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This paper supersedes the old version:
"Rational but Not Prescient: Borrowing during the
Fracking Boom"

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10-J

Borrowing Based on Great Expectations: Evidence from the Origins of Fracking[*]

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January 13, 2025

Abstract

We use the origins of fracking to study how people respond to a large and uncertain permanent income shock. Following the arrival of news in 2003 that fracking was commercially viable, the average person owning rights to natural gas deposits in the Barnett Shale could plausibly expect to earn a present value of about $33,000 from leasing the rights to energy firms. Anticipating the income, people who signed leases after 2006 borrowed $5,400 more than non-leaseholders as of 2006. Leases not yet signed could not be collateralized, suggesting that expectations of increased permanent income rather than relaxed credit constraints drove leaseholder borrowing. A consumption smoothing model that uses observed well productivity and Hotelling's rule for pricing non-renewable resources suggests that borrowing as of 2006 was rational to conservative. When natural gas prices unexpectedly crashed during 2009-2019, leaseholders reduced their debt and had delinquency and bankruptcy rates that indicate limited financial distress, suggesting that their borrowing prior to signing a lease was not impulsive.

Keywords: income shocks, expected royalties, leases, borrowing, rational, expectations
JEL Classification Numbers: D12, G51, Q33

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1   Introduction

Many people in the United States own the rights to the oil or natural gas beneath their land. Thus, in 2003 they faced a potentially large windfall when hydraulic fracturing and horizontal drilling unexpectedly made large natural gas deposits in the Barnett Shale economical to exploit. In exchange for leasing out their gas rights, they would receive a one-time signing bonus followed by a stream of royalties over several decades that depended on natural gas prices and drilling outcomes. While signing bonuses were generally modest, expected royalties represented a positive permanent income shock of roughly $33,000 because of a bullish outlook for domestic natural gas prices.

We study the borrowing behavior of consumers during 2003-2006 who signed fracking leases in 2007 or later. Because fracking leases not yet in existence could not be collateralized, the setup sheds light on questions about the effect of unanticipated and uncertain income shocks apart from any loosening of credit constraints. Consistent with the permanent income hypothesis (Jappelli and Pistaferri, 2010), did consumers borrow more before receiving any lease income? If so, was the borrowing rational given the income that could be expected based on the information at the time (Lucas and Lucas, 1987; Sargent, 2013)? Or is the permanent income hypothesis irrelevant because consumers did not respond at all to the news? Lastly, following the dramatic fall in natural gas prices in 2009 and subsequent low prices, did leaseholders reduce their debt as predicted by the permanent income hypothesis?

To answer these questions, we study fracking where it first emerged as a commercially viable technology, the natural-gas rich Barnett Shale, which covers the Western half of Dallas-Fort Worth Texas. Using archival sources, we document that the emergence of fracking at the end of 2002 and into 2003 was a positive shock to expected permanent income for owners of natural gas rights and who eventually signed fracking leases. To understand how people respond to a large and uncertain positive income shock, we construct a dataset that tracks financial outcomes from 2000:Q1 to 2019:Q4 for more than 5,500 people who lived in the Barnett Shale prior to the boom and who signed leases with energy firms in 2007 or later.

Thus, our dataset spans a period before, during, and after the arrival of news that fracking was commercially viable, and lends itself to a difference-in-differences empirical approach.

The data come from two proprietary sources: Enverus data covering the near universe of oil and gas leases in the Barnett Shale and the New York Federal Reserve Bank's Consumer Credit Panel, which is a five-percent anonymous, random sample of the U.S. consumer population (Lee and van der Klaauw, 2010). To refine our control group and create a credible counterfactual, we follow Imbens (2015) and match local resident leaseholders with non-leaseholders living outside the shale but still in the Dallas- Forth Worth Metropolitan Area. With more than 66,000 potential control observations, we obtain close to exact matches.

By 2006, before any of our sample leaseholders had signed a lease, on average they had accumulated $5,400 in greater debt compared to non-leaseholders in anticipation of receiving a $33,000 increase in permanent income. We note that Mian and Sufi (2011) estimate the borrowing response of households in the USA during 2002-2006 in response to gains in the value of home equity. Using an instrumental variables strategy that eliminates the potential impact of omitted variables such as anticipated permanent income shocks, they find that households on average borrowed roughly 25 cents per dollar gain in home equity. Our estimates imply that leaseholders borrowed roughly 16 cents per dollar of anticipated permanent income.

Our study relates to Agarwal and Qian (2014) who analyze how Singapore citizens responded to their government's surprise announcement in February 2011 that all adults would receive a growth dividend by the end of April 2011. They find that citizens versus a closely matched control group of foreigners largely "borrowed" from the future payment and "started spending immediately upon announcement" (pp. 4219). However, there are several differences with our setting. First, the Singapore disbursement was nearly certain; income from fracking leases was not as it depended upon signing a lease, a well being drilled, and future prices and production levels. Second, while income in Singapore was disbursed about two months after the announcement, leases were signed in 2008 on average, with production

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expected to occur over decades. Finally, while the typical Singaporean received a one-time payment equal to roughly 1.5 percent of annual median income, our estimates indicate that the average future leaseholder in 2006 in the Barnett Shale could reasonably expect to enjoy a roughly 3 percent increase in *permanent income*. Thus, our results indicate that consumers also respond to an unanticipated permanent income increase that is larger and more uncertain.

To assess whether the magnitude of the borrowing response was rational versus impulsive we calibrate the canonical model of consumption smoothing and permanent income (Jappelli and Pistaferri, 2010). To estimate expected lease income, we draw well production parameters from a widely circulated newsletter on the Barnett Shale. We convert production into leaseholder income streams using the average parcel size and average royalty rate. Lastly, to derive expected income, we use natural gas spot prices and project them forward using the Hotelling rule for non-renewable resource prices. To operationalize rationality, we assume that the representative consumer's discount factor equals the reciprocal of the gross real interest rate where two and three percent are used as lower and upper bounds. Depending on the assumed prices and interest rates, the lower and upper bound of optimal borrowing in 2003 was between $1,500 and $1,800. By 2006, the model predicts accumulated borrowing between $6,200 and $7,400. By comparison, we estimate that they actually borrowed about $1,300 in 2003 and $5,400 by 2006, suggesting that the average leaseholder was forward looking but not impulsive. This qualitative conclusion holds even when assuming that a relatively large number of leaseholders did not want to lease and thought they could avoid doing so ex-ante.

While leaseholders were not impulsive when natural gas prices were rising, they could not foresee the future general equilibrium effects of the rapid diffusion of fracking technology beyond the Barnett Shale. The diffusion spurred a surge in production, causing natural gas prices to crash in 2009 and to remain low over the subsequent decade. As a result, about half of leased acreage was drilled, and production that did occur was valued at a lower

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price. In turn, royalties were about one tenth of what was projected for Barnett leaseholders (Cookson et al., 2022), and leaseholders adjusted accordingly and began reducing their debt. Despite the dramatically lower-than-expected royalty payments, their delinquency rate over the 2009-2019 period was less than that of non-leaseholders while their bankruptcy rate were marginally higher. The limited financial distress is noteworthy in light of how lower-than-expected prices affected oil and gas exploration and production firms: more than 250 such firms with \$121 billion in debt filed for bankruptcy in the U.S. during 2015-2019 (Haynes Boone, 2022).

Our study contributes to recent research on the consequences of excessive borrowing. As noted by Mian and Sufi (2015), periods where there are runups in household debt that are followed by household spending cutbacks and defaults have been a catalyst for major economic downturns including the Great Depression of 1929-1939. Mian and Sufi (2011) and Bhutta and Keys (2016) show that the excess borrowing preceding the Great Recession of 2007-2009 was most pronounced for households with low credit scores and high credit card utilization rates. Moreover, because the runup in borrowing was driven by rising home values and low interest rates that both increase permanent income and reduce credit constraints, increased borrowing could have two very different interpretations. It could reflect irrational behavior unleashed by rising credit limits or a rational response to greater permanent income and that only looks irrational after an unforeseeable shock.

