Oregon, and finds no negative effect on property values in a difference-in-differences framework. Beyond this paper, however, most other attempts to capture pipeline capitalization are consulting studies that do not credibly account for unobserved housing characteristics and other omitted variables. More broadly, our paper contributes to a growing literature on the the relationship between house prices and energy infrastructure, such as natural gas wells (Muehlenbachs et al., 2015) and power plants (Davis, 2010).

There is also an empirical literature exploring the impact of imperfect information on hedonic models. Pope (2008) was one of the first papers to explicitly discuss how asymmetries in buyer and seller information can affect the hedonic price gradient and complicate analysis. A number of other papers have expanded upon this empirically, testing how information disclosure may affect the capitalization of an amenity. Some more recent examples include Mastromonaco (2015) and Guignet (2013).

The rest of this paper proceeds as follows. Section 2 provides an overview of the natural gas pipeline system and the events in California related to and following the San Bruno pipeline explosion. Section 3 describes the data, Section 4 discusses our various empirical strategies, and Section 5 presents the results. Sections 6 and 7 discuss policy and other implications and conclude.

2 Background

2.1 Natural Gas Pipelines

For all intents and purposes, pipelines are the only real option for transporting natural gas from the wellhead to the end-user.[6] This stands in contrast to crude oil, where pipelines compete with barge and railway shipping. There are three main types of natural gas pipelines: gathering, transmission, and distribution. Gathering pipelines are found in the producing region, and collect gas from the wellhead and ship it a processing plant. Transmission lines then send large quantities of processed natural gas to demand centers. Because of the distance and volume involved, these pipelines are larger in diameter (20-42 inches) and operate at much higher pressure than gathering or distribution lines. Once the gas has reached its destination, the gas is depressurized. Some of the

[6]While an increasing amount of natural gas being shipped as liquefied natural gas (LNG) on enormous tankers, the costs of liquefaction are prohibitively high except on very large scales in the presence of substantial price differentials.

gas will be delivered directly to industrial customers or electricity generation facilities. Residential, commercial, and some industrial users are serviced by distribution pipelines. These pipes are much smaller in diameter and operate at low pressure.

This paper focuses on transmission pipelines, which carry large quantities of gas at very high pressure. There over 300,000 miles of natural gas transmission lines in the United States, but recent upstream and downstream shocks have prompted a wave of expansion requests. Since the advent of hydraulic fracturing and horizontal drilling, U.S. natural gas production has skyrocketed and shifted in geographic terms. On the demand side, retiring coal-fired and nuclear power plants are increasingly being replaced by natural gas generators, further stressing the existing grid. In light of these changes, thousands of miles of new and expanded natural gas transmission pipelines have been proposed. The Department of Energy projects that $42 billion will be spent on expanding natural gas pipeline infrastructure during 2015-2030 (United States Department of Energy, 2015).

Interstate natural gas pipelines are regulated by the Federal Energy Regulatory Commission (FERC). They are granted power of eminent domain, but must meet the requirements for a Certificate of Public Need. The approval process typically involves an environmental impact statement or assessment, a public comment period, and public meetings. This process, along with easement negotiations, will inform local residents about the construction plans, future existence of the pipeline, and may prompt further information acquisition.

The information available and attention given to pipelines during the siting process declines considerably once they are in operation. As a recent review on the subject concluded, "Americans often pay little attention at all to the nation's energy infrastructure until they face a nearby pipeline leak, rail accident, or other natural or man-made disaster" (Klass and Meinhardt, 2014). Part of this is because pipelines are not well marked unless necessary. Further, obtaining information on pipeline location was made more difficult by the advent of the Critical Energy Infrastructure Information (CEII) designation following 9/11. Although FERC revised its rules in 2006 to exclude purely locational information from the CEII designation, the only publicly available source of information on transmission pipeline location remains the National Pipeline Mapping System (NPMS). This website does not allow one to download spatial data, view more than one county at a time, or resolve the location of pipelines beyond a 500 foot tolerance. The only individuals allowed to access the database directly are government employees (who may access pipeline data under their jurisdiction) or pipeline operating companies (who may access data about their own pipelines).

2.2 The San Bruno Explosion and Aftermath

On September 9, 2010, a segment of 30-inch diameter PG&E transmission pipeline 132 exploded in the middle of the Crestmoor neighborhood in San Bruno, CA. Eight people were killed, 38 homes were destroyed and an additional 70 homes had major or minor damage as a result of the explosion and fire.[7] The explosion occurred when an electrical glitch led to an increase in pressure, which blew open an existing welding flaw. In the aftermath of this disaster, PG&E was fined $1.6 billion

[7] Appendix Figure A.1 provides a sense of the scale of the damage.

by the California Public Utilities Commission, paid out over $565 million in civil settlements, and was eventually found guilty of six criminal counts in federal court.[8]

Media coverage of the disaster was widespread, and often focused on the existence of local pipelines running along major roads or through neighborhoods.[9] Shortly after the incident, PG&E was pressured to release a list outlining the 100 pipeline segments of highest priority for maintenance and monitoring. Although this list was generated using a number of criteria, the press coverage dubbed these segments the 100 "riskiest" pipeline segments, generating further publicity for the location of natural gas transmission pipelines throughout Northern California. In November 2010, one community in Northern Sacramento even closed an elementary school mid-year after discovering that it was near PG&E pipelines and natural gas storage tanks.[10]

The spike in attention suggested by these anecdotes about media coverage are backed up by Google search activity. We collected Google Trends data on searches for stories that Google has determined are related to the San Bruno pipeline explosion. Figure 1 displays search activity for this set of stories over time, relative to the overall level of search activity in the geographic area.[11] In the first graph, we compare search rates in various media markets. All three major California markets saw substantial search activity, though LA was less affected. New York City also shows some activity, suggesting that, while this was a major national news story, it got disproportionate attention in California.

