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Collateral Damage: The Impact of Shale Gas on Mortgage Lending
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ABSTRACT

We analyze mortgage lenders' behavior with respect to shale gas risk during the period of the U.S. shale gas boom, which coincided with fluctuations in the U.S. housing market and increased scrutiny in the lending industry. Shale gas operations have the potential to place affected houses into technical default such that government sponsored enterprises like Fannie Mae and Freddie Mac are unable to maintain them in their portfolios. We find that lenders changed from being willing to pay $814 on average to avoid one unit of shale risk before the financial distress of 2008 and subsequent increased scrutiny, to $3,137, or 1.6% of profit earned on an average mortgage, afterwards. Our approach provides an alternative to the traditional property value hedonic measurement of the disamenities associated with shale gas development by looking at the decisions of mortgage professionals.

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1 Introduction

The Energy Information Administration reports that between 2007 and 2018, annual natural gas withdrawals from shale deposits in the U.S. rose from 1.99 to 23.5 million cubic feet,[1] growth that led to lower natural gas prices, higher natural gas demand, and substitution from other forms of fossil fuel consumption like coal. The rise of shale gas has been spurred by technological development that combines large-scale hydraulic fracturing and horizontal drilling techniques with other advances in three-dimensional surveying techniques. In addition to facilitating more efficient extraction from broad, tight-shale layers, the horizontal drilling technology increases access to large areas of shale from relatively confined surface areas, which allows firms to extract oil and natural gas stored in tight-shale formations located beneath densely populated neighborhoods.[2] Unlike traditional oil and natural gas reservoirs, settlement patterns throughout the U.S. have evolved for decades with indifference to the location of shale. Consequently, we now often find residential properties located on top of those resources, bringing shale gas activity into homeowners' backyards. By 2014, more than 15 million Americans were living within one mile of an active oil or gas shale well.[3] Our paper explores how changes in extraction technology have altered mortgage markets by evaluating how lenders internalize the increased risks borne by leveraged houses located near to shale oil and natural gas development.

What risks does being located in close proximity to these large-scale, hydraulically fractured wells present? The current literature is evolving to identify and measure the health, economic, and geologic consequences of proximity to these industrial activities, especially in light of increased household exposure. Among the identified risks is air pollution from well production and transmission activities.[4] Another risk is that waste water disposal from fractured wells is linked to surface water contamination caused by radioactive salts and metals or by the chemicals used to the treat the fractured wells.[5] There is a growing literature linking the employment of large-scale fracturing technology and increased incidence of tremors,[6] and more broadly, communities experience degradation of amenities through increased noise, road damage, and traffic

[1] Energy Information Administration, `https://www.eia.gov/dnav/ng/hist/ngm_epg0_fgs_nus_mmcfa.htm`

[2] In particular, many horizontal laterals can be drilled in different directions from a single wellpad, which may comprise less than an acre of land. Horizontal laterals can extend in mile-long segments beneath suburban and urban regions.

[3] Gold and McGinty (10/25/13). "Energy Boom Puts Wells in America's Backyards." *Wall Street Journal*.

[4] The literature describes the impact of pollution emissions generated during the drilling, fracturing and production phases of well development. Caulton et al. (2014) and Brandt et al. (2014) focus on methane emissions, while Colborn et al. (2011) and Roy et al. (2014) provide evidence on particulate matter and Gilman et al. (2013) discusses volatile organic compounds.

[5] Olmstead et al. (2013), Warner et al. (2013), Fontenot et al. (2013), and Hill and Ma (2017).

[6] Koster and van Ommeren (2015), Metz et al. (2017), Ferreira et al. (2018), and Cheung et al. (2016).

accidents.[7] Conversely, the literature also identifies and measures economic benefits to having an active extraction industry, which includes higher wages, income, and municipal revenue.[8] Added to the economic benefits are royalties and bonus payments earned by households that own (and lease) the rights to their sub-surface minerals. We contribute to this literature by identifying and measuring the cost of these technologies that is internalized by the mortgage lending industry and passed on to homeowners through higher lending rates.

The fact that shale development has the potential to impact property values means that it also has the potential to interact in a variety of ways with mortgage lending practices. First and foremost, a mortgage loan is commonly secured for both surface and subsurface rights. Mortgages do not generally allow homeowners to sell or lease parts of their property without prior approval from the lender; however, mortgage experts generally report that requests for approval are rare (The New York Times, 2011; Law, 2011).[9] The situation is further complicated by the fact that most mortgages are not held in the portfolio of the primary lender, but are instead sold on the secondary mortgage market. Lenders participating in the secondary mortgage market, in effect, sell their loans to government sponsored enterprises (GSEs)[10] or investment banks that bundle the loans (securitize) and sell the resulting securitized assets (mortgage-backed securities) to individual investors. Participation in the secondary market increases lenders' liquidity; however, GSEs are prohibited from purchasing mortgages on properties engaged in industrial activities including transport or storage of toxic substances (chemicals, oil and gas products, or radioactive materials) (Law, 2011), and shale gas extraction involves a number of activities that have the potential to violate these rules, which would leave the borrower (without prior approval) in technical default.[11,12] Because the primary lender is responsible if the borrower defaults due to

[7] Muehlenbachs and Krupnick (2013) and Graham et al. (2015) link increased incidence of traffic accidents to drilling activity.

[8] Mason et al. (2015) and Bartik et al. (2019) measure some of the economic benefits, and Cesur et al. (2017) documents the benefits to infant mortality that are attributable to energy generation from natural gas as opposed to coal.

[9] Nationwide, Bank of America reports receiving approximately 100 such requests per month, fewer than a dozen are sent to Fannie Mae and Freddie Mac each year. (The New York Times, 2011) At times Chesapeake Energy, one of the largest drilling companies, evidently only sought permission from lenders before a property was drilled, not before was is leased; this violates mortgage rules, which require approval to sign a lease (The New York Times, 2011).

[10] Government sponsored enterprises (GSEs) include Fannie Mae (Federal National Mortgage Association) and Freddie Mac (Federal Home Loan Mortgage Corporation).

[11] Further, there may be other discrepancies between the terms specified in an oil or natural gas lease agreement and those specified in a mortgage. For example, some states void title insurance if a property is used for any commercial venture (Law, 2011) and, without title insurance, participation in the secondary market is limited. Homeowner insurance policies will also be violated if industrial activities are present, leading to default (May, 2011).

[12] Borrowers may even find themselves in violation of their mortgage agreement through no fault of their own, but rather simply because they happen to be located in close proximity to another property that engaged in shale development. For example, news reports described a couple in Washington County, PA who were denied a new mortgage

shale extraction activities, lenders have strong incentives to precisely evaluate the risks incurred by lending to homeowners in regions with high levels of shale development.

We use the mortgage market to learn about additional external costs associated with the "fracking boom" by quantifying the relationship between shale drilling risks and the frequency of subprime (higher priced) lending. In particular, we use loans issued to buy homes in Tarrant, Denton, and Dallas Counties, Texas, to test whether lenders mitigate shale development risks by issuing more subprime loans to households that are susceptible to drilling externalities. We then measure the extent to which lenders' preferences (distaste) for shale gas risk have shifted relative to other forms of risk since 2010, i.e., during a period when the industry reconsidered its lending practices (Ivashina and Scharfstein, 2010; Kruger, 2018), and shale gas activities rapidly expanded. In particular, the rise in shale extraction was coupled with the collapse of the housing market and, with it, an increased scrutiny of GSE activities which lead lenders to worry they may have to assume control of the shale-exposed mortgages as a consequence of technical default. We find that it is important to estimate differential preferences for shale risk (relative to income risk) before and after this period in which technical default and lost property values become more significant concerns among lenders. In particular, we ask whether lenders treat properties differently, based on the different degrees of likelihood that a property is exposed to hydraulic fracturing operations.

We use a combination of housing, lending, and drilling data to capture variation in subprime lending practices across households that are more or less susceptible to the negative externalities of nearby drilling behavior. Our data spans the growth of shale gas activity and the periods before and after the financial crisis, and we are able to estimate how lenders' preferences differed across these two periods along several dimensions. We then use a non-parametric estimator (Frölich, 2006) to capture firms' preference heterogeneity for income and shale risks and to estimate the trade-offs across our two types of risk without imposing functional form assumptions. We find that after the financial crisis, lenders are willing to bear significantly more income risk to reduce their exposure to shale risk.

Our paper adds to the existing shale gas literature by focusing on the decisions of lenders who, we argue, are more likely than a typical household to internalize risks especially in light

for their property by Quicken Loans because of shale development on a neighboring plot. Quicken responded by saying – "While Quicken Loans makes every effort to help its clients reach their homeownership goals, like every lender we are ultimately bound by very specific underwriting guidelines. In some cases conditions exist, such as gas wells and other structures in nearby lots, that can significantly degrade a property's value. In these cases, we are unable to extend financing due to the unknown future marketability of the property." `http://www.wtae.com/investigations/Couple-denied-mortgage-because-of-gas-drilling/12865512#.T6mu842bM44.facebook` of greater scrutiny in lending practices post-financial crisis, which evolved throughout 2008 and 2009.[13] In doing so, the methods we describe provide an alternative to traditional approaches to hedonic non-market valuation of local (dis)amenities based on housing transaction prices and the decisions of buyers. Lenders face trade-offs between different types of lending risk on a daily basis, allowing them to develop an expertise in weighing the risks inherent in any particular loan. Conversely, households may only buy a few houses over the course of their lives, creating a large information burden when deciding how to internalize perceived shale risks. Using measures that capture shale and income risks, along with other household characteristics, we non-parametrically estimate lenders' preferences to issue high risk loans, as indicated by subprime mortgages. Following Bajari and Benkard (2005) and Frölich (2006), we characterize lenders' heterogeneous preferences and trade-offs between two types of risks: income and shale.

In addition to the already cited environmental economics literature identifying and measuring the costs and benefits of the growing shale extraction industry, this paper contributes to literature concerned with the effects of the financial crisis on lending practices, and subprime lending practices more generally. Our analysis controls for each household's race and ethnicity in order to capture the often-cited relationship between subprime lending and sociodemographic characteristics. Munnell et al. (1996) is among the papers that use data assembled in compliance with the Home Mortgage Disclosure Act to study potential discriminatory lending practices toward minority households.[14] Gerardi and Willen (2009) study Massachusetts property-level data and find that subprime lending leads to more turnover in minority neighborhoods.