Because royalties in fracking leases that were not in hand could not be collateralized, our study enables us to rule out the credit constraint channel and focus on whether leaseholders were forward looking and, if so, rational or over-confident when they borrowed from their expected permanent income. Our study indicates that property owners who were plausibly credit constrained and/or impulsive did not borrow impulsively off their anticipated income gains from fracking. Thus, our study suggests that relaxing credit constraints combined with unforeseeable shocks drives the defaults on loans observed during the Great Recession of 2007-2009.

Our study also provides insights into the effects of natural resource booms and busts whose timing and scale are hard to predict (Jacks, 2019). Several studies document the local effects of resource extraction, often through these boom and busts cycles (Black et al., 2005; Michaels, 2011; Jacobsen and Parker, 2016; Feyrer et al., 2017; Allcott and Keniston, 2018; Bartik et al., 2019), some of which have looked at measures related to consumer debt (Brown, 2021; Cunningham et al., 2021). Cunningham et al. (2021), for example, track mortgages through time and find that fracking activity reduced delinquency rates as local wage and especially royalty income grew.

Most studies estimate effects on places rather than people (Marchand and Weber, 2018). Two recent studies, however, follow people exposed to booms (or busts) through time to see how they fare, wherever they may live subsequently (Jacobsen et al., 2021; Chuan, 2022). We follow their approach and provide evidence of the long-term effect of fracking on people thought to be one of its major beneficiaries–those who own the resources in the ground. Our focus on leaseholders in particular highlights the implications of private resource ownership. In most of the world, subsurface resources like oil and gas are publicly owned, with royalties often leading to increased public spending and in some cases corruption (e.g. Caselli and Michaels (2013)). In our case, private gas owners individually decided how to respond in the good times and did so in a way that caused limited financial stress when royalty payments fell far below expectations.

2   The Fracking Surprise

Oil and gas producers typically acquire access to reserves by leasing oil and gas rights from the owners–often farmers and homeowners who obtained the rights when they bought their land or house. Producers compensate leaseholders through a bonus payment paid upon signing a lease and subsequent royalty payments based on the value of production from any wells that draw from the property. Because fracking allowed producers to tap vast reserves

in shale rock that had been uneconomical using prior methods, it created an expectation of future royalty income among owners of oil and gas rights. By 2014, wells in shale formations across the U.S. were generating a total of $44 billion in royalties (Brown et al., 2019).

2.1 The Barnett Shale and the Shock to Expected Incomes

Fracking emerged as commercially viable in Texas' Barnett Shale, causing a surge in media interest, leasing activity, and expectations of future income. Horizontal drilling requires leasing of large, contiguous areas, usually in a rectangular shape. In the Barnett, these contiguous areas, known as drilling units, averaged 1,662 acres in size according to proprietary spatial data from Enverus. Given our average leaseholder leased out 0.4 acres, the average drillng unit might include over four thousand leaseholders. Moreover, 68 percent of the area of shale counties was eventually in a unit, and an even larger percentage would have been leased because some leases do not make it into a drilling unit. Creating a contiguous area for drilling is enabled by Texas law that allows unleased tracts to be "force pooled" into the drilling unit (Blackwell, 2010). The law enables more efficient extraction while ensuring that nearby owners will be compensated for wells off their property but that would inevitably draw oil or gas from it.

Because of the spatially-comprehensive nature of horizontal drilling, leasing efforts sought to reach essentially all gas-right owners in our shale counties. Efforts were led by "landmen" who researched gas-right ownership, which is public record, and pursued owners with fliers, mailings, and visits. Citing local news articles from 2006, Burt (2008) describes how residents were pursued:

> Some offers just started arriving in residents' mailboxes, while others learned about the Barnett Shale through various oil gas company representatives or landmen who were busy going door-to-door with lease forms in hand, seeking permission to drill for the natural gas under the homes and businesses of Tarrant County residents. One Tarrant County newspaper likened the urban leasing

effort to a "well-orchestrated" and "well-funded" political campaign.

Archival work indicates a shift in expectations about the shale towards the end of 2002 and into 2003. In February of 2002 the Fort Worth Star-Telegram reported that residents of a suburb of Forth Worth were looking forward to the prospect of receiving monthly royalty checks from drilling that was likely to happen under their properties. The first commercially successful horizontal well was drilled in 2002 (Durham, 2006), and in 2003 several local news articles reported company plans to expand drilling. In 2003, Gene Powell began the Powell Barnett Shale Newsletter in order to provide a summary of news, research, and analysis on the Barnett. Also in 2003, the U.S. Geological Survey released its first assessment of the Barnett, estimating that it held a massive amount of gas.[1] In line with these events, leasing data (described later) show a jump in leasing early in 2003 (Appendix Figure A1). About one to two hundred leases were being signed monthly in 2002 and early in 2003. In April of 2003 the number jumped to around 500 and marked the beginning of an upward trend and by 2005 about 1,000-1,500 leases were being signed every month.

As leasing and drilling expanded, so did expectations of future income for potential leaseholders. The Powell Newsletter forecasted royalties by plugging in relevant parameters into the royalty rate formula, which is the product of the royalty rate, production, and price. This plugging-and-chugging with average or expected values was representative of how leasing agents for energy companies would calculate and report expected royalty streams to gas right owners. We do the same and use Powell's production parameters for the average well in Tarrant County, where most of our leases are located.[2] We use Powell's parameter for the area drawn by one well and combine it with the average royalty rate (23.8 percent) and parcel size for sample leaseholders (0.4 acres). For prices, we take the average spot market

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[1] The 2003 assessment of 26.2 trillion cubic feet is mentioned in a 2015 update by the USGS.

[2] Although not an academic analysis, the Powell analysis of production is in line with later analysis drawing from more wells and production history. For example, the cumulative 20-year production under the Powell assumptions is 3.2 billion cubic feet (Bcf) while Patzek et al. (2013) estimate an ultimate recovery of 1.8 Bcf for the average well in the Barnett, not just those in the highly productive Tarrant County. We also note that the length of a well's economical life is uncertain and in addition to productivity will depend upon natural gas prices during the well's later years. Gülen et al. (2013), for example, assume a 25 year lifespan.

price in either 2003 or 2006 and, in line with Hotelling (1931), assume that it grows at a lower bound real interest rate of 2 percent and upper bound of 3 percent.[3] The parameters imply that over 20-years, the expected lease duration at the time, the average leaseholder in 2006 would receive a present value of royalties of around $33,000 (in 2010 constant dollars).

It would not be surprising if price expectations among leaseholders seem optimistic in hindsight because of the tendency to heavily weight recent high and rising prices (Fuster et al., 2010). Spot prices more than doubled from 2002 to 2005 and remained high through 2008 with occasional spikes (Figure 1). In general, the public had bullish expectations for energy prices in the mid 2000s. At various times over the 2000 to 2018 period, Gallup has conducted a national survey asking about the rise in gasoline prices and whether people thought it was permanent or temporary. The mid 2000s had the highest percentage of people expecting the rise in energy prices to be permanent, with a high of 78 percent in 2008.[4]

The Gallup survey results are consistent with the resurfacing of the narrative of energy scarcity in the mid-2000s, which is illustrated by discussions of global peak oil production (oil and natural gas production are often produced from the same well). An influential 1998 article in Scientific American predicted that peak global oil production would occur in 2005 (Bardi, 2019). The prediction matches data from Google Trends, which show the number of searches for a particular term over time. For the 2004-2019 period, searches for "peak oil" peaked in 2005, with smaller peaks in 2006 and 2008. According to Goetzmann et al. (2022), such narratives in the popular press are influential in shaping beliefs about the future and therefore actions in the present.