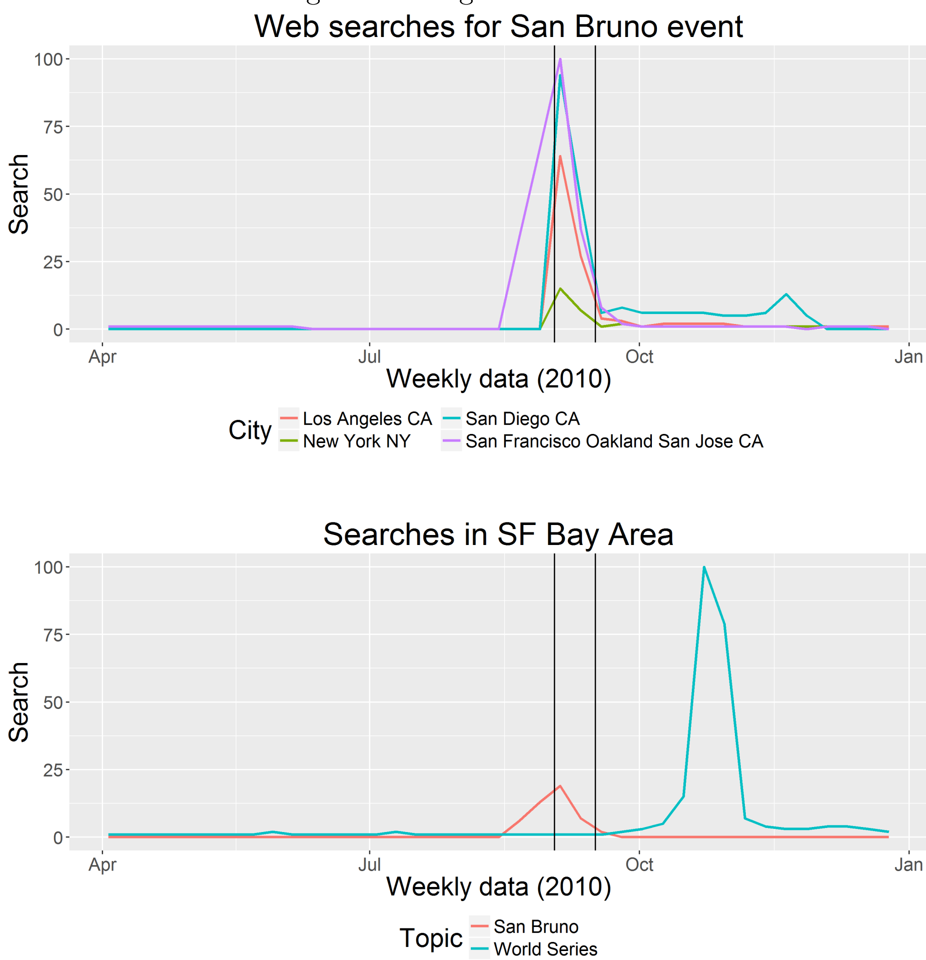
[8] See, respectively, "PG&E slapped with record $1.6 billion penalty for fatal San Bruno explosion" (April 9, 2015); "San Bruno blast: PG&E settles nearly all remaining lawsuits for a $565 million total" (Sept. 9, 2013); and "PG&E loses ruling in San Bruno explosion trial" (Nov. 17, 2016); all in the *San Jose Mercury News*.

[9] For example: "PG&E Says the Valley has 4 High Risk Gas Pipelines", *KMPH News* (Sept. 21, 2010); "Natural gas transmission lines run near Highway 101 in Marin", *Marin Independent Journal* (Sept. 13, 2010); "Pipeline in San Bruno blast runs through Palo Alto", *Palo Alto Online* (Sept. 20, 2010).

[10] "Quick closure of N. Sacramento school debated", *Sacramento Bee* (Nov. 20, 2010).

[11] That is, these numbers can be interpreted as the "search rate", and are comparable across search terms and/or geographies within a given graph.

Figure 1: Google search rates



Figures show weekly relative search rates related to the "San Bruno Pipeline Explosion" event and the "World Series" as determined by Google algorithm.

We cannot observe absolute search activity, but we can compare the San Bruno event to another group of stories thought to be important to Bay Area residents. In the second graph, we compare the San Bruno explosion search rate to that for stories related to the Major League Baseball World Series, which was won by the San Francisco Giants in October 2010. Searches related to San Bruno were roughly 20% of the peak search activity related to the Giants' Series win, suggesting that pipeline-related coverage and information acquisition were substantial.

By Spring 2011, regulatory pressure led PG&E to send letters to customers living within 2000 feet of a natural gas transmission pipeline. These letters (presented in Appendix Figure A.2) noted the tragic nature of the San Bruno explosion, informed the resident that they lived within 2000 feet of a pipeline, provided a link to their online pipeline location map and the National Pipeline Mapping System (NPMS), and outlined some of the new safety measures that PG&E was implementing. The letter did not give residents any detailed information about their specific distance to the pipeline, or the location of that nearest pipeline. According to the local real estate community, this letter could be considered "knowledge of material fact", which technically requires the homeowner to disclose this information to any potential buyer.[12] An important detail is that if a transmission pipeline is near – but not actually encroaching – the property, there is otherwise no requirement to disclose this information to a potential buyer.[13] We discuss the implications of this disclosure ambiguity in Section 6

3 Data

To study the impact of the San Bruno events, we combine data on housing transactions with a map of pipeline locations. We purchased detailed GIS shapefiles of pipeline infrastructure from S&P Global Platts, a private firm that specializes in data related to energy and other heavy industry. These maps provide us with a snapshot of all natural gas pipelines in the state of California, as of October 2015. We observe the owner of the pipeline segment, and (in some cases) the parent pipeline's name and the segment's diameter. As our policy questions and treatments relate to transmission pipelines, we take measures to pare the pipeline map down to segments that are most likely used for transmission purposes.[14] Although we cannot independently verify this, Platts claims that these maps are highly accurate, coding all but two segments in the shapefile as being within 40 feet (78% of all pipeline segments in the sample) or within 165 feet.

We combine this pipeline map with information on all housing transactions in the state of California from January 1996 - June 2012. The data come from DataQuick (now a part of CoreLogic), a firm that aggregates and produces housing data from markets across the United States. In addition to information on the parties and transaction price, the data contain information on the the exact street address and accompanying geolocation, and housing characteristics such as year built, square footage, number of rooms, number of bathrooms, the presence of a pool, and the presence of a garage. The housing characteristics are observed once – they are the most recent assessment at the time the data were collected for our purposes. Similar data have been used in many hedonic applications in the last several years (e.g., Muehlenbachs et al., 2015).

3.1 Sample construction

Like the rest of the United States, California's housing market experienced a sharp correction in late 2008. Figure 2 plots the average log housing price by month for houses near and far away from

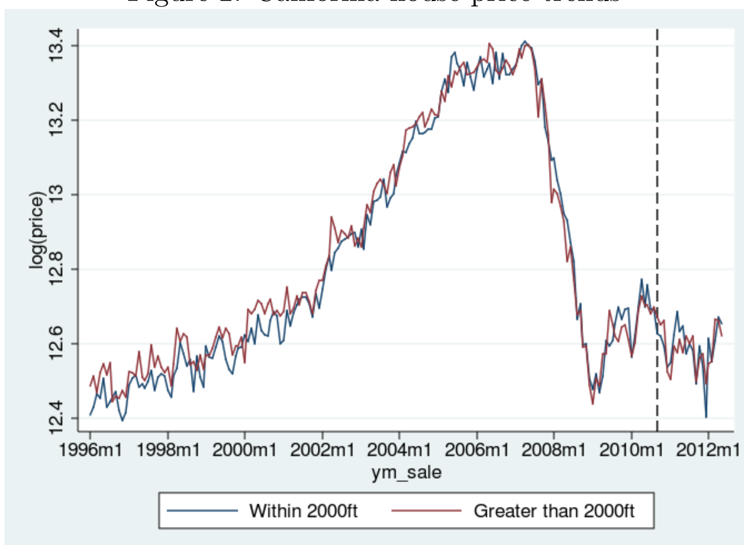
[12]This issue was raised in a press release by a real estate disclosure firm (http://www.firstamsms.com/content/natural-gas-pipelines-now-disclosed-1), and confirmed by Kate Konschnik of the Harvard Environmental Law Clinic (Kate Konschnik, 2016).

[13]As of July 1, 2013, all contracts for the sale of residential real property in California must contain a specified notice pertaining to gas and hazardous liquid transmission pipelines (California AB 1511, year 2012). However, this notice simply informs the buyer that pipelines exist (not necessarily near the property), and that they should go to the NPMS to find out if there is one nearby. It does not discriminate on the basis of actual pipeline proximity in any way. Unfortunately, our housing data ends prior to this law going into effect.