Another relevant literature explores the relationship between unconventional energy development and the local banking sector. Plosser (2014) studies the deposit shock resulting from landowners profiting from nearby shale gas development and the banks' resulting capital allocation decisions. Gilje (2019) uses shale discoveries as a natural experiment to study credit supply and its implication for economic outcomes especially in areas dominated by smaller banks, and Gilje et al. (2016) explores whether banks export liquidity because they are exposed to positive shale gas shocks. Finally, there is an older literature that employs models to capture the default

[13]Our study is a complement to literature exploring whether there is an observed difference in mortgage default behavior for households living in active shale regions compared to non-shale. McCollum and Upton Jr (2018) study the probability of default in the presence of shale gas development, examining the default behavior of landowners in a period when national default rates were rising. They find that landowners living in shale gas regions are less likely to default on their mortgage loans, lending credence to the positive economic impacts of shale gas development. Shen et al. (2015) conduct a similar study with data describing default behavior of households in Pennsylvania located over the Marcellus Shale.

[14]The authors build on the literature analyzing discriminatory lending practices in mortgage markets that include Black et al. (1978), King (1980), Schafer and Ladd (1981) and Ladd (1998), among many others with additional literature summarized in Yinger (1996) and LaCour-Little (1999). A more descriptive analysis of the HMDA data and sociodemographic heterogeneity can be found in Avery et al. (2006).

probabilities for mortgages as a function of factors like loan-to-value ratios and house-price depreciation (Quercia and Stegman, 1992; Kau et al., 1994). In our paper, we use a novel data to show that lenders are willing to bear significantly more income risk to reduce their exposure to shale risk after the financial crisis.

The remainder of the paper proceeds as follows. We begin by describing the secondary market for mortgages in Section 2 and our data set in Section 3, which combines information from the Home Mortgage Disclosure Act with data on property appraisals and well locations. Section 4 illustrates the theory used to describe lenders' relative preferences for shale and income risk and Section 5 describes the empirical framework. Section 6 reports estimates and Section 7 converts those estimates into a willingness-to-pay measure. Section 8 concludes with a discussion of policy relevance.

2 Secondary Markets for Mortgages

Lenders interested in selling their mortgages to GSEs, like Fannie Mae (Federal National Mortgage Association) and Freddie Mac (Federal Home Loan Mortgage Corporation), on the secondary market must meet certain criteria that may be violated by proximity to shale development. These details are noted in the following section along with a short history of GSEs and potential risks of shale gas development.

The government established GSEs to introduce additional liquidity into the mortgage market and promote home ownership. In the U.S., 90% of all houses are purchased with mortgage financing. Lending institutions typically do not rely on their own capital to support most of the loans that they write over the long-term. Instead, loans are bundled (securitized) and sold to investors as mortgage-backed securities. The federal government, primarily through its GSEs, is the largest of these investors, purchasing over 90% of mortgages in the US today.[15] Fannie Mae and Freddie Mac assume the credit risk for all mortgages that are re-sold as mortgage-backed securities. In exchange for bearing this risk, the GSEs keep the guaranty fees associated with the loans. By 2008 Fannie Mae and Freddie Mac owned or guaranteed about half of the U.S.'s $12 trillion mortgage market.

After the housing market crash of 2008, lenders began to evaluate the standards under which home mortgage loans were approved and credit was subsequently tightened. Both GSEs underwent significant scrutiny, were restructured, and fell under the conservatorship of the Federal Housing Finance Agency. Since that time, both the House Financial Services and Senate Bank-

[15] https://smartasset.com/mortgage

ing Committees passed reforms that would have reduced the government's footprint in housing finance (although neither was passed into law),[16] and a similar plan was proposed by the Obama administration.[17] With this increased scrutiny as a backdrop, the continued growth of shale gas in the U.S. led to congressional hearings beginning in 2009, continuing in 2010,[18] and culminated in a flurry of activity in the fall of 2011 both inside and outside Washington. In particular, the U.S. House of Representatives made inquiries into how the GSEs planned to address the potential for technical defaults owing to oil and gas development, and representatives of the real estate and banking industries wrote to state governments seeking additional clarity on their potential liability.[19]

2.1 The GSEs and Shale Gas

The GSEs specify a set of criteria to which lenders must adhere if they want to be able to sell mortgages on the secondary market, and there are many areas where these criteria may conflict with standard practice in shale gas or oil development. For example, Freddie Mac guidelines 39.4(i) specify that a mortgage can only be issued on a leased property if "exercise of the rights will not result in damage to the mortgaged premises or impair the use or marketability for residential purposes." Furthermore, the guidelines prohibit "right of surface or subsurface entry within 200 feet of a residential structure," and require "comprehensive endorsement to the title insurance company that affirmatively ensures the lender against damage or loss from exercise of such rights." Practically, this requires "no structure erected on premises exceeding three stories or 35 feet," that the premises "shall not be used for storage of any material machinery, equipment, or supplies," and that the property will "not be used for commercial purposes." Furthermore, the Freddie Mac guidelines 39.4(m) require that lenders must warrant that activities on the property:

1. must not interfere with the use and enjoyment of any present or proposed improvements on the mortgaged premises or with the use and enjoyment of the balance of the mortgaged premises not occupied by improvements,
2. must not affect the marketability of the mortgaged premises,
3. must have no or minimal effect on the value of the mortgaged premises,

[16] https://www.nafcu.org/HousingFinanceReform/

[17] https://www.treasury.gov/initiatives/Pages/housing.aspx

[18] Bateman, C. (June 2010)."A Colossal Fracking Mess." Vanity Fair. http://www.vanityfair.com/news/2010/06/fracking-in-pennsylvania-201006.

[19] Urbina, I. (November 24, 2011). "Officials Push for Clarity on Oil and Gas Leases." New York Times. http://www.nytimes.com/2011/11/25/us/officials-push-for-clarity-on-oil-and-gas-leases.html?_r=0

4. must be commonly acceptable to private institutional mortgage investors in the area.

Fannie Mae and Freddie Mac have a fiduciary duty to establish rules that reduce the risk of lost house value or default. As noted in the introduction, the extraction of shale gas involves a number of activities that have the potential to violate these rules, which would leave the borrower (without prior approval) in technical default. Toxic chemicals are pumped, along with million gallons of water and sand, directly under mortgaged homes. "Produced" water, which is forced back out of the well, contains brine, fracking chemicals, and even radioactive substances, and it is often stored on-site, sometimes in open holding ponds. Permanent easements for truck and pipeline transport, production platforms, and storage facilities (that can spill) are common on properties with or near drilling activity. Risks to home values can be a particular problem for homes where the water supply is threatened. Finally, without title insurance (see above), secondary lenders may not be able to hold mortgages.

The primary lender is responsible if the secondary lender does not know about the lease and the house goes into technical default as a result. Fannie Mae and Freddie Mac can demand that the originating lender buy back any loans that do not meet secondary market requirements (Carpenter, 2011). To our knowledge there is not a good measure of how many mortgages may currently be in violation of secondary mortgage market rules.

In light of these growing concerns, a primary lender who believes that a property may soon be approached for shale development may worry that the property could default, would have to be foreclosed upon, or that shale development might hamper its ability to sell the mortgage on the secondary market. A related concern might be that noncompliant mortgages already sold on the secondary market would have to be bought back. As such, that lender may charge a premium to lend when there is concern over impending shale development. Alternatively, to the extent that they are able, lenders may simply exit markets where shale gas is prevalent.[20]

In the remainder of this paper, we quantify changes in lenders' preferences by estimating the changes in trade-offs between income and shale risk before and after the financial crisis and concurrent increased interest in shale gas at the federal level. This provides us with a new perspective on the costs of the risks associated with shale gas development for nearby homeowners, specifically measured via the decisions made by mortgage lenders.

[20] The New York Times (2011) reports that in 2011 at least eight local or national banks did not typically issue mortgages on properties exposed to shale gas development. In other instances, lenders began requiring drilling companies to indemnify property owners against any future losses to home value, or requiring home owners to expressly agree not to sign a lease as long as they hold the mortgage.

3 Data

The following subsections describe our study area, data sources, and our variable construction methods. Our data are comprised of housing, drilling, and lending data that allows us to construct a household-level portrait of house transactions, household characteristics, and income and shale risk factors related to our dependent variables of interest, namely high-interest loans and foreclosures.

3.1 Tarrant, Denton, and Dallas Counties

Our analysis will focus on shale gas development and its impact on property markets in Tarrant County, Texas and surrounding counties. Tarrant County, located in north-central Texas, is the home to approximately 1.8 million residents. It is comprised of 41 incorporated areas, including Fort Worth, which is the county seat. The population of Tarrant is approximately 27% ethnically Hispanic or Latino (of any race).[21] Tarrant County and the underlying Barnett shale are typically considered to be the birthplace of modern hydraulic fracturing because of innovations made there by Mitchell Energy.

We also report summary statistics and present model specifications that include Denton County, located north of Tarrant, where there is also active drilling but in a more rural setting. Finally, we estimate counter-factual relationships using Dallas County data where firms are restricted to drill wells located at least 1,500 feet away from residential and commercial buildings, effectively a drilling moratorium.[22] Dallas is located directly east of Tarrant County, and since there is no drilling, our counterfactuals assume lenders need only evaluate income risk (as compared to income and shale risk).

3.2 HMDA

HMDA was established to determine whether lenders serve communities' financial needs and facilitate enforcement of fair lending laws. When buying a house, one typically fills out a form at closing that transmits information about the race, sex and income of the buyer along with the loan amount and terms. In 1989, the HMDA law was amended to require disclosure of loan-level information, and in 2004, it was further amended to require disclosure of information about loan pricing. As of 2006, there were 8,850 lenders covered by the disclosure rules (approximately

[21] www.tarrantcounty.com/en/county/about-tarrant.html

[22] These setback rules are quite stringent compared to Fort Worth where setbacks are 600 feet. https://www.texastribune.org/2013/12/11/dallas-city-council-tightens-gas-drilling-ordinanc/

80% of home lending nationwide). Specifically, the lender was required to report the spread between the annual percentage rate and the applicable Treasury yield if it was greater than or equal to 3 percentage points for a first-lien loan. After 2009, the rule for first-lien loans was changed to require reporting if the difference between the annual percentage rate and the applicable average prime offer rate was greater than or equal to 1.5 percentage points (i.e., both the baseline and the cutoff rule changed, see Consumer Financial Protection Bureau 2019). As such, HMDA does not specifically identify subprime loans, but rather "higher priced" loans; we use their reporting requirement in each period as the determinant of a loan being "higher priced." We also follow the common practice in the literature and use the terms "higher priced" and "subprime" interchangeably. In 2004, the first year when pricing information was provided, fewer than 20% of households had higher priced loans, and higher priced loans were more common amongst black and Hispanic borrowers. The number of loans reported as higher priced depends upon many factors, some of which have nothing to do with the borrower's riskiness. In particular, a narrowing of the difference between short and long-term interest rates can increase the number of loans exceeding the higher priced threshold, and we account for this in our empirical model below.