2.2 Foiled Expectations

The cost-effectiveness of fracking, however, foiled price expectations as supply growth overwhelmed demand. From 2007 to 2019, new-well production per drilling rig (a measure of

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[3] The bounds roughly reflect the difference between the rate of the 10-year Treasury rate and the inflation rate over the 2000-2006 period. See fred.stlouisfed.org/series/FPCPITOTLZGUSA for the inflation rate and fred.stlouisfed.org/series/DGS10 for the yield on U.S. Treasury Securities at 10-year constant maturity.

[4] See https://news.gallup.com/poll/2167/energy.aspx.

drilling effort) increased more than eight-fold in key producing regions (CEA, 2019). Compared to what actually occurred, the Energy Information Administration (EIA) projected half as much future production at double the price. In the 2008 Annual Energy Outlook it projected U.S. natural gas production of around 19 trillion cubic feet annually over the coming decades. By 2019 actual production had more than doubled the projection, exceeding 40 trillion cubic feet.[5] Natural gas prices did the opposite: from the summer of 2008 to the summer of 2009, the Henry Hub price of natural gas fell from above $10 per Mcf to less than $4 and would not recover in the subsequent decade (Figure 1).

The large and unexpected price decline in natural gas also dramatically changed firms' expectations on the outlook for the U.S. natural gas market. In the early and mid 2000s, Cheniere invested billions in a Gulf Coast facility to import liquified natural gas (LNG) into the U.S. Such expensive and long-lived facilities are not built based on short-term market gyrations but on expectations of long-term trends–in this case the expectation of rising domestic prices stemming from rising domestic demand that would outstrip stagnant domestic production. By 2010, however, prices had fallen, and Cheniere announced that it was building capacity to export liquified natural gas to take advantage of the domestic supply glut. In 2016 it exported its first cargo of LNG. Other firms followed suit and, by the end of 2021, the U.S. was exporting more LNG than any country in the world.[6]

3 Fracking, Permanent Income, and Consumption Smoothing

How would owners of oil and gas rights in the Barnett Shale rationally respond to the news around 2003 that fracking had become commercially viable? The average owner signed a lease in 2008 and received a small signing bonus. On average and consistent with the common

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[5] See annual gross withdrawals at `www.eia.gov/dnav/ng/ng_prodsum_a_EPG0_FGW_mmcf_a.htm`

[6] For Cheniere's history, see www.cheniere.com/about/history. For global LNG exports, see www.aljazeera.com/economy/2022/1/4/us-becomes-worlds-top-lng-exporter-for-first-time-ever.

view that wells would have economical production for roughly twenty years she would expect a royalty stream during 2010-2029. We use a stylized dynamic optimization model to roughly capture how the expected income stream would affect her borrowing before she has a lease in hand. We calibrate the model to predict the stock of debt over time, focusing particularly on 2003, when much news arrived, and 2006, which captures accumulated borrowing before anyone in our sample signed a lease. In the calibration exercise, revenue from the bonus payment arrives in 2008 and royalties are paid out during the 2010-2029 period, with their value based on either the 2003 or 2006 natural gas spot price and the Hotelling (1931) rule for pricing a non-renewable natural resource, which is that the price rises at the real interest rate.

Consider a leaseholder who maximizes her utility over current and future consumption for a time horizon that includes her expected royalty stream:

$$U(c_{2003}, c_{2004}, ...c_T) = \sum_t^T \beta^{t-2003} u(c_t) \tag{1}$$

where $t = 2003, 2004, ..., T = 2029$, c_t is the flow of consumption during year t, and β is the discount factor. Because the leaseholder is rational rather than impulsive, $\beta = 1/(1+r)$ where r is the borrowing interest rate. For computational simplicity, $u_t(c_t) = ln(c_t)$, which implies that the elasticity of substitution between current and future consumption is unitary.[7] In this setup consumption includes payments for housing debt, auto loans and other debt.

In each year the leaseholder can borrow and consume more than her current income and assets or, she can save and consume less. However, in the terminal year of the lease, $T = 2029$, she pays off her remaining debts or consumes her remain savings. This implies that she has an intertemporal budget constraint:

$$\sum_{t=2003}^{T=2029} \frac{c_t}{(1+r)^{t-2003}} = \sum_{t=2003}^{T=2029} \frac{Q_t}{(1+r)^{t-2003}} = PI. \tag{2}$$

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[7] It also implies that the coefficient of relative risk aversion is unitary.

where the variable PI denotes permanent income in 2003 (the present discounted value of income during the period t=2003 to T=2029), and Q_t is expected income in each year, and r is the discount rate. We consider a stationary world where real income is fixed over the time horizon: $Q_t = Q$, which implies

$$PI = \sum_{t=2023}^{T=2029} \frac{Q}{(1+r)^{t-2003}} \tag{3}$$

In 2003 the leaseholder chooses a consumption plan $((c^*_{2003}, c^*_{2004}, ...c^*_{2029}))$ that optimizes equation (1) subject to equation (2):

$$u'(c^*_{2003}) = u'(c^*_{2004}) = ... = u'(c^*_{T=2029}). \tag{4}$$

and that satisfies the no Ponzi scheme condition where the consumer has drawn all savings or paid off all debt in the terminal year of 2029. Recalling that $\beta = \frac{1}{1+r}$, then consumption is smoothed and is the same every year during 2003-2029:

$$c^*_t = c* = Q. \tag{5}$$

Thus, in this stationary economy, there is no borrowing or saving in the scenario without leasing.

We use the model to understand the borrowing response of leaseholders as they anticipate higher permanent income. Suppose the future leaseholder in 2003 has a stationary real income of \$56,900 during 2003-2029, which is roughly (in 2010 dollars) the median household income in Tarrant County at the time.[8] And she expects that the average real interest rate has a lower and upper bound of two and three percent. In this scenario, before the arrival of fracking news, her present discounted value of income (permanent income) in 2003 is

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[8] See the US Census Bureau Small Area Income and Poverty Estimates for Tarrant County at fred.stlouisfed.org/series/MHITX48439A052NCEN.

$1,202,000 and $1,074,000 for two and three percent real interest rates. Following the arrival of the fracking news around 2003, her expected permanent income increases in the range of $33,000 to $35,000 if we use 2006 prices and 2 and 3 percent interest rates; and the increase is about $32,000 if we use 2003 prices.

The stock of debt increases immediately following the news in 2003 and peaks in 2009, the year before royalty payments begin. Our focus is on 2003, the year of initial news, and 2006, the last year before any lease signing and therefore before any payments. Table 1 shows the predicted borrowing response (rounded to the nearest hundred) under different scenarios. The 2003 borrowing response ranges from roughly $1,500 to $1,800 depending on the base price year and real interest rate. Similarly, by 2006 the model predicts that future leaseholders will have accumulated between $6,200 and $7,400 in greater debt. The incremental rise in borrowing reflects the leaseholder's incentive to shift consumption to the present in a way that minimizes borrowing costs.[9]

There are several caveats with this test of whether leaseholders were forward looking and rational. Given the uncertainty surrounding future royalty payments, one might expect gas right owners to prefer to sell their rights instead of leasing them. Rights are sometimes sold, but the industry norm is for exploration and production companies to access resources through leasing. Doing so allows them to make limited capital go farther. Many of the firms leasing in the Barnett were not capital-rich public companies but private partnerships that raised funds through loans or small groups of investors (Hinton, 2012).