[14]Specifically, we drop any pipe from a system with a name that indicates distribution activity or if the diameter is known to be less than 6 inches. We also drop a pipe if the diameter is missing, unless it has information about the system it belongs to or is an interstate pipeline. Our results are very similar using the full network of pipelines.

pipelines. Our identifying events occur in the immediate aftermath of that crash. Thus, although we obtained house price data going back to 1996, in our empirical analysis we restrict our sample to begin on June 16, 2009, after the housing market began to recover and 450 days prior to the San Bruno explosion. In Section 4, we discuss strategies to address related potential threats to identification.

Figure 2: California house price trends



We then take a number of steps to ensure that our dataset contains only valid, arms-length transactions that reflect the valuation of potential homeowners. We drop any transactions that are flagged as non-arms length transfers, are non-residential properties, mobile homes, and those whose addresses could not be mapped to a valid latitude and longitude. In each year, we drop transactions with prices in the top and bottom one percent. Finally, we drop properties that sell more than 5 times in our 16 year dataset, properties with more than 5 bedrooms or bathrooms, transactions in which the buyer appeared to be a corporate entity, and transactions that took place less than one year since the previous sale. Our main DD specification restricts the sample to counties that are unambiguously serviced by PG&E, excluding any homes within 1 kilometer of the site of the San Bruno explosion.[15] Table 1 reports the number of transactions by time period and distance group after making these sample restrictions.

[15]These counties are Alameda, Amador, Butte, Calaveras, Colusa, Contra Costa, Glenn, Humboldt, Lake, Marin, Mariposa, Mendocino, Merced, Monterey, Napa, Sacramento, San Benito, San Francisco, San Joaquin, San Mateo, Santa Clara (excluding Palo Alto, which is serviced by a municipal utility), Santa Cruz, Solano, Sonoma, Stanislaus, Sutter, Tehama, Tuolumne, Yolo, and Yuba.

Table 1: Sample observations by time-period and distance to nearest pipeline

	0-1000	1000-2000	2000-4000
Pre	19,467	17,875	26,788
Post-Exp.	8,818	7,941	12,041
Post-Letter	16,303	14,419	21,485

The "Pre" period includes sales from June 16, 2009 up until the day before San Bruno. The explosion period ("Post-Exp") runs from September 9, 2010 to April 20, 2011 when the PG&E letters were sent. The "Post-Letter" period runs from that date until the end of the sample, June 30, 2012.

3.2 Descriptive statistics

A fundamental concern with using house price differentials to infer latent preferences for avoiding pipelines is that pipelines are not located randomly. Figure 3 plots histograms of covariates for houses 0-2000 and 2000-4000 feet from the nearest pipeline. The overall distribution of these variables is generally quite similar across the two bins, with substantial overlap. Table 2 formalizes this by regressing each covariate on distance bin dummies and census tract fixed effects. Houses within 1000-2000 feet of a pipeline are generally more similar than houses within 1000 ft to the 2000-4000 ft. control bin. Relative to the sample means, these differences are modest, but they should be pointed out. Houses near pipelines tend to be slightly smaller, less likely to have a pool or garage, and were more likely to be sold under some measure of foreclosure distress. Although our difference-in-difference approach should alleviate most concerns, we also allow for rich local trends as well as recent local foreclosure activity.

Figure 3: Housing characteristic support by distance from pipeline

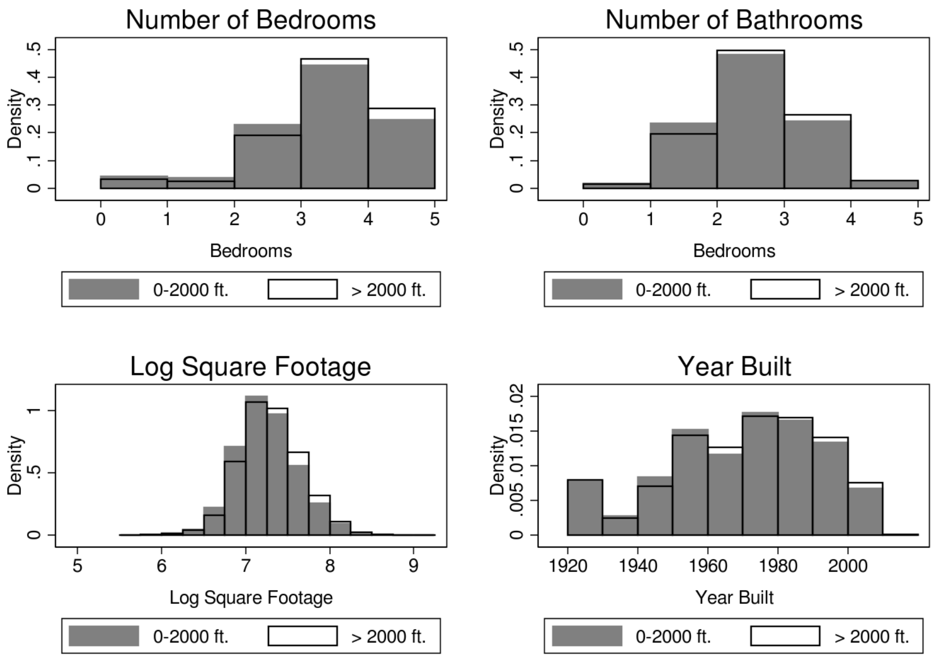


Table 2: Housing transaction summary statistics

	(1) Price	(2) Beds	(3) Baths	(4) Pool	(5) Garage	(6) Sq. Ft.	(7) Distress
1000ft	-34494.4***	-0.091***	-0.073***	-0.015***	-0.025***	-75.7***	0.026***
	(1267.3)	(0.0066)	(0.0054)	(0.0021)	(0.0021)	(4.15)	(0.0035)
2000ft	-17641.7***	-0.044***	-0.040***	-0.0024	-0.0083***	-38.7***	0.018***
	(1172.4)	(0.0061)	(0.0050)	(0.0019)	(0.0019)	(3.84)	(0.0032)
Mean: 2000-4000 ft.	378848.4	3.05	2.14	0.089	0.69	1627.8	0.59

Coefficients come from a regression of the housing characteristic on pipeline distance bins and census tract fixed effects.

4 Empirical strategy

We begin with a hedonic equation relating house prices to pipeline proximity,

$$\ln P_{it} = \alpha_o + \gamma_{it}\alpha_1 Close_i + X_{it}\delta + \epsilon_{it} \quad (1)$$

where P_{it} is the sale price of house i with characteristics X at time t, and $Close_i$ is an indicator for whether the household is close to a natural gas pipeline. To capture the fact that home buyers may not be aware of or attentive to pipeline proximity, we introduce a discount factor $\gamma \in [0, 1]$. When people are imperfectly informed or inattentive ($\gamma < 1$), this discounting attenuates the observed empirical relationship between pipelines and equilibrium home prices towards zero, limiting our ability to recover the true, informed, relationship, α_1, which is the policy parameter of interest.