We employ the loan-to-income ratio as our measure of *income risk*. *Ceteris paribus*, given two borrowers with the same income, the borrower with the larger total loan amount will be more at risk of shocks that will prevent repayment of the loan, leading to default. HMDA reports both the size of the loan and the borrower's (self-reported) income. Further, HMDA describes whether or not the loan was securitized by a government agency or a commercial lender and whether the loan was issued by the Federal Housing or Veterans Administrations, which are important control variables included in the empirical specifications.

3.3 Dataquick & Corelogic

Data from the real estate data services companies Dataquick and Corelogic are accessed through a licensing agreement with the Duke University Department of Economics are used in conjunction with information from the Tarrant County Assessor's Office to measure the sale and assessed values of homes located in Tarrant, Denton, and Dallas counties of Texas, sale dates, and other house attributes like the counts of bedrooms, bathrooms, and living and land square footages. Further, these companies provide information describing the lenders and loan characteristics including loan amount and whether or not the loan was issued by the Federal Housing or Veterans Administrations. Corelogic uniquely identifies whether the home is eventually foreclosed. We connect the HMDA data to our housing data by merging on lender name, lender amount, zip codes, and sale dates.

3.4 Summary Statistics

We conclude this section by describing the dependent and independent variables, the characteristics of households with and without subprime mortgage rates, and motivating the inclusion of important control variables. It is particularly important to control for household characteristics, including race and ethnicity, loan characteristics, and if the loans are securitized.

Table 1 summarizes the house, household, sale, and loan characteristics of all transaction occurring from 1999 to 2016 in Dallas, Tarrant, and Denton counties. Denton County is comprised

Table 1: Summary Statistics by County

	Tarrant		Denton		Dallas	
	Mean	(Std. Dev.)	Mean	(Std. Dev.)	Mean	(Std. Dev.)
House Characteristics						
Beds	3.354	(0.642)	3.466	(0.652)	3.287	(0.686)
Baths	2.104	(0.583)	2.494	(0.828)	2.367	(0.914)
Living (sqft)	2121.508	(811.609)	2360.904	(853.044)	2025.629	(855.58)
Land (sqft)	10257.93	(8269.194)	10644.38	(9941.089)	9595.025	(5274.123)
Age (year)	18.733	(20.044)	11.647	(11.925)	29.072	(21.915)
Shale Exp. (wells)	0.575	(1.728)	0.269	(1.173)		
Household Characteristics						
White	0.81	(0.392)	0.844	(0.363)	0.684	(0.465)
Hispanic	0.193	(0.394)	0.117	(0.321)	0.282	(0.45)
Black	0.088	(0.284)	0.052	(0.222)	0.163	(0.369)
Asian	0.05	(0.218)	0.074	(0.262)	0.061	(0.239)
Income	$81,532	(54,401)	$95,642	(57,043)	$90,930	(80,411)
Transaction & Loan Characteristics						
High Interest Loan	0.104	(0.306)	0.077	(0.267)	0.135	(0.342)
Loan-to-Income	2.094	(0.779)	2.245	(0.811)	2.193	(0.819)
Sale Amount	$140,567	(75,243)	$174,226	(83,716)	$164,406	(114,879)
Loan Value	$150,061	(89,366)	$189,921	(101,263)	$171,042	(135,883)
Annualized L2I	0.166	(0.058)	0.172	(0.061)	0.181	(0.064)
Foreclosure	0.077	(0.266)	0.064	(0.245)	0.086	(0.281)
FHA Loan	0.294	(0.456)	0.216	(0.412)	0.266	(0.442)
VA Loan	0.061	(0.24)	0.057	(0.231)	0.028	(0.165)
Secured	0.85	(0.357)	0.872	(0.334)	0.821	(0.383)
Obs.	202,286		78,792		178,222	

Notes. Summarizes the primary variables used to describe the house, household, sales, and loan characteristics.

of fewer minorities while Dallas is comprised of more, and, on average, Denton sells larger homes measured by both the parcel (land) size and the living space. Tarrant and Denton counties both have drilling activity, though average well exposure is greater in Tarrant County, whereby shale exposure is measured by the count of producing wells located within 1,000 meters of the house at the sale date. Sales, loan, and income values are highest in Denton followed by Dallas. The frequency of foreclosures and the average mortgage interest rates (among those reported) in Tarrant fall between Denton, reporting the lowest, and Dallas, reporting the highest.

FHA or VA Loans. The models also control for whether the loan is insured by the Federal Housing Administration or Veterans Administration. The FHA is a government agency that helps borrowers obtain mortgage loans by lowering the down payment requirements to as low as 3.5 percent down for qualified borrowers, whereas traditional lenders require up to twenty percent down, and in fact, the FHA insured more loans after the subprime crisis as demonstrated in Figure 1.[23,24]

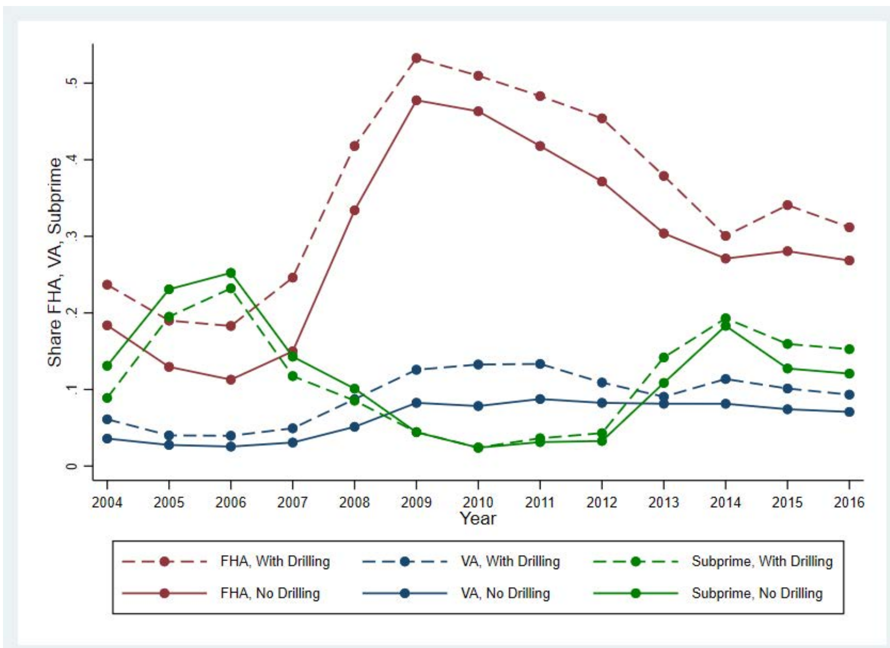


Figure 1: Frequency Originated Loan is FHA, VA, Subprime (by Shale Exposure)

Notes. Plots the share of loans issued by the FHA and VA or that are likely subprime across the state of Texas. The dashed lines indicate the share among counties with drilling activity, and the solid lines indicate the shares among counties with no drilling activity.

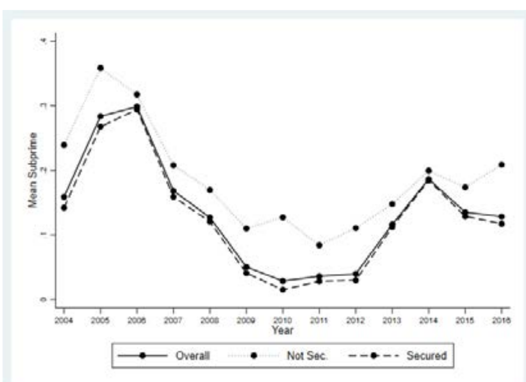
Borrowers that take advantage of FHA loans pay a mortgage insurance premium that varies with the financed amount. By around 2003, subprime lending supplanted much of the FHA loans by relaxing lending requirements further (some requiring zero down payments) and expediting the application process. After the subprime lending market crashed in 2007, the FHA increased

[23]The administration was established as part of the National Housing Act of 1934, and in 1965, it became part of the Department of Housing and Urban Development.

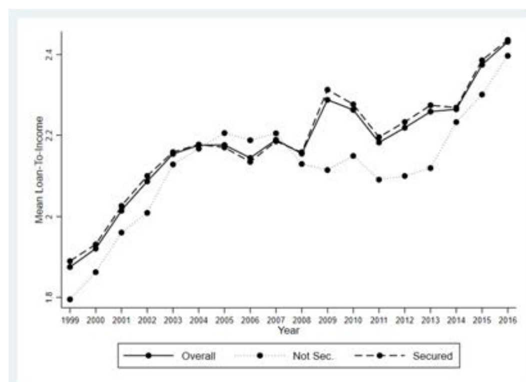
[24]FHA interest rates do not vary with the borrowers' credit scores as they do with conventional loans that typically spike if the credit score is less than 620.

the number of approved loans, which reached 43.8% of all mortgages originated in November of 2009, and after the recession, FHA lending decreased to roughly 11%.[25] Figure 1 plots the share of loans insured by the FHA, VA, or which are subprime. The dashed line plots those shares for regions with drilling activity while the solid lines are for regions without drilling activity. The share of subprime loans is slightly greater in drilled regions of Texas post-2010, and for the whole duration, FHA insured loans represent a greater share of the loans originating in drilled regions.

Securitized Loans. Loans may never be securitized, they may be securitized by a government entity like Freddie or Farmer Mac and Fannie or Ginnie Mae, or they may be securitized by a commercial entity. Since primary lenders are held responsible for default, it may matter to whom they sell the originated loans. Figure 2a describes the mean frequency with which a loan is issued with a high interest rate. Loans originated between 2009 and 2012 tend to have lower interest rates, and those with the highest interest rates are often not securitized. Figure 2b describes the mean loan-to-income values across securitized and non-securitized loans. From 2008 onwards, the loan-to-income values are lower among non-securitized loans.[26]



(a) Mean Frequency of Subprime Interest Rates (by Securitized)



(b) Mean Loan-to-Income (by Securitized)

Figure 2: Securitized Summary

Notes. 2a tracks the mean likelihood a securitized loan is issued with a high interest rate. Not securitized loans have the most consistently high interest rates, whereas the commercial loans are more likely to have higher interest rates before and after the subprime crisis. 2b tracks the mean loan-to-income values among all borrowers and stratified by whether the loan is securitized.