If the leaseholder is credit constrained, she cannot borrow against her future income from fracking. She would borrow more, however, if fracking income loosens her credit constraint. It is hard to imagine collateralizing a lease that would not come into existence for a year or more because it is doubtful that people can collateralize leases already signed. From the standpoint of a lender, it is uncertain how much royalties a signed lease will generate, if any. Anecdotally, we spoke with several people involved in lending in the region, and no one knew

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[9] The model implicitly assumes that the leaseholder has no savings from which to self-borrow. In practice, leaseholders might have savings but they are illiquid such that they prefer to borrow from the bank.

of cases where someone collateralized an existing lease for a loan, let alone an anticipated lease.

4   Data and Sample

Our analysis is made possible by merging two previously unmerged proprietary datasets, one on oil and gas leases and the other on consumer credit activity. To give an overview, we had Equifax, a credit reporting agency, match name and address information from leases with its consumer credit records.

For the leases, we received academic access to Enverus's database of digitized and scanned leases, which are public documents held by county governments. The database represents the near-universe of leasing activity in the U.S. in areas with active shale development between 2000 and 2017. Each lease includes the leased parcel's size and location, the date the lease was signed, and, most importantly, the name and address of the parcel owner. We cleaned the data to identify the timing and extent of oil and gas leasing in the Barnett Shale for each individual as represented by a name-address key. This involved rectifying common issues in Optical Character Recognition done by Enverus (e.g., misread state abbreviations in lessor addresses), standardizing naming conventions (e.g., consistent use of street type abbreviations), and separating multi-party leases into single-party leases (e.g., "John and Jane Doe" into separate leases for "John Doe" and "Jane Doe").

Equifax then matched names and addresses from the leases with its master consumer credit records. More than three quarters (77 percent) of the name and address pairs in the leasing data were found in Equifax records. Of these, 13 percent were found in the New York Federal Reserve Bank's Consumer Credit Panel, which is also an Equifax data product.[10] The Consumer Credit Panel contains a five percent anonymous, random sample of the full population of credit holders plus all other household members with credit activity and a social security number. It contains quarterly information on individual's debt balances in total and

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[10] https://www.newyorkfed.org/research/staff_reports/sr479.html

for various categories as well as their age, location, Equifax Risk Score (credit score), length of credit history, and bankruptcy filling status (Lee and van der Klaauw, 2010). The matched data were used to construct a quarterly panel between 2000:Q1-2019:Q4 of people who signed oil and gas leases and were in the Consumer Credit Panel.

We focus on people who leased their gas rights in the six main Barnett Shale counties, which lie on the West side of the Dallas-Fort Worth Metropolitan Statistical Area in a 2 x 3 block: Wise and Denton (North); Parker and Tarrant (Central); Hood and Johnson (South) (Figure 2). To focus on a more homogeneous sample of smaller leaseholders, we limit the sample to leaseholders with less than 15 acres, which accounts for 97 percent of the Barnett leaseholder sample found in the Consumer Credit Panel. We further require that we observe leaseholders over the full 2000:Q1-2019:Q4 period.

Our goal is to isolate the anticipation effect of signing a fracking lease on borrowing before the lease signed. Our model makes predictions about the pre-treatment period, 2000-2002, when fracking was not economically viable, and the anticipation period, 2003-2006, when the news about frackings viability diffused throughout the shale. To focus on the borrowing behavior of ordinary homeowners versus speculative investors our treated group includes only people who, as of the pre-treatment period 2000-2002, were residents of the Barnett Shale county in which their post-2006 leases were signed. To pin down anticipation effects, we drop from the sample the 14 percent of these owners who signed leases before 2007. Applying the restrictions yields a sample of 5,516 leaseholders.

5   Empirical Approach and Identification

We use a matched differences-in-differences approach, comparing the change in borrowing among leaseholders living in the Barnett Shale with closely matched non-leaseholders living off the shale but nearby in the Dallas-Fort Worth area. An exogenous shock–the "news" of fracking's commercial viability–created an expectation of future lease income for gas-right

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owners in the shale and not for people living off the shale in the rest of the Dallas-Fort Worth area. Because all eventual leaseholders received the "news" of fracking at the same time there is no concern for staggered treatment. Our quarterly data span the first quarter of 2000 to the last quarter of 2019, which we use to estimate year-by-year differences-in-differences in debt.

$$Debt_{it} = \alpha_i + \delta_y + \sum_{y=2000}^{Y=2019} \beta_y (Year_{y(t)} \times Treatment_i) + \varepsilon_{it}, \tag{6}$$

where i refers to an individual, t to a particular year-quarter, and $y(t)$ to the year of quarter t. The term α_i is an individual fixed effect and δ_y is a year fixed effect. The binary variable $Treatment_i$ equals 1 for people who live in the Barnett Shale as of 2000-2002 and who sign a lease in the same county of their residence in 2007 or later. $Treatment_i$ equals 0 for people living off the shale but close by in the Dallas-Fort Worth area. The treatment variable's interaction with $Year_{y(t)}$, a binary variable indicating the year of quarter t, gives the difference in treatment and control group means in year y relative to the difference in means in the omitted year (2002). These differences are captured by the β_y coefficients. To allow for an individual's error term to be correlated over time, we report standard errors clustered at the individual level.

The ideal treatment group would include two subgroups: the residents of the Barnett Shale who owned gas rights and who expected to sign a lease and wanted to sign a lease, and those who expected to sign a lease because they would be compelled to do so by the pooling arrangements described in Section 2.1. Our observational treated group contains both subgroups: however, it also contains a third subgroup of "expected non-compliers" who did not want to sign a lease, who believed that they could avoid signing a lease, and who in 2007 or later were compelled to sign a lease. When fracking was news during 2003-2006 the "expected non-compliers" would not have expected receiving future income from leasing and therefore would not have borrowed more.

Our observational treated group excludes people who expected to lease—and may therefore have borrowed more–but who were never offered a lease. Because we cannot identify

unleased gas-right owners from other local residents, we draw our control group from people living outside of the shale rather than from non-leased shale residents. We also exclude from the control group any residents outside the shale who happened to own and lease gas rights in the shale.

To understand how our analysis of observational data differs from an ideal experiment we consider the components of the treated and control groups. Let $t \in [2000, 2006]$ denote a time in the pre-leasing period which is captured in our model in Section 3; and let $t_a \in [2003, 2006$ and $t_p \in [2000, 2002]$ denote a time during the anticipation period and a time during the pre-anticipation period. And, let $t \in [2007, 2019]$ denote a time in the leasing period. Let $O_{it} = 1$ if person i knows during $t_a \in [2003, 2006]$ that they own leasable gas rights and $O_{it} = 0$ otherwise; let $A_{it} = 1$ if person i anticipates during $t_a \in [2003, 2006]$ signing a lease during $t \geq 2007$ and $A_{it} = 0$ otherwise; and, let $S_{iT} = 1$ for people who sign a lease during $t \geq 2007$ and $S_{iT} = 0$ otherwise. And, let $Debt_{it}(O_{it}, A_{it}, S_{iT})$ denote person i's debt during $t \in [2000, 2006]$.

Then for any $t \in [2003, 2006]$ the average debt in the observed treated group during the anticipation period reflects the borrowing of the treated who expect to sign, $Debt_{t_a}(1, 1, 1)$, and those who do not, $Debt_{y_a}(1, 0, 1)$. And, for any $t \in [2000, 2002]$ the debt of the two subgroups is $Debt_{t \in [2000, 2002]}(0, 0, 1)$. If we limit the control group to people who live in counties in the Dallas-Fort Worth Metro Area but outside the shale, then they always know that they do not own leasable gas rights, they never anticipate signing a lease, and in fact they never sign one. Thus, the debt of the control group preceeding and during the anticipation is period is $Debt_{t_p}(0, 0, 0)$ and $Debt_{t_a}(0, 0, 0)$.