In this paper, we seek to estimate the extent of this attenuation in California prior to San Bruno. To do this, we employ a difference-in-differences (DD) approach, comparing properties near a pipeline to those farther from a pipeline, before and after the explosion and subsequent letter campaign.

$$\ln P_{it} = \alpha_{tr} + \mu_t + \beta_{Pre}Close_i + \beta_{Expl}Close_i \times Expl_t + \beta_{Letter}Close_i \times Letter_{it} + X_{it}\delta + \epsilon_{it} \quad (2)$$

Where $Expl_t$ indicates that the sale happened between 9/9/2010 and 4/20/2011 (the "post-explosion" period), $Letter_t$ indicates that the sale happened after 4/20/2011 (the "post-letter" period). 30-day time period dummy variables μ_t are constructed such that they perfectly partition the pre- and post- San Bruno periods. α_{tr} is a locational fixed effect for the property's census tract, which is a relatively homogeneous geographic unit containing an average of 4000 residents.

An alternative to tract level fixed effects would be to include property fixed effects. While this would account for any time-invariant house heterogeneity within census tracts, the downside of this approach is that it requires us to restrict the sample to properties that sell multiple times in the data. As was discussed in Section 3.1, the period of interest comes on the heels of a massive housing market correction, which limits the explanatory power of time invariant unobservables and hedonic price gradients. The implications of eschewing property fixed effects are further discussed in Appendix B.

It is important to note that this empirical specification does not allow us to recover the true WTP to avoid living near a pipeline (α_1) without additional assumptions.[16] During our sample, the pipeline network is constant, and we are just looking at changes in price around existing pipelines. To provide a mapping between Equations 1 and 2, let γ_{Pre}, γ_{Expl}, and γ_{Letter} be the discount factor households use prior to San Bruno, after the explosion, and after receiving a letter. Then

$$\beta_{Pre} = \gamma_{Pre}\alpha_1$$

$$\beta_{Explosion} = (\gamma_{Expl} - \gamma_{Pre})\alpha_1 \quad (3)$$

$$\beta_{Letter} = (\gamma_{Letter} - \gamma_{Pre})\alpha_1 \quad (4)$$

This means that even if we assume $\gamma_{Letter} = 1$, we cannot recover the full effect, $\alpha_1 = \beta_{pre} + \beta_{Letter}$, without assuming away any time invariant unobservables that are correlated with pipeline proximity and house prices. As we showed in Section 3, this is unlikely to be the case. Thus, instead of recovering α_1, our goal is to consistently estimate the change in pipeline aversion following the explosion and letter campaign. We further discuss the interpretation of $\beta_{Explosion}$ and β_{Letter} in Section 6.

Consistent estimation of $\beta_{Explosion}$ and β_{Letter} requires the assumption of parallel trends: absent

[16]As we discuss in Section 4.1, we would require additional assumptions to claim that the capitalization effect α_1 equals WTP.

the San Bruno events, the difference in unobserved price drivers between properties near and far from pipelines would have remained constant. To lend credibility to this assumption we restrict the sample to properties within 4000 feet of a natural gas pipeline. We define $Close_i$ to be indicators if the property is within 1000 feet of the nearest pipeline or between 1000 and 2000 feet from the nearest pipeline. The control group is houses between 2000 and 4000 feet from the nearest pipeline.

We also take several steps to account for the fact that these identifying events occur in the aftermath of an unprecedented housing crash. It is known that there were systematic local trends in the housing market during this time driven by factors like foreclosure activity (Campbell et al., 2011). First, we include very fine space-time fixed effects: tract-specific period dummies and tract-specific quarter dummies, where periods line up with our DD periods. This approach allows census tracts to flexibly differ in their recoveries from the crash. Second, we flexibly control for foreclosure activity. If there is any indication that a sale involved a property in distress, we control for the nature of this distress. In another robustness check, we control for the number of foreclosure sales that occurred within one-quarter mile of the sale in the previous six months. This operates as a highly localized measure of the severity of the housing crisis and recovery, while also accounting for the potential spillover effects of neighboring foreclosures (Campbell et al., 2011; Anenberg and Kung, 2014).

4.1 Regression discontinuity

Recent work by (Banzhaf, 2015; Kuminoff and Pope, 2014) discusses concerns with using difference-in-difference strategies to identify hedonic models. In particular, Banzhaf shows that the DD estimator is a lower bound on the true equivalent surplus associated with an amenity change. We cannot directly address this concern for our entire analysis. However, the letter sent by PG&E lends itself to a regression discontinuity design (RDD), which exploits only cross-sectional variation rather than relying on parallel trends and a time-invariant hedonic equilibrium. Specifically, we are able to compare houses on either side of the 2000 foot mailing cutoff and test whether housing prices change at that threshold. We follow the suggestion of Imbens and Lemieux (2008) and take a local linear approach within a relatively narrow bandwidth. The sample is further restricted to only house sales after the letters were distributed and only properties between 1000 and 3000 feet from a pipeline. We then control for separate linear functions on either side of the cutoff, and estimate whether there is a jump at 2000 feet. Formally, we estimate:

$$\ln P_{it} = \alpha_0 + \beta_0(d_i - 2000) + \beta^{RD}_{Letter} * (-1)(d_i > 2000) + \beta_1(d_i - 2000) * (d_i > 2000) \tag{5}$$

where d_i is the distance from the property to the nearest natural gas transmission pipeline. Assuming that no other unobservables change discontinuously at this cutoff, the estimate β^{RD}_{Letter} reflects the causal effect of letter receipt. We multiply the discontinuity at 2000 feet by (-1) so that the sign on this coefficient matches that of our DD estimator. The main weakness is that the estimated effect is a local average treatment effect at 2000 feet, which is outside the blast zone of any existing pipeline. Still, this provides a test of whether information conveyed by the letter, along with follow-up information acquisition, affected housing prices.

5 Results

5.1 Difference-in-differences

We begin by presenting the estimates from Equation 2 in Table 3. The sample is restricted to households living within 4,000 feet of a natural gas pipeline and living in a county served by PG&E. All specifications include month of sample dummies and controls for housing and transaction characteristics.[17] Moving from left to right in Table 3, the specifications in Columns 1 through 4 include increasingly fine controls for spatial and temporal unobservables. Column 1 contains time-invariant tract fixed effects. In Column 2, tracts are partitioned into properties 0-1000, 1000-2000, and 2000-4000 feet from the nearest pipeline, and a time-invariant control is included for each tract-distance group. In Column 3, the tract fixed effects are interacted with DD time period indicators. Column 4 interacts the tract fixed effects with quarter-of-sample dummies, where quarters are defined as three consecutive 30-day sample windows.