Race & Ethnicity. It is important to control for the racial and ethnic composition of borrowers

[25] `https://www.clevelandfed.org/newsroom-and-events/publications/economic-trends/2015-economic-trends/et-20150414-fha-lending-rebounds-in-wake-of-subprime-crisis.aspx`. This analysis explores whether FHA standards increased after the subprime lending market crashed by lending to more creditworthy borrowers. The authors find that FHA loans were extended to fewer deep subprime borrowers by the end of 2007 and to none by 2010.

[26] Online appendix A.3 reports summaries of the data by whether the loans are not secured, commercially secured, or government secured.

when performing empirical analyses that assess mortgage lending practices. As noted in the literature and data sections, HMDA was established, in part, to ensure lending practices were non-discriminatory. In Table 2 we see that a subprime mortgage is more often associated with minority status (black or Hispanic, in particular) and with lower income. Further, minority households are more likely to be issued loans insured by the Federal Housing Administration, described next in the text, and the loans are less likely to be secured by a government entities like Freddie or Farmer Mac and Fannie or Ginnie Mae.

Table 2: Summary Statistics by Race & Ethnicity

	Black		Asian		White		Hispanic	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Transaction & Loan Characteristics								
High Interest Loan	0.243	(0.429)	0.057	(0.232)	0.105	(0.307)	0.205	(0.404)
Loan-to-Income	2.309	(0.788)	2.194	(0.911)	2.138	(0.801)	2.312	(0.789)
Income	$69,513	(45,973)	$92,619	(66,026)	$91,589	(68,454)	$56,037	(41,639)
Sale Amount	$135,651	(73,152)	$166,959	(91,133)	$159,936	(97,796)	$108,744	(60,177)
Loan Value	$143,716	(80,294)	$173,240	(108,902)	$171,252	(116,492)	$114,305	(67,467)
Annualized L2I	0.188	(0.063)	0.169	(0.067)	0.167	(0.06)	0.189	(0.06)
Foreclosure	0.117	(0.321)	0.106	(0.308)	0.074	(0.262)	0.112	(0.315)
Fixed Loan	0.806	(0.395)	0.887	(0.316)	0.883	(0.322)	0.885	(0.319)
FHA Loan	0.401	(0.490)	0.122	(0.327)	0.255	(0.436)	0.406	(0.491)
VA Loan	0.072	(0.258)	0.01	(0.099)	0.048	(0.214)	0.03	(0.170)
Secured	0.86	(0.347)	0.853	(0.354)	0.846	(0.361)	0.776	(0.417)
Obs.	55,760		29,243		385,188		31,206	

Notes. Summarizes the financial and loan characteristics of all transactions by race and ethnicity. Black and Hispanic households have higher rates of high interest and FHA loans and lower incomes and sales values.

Shale Exposure. Table 3 summarizes the data across shale and non-shale exposed regions. The houses are slightly larger in areas with slightly greater levels of shale exposure. They are also more expensive when not located near shale, yet the loan values are lower. Descriptions of well permitting and production activities, along with drilling locations, come from two sources: the Texas Railroad Commission and DrillingInfo, a proprietary aggregator of drilling activity information. Figure 3 illustrates where producing wells emerged in Tarrant County at different time periods. It is clear that first the producing wells did not emerge uniformly across the County. From 2001-2004, wells were mostly located in the north west corner of Tarrant County, but after 2004 they began to emerge from the south as well. Moreover, the speed of emergence is different for different regions. Once wells started to emerge near a neighborhood, drilling activities became much more prevalent in that neighborhood relative to other neighborhoods where no producing wells had yet been established. Therefore, any specification that only considers one characteristic (i.e., distance or number of wells within a certain distance) and assumes a linear relationship with that characteristic may mis-measure shale risk.

Table 3: Summary Statistics by Shale Exposure

	No Shale Wells		Shale Wells	
	Mean	Std. Dev.	Mean	Std. Dev.
House Characteristics				
Beds	3.345	(0.643)	3.406	(0.619)
Baths	2.094	(0.593)	2.161	(0.488)
Living (sqft)	2098.952	(812.97)	2262.779	(776.325)
Land (sqft)	10136.71	(7612.469)	11129.84	(11610.4)
Age (year)	20.329	(20.393)	12.063	(16.666)
Shale Exp. (wells)			3.53	(2.811)
Household Characteristics				
White	0.805	(0.396)	0.84	(0.367)
Hispanic	0.199	(0.399)	0.174	(0.379)
Black	0.085	(0.278)	0.10	(0.299)
Asian	0.049	(0.216)	0.05	(0.218)
Income	$80,831	(54,728)	$82,840	(52,208)
Transaction & Loan Characteristics				
High Interest Loan	0.102	(0.302)	0.114	(0.318)
Loan-to-Income	2.067	(0.767)	2.203	(0.815)
Sale Amount	$141,525	(77,182)	$133,295	(65,011)
Loan Value	$147,381	(91,163)	$156,983	(76,204)
Annualized L2I	0.166	(0.058)	0.165	(0.057)
Foreclosure	0.072	(0.259)	0.109	(0.311)
Fixed Loan	0.893	(0.31)	0.936	(0.246)
FHA Loan	0.275	(0.447)	0.389	(0.487)
VA Loan	0.052	(0.223)	0.096	(0.295)
Secured	0.842	(0.365)	0.883	(0.321)
Obs.	161,000		36,786	

Notes. Summarizes the primary variables used to describe the house, household, sales, and loan characteristics. Shale exposure means that there is active drilling activity within 1-km radius of the property. The first and second columns compare the mean and standard deviations across households with and without shale exposure.

To better estimate shale risk, we propose a survival model (a proportional hazard, or PH model) to calculate shale risk. In particular, shale risk is measured by the cumulative hazard function, which measures the total amount of risk that has been accumulated up to time t. In the PH model, let τ be a non-negative random variable denoting the time to a failure event. Denote $S(t)$ as τ's survivor function and $h(t)$ as its hazard function:

$$S(t) = 1 - F(t) = Pr(\tau > t)$$
$$h(t) = \lim_{\Delta t \to 0} \frac{Pr(t + \Delta t > \tau > t | \tau > t)}{\Delta t} = \frac{dF(t)/dt}{S(t)}$$

In our PH model, we assume that the hazard function $h(t)$ has a Weibull distribution, with time-varying covariates:

$$h(t) = h_0(t)\exp(\beta_0 + \mathbf{x}(\mathbf{t})'\beta)$$
$$= pt^{p-1}\exp(\beta_0 + \mathbf{x}(\mathbf{t})'\beta)$$

For each property i, exposure starts when a well appears within the 3,000 meters radius of the sold house and a failure event occurs when a well appears within the 1,000 meters radius. For properties where a failure has not yet occurred, we consider the following time-varying attributes (denoted by $\mathbf{x_{it}}$ where t indicates year-month) in calculating the cumulative hazard function: number of producing wells within 2,000 meters radius and distance to the nearest producing well. Shale risk is defined as the total amount of risk that has been accumulated up to time t, which is represented by the cumulative hazard function:[27]

$$H(t) = \int_0^t h(u)du \tag{1}$$

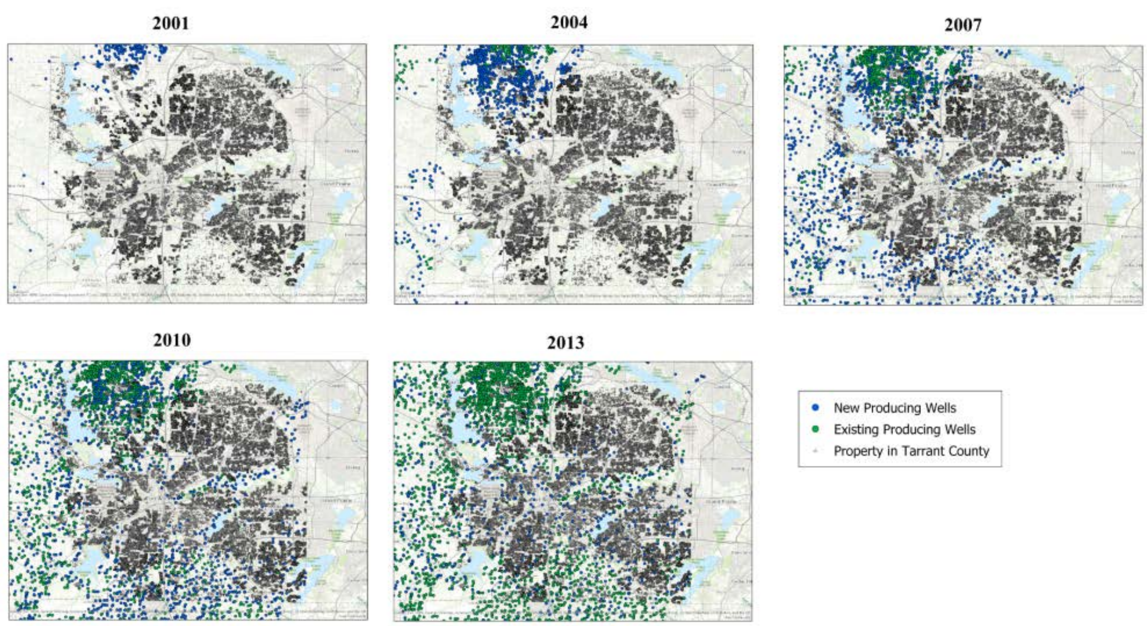


Figure 3: Patterns of Producing Activities

Notes. Illustrates how drilling activities developed in Tarrant County from 2001 to 2013. The green dots show the locations of existing producing wells in each year, the blue dots show the locations of new producing wells, and the small gray triangles show the locations of houses in Tarrant County.

[27] Figure A.1 in the online appendix depicts the distributions of cumulative hazard rates across years. From 2001 to 2016, the distribution of cumulative hazard rates kept shifting to the right, which means in general houses were exposed to higher shale risk.