We measure borrowing as the change in the stock of debt over time. For the treated group, for example, borrowing as of time t in the anticipation period is given by $Debt_{t_a}(1, 1, 1) - Debt_{t_p}(1, 1, 1)$. If we estimate counter-factual borrowing in the treated group by matching with members of the control group, our expectations from theory are that for any $t_a \in$

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[2003, 2006] and for any $t_p \in [2000, 2002]$:

$$(Debt_{t_a}(1,1,1) - Debt_{t_p}(1,1,1)) - (Debt_{ta}(0,0,0) - Debt_{t_p}(0,0,0)) > 0 \tag{7}$$

and

$$(Debt_{t_a}(1,0,1) - Debt_{t_p}(1,0,1)) - (Debt_{t_a}(0,0,0) - Debt_{tp}(0,0,0)) = 0 \tag{8}$$

Let $PopShare(1,1,1)$ and $PopShare(1,0,1)$ denote the population shares for subgroups of the treated people that anticipate signing a lease and those that do not: $PopShare(1,1,1) + PopShare(1,0,1) = 1$. Then, for any $t_a \in [2003, 2006]$ the estimated average treatment effect using our observational data is:

$$ATE_{it}^{est} = PopShare(1,1,1)[(Debt_{t_a}(1,1,1) - Debt_{t_{p=2002}}(1,1,1)) - \tag{9}$$

$$(Debt_{t_a}(0,0,0) - Debt_{t_{p=2002}}(0,0,0))] \tag{10}$$

where 2002 is the baseline year. In an ideal experiment, the average treatment effect, ATE^*, would include only the subgroup of the observed treated population that anticipate signing a lease matched with members of the control group:

$$ATE^* = \frac{ATE^{est}}{PopShare(1,1,1)} \tag{11}$$

Thus, our estimator is downward biased when $PopShare(1,1,1) < 1$. And, the bias is exacerbated the larger that is $PopShare(1,0,1) = 1 - PopShare(1,1,1)$.

One might expect a third group in the observational treated group: those who did not anticipate signing a lease because they did not know that they owned gas rights or because they were unaware of the rising demand for leasing rights. For reasons described in Section 2.1, we expect such leaseholders to be a negligible portion of the observational treated group,

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particularly by 2006 when the pursuit of gas right owners by landmen was widespread and would have been common knowledge among local residents.

5.1 Trimming the Control Group Through Matching

Many gas-right owners would have acquired their rights incidentally when they purchased their home or inherited property in the Dallas-Fort Worth area. Thus, we expect owners to potentially differ from randomly selected people but in observable ways. We therefore refine our differences-in-differences approach by using matching to trim the control group to those most similar to the treated group in the pre-treatment period.

Our matching strategy builds on the Cookson et al. (2022) study of leaseholder finances in the Barnett Shale. Using data from a different credit reporting company Experian, they compare leaseholders to a control group matched on several covariates as of 2005. They trim the control sample based on geography and age and then further match on the propensity to be a leaseholder as predicted by a person's credit score in 2005 and his length of credit history. We extend their approach by matching on more covariates and from an earlier period (2000-2002). As presented earlier, leasing data and newspaper stories suggest that expectations surrounding fracking and leasing shifted around 2003.

We take additional measures to trim our large pool of potential matches to include only people living in a non-shale county of the Dallas-Fort Worth Metropolitan Area. We also follow Cookson et al. (2022) and trim on age, excluding potential controls whose age is outside the range of leaseholder age. We then specify our propensity score estimation using the search algorithm proposed by Imbens (2015), starting with a base set of covariates from the pre-treatment period (2000-2002 in our case). The question is then what additional variables to include linearly from a larger set of potential covariates. This is done sequentially and iteratively, starting with a regression including the base covariates and one variable from the set of additional potential covariates. After estimation, the additional covariate is dropped and another included in its place. After doing this for all potential additional covariates,

a likelihood ratio test statistic for the additional covariate is collected from all regressions, and the most statistically significant additional covariate is selected, assuming its statistic passes a minimum critical value (Imbens suggests 1.0). The additional covariate is then added permanently to the regression and the process repeats until none of the likelihood ratio statistics passes the threshold or all of the potential covariates have been permanently added.

We use the two covariates from Cookson et al. (2022), credit score and length of credit history, as base covariates. For additional potential covariates, we consider the average individual debt level from 2000-2002, their change in debt from 2000:Q4 to 2002:Q4, age, an indicator for whether the person ever filed for bankruptcy over 2000-2002, as well as indicators for having mortgage debt or auto debt. The algorithm selected all variables for inclusion in the propensity score model. We note that the covariates used in matching span the types of data available in the Consumer Credit Panel. The Panel lacks some data that one might like to match on such as income and housing wealth.

The specification search also considers all pairwise interactions of the linear terms. For example, age is interacted with itself and then interacted with debt, the change in debt, and so on. The same iterative selection method is then applied to the interaction terms, though using a different threshold critical value (Imbens suggests 2.71). The algorithm selected roughly half of the pairwise interactions for inclusion. See Appendix Table A1 for estimation of the propensity score. We then follow Imbens (2015) matching protocol used in a setting similar to ours–the case of a large pool of potential controls (the nonexperimental Lalonde data) to match with a much smaller number of treated units and do a nearest neighbor match on the propensity score without replacement. We require the matches to have common support.

6 Descriptive Statistics and Balance Tests

Pre-matching comparisons suggests that people who found themselves in a position to lease out gas rights in the Barnett Shale were somewhat different from the broader population in the Dallas-Fort Worth area in ways that are not surprising. For three of the eight covariates, the difference in means is larger than 0.25 standard deviations before matching (Table 2). As expected, leaseholders were more likely to have mortgage debt than non-leaseholders (65 percent vs 46 percent), which is consistent with many leaseholders acquiring their gas rights by purchasing real estate. They also have higher credit scores and greater total debt.

Our rich propensity score specification, shown in Table A1, leads to good matches, yielding leaseholder and non-leaseholder samples that are nearly perfectly balanced across the eight covariates (Table 3). The largest difference in means is 0.02 standard deviations, and all of them are economically small. For example, both groups had an average credit score of 695, and the previously large difference in the percentage with mortgage debt is now only 1 percentage point. Importantly, the change in debt over the 2000-2002 pre-period is similar across the two groups, indicating parallel prior trends for our key independent variable.

To put the quality of the matches in perspective, the well-known randomized control trial by Dehejia and Wahba (1999) resulted in a treatment and control group whose normalized difference in means was larger than 0.10 for five of the ten covariates (see Table 10 in Imbens (2015)). Similarly, Imbens et al. (2001) study the effect of unearned income by comparing winners of large and small lottery prizes. Even after trimming extreme values of the propensity score, Imbens (2015) find that the winners of large versus small prizes had normalized differences in means greater than 0.10 for half of the covariates considered, the same as in the Dejejia and Wahba case.

7 Findings

Figure 3 shows mean quarterly debt for leaseholders and non-leaseholders from 2000 to

2019 and points to our main findings. Leaseholder and non-leaseholder debt move together in the early 2000s, indicating similar debt trends for leaseholders and non-leaseholders before the news of fracking's commercial viability became widespread. Afterwards, debt begins increasing more for leaseholders, and they continued to accumulate more debt through 2007 and 2008 when most leasing occurred and natural gas prices were high. In contrast, non-leaseholder debt levels off around 2005, which is consistent with Bhutta and Keys (2016) who show that the federal funds rate increased sharply in the 2004-2006 period and was accompanied by fewer households extracting equity from their homes. Leaseholder borrowing would have likewise leveled off had it not been for the expectation of lease payments. Following 2008, when natural gas prices crashed and most of the leaseholders in our sample had a lease in hand, the difference in debt narrowed considerably through 2011 and more slowly through 2019, with the narrowing driven by greater reductions in debt among leaseholders.