Table 3: Difference-in-difference estimates: housing prices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1000ft	-0.0383***		-0.0379***	-0.0377***	-0.0335***	-0.0353***	-0.0329***
	(0.00523)		(0.00521)	(0.00542)	(0.00783)	(0.00822)	(0.00492)
2000ft	-0.0152***		-0.0156***	-0.0159***	-0.00727	-0.00923	-0.0138***
	(0.00383)		(0.00385)	(0.00397)	(0.00567)	(0.00595)	(0.00376)
PostExp-1000ft	-0.00204	-0.00153	-0.000763	-0.00176	-0.00884	-0.00748	-0.000947
	(0.00442)	(0.00430)	(0.00517)	(0.00532)	(0.00672)	(0.00681)	(0.00520)
PostExp-2000ft	0.000817	0.00177	0.00137	0.00139	-0.00853	-0.00644	0.00112
	(0.00390)	(0.00386)	(0.00436)	(0.00458)	(0.00608)	(0.00637)	(0.00442)
PostLetter-1000ft	0.00467	0.00471	0.00166	0.00407	-0.00330	0.000746	0.00237
	(0.00450)	(0.00441)	(0.00467)	(0.00494)	(0.00606)	(0.00641)	(0.00467)
PostLetter-2000ft	0.000260	0.000516	-0.000902	0.000990	-0.0101*	-0.00675	-0.000917
	(0.00380)	(0.00377)	(0.00394)	(0.00415)	(0.00557)	(0.00581)	(0.00395)
Tract FEs	Tr	Tr-Dist	Tr-Per	Tr-Q	Tr-Per	Tr-Q	Tr-Per
Bay Area					X	X	
Add'l. Covars.							X
Observations	145102	144959	144940	143221	81559	80607	144940
R-Squared	0.922	0.927	0.926	0.934	0.906	0.916	0.926

The dependent variable in each regression is log house price. All models contain month of sample dummies and housing characteristic controls. Standard errors clustered by census tract are reported in parentheses.

The results are quite stable across specifications. The main effect on the distance bins reveal that properties within 1000 and 2000 feet of a pipeline are worth about 3% and 1.5% less, respectively,

[17] These characteristics are the number of bedrooms and bathrooms, log of square footage, presence of a pool, presence of a garage, type of property (e.g., single-family vs. condo), 10-year bins of property age at time of sale, and dummies for categories of distress.

than properties within the same tract 2000 to 4000 feet away. However, as discussed above, these estimates are also picking up any unobserved neighborhood and housing characteristics correlated with pipeline presence.[18] Turning to the coefficients of interest β_{Expl} and β_{Letter}, there is no evidence across any of the models that this difference in home value changed after either the explosion or the subsequent informational letter. Taking Column 3 as an example, the average price effect of the explosion on houses within 1000 feet of a pipeline is -0.07%, with a 95% confidence interval of [-1.05%, 0.91%].

The remaining three columns in the table present robustness results. Columns 5 and 6 are analogous to Columns 3 and 4, except that we restrict the sample to the "core Bay Area" counties of Alameda, Contra Costa, Marin, San Francisco, San Mateo, and Santa Clara. In Column 7, we turn back to the full PG&E sample with tract-period fixed effects, but also control for the number of foreclosures within one-quarter mile in the six months preceding the sale and the distance to nearest highway interacted with our DD periods. The results for the Bay Area only sample are small and not statistically different from zero as well. However, the point estimates, while not statistically distinguishable, are slightly larger than our estimates for the full PG&E territory. This may represent statistical noise, or some hint of a response in the area closest to the explosion. In Column 7, the additional covariates meant to capture highly localized market trends do not have an appreciable effect on our estimates.

5.2 Triple difference

One possible concern with the difference-in-differences strategy is divergent trends. There could be price trends in other neighborhood characteristics that are correlated with pipeline locations, perhaps due to the housing crisis, that would confound our estimates. While we cannot directly test for this, we run a triple-difference estimator where we use Southern California as a control group. Equation 2 becomes:

$$\begin{aligned}\ln P_{it} &= \alpha_{tr} + \mu_t + X_{it}\delta + \beta_{Pre}Close_i + \beta_{Expl}Close_i \times Expl_t + \beta_{Letter}Close_i \times Letter_{it} \\ &\quad + PGE_i \times [\beta^{PGE}_{Pre}Close_i + \beta^{PGE}_{Expl}Close_i \times Expl_t + \beta^{PGE}_{Letter}Close_i \times Letter_{it}] + \epsilon_{it} \quad (6)\end{aligned}$$

where PGE_i denotes that the property is in PG&E's service territory. Now β^{PGE}_{Expl} and β^{PGE}_{Letter} are the coefficients of interest. In this specification, β^{PGE}_{Expl} and can be interpreted in one of two ways. First, if we assume there is no San Bruno explosion effect outside of PG&E territory, then this can be interpreted as the full effect. Otherwise, we can interpret it as the differential impact of the media coverage in Northern California and see if there is a raw difference-in-difference effect in Southern California. As there was no letter sent in the spring/summer of 2011 in Southern California, β^{PGE}_{Letter} should represent the causal price effect under the normal triple-difference identification assumptions.

The results from the triple-difference specification are given in Table 4. Columns 1 and 2 present

[18] It is interesting to note that these result differ from other cross-sectional studies referenced by FERC (INGAA, 2016; Fruits, 2008). Those studies typically find no correlation between house prices an pipelines either in in cross-sectional regression or in a "comparables" study carried out by appraisers.

the triple-difference results using PG&E territory as the area of interest, with Southern California Gas and San Diego Gas and Electric service territories as a control group. Again, we find no impact on prices, and can rule out even modest price decreases. Columns 3 and 4 restrict the Northern California sample to the Bay Area, and use only Los Angeles and Orange Counties as the control group. We find that the treatment effect in the Bay Area is very close to zero when measured relative to trends in the Los Angeles area.

Table 4: Triple difference estimates: housing prices

	(1)	(2)	(3)	(4)
PostExp-1000ft	-0.00728*	-0.00586	-0.00883*	-0.00832
	(0.00436)	(0.00449)	(0.00532)	(0.00548)
PostExp-2000ft	-0.00390	-0.00389	-0.00468	-0.00640
	(0.00414)	(0.00427)	(0.00506)	(0.00529)
PostExp-1000ft-PGE	0.00621	0.00393	0.000387	0.00139
	(0.00681)	(0.00701)	(0.00866)	(0.00884)
PostExp-2000ft-PGE	0.00482	0.00479	-0.00453	-0.000686
	(0.00602)	(0.00627)	(0.00796)	(0.00833)
PostLetter-1000ft	-0.00488	-0.00332	-0.00824*	-0.00747
	(0.00374)	(0.00397)	(0.00465)	(0.00499)
PostLetter-2000ft	0.00272	0.00315	-0.000814	-0.00161
	(0.00343)	(0.00360)	(0.00429)	(0.00453)
PostLetter-1000ft-PGE	0.00658	0.00775	0.00528	0.00873
	(0.00604)	(0.00640)	(0.00772)	(0.00821)
PostLetter-2000ft-PGE	-0.00367	-0.00219	-0.00942	-0.00525
	(0.00525)	(0.00552)	(0.00705)	(0.00739)
Tract FEs	Tr-Per	Tr-Q	Tr-Per	Tr-Q
Bay Area			X	X
Observations	320062	314031	206604	202215
R-Squared	0.918	0.928	0.900	0.913

The dependent variable in each regression is log house price. All models contain month of sample dummies and housing characteristic controls. Standard errors clustered by census tract are reported in parentheses.

5.3 Quarterly treatment effects

The previous regressions failed to find any evidence of a permanent shift in the hedonic price gradient after the explosion or the letter. However, it is possible that these shocks to awareness were more fleeting. In order to test for shorter impacts, we also perform an event study-style regression. That is, we allow the difference-in-difference treatment effects to vary by quarter.[19] *A priori*, we do not know how long it should take for the effects of the explosion or letter to arise in equilibrium prices. For example, the letter campaign was announced in a press release and subsequent news coverage on April 20, 2011. However, we do not know the exact rollout dates of these letters, and attempts to obtain them from PG&E or the California Public Utilities

[19]The results are similar if we estimate monthly treatment effects rather than quarterly effects.