We estimate the parameters of the PH model with maximum likelihood estimation:

Table 4: Estimation Results of PH Model

	PH Coefficient
Number of producing wells within 2-km radius	-0.0239***
	(-68.56)
Distance to the nearest producing well	-0.00216***
	(-134.21)
Constant	-6.204***
	(-170.32)
logP	0.615***
	(146.66)
N	82,400

Notes. t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The results in Table 4 suggest that encroaching wells make a "failure" more likely, because the longer is the distance to the nearest producing well, the lower is the likelihood of failure. However, having many wells nearby (i.e., within 2,000 meters) also decreases the likelihood of a failure event. This is because having many wells nearby suggests that an area has already been developed and reduces the likelihood of more wells being drilled very close to the house in question.

4 Theory

The theory for analyzing the decisions made by lenders with respect to various risks and lending rates is similar to that used to describe the trade-offs made by workers choosing amongst risky jobs. This is the idea behind *wage hedonics*, where the compensating differentials associated with different job attributes are used to measure their values (Viscusi, 1993). The idea even appears in Adam Smith's seminal work (Smith, 2002, first published in 1776), where risky or unpleasant jobs are noted as commanding a premium. The problem has a simple graphical interpretation, which is described in the following figure. Firms are described by a series of iso-profit curves, denoted by π_A and π_B. Along each curve, a lower risk must be accompanied by a lower wage in order for a constant level of profit to be maintained. Firm A is better at providing a low risk environment and is able to pay a higher wage when risks are low compared with firm B.

Workers face similar trade-offs, which are described by iso-expected utility curves EU_0 and EU_1. In particular, each worker is willing to accept a higher risk in exchange for a higher wage payment, with their willingness to do so, or marginal rate of substitution between risk and compensation, being summarized by the slope of the iso-expected utility curve.

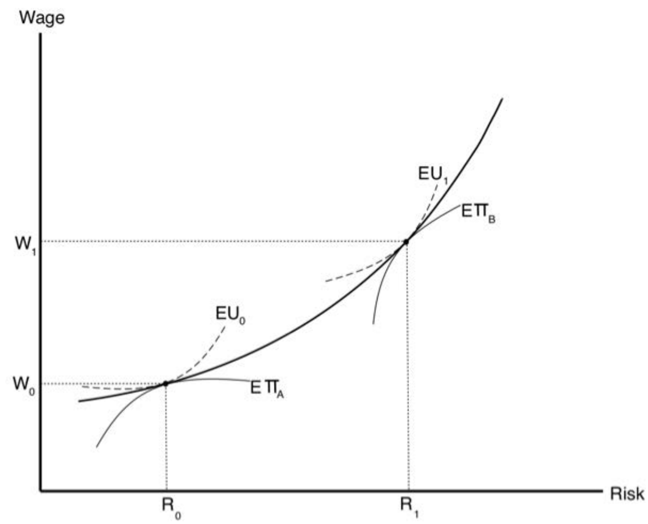


Figure 4: Iso-expected Utility Curves

Notes. Shows the iso-expected utility curves of workers. Each worker is willing to accept a higher risk in exchange for a higher wage payment, and the marginal rate of substitution between risk and compensation is summarized by the slope of the iso-expected utility curve.

As in other hedonic applications, the allocation of workers to jobs involves a sorting process whereby workers match with firms that yield them the highest expected utility, given firms' wage offers described by their iso-profit curves. In particular, the best that worker #0 (who requires relatively little in terms of compensation in exchange for taking on more risk) can do is to match with firm A, which requires relatively small increases in wages in exchange for more risk in order to hold profits constant. Worker #0 ends up netting (R_0, W_0) in hedonic equilibrium. Worker #1 requires more compensation in exchange for taking on additional risk (i.e., a steeper indifference curve) and ends up choosing to match with firm B, yielding (R_1, W_1). With continuously distributed workers and firms, the hedonic wage function describes the set of tangency points between the iso-profit functions of firms and iso-expected utility functions of workers.

We use $U(W)$ to represent the utility from wage W if a worker is in the healthy state and $V(W)$ to represent the utility from the same wage in an injured state; p represents the probability of that injury. EU represents expected utility:

$$EU = (1 - p)U(W) + pV(W)$$

Taking the total differential of expected utility yields:

$$(1-p)U'(W)dW + pV'(W)dW - U(W)dp + V(W)dp = 0$$

With some re-arranging, we derive an expression for the slope of an iso-expected utility curve:

$$dW[(1-p)U'(W) + pV'(W)] + dp[V(W) - U(W)] = 0$$
$$\Rightarrow \quad \frac{\mathrm{d}W}{\mathrm{d}p}\bigg|_{dEU=0} = -\frac{EU_p}{EU_W} = \frac{U(W) - V(W)}{(1-p)U'(W) + pV'(W)}$$

EU will be positively sloped if $U(W) - V(W) > 0$ (i.e., utility from a given wage is greater in the non-injured state) and if $U'(W), V'(W) > 0$ (i.e., utility is increasing in wages regardless of the injury state). Second-order conditions require that curves have convexity as illustrated. Wage hedonic techniques use the slope of the estimated relationship between risk and wage to recover $\frac{dW}{dp}|_{dEU=0}$.

In the case of banks issuing mortgages, there are two forms of risk that we consider: (i) shale (p_1) and (ii) income (p_2). Shale risk refers to the list of reasons that shale development might put a house into technical default according to the standard mortgage guidelines described in the introduction. Foremost is the risk of any outcome that might detract from the house's value as a residential structure. Income risk refers to the standard risk that liquidity constrained individuals will suffer income shocks that make it impossible for them to make timely mortgage payments. Shale risk and income risk combine to create default risk, which is ultimately what concerns the lender. Perceived default risk faced by lender i is $D_i = D_i(p_1, p_2)$, where $0 \leq D_i \leq 1 \; \forall i$ and $\frac{\partial D_i}{\partial p_j} \geq 0 \; \forall i$ and for $j = 1, 2$. Assume that $D_i(p_1, p_2)$ is quasi-convex.

Firm i's expected profit from making a loan with risks p_1 and p_2 is given by:

$$E\Pi_i = (1 - D_i(p_1, p_2))\pi_i^G(\sigma) + D_i(p_1, p_2)\pi_i^B$$

where $\pi_i^G(\sigma)$ measures the profit associated with the 'good' state (i.e., in which there is no foreclosure) when the mortgage rate is σ (i.e., the actual rate or an indicator for subprime). $\pi_i^B(\sigma)$ measures expected profits in the bad state in which a foreclosure takes place and the lender takes control of the property, selling it for a loss. Taking the total derivative of expected profit with respect to the two forms of risk and rearranging, we can find the change in p_2

associated with a small change in p_1 that would hold $E\Pi_i$ fixed.

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}p_j}\right|_{dE\Pi_i=0} = \frac{\frac{\partial E\Pi_i}{\partial p_j}}{\frac{\partial E\Pi_i}{\partial \sigma}} = \frac{\frac{\partial D_i}{\partial p_j}[\pi_i^G(\sigma) - \pi_i^B(\sigma)]}{(1 - D_i(p_1,p_2))\pi_j^{G\prime}(\sigma) + D_i(p_1,p_2))\pi_j^{B\prime}(\sigma)} \quad j = 1,2$$

therefore,

$$\left.\frac{\frac{\mathrm{d}\sigma}{\mathrm{d}p_1}}{\frac{\mathrm{d}\sigma}{\mathrm{d}p_2}}\right|_{dE\Pi_i=0} = \frac{\frac{\frac{\partial E\Pi_i}{\partial p_1}}{\frac{\partial E\Pi_i}{\partial \sigma}}}{\frac{\frac{\partial E\Pi_i}{\partial p_2}}{\frac{\partial E\Pi_i}{\partial \sigma}}} = \frac{\frac{\partial E\Pi_i}{\partial p_1}}{\frac{\partial E\Pi_i}{\partial p_2}}$$

This final term represents the negative of the slope of the iso-expected profit curve. As such, we can recover firm i's willingness to take on additional income risk in exchange for a one-unit reduction in shale risk by taking the ratio of the two hedonic gradients. Under our assumptions, this will be invariant to how we define the lending rate, and we can simply use a probability of subprime rather than an exact rate, which is useful because we do not see the exact rate unless it is a subprime. We therefore learn about the lender's willingness to trade-off one type of risk for another holding the overall perceived default risk constant.

5 Empirical Model

Using a binary indicator variable for a high-priced mortgage as our proxy for subprime, we would like to measure the way in which the likelihood of a subprime mortgage varies with different risk variables without imposing a great deal of structure. Following on the model of Bajari and Benkard (2005), we allow the data to speak to the shape of this equilibrium hedonic function (in two different dimensions of risk) and recover a flexible representation of lender preferences that characterizes the distribution of heterogeneity. We then explore how these preferences vary over time and with water source.

Parametric regression models (such as the probit and logit) are commonly used to study binary dependent variables, but these models impose restrictive functional form assumptions. Semi-parametric binary choice estimators (single-index models) relax these restrictions but they effectively reduce the heterogeneity in the X characteristics to a single dimension. This restricts the interaction between covariates – specifically, the ratio of two marginal effects does not depend on X in the single-index model. Because we are interested in heterogeneity in the tradeoffs between two types of risk (income risk and shale risk), we instead follow Frölich (2006) to perform non-parametric regression for binary dependent variables, a so-called local likelihood logit estimation. The local likelihood logit estimator is:

$$\hat{E}[Y \mid X = x] = \frac{1}{1 + e^{-x'\hat{\theta}_x}}$$

$$\text{where, } \hat{\theta}_x = \arg\max_{\theta_x} \sum_{i=1}^{n} \Big(Y_i \ln \Big(\frac{1}{1 + e^{-X_i'\theta_x}} \Big) + (1 - Y_i) \ln \Big(\frac{1}{1 + e^{X_i'\theta_x}} \Big) \Big) K_H(X_i - x)$$

The regressors include shale risk (defined as cumulative hazard rate), income risk (defined as the debt-to-income ratio), housing characteristics (lot size, house size, number of bathroom, number of bedroom and year built of a property), loan attributes (yield of 30-year treasury bond, whether the rate is fixed or not), and year dummies. The kernel weight $K_H(X_i - x)$ is computed as:

$$K_{h,\delta,\lambda}(X_i - x) = \prod_{q=1}^{q_1} \kappa\Big(\frac{X_{q,i} - x_q}{h}\Big) \prod_{q=q_1+1}^{q_2} \delta^{|X_{q,i} - x_q|} \prod_{q=q_2+1}^{Q} \lambda^{\mathbb{1}(X_{q,i} \neq x_q)} \tag{2}$$

The kernel function measures the distance between X_i and x for each variable through one of three components, depending upon the particular type of variable: continuous regressors (the first term), ordered discrete regressors (the second term) and unordered discrete regressors (the third term). In our application, x's include cumulative hazard rate, debt-to-income ratio, lot size, house size, and yield of 30-year treasury bond as continuous regressors; number of bathrooms, number of bedrooms, and the age of each property as ordered regressors; year dummies, and whether the rate is fixed or not as non-ordered regressors. Values for the bandwidth and hyper-parameters (h, δ, λ) in the kernel function are obtained from cross-validation, and the cross-validation criterion is based on maximizing the leave-one-out fitted likelihood function:

$$CROSSVAL(h, \lambda, \delta) = \sum_{i=1}^{n} \Big[Y_i \ln g(X_i, \hat{\theta}_{-X_i|h,\delta,\lambda}) + (1 - Y_i) \ln(1 - g(X_i, \hat{\theta}_{-X_i|h,\delta,\lambda})) \Big]$$

where $g(\cdot)$ is our local likelihood logit estimator.