Figure 4 shows the year-by-year differences in debt estimated according to Equation 6, with bars representing 95 percent confidence intervals (see also the regression results in Appendix Table A2). The estimates show a $1,300 debt difference emerging in 2003, and by 2006, leaseholders had accumulated about $5,400 more debt than non-leaseholders. This is before any sample leaseholder had signed a lease and therefore before receipt of any lease payments. Moreover, the average leaseholder would not sign a lease for another two years, suggesting that the borrowing stemmed from greater expectations, not the loosening of credit constraints by initial payments. Because everyone received news of the potential income shock from fracking at the same time, there is no concern for staggered treatment in this setting.

The main estimate of the pre-leasing borrowing response is robust to differences in matching and estimation of the propensity score, such as one-to-one matching with replacement, matching to the three nearest neighbors, and estimating the propensity scores using a different specification search algorithm, the elastic net probability model that we describe in the Appendix. The three alternatives give control samples that are neither consistently more

or less comparable than our original control sample as measured by the normalized difference in means (Appendix Table A3). In addition, the alternatives give annual differences in mean borrowing similar to the original matching approach. For example, across the four approaches the estimated increase in borrowing in 2006, which captures the pure anticipation effects of permanent income, ranges from $4,200 to $5,400 (Appendix Table A4).

To further explore the anticipation effect of an increase in permanent income, we breakout debt by three exclusive and exhaustive categories: mortgage, auto, and everything else ("other") (Figure 5). By 2006, leaseholders had increased mortgage debt by about $3,700 and auto debt by about $900 relative to non-leaseholders (see Appendix Table A2 for point estimates). Thus, about 70 percent of the increased debt came from mortgages, which generally have some of the lowest interest rates. All other forms of borrowing such as student loans, credit cards, and home equity lines of credit accounted for about 15 percent of borrowing.

7.1   Heterogeneity in Borrowing

We explore heterogeneity by estimating an individual-specific borrowing response and regressing it on several leaseholder characteristics. Specifically, we measure each leaseholder's total borrowing response by calculating her change in debt from the 2000-2002 period to 2003 or to 2006, and difference from it the same calculation for the leaseholder's match. Using only leaseholders, we then regress the estimated borrowing response on indicators for quartiles based on age, credit score, credit card utilization, and leased acreage.

More acreage will generally provide more royalties, so we expect those with the most acreage to expect the greatest royalties and therefore borrow the most. We note, however, that our measure of acreage is imprecise because we often had to allocate acreage among multiple people on a lease. Regarding differences in borrowing by age, we expect less borrowing among older leaseholders because they can more readily increase current consumption by drawing down their savings, which they can later replenish with royalty income. In effect,

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people closer to or in retirement can self-fund consumption smoothing instead of using banks and debt. Regarding credit score, the cost of credit may decline with credit score to a point, perhaps across those with non-prime credit (roughly the first two quartiles of credit score). Declining cost of credit (r in our theoretical model) would reduce borrowing.

The heterogeneity in borrowing responses in 2003 and 2006 generally fit our expectations: the greatest borrowers are the youngest leaseholders with the most acreage and who were in the second quartile for credit score (Table 5). Those with the highest credit scores, borrowed least, perhaps reflecting more patience (less discounting of future consumption).

The stronger borrowing response by the youngest quartile of leaseholders could reflect generational differences in exposure to energy price volatility. Binder and Makridis (2022) find that people exposed to the energy price shocks of the 1970s (those who were teenagers or older by the late 1970s) responded to gasoline prices over 2008-2017 differently than did younger generations. For our sample, individuals in the youngest quartile were born in 1965 or later and would therefore have generally entered adulthood after the dramatic energy price crash of the mid 1980s. Compared to older generations, they may have been more prone to see the higher energy prices of the mid-2000s as a new normal, encouraging a greater borrowing response.

One characteristic not strongly correlated with the borrowing response in 2006 is credit card utilization: borrowing responses are statistically similar across quartiles. If utilization is a proxy for how close a leaseholder was to their borrowing constraint initially, it does not appear that such constraints were binding for many leaseholders. This is consistent with our finding that leaseholders mostly borrowed via larger mortgages and not other debt such as home equity loans or credit cards, which tend to have higher interest rates. If credit cards are the borrowing option of last resort, we would expect people approaching their borrowing constraint to borrow more via credit cards.

Although the average borrowing response is consistent with plausible royalty payment expectations, the heterogeneity analysis reveals some evidence of unrealistic expectations.

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In the extreme, a person in the first quartile for age, the second quartile for credit score, and the fourth quartile for acreage borrowed $30,400 (= 26,200 + 24,200 + 0 − 20,000) by 2006. Some of the greater borrowing reflects their greater acreage and therefore greater expected royalties, but considering the same person with acreage in the bottom quartile still gives an average borrowing response of $26,100. This suggests irrational expectations about well productivity, natural gas prices, or both.

7.2 The Response to News vs. Payments in Hand

Looking at the same context, Cookson et al. (2022) find that actual receipt of payments caused individuals to reduce debt payments by about $900 per year, which they argue is inconsistent with a forward-looking, consumption smoothing model. Our finding that leaseholders take on more debt seems to contradict their results. However, applying their methods to our data suggests that the difference in findings reflects differences in what is studied—the response to news of greater expected income versus the response to receiving payments.

We first compare their sample data with ours. Applying their sample restrictions to our data yields a slightly different sample than our main sample.[11] This is because they do not exclude leaseholders who signed before 2007, nor do they exclude control observations living in Barnett Shale counties. The comparison that follows adopts their sample restrictions. Our sample size is considerably smaller than theirs, but this primarily reflects our use of leaseholders found in the New York Fed Consumer Credit Panel, which itself is a sample of Equifax's full population of credit bureau records. (See Appendix A9 for a detailed comparison of the development of our sample and that of Cookson et al. (2022)). Despite the difference in sample size the actual sample means are very similar for acreage, year of leasing, and the percent of leaseholders living in Barnett Counties (0.61 acres vs 0.64 acres; 2008 vs 2008; 89 percent vs 90 percent). They report the mean age for their combined sample of leaseholders and matched controls, and it is also similar to our combined sample mean

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[11] This marginally larger sample yields borrowing responses broadly similar to those previously described.

(50.3 years compared to 49.5 years).

We follow their matching approach and baseline difference-in-difference model (defined by their equation 1) and estimated via the Callaway and Sant'Anna (2021) approach. The use of the Callaway and Sant'Anna (2021) approach is warranted since treatment is now defined as the leasing event, which happens at different times, instead of the news of fracking's commercial viability, which happens at the same time for all leaseholders. We find that after the first payment(the bonus payment) leaseholders reduce their annual debt payments by $811 (standard error of 261), very similar to the Cookson et al. estimate of $912 (93). We further estimate their event study model and find, as they did, that the effect becomes larger several years after the first payment, in line with the arrival of royalty payments (see our Figure 6 and their Figure 7).

Upon close inspection one can see the consistency between the difference-in-difference results and our Figure 3. The figure shows that following 2008, when most leaseholders received their first payment, leaseholders had a larger decrease in outstanding debt compared to non-leaseholders. This, however, is after they had increased borrowing considerably following the initial news of fracking circa 2003. Thus, leaseholders were forward-looking when they first learned about fracking, borrowed more, and then began paying down the debt after the first payment arrived.