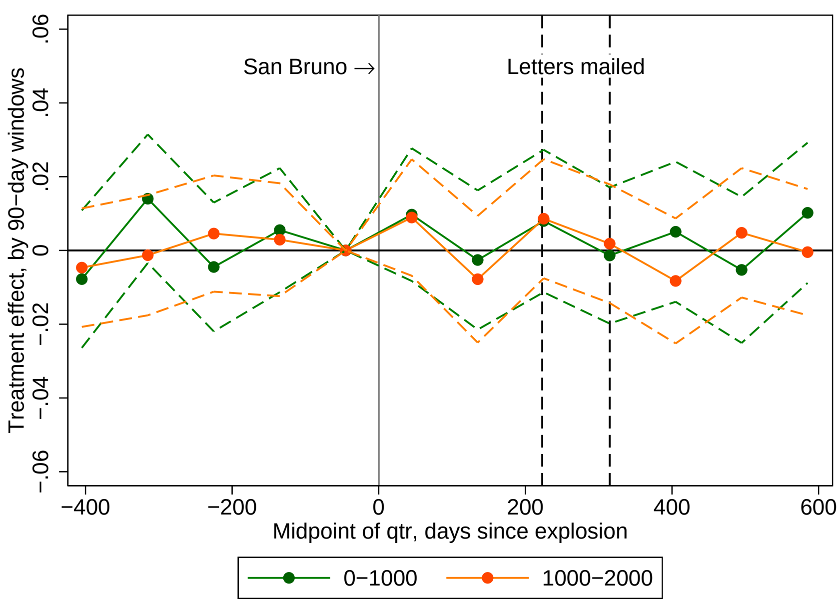
Commission have been unsuccessful.[20] This specification can be written as:

$$\ln P_{it} = \alpha^q_{tr} + \mu_t + \sum_q \beta^q_{Qtr} Close_i \times Qtr^q_t + X_{it}\delta + \epsilon_{it} \quad (7)$$

where α^q_{tr} is census tract-quarter fixed effect and Qtr^q_t is a indicator for whether t in the 90 day sample period q. β^q_{Qtr} is therefore the quarterly average difference between properties near and far from pipelines within the same census tract.

The results are presented in Figure 4. The solid black line denotes the date of the San Bruno explosion. The dashed black vertical lines represent the announcement of the PG&E letter campaign (4/20/2011, which defines the beginning of the "Letter" period in the DD specification) and the latest date of letter receipt we could find in the media (7/21/2011 in Napa, CA). The dotted lines are 95% confidence intervals. There is no discernable pattern in the quarterly estimates for either bin over time.

Figure 4: Quarterly treatment effects



Dotted lines are 95% confidence intervals derived from standard errors clustered by census tract.

5.4 Regression discontinuity

Before turning to the regression discontinuity estimates, it is useful to examine the the price data around the discontinuity visually. Figure 5 presents the binned mean log(price) values along with

[20]The limited news coverage we found indicates that Berkeley residents received letters during the last week of June 2011, while Napa residents received them in mid-July.

95 percent confidence intervals within 1000 feet of the letter cutoff.[21] Visually, there is no clear evidence of a discontinuity.

Figure 5: Graphical RD results

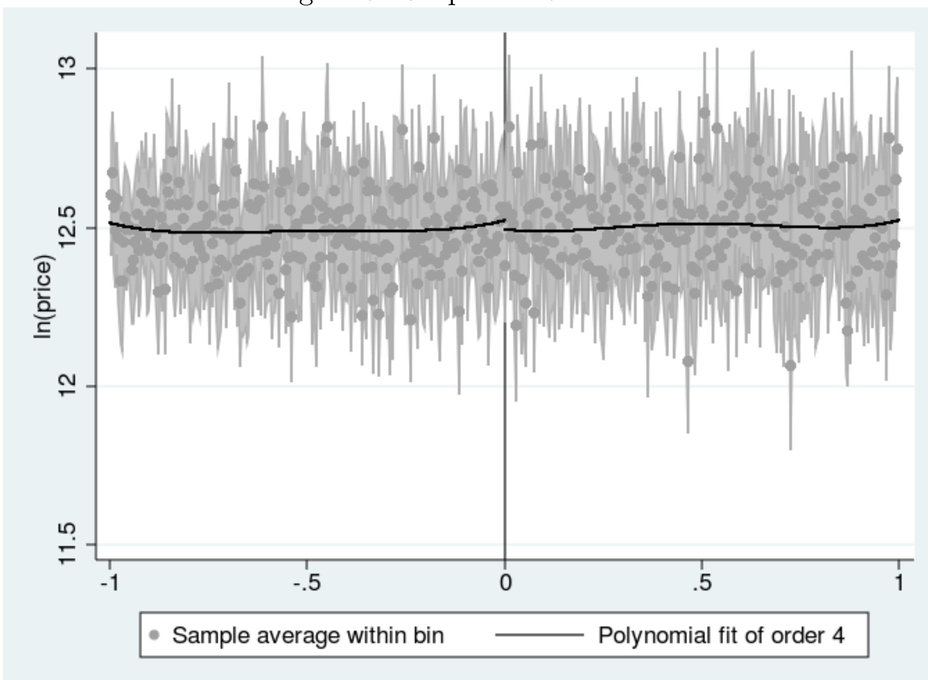


Table 5 confirms this visual interpretation using the linear regression from Equation 5. Column 1 presents the results where the only controls included are month dummies. The point estimate implies that houses just within the letter radius are 0.2% *more* valuable than houses just outside the radius that were not sent a letter. Column 2 and 3 add in tract dummies and housing characteristic controls. Column 4 narrows the bandwidth further to include just households within 1,500 and 2,500 of a PG&E pipeline. In all four models, β^{RD}_{Letter} is statistically indistinguishable from zero.

Table 5: Regression discontinuity results

	(1)	(2)	(3)	(4)
RD_Estimate	0.00188	0.00900	-0.00853	0.0148
	(0.0195)	(0.00869)	(0.00586)	(0.0119)
Bandwidth	1000 ft	1000 ft	1000 ft	500 ft
Hedonics			X	
TractFEs		X	X	X
Observations	26309	26309	26309	13069

The dependent variable in each model is log(price), and all models include month of sale dummies. Robust standard errors presented in parentheses.

[21] This plot was created with the rdrobust package from Calonico et. al., available at https://sites.google.com/site/rdpackages/.

6 Discussion

What do these results tell us about willingness to pay to avoid natural gas pipeline risk? As was discussed in Section 4, the answer depends on the magnitude of $(\gamma_{Expl} - \gamma_{Pre})$ and $(\gamma_{Letter} - \gamma_{Pre})$. The background evidence presented above suggests γ_{Pre} was well below 1 prior to the explosion. Coverage lamenting lack of information was ubiquitous, and even first responders were uninformed about pipeline locations. Moreover, the PG&E letter was initiated precisely because awareness was so low.