We are interested in recovering banks' willingness to trade income risk for shale risk, which is revealed in the ratio of the two hedonic gradients, where:

$$\rho(x) = \frac{\frac{\partial \hat{E}[Y|X=x]}{\partial x_1}}{\frac{\partial \hat{E}[Y|X=x]}{\partial x_2}} = \frac{\hat{\theta}_1(x)}{\hat{\theta}_2(x)} \tag{3}$$

Unlike the single index models, this ratio is a flexible function of the regressors, x. The negative of this ratio defines the negative of the slope of the expected iso-profit curve drawn in (shale risk, income risk)-space.[28] A higher value suggests that iso-curve has become steeper, implying that lenders require a larger reduction in income risk in order to accept another unit of shale risk, holding expected profits constant.

6 Results

We begin our analysis by exploring the determinants of subprime status. In particular, we model the likelihood of subprime as a function of housing attributes, loan attributes (fixed or variable rate, and yield curve of 30-yr treasure bond), year dummies, the debt-to-income ratio (income risk), and the shale risk (cumulative hazard rate as defined in equation 1). We estimate this model separately for two time periods — preceding and following the financial crisis (2001-2007 and 2010-2016). We expect that relative concerns of lenders over various sources of default risk might have changed after the financial crisis; in particular, the discussion in Section 2 suggests that policy makers placed increasing attention on shale risk beginning in 2010. Table 5 shows the results of Tobit model, which uses the actual mortgage rate as the dependent variable, recognizing that the rate is censored if it is within 1.5 percentage points of the prime rate. First, the Tobit results show that conditional on a loan being approved, the income risk parameter became smaller in period 2. Meanwhile, the shale risk parameter became larger in that period. Second, the results show that the lender's average willingness to trade-off income risk for shale risk rose substantially, because the ratio of the shale risk to income risk parameters rose substantially in period 2.[29] While the Tobit results suggest that lenders may have become increasingly concerned about shale risk following the financial crisis, the strong functional form restrictions placed on the model may constrain our ability to learn about these relationships. Therefore, we relax these constraints by employing a flexible local logit specification.

We use the flexible local logit specification to estimate preference ratios $\rho(x)$ that illustrate lenders' indifference curves in (shale risk, income risk) space. We begin by taking the distribution of the ratios of shale risk and income risk, as it was defined in equation 3. These ratios represent the slopes of lenders' "indifference curves", drawn in the space of the two types of risks. We then calculate the kernal weighted averages of all estimated preference ratios at each point in risk space, where the smoothing parameter is set using Silverman's rule. The subsequent mapping

[28] Figure B.1 shows an example of iso-profit curves.

[29] In our analysis, shale risk is measured by cumulative hazard rate. As a robustness check, in the online appendix C we show the results of using two alternative measures of shale risk: distance to the nearest producing well and number of producing wells within 2,000 meters. We also show the results using both the Tobit specification shown here and a logit using a subprime indicator as the dependent variable. Results of robustness analysis are consistent with our findings here.

Table 5: Regression Results

	Tobit Model period 1: 2001-2007	Tobit Model period 2: 2010-2016
Cumulative hazard rate (shale risk)	0.0399***	0.0818***
	(0.00805)	(0.0165)
Debt-to-income	0.112***	0.0519**
	(0.00722)	(0.0164)
FHA loans	-1.918***	1.254***
	(0.0324)	(0.0339)
VA loans	-2.851***	-1.810***
	(0.162)	(0.165)
Securitized loans	0.727***	-0.222***
	(0.0127)	(0.0273)
Yield of 30 year treasury bond	-0.191***	0.00947
	(0.0268)	(0.0390)
Number of bedrooms	0.202***	0.145***
	(0.0121)	(0.0291)
Number of bathrooms	-0.171***	-0.0361
	(0.0153)	(0.0369)
Living size	-0.000306***	-0.000440***
	(0.0000119)	(0.0000303)
Land size	-0.00673***	-0.000446
	(0.000891)	(0.00215)
Age of property	0.00647***	0.00557***
	(0.000347)	(0.000743)
Non-White	0.443***	-0.00933
	(0.0127)	(0.0320)
Constant	-3.242***	-3.580***
	(0.217)	(0.433)
Sigma	1.185***	1.482***
	(0.00735)	(0.0200)
N	131,548	51,264
Year Fixed Effects	Y	Y
City Fixed Effects	Y	Y

Notes. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

describes the indifference curve map at every point in risk space. In Figure 5 darker black arrows are used to describe mean estimates, while lighter gray arrows describe the 5% and 95% confidence bands calculated from bootstraps.

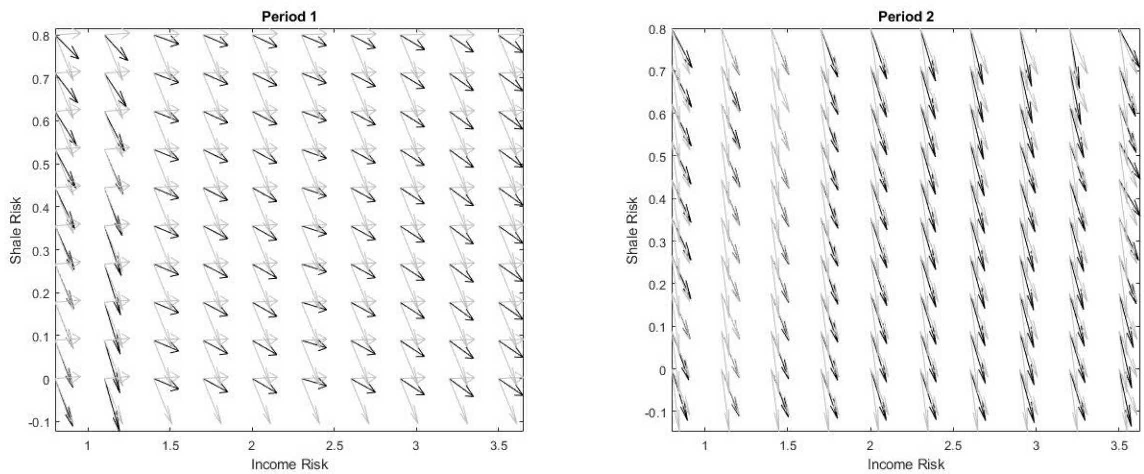


Figure 5: Indifference Curve Map

Notes. Shows lender's indifference curves in (shale risk, income risk) space. The black arrow shows the mean estimates of the ratios of shale risk and debt-to-income. The gray arrows shows the 5% and 95% confidence bands.

A number of interesting features appear immediately. First, in the period before the financial crisis, the slope of the indifference curves are statistically indistinguishable from zero. Assuming that income risk is always considered by lenders to be a "bad," this would imply that shale risk was not taken into consideration by banks in the earlier period. The right panel of figure 5 shows that, after the financial crisis, lenders' indifference curves become negatively sloped for those houses, and those slopes are statistically significant. Put differently, the results show that lenders are willing to take on significantly more income risk to avoid additional shale gas risk in the post-crisis period.

7 Valuing Shale Risk

In section 6 we showed how lenders' preference over shale risk relative to income risk changed after the financial crisis. In order to monetize lenders' willingnesses-to-pay to avoid shale risk, we use transaction and foreclosure information from Dallas County. Dallas neighbors Tarrant County and has comparable land and population sizes and population density, yet Dallas does not have active oil and natural gas drilling.[30,31]

Our calculation combines the estimated relationships between the debt-to-income ratio and rate of foreclosure, as described in the left panel of Table 6,[32] and between the foreclosure rate and transaction value, as described in the right panel of Table 6. In particular, we observe that a standard deviation increase in the debt-to-income ratio increases the likelihood that a home is foreclosed in the future by 0.129 in Dallas County. Moreover, a foreclosed home in that county sells at a 28% discount, controlling for other observable house characteristics and city and year fixed effects.

Table 6: Simple Foreclosure Logit & Hedonic

	Tarrant	Dallas
Dependent Variable: Loan Foreclosed Dummy		
Loan-to-Income	0.23083***	0.12853***
	(0.01035)	(0.01002)
Observations	216,819	192,206
Year FE	x	x
City	x	x

	Tarrant	Dallas
Dependent Variable: Log Sales Values		
Foreclosure	-0.22386***	-0.28039***
	(0.00221)	(0.00255)
Observations	206,601	222,065
City FE	x	x
Year FE	x	x

Notes. Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Using the logarithm of the mean sales value for single-family residential homes located in Dallas County, we calculate the willingness-to-pay to avoid income risk using the formula:

$$WTP = \frac{\partial V_0}{\partial foreclosure} P(foreclosure|X)$$
$$= exp(11.12) - exp(11.12 - 0.129 * 0.28) = 2,394.9$$

where V_0 is the mean value of a property sold in Dallas County within the sample period. The estimates from Dallas County suggest that an additional unit of income risk is valued at $2,394.9, which is roughly 1.4% of the mean sales value among all homes sold in Dallas County during the sample period. The median ratio of shale risk to income risk is 0.34 in the first period and 1.31 in the second period. So, the WTP for one unit of shale risk is $\$2,394.9 * 0.34 = \$814$ in the first period and $\$3,137$ in the second period. The next question is how to understand one unit of shale risk. Based on the parametric form of the proportional hazard model, cumulative

[30] In particular, Dallas County is comprised of 909 square miles, 2.5 million people, and a population density of 2,950 individuals per square mile. Tarrant County, on the other hand, is comprised of 902 square miles, 1.8 million people, and a population density of 2,095 individuals per square mile.

[31] Online appendix D describes the rate of foreclosure by county across time.