7.3 Unmet Expectations, Delinquency, and Bankruptcy

The average leaseholder's expectation of tens of thousands of dollars of royalty payments were not fulfilled. From 2005 to 2015, Cookson et al. (2022) estimate that the average leaseholder received only $3,410 in royalties, about one tenth of the payments plausibly expected at the 2008 peak and about half of the average amount borrowed. The supply-driven decline in natural gas prices reduced royalties by affecting the price used to value production and determine royalties. It also reduced the quantity of production by discouraging producers from ever drilling their leased acreage. As a result, many landowners who signed a lease received

only the bonus payment and no royalties. Our sample data do not include information on whether a person's acreage was drilled, however, the data from Covert and Sweeney (2023) show that only 47 percent of leased public school land in the Barnett Shale was drilled.[12]

To consider the effect of unmet expectations, we look at the percent of leaseholders and non-leaseholders that were delinquent on debt (90 days or more past-due in the quarter) or that ever filed for bankruptcy over the period of lower natural gas prices (2009-2019). We find that the much lower-than-expected royalty payments created limited financial distress for leaseholders. The share of leaseholders with delinquent debt over the decade was 2.8 percentage points (s.e. 0.8 pp) below that of non-leaseholders (30.2 vs. 33.0). Over the same period, the share of leaseholders who filed for bankruptcy was 0.2 percentage points (s.e. 0.4 pp) higher than for non-leaseholders (6.0 vs 5.8), although the difference was not statistically significant.

Compared with industry players, small-scale leaseholders in the Fort Worth suburbs fared quite well over the low-price period. The firm Haynes Boone began tracking bankruptcies of U.S. oil and gas exploration and production firms in the first quarter of 2015 after a sharp fall in energy prices. Over 2015-2019, more than 250 energy firms with $121 billion in debt filed for bankruptcy (Haynes Boone, 2022). Equity values also show a boom and bust in financial health. The MVIS Global Unconventional Oil and Gas Index (MVFRAK) tracks companies that derive at least 50 percent of their revenues from unconventional sources like shale gas.[13] The Index roughly doubled in value from its inception at the beginning of 2007 to its 2008 peak. It had a precipitous drop in 2009 and another in 2015. By the close of 2019, it had lost more than two thirds of its 2008 value.

8 Discussion

Mian and Sufi (2011) find that borrowing against rising home equity values during 2002-2006

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[12]We thank Thomas Covert for sharing code and replication files for this tabulation.
[13]www.mvis-indices.com/indices/hard-asset/mvis-global-unconventional-oil-gas.

was concentrated primarily among homeowners that are plausibly credit constrained because they had the lowest credit scores and the highest credit card utilization rates. However, such homeowners might also be impulsive. Because anticipated fracking leases could not be collateralized in our study, the borrowing response of leaseholders with low credit scores and high credit card usage is not driven by relaxation of credit constraints.

Two lines of evidence suggests that this group was not impulsive. First, as of 2006, a leaseholder in the bottom quartile for credit score, the top quartile for credit card utilization, and the second quartiles for age and acreage borrowed about \$5,700 (=20,400 + 0 +16,600 + 11,300 − 20,000), close to the average borrowing response and within the bounds of rational behavior. Section 5 explains that our average treatment effect estimate might be biased downward because the treatment group could include some gas-right owners who thought they could avoid leasing and would therefore have had no borrowing response. If 20 percent of our treated group consisted of expected non-compliers, the implied borrowing response among those anticipating leasing income would still fall in line with our consumption smoothing model, which predicted borrowing of \$7,400 in 2006, assuming 2006 prices and a 3 percent real interest rate. Given the prevalence of leasing in the area and its discussion in local newspapers, it would be surprising that as of 2006, 20 percent of future leaseholders believed they could avoid leasing.[14]

Second, leaseholder delinquency and bankruptcy rates over the 2009-2019 period, when the price of natural gas plunged, roughly matched those of non-leaseholders. Thus, if our study of fracking has external validity for Mian and Sufi (2011), it suggests that the excessive borrowing during 2002-2006 that led to the housing crisis in 2007-2009 was driven by credit constraints and not impulsiveness.[15] This suggests that lenders should pay more attention to credit histories in times of credit expansion and buoyant income and wealth expectations.

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[14] If 80 percent of the treated group expected leasing income, then their borrowing response B is given by 0.80B = 5,700 or B = 7,125.

[15] An external validity test would require that we expand our sample of leaseholders and non-leaseholders beyond the Barnett Shale and Dallas-Fort Worth areas. However, such a study would have less internal validity because fracking technology first emerges in the Barnett Shale and when it diffuses to areas outside the Barnett its commercial viability is no longer news.

9   Conclusion

The case of natural gas leases in Texas' Barnett Shale indicates that on average leaseholders were forward looking and borrowed more as news arrived that raised their expected future income. The amount borrowed was broadly consistent with a consumption smoothing model and plausible price expectations. The borrowing response is hard to reconcile with widespread self-control problems among leaseholders. Such problems would have previously pushed leaseholders to their borrowing limits, preventing them from borrowing more around the time of leasing given that leases did not loosen constraints.

Pervasive self-control problems would have also manifested themselves through more widespread delinquency and bankruptcy when royalty income failed to meet expectations. The success of fracking brought a glut of natural gas and a decade of dramatically lower prices and therefore much less royalty income than expected. Leaseholders were not the only group surprised by the supply growth and price effects of fracking as evidenced by bankruptcies among oil and gas exploration and production firms. Thus, both leaseholders and the companies leasing their gas rights for drilling appear to have underestimated the likelihood that fracking would unleash enough supply to dramatically reduce prices and keep them low. In contrast to firms, however, the higher borrowing by rational but not prescient leaseholders did not bring severe financial distress over the period of low natural gas prices.

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Figure 1: Quarterly Henry Hub Natural Gas Price, 2000-2019

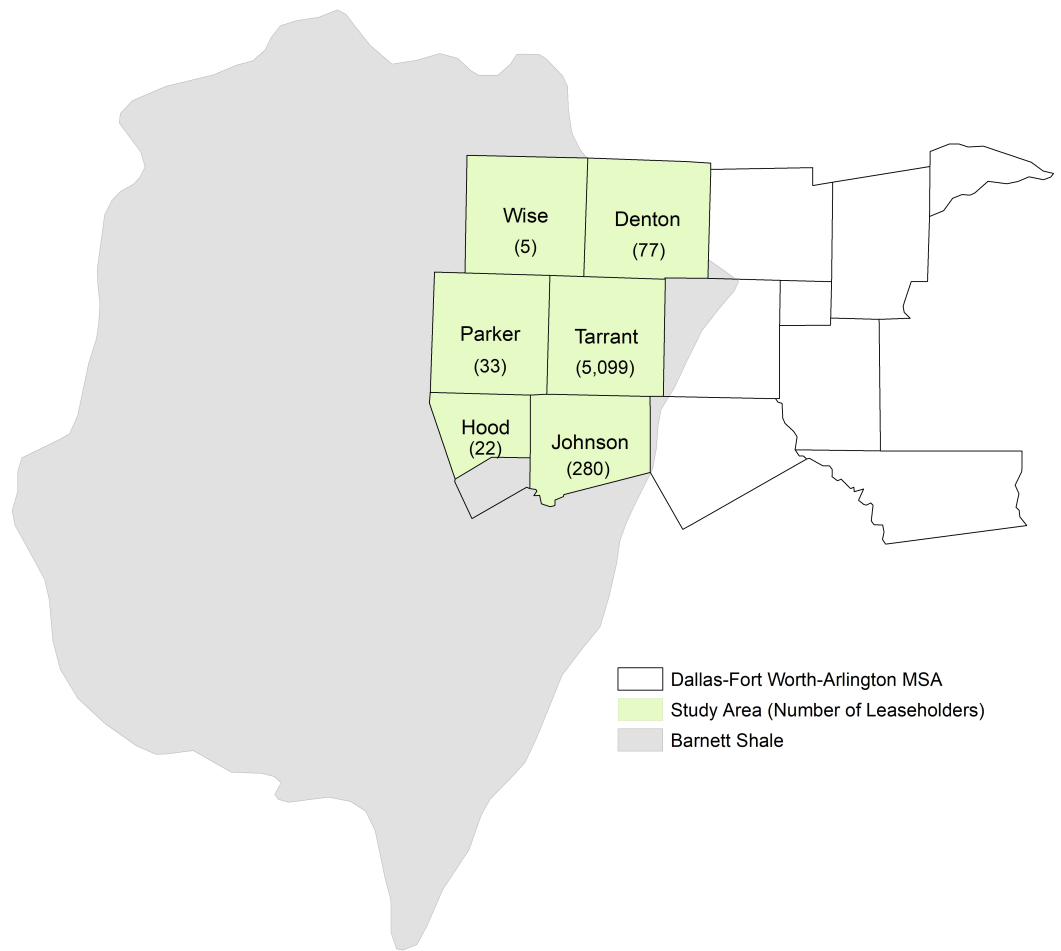*Source*: U.S. Department of Energy, Energy Information Administration.