While it seems safe to assume γ_{Pre} was close to zero, taking a stand on the change in γ after the explosion and letter is more difficult. This was the top national news story for a week, and coverage persisted much longer in California. As the Google search data shows, many of those living Northern California also turned to the internet for information on pipelines at a rate never seen before. While we cannot relate this directly to the number of homebuyers affected, let alone their priors, it seems reasonable to assume that this bump in attention was non-negligible.

Turning to the change in γ from the letter, this is also tough to gauge. On the one hand, this is about as powerful an information treatment as we could imagine implementing at scale. PG&E compiled a list of all residents living within a relatively large area around each of its pipelines. It then sent millions of residents a concise letter invoking the still salient tragedy of San Bruno, alerting them of their situation, and directing them to a website for more information. Like all mailers, we have no way of knowing how many of these letters were opened and internalized.

A potentially larger limitation of the letter treatment is that the information was only given to homeowners, not buyers. As was discussed above, there is conflicting information over whether this was a legally material fact that should be disclosed when closing. Regardless of the literal letter of the law, we doubt that this disclosure often happened in practice. Instead, we interpret any change in γ as coming from coverage of the letters and word of mouth, rather than from a formal disclosure process. Given this, it is important to note the distinction between this paper and earlier disclosure work by Pope (2008), which focused on disclosure laws explicitly mandating disclosure to potential buyers.

If we assume that the shock to γ from either the explosion or the letter was significant, then our results suggest even a fully informed housing market would reveal little willingness to pay to avoid pipeline safety risk. This is consistent with fully informed households having rational expectations about this small risk. We can invert the standard VSL formula to back out an implied willingness to pay to avoid this risk.

$$MWTP = VSL \times PiplineRisk$$

Between 1996 and 2015, there were 12 fatalities from natural gas transmission pipeline incidents in California (including San Bruno). In the CoreLogic data, 28% of CA households are within 2000 feet of a transmission pipeline, which implies an annual pipeline risk of 0.053 deaths per million people. Using the current EPA VSL figure of \$8.5M, this implies an annual willingness to pay of just \$1.32 per household.

How can we relate this revealed rational apathy, to the current stated opposition to new pipelines? One possible reconciliation is preference heterogeneity. If the most concerned households have already sorted, then the loss in utility from pipelines that encroach into new areas may be steep, even if the gradient near old pipelines appears flat.

An alternative explanation for this apparent disconnect between stated and revealed concern is NIMBYism. New pipelines do impose some distinct disamenities on local communities, particularly during construction or when eminent domain is invoked. These affected parties may realize that messages related to pipeline safety are particularly effective at drumming up community and political support. Even if this is the case, it should be noted that efforts to increase pipeline awareness and information availability may still be valuable, even if they do not affect avoidance behavior. Accurate information allows those living near pipelines to make safety plans and respond accordingly should another disaster like San Bruno occur.

7 Conclusion

Safety concerns are a major impediment to making necessary expansions to the natural gas pipeline network. While there appears to be very little revealed willingness to pay to avoid existing natural gas pipelines, it is difficult to know if this reflects true ambivalence or simply a lack of salience and awareness. In this paper, we attempt to resolve this ambiguity by studying the fallout from the San Bruno disaster, which shocked both salience and information. Using multiple identification strategies, we fail to to find any evidence of a meaningful shift in the hedonic price gradient following these events. While there efforts to raise information and salience may still be valuable, these results suggest their absence are not obscuring some large latent pipeline aversion. Extending this null result to new pipelines involves making assumptions about construction disameneites and heterogeneity in preferences. This topic is left for future work.

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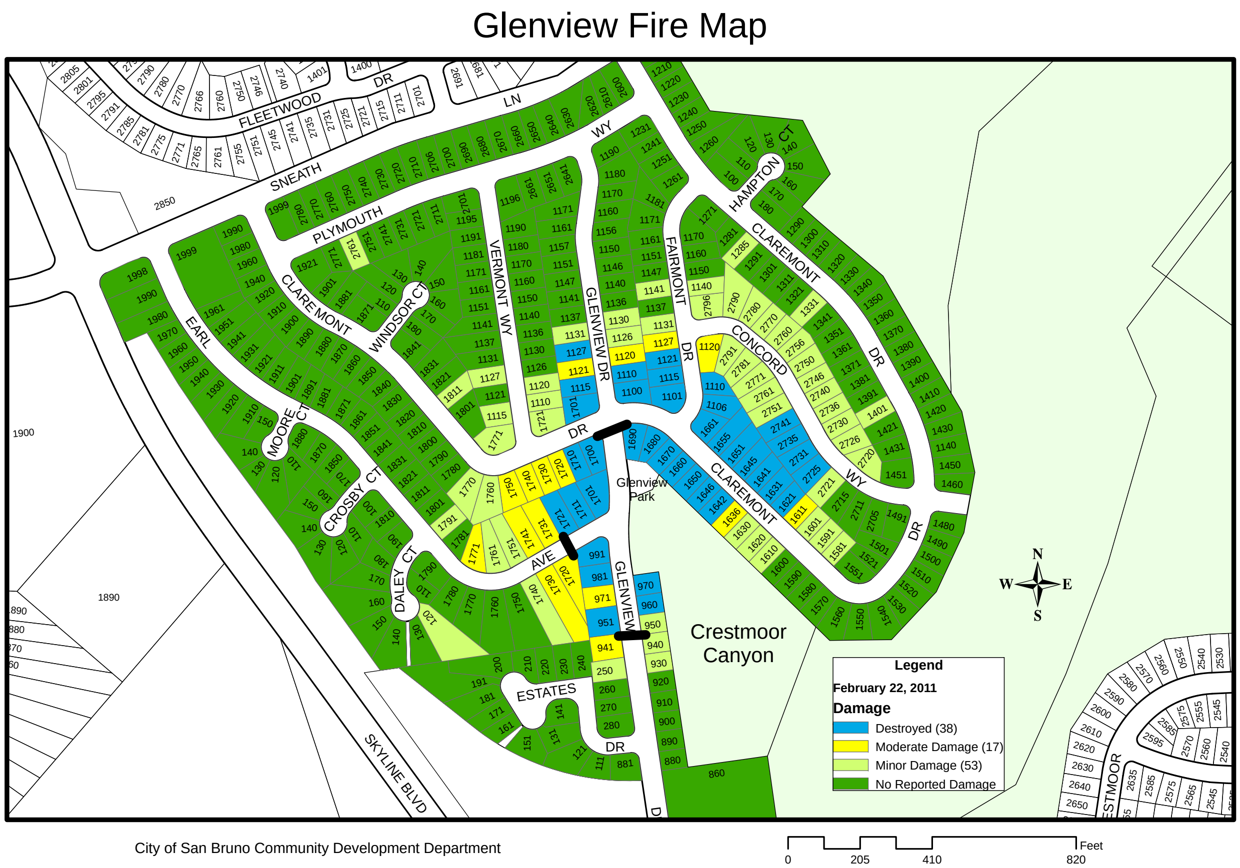
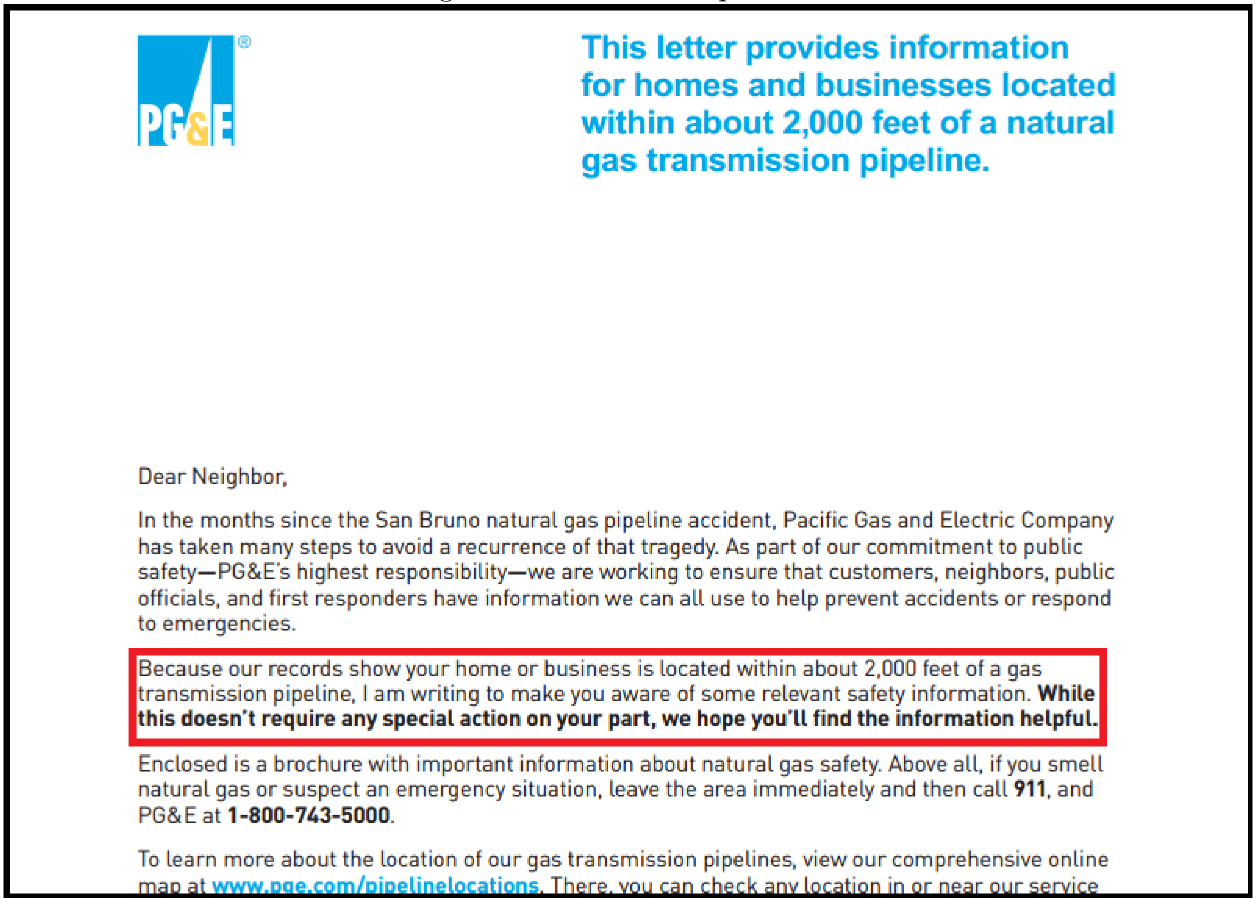
A Additional figures