[32] Table 6 also includes estimates using data from Tarrant County to demonstrate similarity across counties. However, note that debt-to-income has a smaller effect on the likelihood of foreclosure and foreclosed homes sell for more, on average, than those located in Dallas.

hazard rate is derived as:

$$H(t) = \int_0^t h(u)du = \int_0^t pu^{p-1} \exp(\mathbf{x}'\beta)du$$
$$= \exp(\mathbf{x}'\beta) \cdot t^p$$

Therefore to increase cumulative hazard rate by 1 is roughly equal to adding t months of exposure, where t satisfies:

$$1 = \exp(\bar{\mathbf{x}}'\beta) \cdot t^p$$

Given the median value of independent variables, banks are willing to sacrifice \$814 for one unit of shale risk, which is 10,884 months in the first period, and banks are willing to sacrifice \$3,137 to postpone drilling activities by 113 months in the second period. In other words, to postpone nearby drilling activity by one year, banks are willing to give up \$334 in the second period but only \$0.89 in the first period.

In order to scale the willingness-to-pay, we compare that value to the mean value earned on an average mortgage issued in Dallas. We approximate that the average mortgage interest rate is roughly 6.7% and the average loan amount is \$151,476. Further, most of the loans in Dallas have 30 year term lengths and lenders earn around \$190,513 on the average loan. Our willingness to pay to avoid one unit of shale risk in the latter period comprises roughly 1.6% of the profit earned on an average Dallas mortgage.

8 Conclusion

This paper explores the housing market impacts of shale gas development. Previous work has done so using data on the capitalization of shale gas activities into housing prices and hedonic theory to give those estimates a welfare interpretation. In this paper, we approach the question from a different perspective, focusing instead on the pricing decisions of mortgage lenders. Mortgage lenders bear the risk that borrowers will default — a fact highlighted by a housing market bust and financial collapse over a decade ago. These swings in the housing market coincided with the U.S. shale boom. By 2010, lenders and policy-makers had become much more mindful of these risks and began to recognize the role that shale gas development might play in default.

From the perspective of hedonic analysis, leveraging the actions of lenders provides an advantage over using the decisions of home buyers, since the latter engage in only a few transactions over the course of their lifetimes and may not properly "price" features such as the risk from shale proximity into the value of a house. Lenders, who may make thousands of loans, have the market experience to do this. We estimate their relative preferences for two different types of risk — shale and income. We find strong evidence that lenders became more concerned with shale risk, in terms of their willingness to trade it for increased income risk, in the period following the financial crisis. These results confirm the conclusions of previous research with respect to the expected house price impacts of shale gas development (Muehlenbachs et al., 2015) and suggest that policymakers need to consider the effects of rules and regulations involving the shale gas industry on other markets, including the market for home loans.

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A Data

A.1 Distribution of Cumulative Hazard Rate

Figure A.1 depicts the distributions of cumulative hazard rates across years. The mass point at 0 indicates the number of houses that have not yet been exposed to any shale risk. The mass point at 2 indicates houses that have had a failure (a producing well appears within 1-km radius).

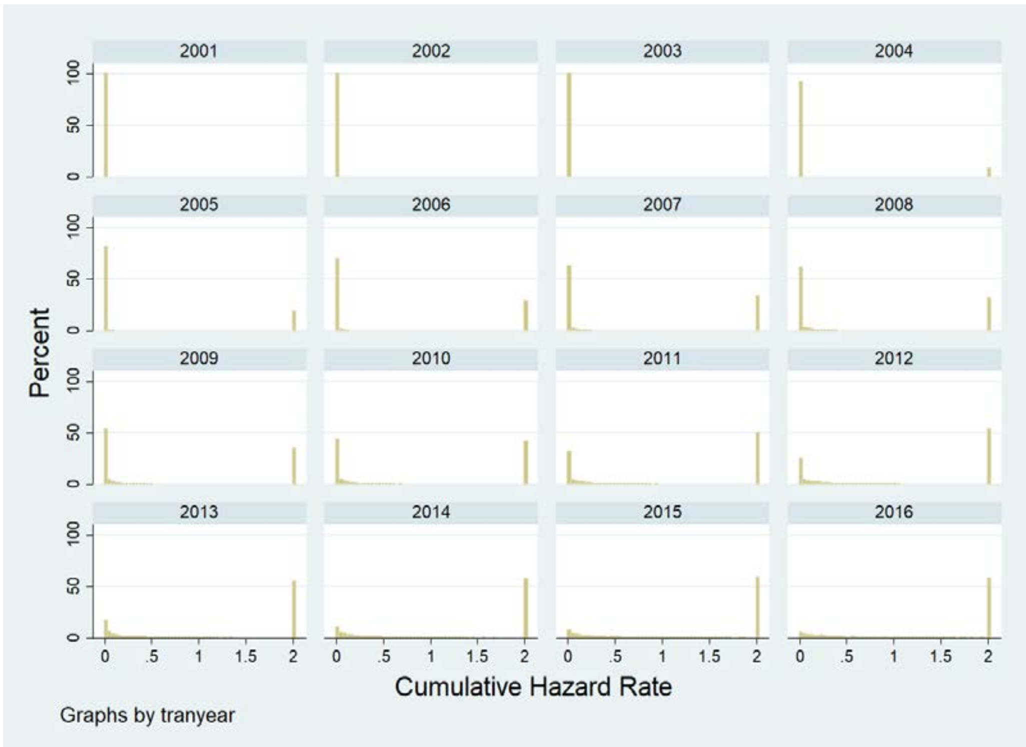


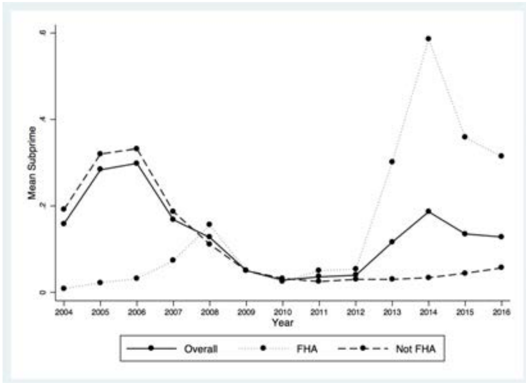
Figure A.1: Distribution of Cumulative Hazard Rate

Notes. Shows the distribution of cumulative hazard rates and how it changed across years.

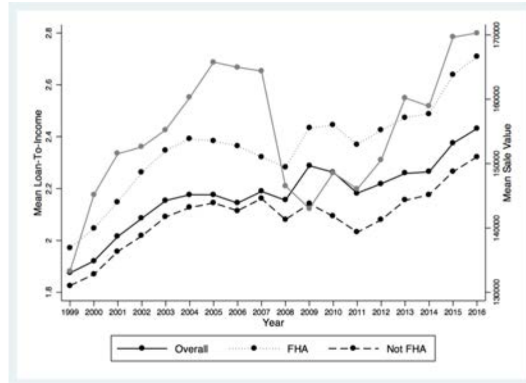
From 2001 to 2016, the distribution of cumulative hazard rates kept shifting to the right, which means in general houses were exposed to higher shale risk. The mass at 2 kept increasing means that more houses had a failure (having a producing well appears within 1-km radius), and the mass at 0 kept decreasing means that more houses started to be exposed to shale risk (having a producing well appears within 3-km radius).

A.2 FHA and VA

Figures A.2a and A.2b utilize the Texas-wide HMDA data to describe the frequency of high interest rate loans and mean loan-to-income values across years, stratified by whether the loan was insured by the Federal Housing Administration or not. With a decrease in FHA loans more generally, we find that FHA loans are less likely to be issued with high interest rates before 2007 as demonstrated in Figure A.2a. After 2012, the frequency of FHA, high interest loans soar, commensurate with an overall increased dependency on FHA. Figure A.2b demonstrates that FHA consistently insures loans issued to higher loan-to-income borrowers. The gray line demonstrates the mean sale value of homes across the same period (second y-axis), and one can visually see the fall in home prices in 2008 and 2009.



(a) Mean Frequency of Subprime Interest Rates (by FHA)



(b) Mean Loan-to-Income (by FHA)

Figure A.2: FHA Summary

Notes. A.2a tracks the mean likelihood that an FHA loan is issued with a high interest rate. We find that there are significantly higher interest rates among FHA loans after the subprime crisis. A.2b tracks the mean loan-to-income values among all borrowers and stratified according to whether the purchased home is insured by FHA. The gray line describes the mean sales values using the second y-axis.

A.3 Year-Specific Effects by Securitization

Table A.1 summarizes the sale and loan characteristics across loans that are not securitized (in the data) and commercially and government securitized. Loans securitized by a government entity like Freddie or Farmer Mac and Fannie or Ginnie Mae, are associated with lower income buyers, value homes, and loan-to-income ratios.

Table A.1: Summary Statistics by Securitization

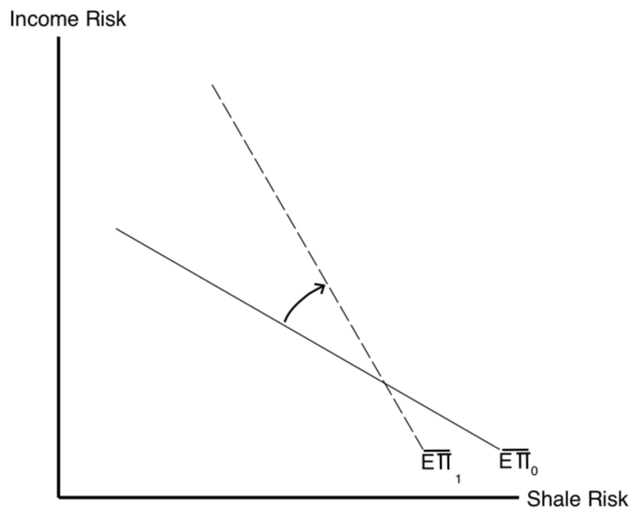
	Not Secured		Gov't Secured		Commercially Secured	
	Mean	(Std. Dev.)	Mean	(Std. Dev.)	Mean	(Std. Dev.)
High Interest Loan	0.155	(0.362)	0.043	(0.202)	0.142	(0.349)
Income	$101,355	(92,370)	$84,116	(55,295)	$85,716	(62,805)
Loan-to-Income	2.115	(0.838)	2.101	(0.787)	2.206	(0.799)
Sale Amount	$165,756	(123,645)	$151,275	(80,178)	$155,358	(93,594)
Loan Value	$181,122	(164,265)	$154,592	(83,170)	$166,751	(108,634)
Annualized L2I	0.173	(0.069)	0.167	(0.057)	0.175	(0.061)
Foreclosure	0.089	(0.285)	0.074	(0.262)	0.077	(0.267)
Fixed Loan	0.785	(0.411)	0.951	(0.215)	0.855	(0.352)
FHA Loan	0.101	(0.301)	0.281	(0.45)	0.314	(0.464)
Owner Occ.	0.875	(0.331)	0.931	(0.253)	0.934	(0.249)
Obs.	91,311		188,701		300,550	

Notes. Summarizes the primary variables used to describe the loan characteristics across loans that are and are not securitized.

B Theory

Figure B.1 illustrates a simple case with linear iso-profit curves.

Figure B.1: Iso-profit Curves



The negative of the ratio of the two hedonic gradients defines the negative of the slope of the expected iso-profit curve drawn in (shale risk, income risk)-space. A higher value suggests that iso-curve has become steeper, implying that lenders require a larger reduction in income risk in order to accept another unit of shale risk, holding expected profits constant.

C Robustness of Regression Results

Table C.1 shows the results of simple logit regression. Result here is consistent with our main finding: the lender's average willingness to trade-off income risk for shale risk rose substantially in period 2, because the ratio of the shale risk to income risk parameters rose substantially.

Table C.1: Simple Logit Regression Results

	Logit Model period 1: 2001-2007	Logit Model period 2: 2010-2016
Cumulative hazard rate (shale risk)	0.0764***	0.107***
	(0.0129)	(0.0228)
Debt-to-income	0.187***	0.0610**
	(0.0115)	(0.0225)
FHA loans	-3.263***	1.860***
	(0.0660)	(0.0443)
VA loans	-5.348***	-3.041***
	(0.448)	(0.356)
Securitized loans	1.157***	-0.158***
	(0.0200)	(0.0370)
Yield of 30 year treasury bond	-0.266***	0.0922
	(0.0433)	(0.0562)
Number of bedrooms	0.337***	0.186***
	(0.0195)	(0.0404)
Number of bathrooms	-0.283***	-0.0663
	(0.0251)	(0.0522)
Living size	-0.000502***	-0.000616***
	(0.0000195)	(0.0000431)
Land size	-0.0109***	-0.00172
	(0.00148)	(0.00315)
Age of property	0.0105***	0.00651***
	(0.000552)	(0.00101)
Non-White	0.749***	0.00573
	(0.0202)	(0.0438)
Constant	-6.588***	-5.141***
	(0.490)	(0.665)
N	131,489	51,198
Year Fixed Effects	Y	Y
City Fixed Effects	Y	Y

Notes. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C.2 shows the results using the minimum distance to the nearest well as the measure of shale risk, and Table C.3 shows the results using the number of producing wells within 2-km as the measure of shale risk. Table C.2 shows that the estimated coefficient of shale risk has increased by 10 times following the financial distress, which means lenders may have become increasing concerned about shale risk after the financial crisis. Although the coefficient of shale risk is insignificantly different from zero in both the before and after periods, the standard error of the coefficient of shale risk is much smaller in the second period. The insignificance is mainly caused by the fact that these simple measures of shale risk cannot accurately measure the shale risk, as explained in section 3.4. Regardless of the insignificance, however, results in Table C.2 and Table C.3 are qualitatively consistent with our main findings.

Table C.2: Regression Results with nearest producing well

	Logit Model period 1: 2001-2007	Logit Model period 2: 2010-2016	Tobit Model 2001-2007	Tobit Model 2010-2016
Distance to the nearest producing well	-0.00000347	-0.0000489	-0.00000232	-0.0000323
	(0.00000339)	(0.0000288)	(0.00000211)	(0.0000195)
Debt-to-income	0.187***	0.0638**	0.112***	0.0542***
	(0.0115)	(0.0224)	(0.00722)	(0.0164)
FHA loans	-3.288***	1.864***	-1.938***	1.258***
	(0.0665)	(0.0442)	(0.0327)	(0.0339)
VA loans	-5.360***	-3.039***	-2.854***	-1.812***
	(0.448)	(0.356)	(0.161)	(0.165)
Securitized loans	1.164***	-0.156***	0.732***	-0.220***
	(0.0200)	(0.0370)	(0.0127)	(0.0274)
Yield of 30 year treasury bond	-0.262***	0.0920	-0.188***	0.00918
	(0.0434)	(0.0563)	(0.0270)	(0.0390)
Number of bedrooms	0.338***	0.188***	0.203***	0.146***
	(0.0195)	(0.0404)	(0.0121)	(0.0291)
Number of bathrooms	-0.287***	-0.0704	-0.174***	-0.0397
	(0.0251)	(0.0522)	(0.0153)	(0.0370)
Living size	-0.000504***	-0.000620***	-0.000307***	-0.000443***
	(0.0000195)	(0.0000431)	(0.0000119)	(0.0000304)
Land size	-0.0107***	-0.00149	-0.00673***	-0.000221
	(0.00149)	(0.00316)	(0.000893)	(0.00216)
Age of property	0.00961***	0.00554***	0.00610***	0.00479***
	(0.000542)	(0.00102)	(0.000340)	(0.000742)
Non-White	0.754***	0.00928	0.448***	-0.00627
	(0.0203)	(0.0437)	(0.0127)	(0.0320)
Constant	-1.031***	-4.912***	-0.501**	-3.418***
	(0.256)	(0.663)	(0.159)	(0.432)
Sigma				
			1.180***	1.483***
			(0.00732)	(0.0200)
N	87,583	51,198	87,623	51,264
Year FE	Y	Y	Y	Y
City FE	Y	Y	Y	Y

Notes. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C.3: Regression Results with Number of Producing Wells

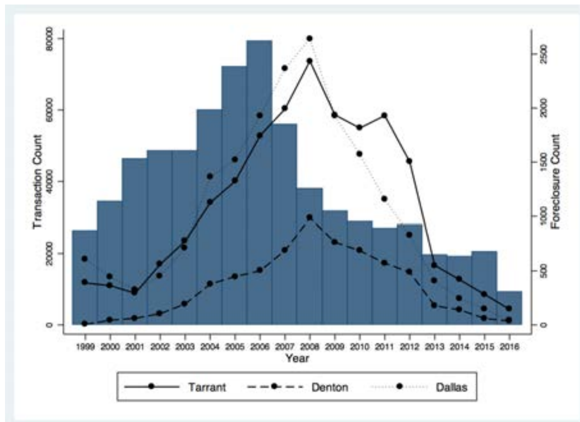
	Logit Model period 1: 2001-2007	Logit Model period 2: 2010-2016	Tobit Model 2001-2007	Tobit Model 2010-2016
Number of producing wells within 2000m	0.00432*	0.00232	0.00258*	0.00172
	(0.00174)	(0.00146)	(0.00110)	(0.00108)
Debt-to-income	0.187***	0.0643**	0.113***	0.0546***
	(0.0115)	(0.0224)	(0.00722)	(0.0164)
FHA loans	-3.274***	1.865***	-1.924***	1.259***
	(0.0660)	(0.0442)	(0.0325)	(0.0339)
VA loans	-5.363***	-3.039***	-2.861***	-1.812***
	(0.448)	(0.356)	(0.162)	(0.165)
Securitized loans	1.162***	-0.157***	0.730***	-0.220***
	(0.0200)	(0.0370)	(0.0127)	(0.0274)
Yield of 30 year treasury bond	-0.265***	0.0899	-0.190***	0.00708
	(0.0433)	(0.0562)	(0.0268)	(0.0390)
Number of bedrooms	0.338***	0.189***	0.202***	0.147***
	(0.0195)	(0.0404)	(0.0121)	(0.0291)
Number of bathrooms	-0.285***	-0.0714	-0.172***	-0.0408
	(0.0251)	(0.0522)	(0.0153)	(0.0370)
Living size	-0.000503***	-0.000620***	-0.000306***	-0.000443***
	(0.0000195)	(0.0000431)	(0.0000119)	(0.0000304)
Land size	-0.0107***	-0.00161	-0.00668***	-0.000333
	(0.00148)	(0.00316)	(0.000892)	(0.00216)
Age of property	0.00977***	0.00552***	0.00615***	0.00479***
	(0.000542)	(0.00102)	(0.000341)	(0.000744)
Non-White	0.751***	0.0118	0.444***	-0.00444
	(0.0202)	(0.0437)	(0.0127)	(0.0320)
Constant	-6.585***	-5.003***	-3.245***	-3.479***
	(0.490)	(0.664)	(0.217)	(0.433)
Sigma				
			1.185***	1.483***
			(0.00735)	(0.0200)
N	131,489	51,198	131,548	51,264
Year FE	Y	Y	Y	Y
City FE	Y	Y	Y	Y

Notes. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D Rate of Foreclosure by County

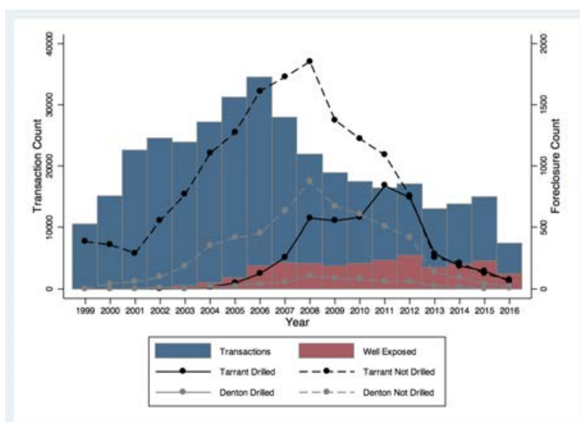
Figure D.1 describes the rate of foreclosure by county across time, and Figure D.2 describes foreclosure rates for homes with well exposure and not for Tarrant and Denton counties. Interestingly, shale exposed areas of Tarrant County experience the peak foreclosure period in 2011 rather than 2008 like the non-exposed regions, including Dallas County. The year 2011 is during a period of volatile natural gas prices, which likely affected the streams of royalty incomes for individuals with active oil and natural gas leases.

Figure D.1: Foreclosures by County



Notes. Count of foreclosed sales by year and county (right y-axis) layered on the count of total transactions (left y-axis).

Figure D.2: Foreclosures by Shale Exposure



Notes. Count of foreclosed sales by year and whether the property is exposed to drilling activity in Tarrant County (right y-axis) and layered on the count of total transactions (blue) and shale exposed transactions (red) each year.