Figure A.1: Map of San Bruno Damage



Source: City of San Bruno (https://sanbruno.ca.gov/civicax/filebank/blobdload.aspx?blobid=22862)

Figure A.2: PG&E Sample Letter



This letter provides information for homes and businesses located within about 2,000 feet of a natural gas transmission pipeline.

Dear Neighbor,

In the months since the San Bruno natural gas pipeline accident, Pacific Gas and Electric Company has taken many steps to avoid a recurrence of that tragedy. As part of our commitment to public safety—PG&E's highest responsibility—we are working to ensure that customers, neighbors, public officials, and first responders have information we can all use to help prevent accidents or respond to emergencies.

Because our records show your home or business is located within about 2,000 feet of a gas transmission pipeline, I am writing to make you aware of some relevant safety information. **While this doesn't require any special action on your part, we hope you'll find the information helpful.**

Enclosed is a brochure with important information about natural gas safety. Above all, if you smell natural gas or suspect an emergency situation, leave the area immediately and then call **911**, and PG&E at **1-800-743-5000**.

To learn more about the location of our gas transmission pipelines, view our comprehensive online map at www.pge.com/pipelinelocations. There, you can check any location in or near our service

Source: City of San Bruno (https://sanbruno.ca.gov/civicax/filebank/blobdload.aspx?blobid=22862)

B Property fixed effects

One potential concern with our approach is that we are not sufficiently controlling for unobservable housing characteristics that are correlated with pipeline proximity. Given that our housing data strectches back to 1996, property fixed effects allow us to examine this concern. The housing market equilibrium has clearly changed substantially during and after the housing crisis. Thus, we do not want to use data stretching back that far as our "pre" period. Unfortunately, restricting ourselves to four years of repeat sales data both reduces our sample considerably, and also introduces severe sample selection problems. Instead, we use the full sample, but include a "double-difference" term for the period before 6/16/2009. We want to compare the post-explosion period to a reference period that is relatively stable. This approach "removes" the data generated in the pre-crash market equilibrium from directly "helping" to estimate the treatment effect. We still leave this data in because it allows us to use property fixed effects in some specifications without losing all of our data (or selecting on properties that sell twice during 2009-2012). We estimate the following specification:

$$\ln P_{it} = \alpha_i + \mu_t + \beta_{Pre} Close_i + \beta_{PC} Close_i \times PreCrash_t + \beta_{Expl} Close_i \times Expl_t + \beta_{Letter} Close_i \times Letter_{it} + X_{it}\delta + \epsilon_{it} \quad (8)$$

which is identical to Equation 2, except that we now include property fixed effects α_i and the extra "Pre-crash" DD term. We present the results of Equation 8 in Table B.1. Comparing Column 1 to Column 2 and Column 3 to Column 4, it is clear that accounting for unobservable time-invariant housing characteristics has very little effect on the difference-in-difference estimates.

Table B.1: Difference-in-difference estimates with property fixed effects: housing prices

	(1)	(2)	(3)	(4)
PostExp-1000ft	-0.00172	0.00363	-0.00921	-0.00292
	(0.00723)	(0.00891)	(0.00758)	(0.00889)
PostExp-2000ft	0.00242	0.00249	0.00163	0.00696
	(0.00676)	(0.00839)	(0.00667)	(0.00799)
PostLetter-1000ft	0.0103	0.00701	-0.00657	-0.00723
	(0.00689)	(0.00828)	(0.00628)	(0.00678)
PostLetter-2000ft	0.00137	0.00322	-0.00495	0.00000795
	(0.00631)	(0.00754)	(0.00572)	(0.00645)
Property FE	N	Y	N	Y
Other FE	Tr		Tr-Per	Tr-Per
Observations	509823	509823	509451	509206
R-Squared	0.863	0.934	0.882	0.948

The dependent variable in each regression is log house price. All models contain month of sample dummies and housing characteristic controls. Standard errors clustered by census tract are reported in parentheses.