Figure 2: Barnett Shale in Dallas-Forth Worth-Arlington MSA

Source: Enverus; U.S. Department of Energy, Energy Information Administration. *Notes*: The number in parentheses corresponds to the number of sample leaseholders in each county.
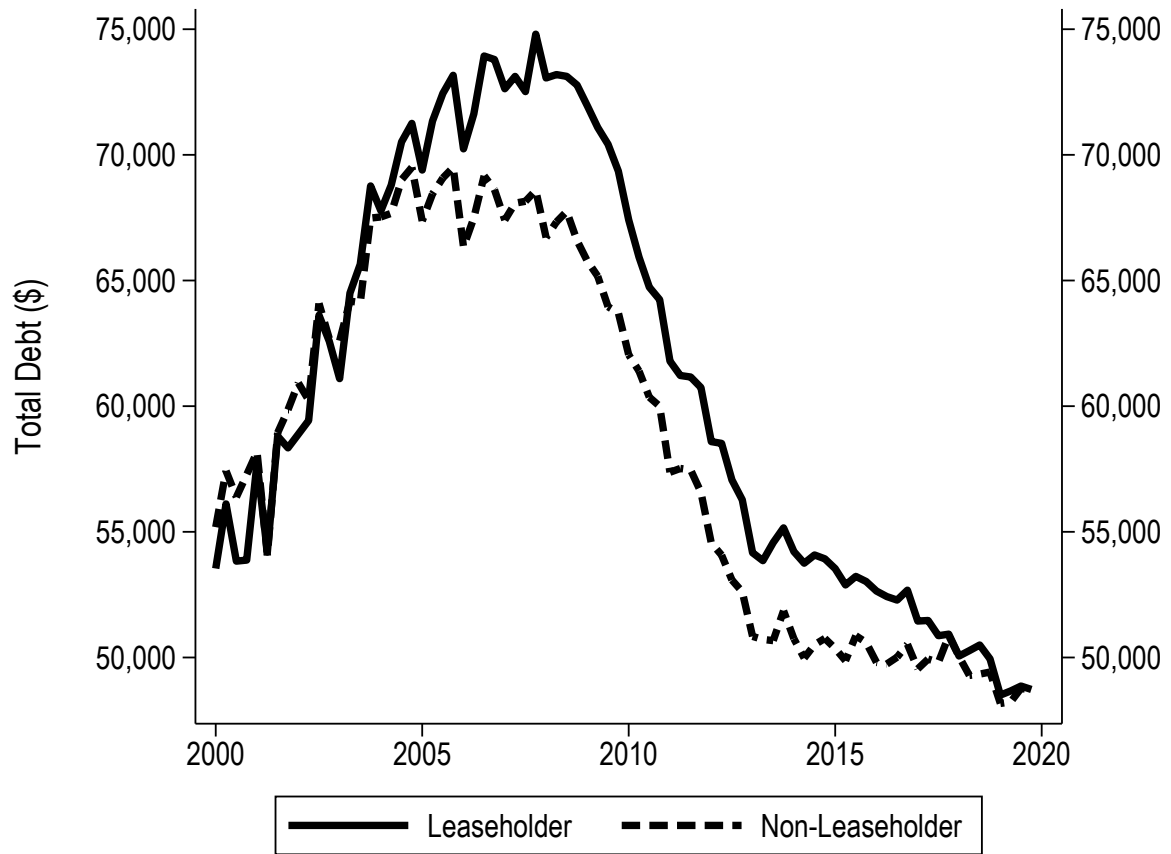
Figure 3: Mean Total Debt, 2000 to 2019

Source: New York Fed Consumer Credit Panel, Enverus. *Notes*: The figure shows the mean total debt for 5,516 leaseholders and the same number of matched non-leaseholders.
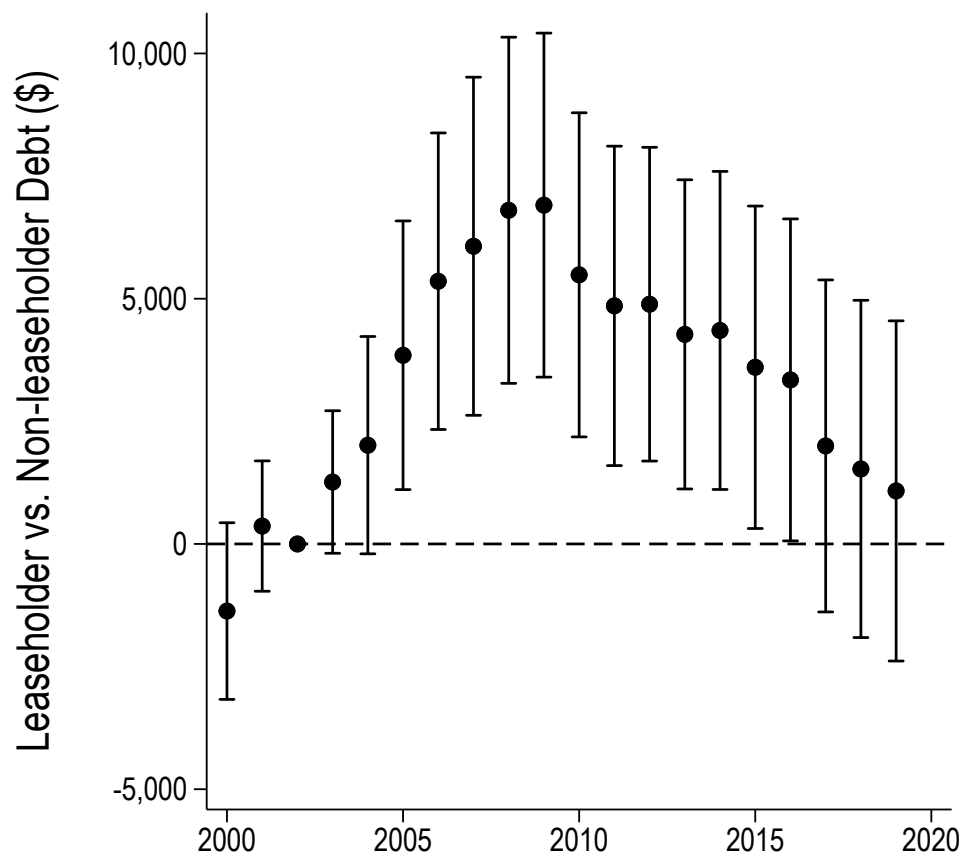
Figure 4: Estimated Differences in Total Debt, Leaseholders vs Matched Non-leaseholders

Source: New York Fed Consumer Credit Panel, Enverus. *Notes*: The figure shows the estimated β coefficients from Equation 6, estimating using 5,516 leaseholders and the same number of matched non-leaseholders. The bars show the 95 percent confidence intervals.
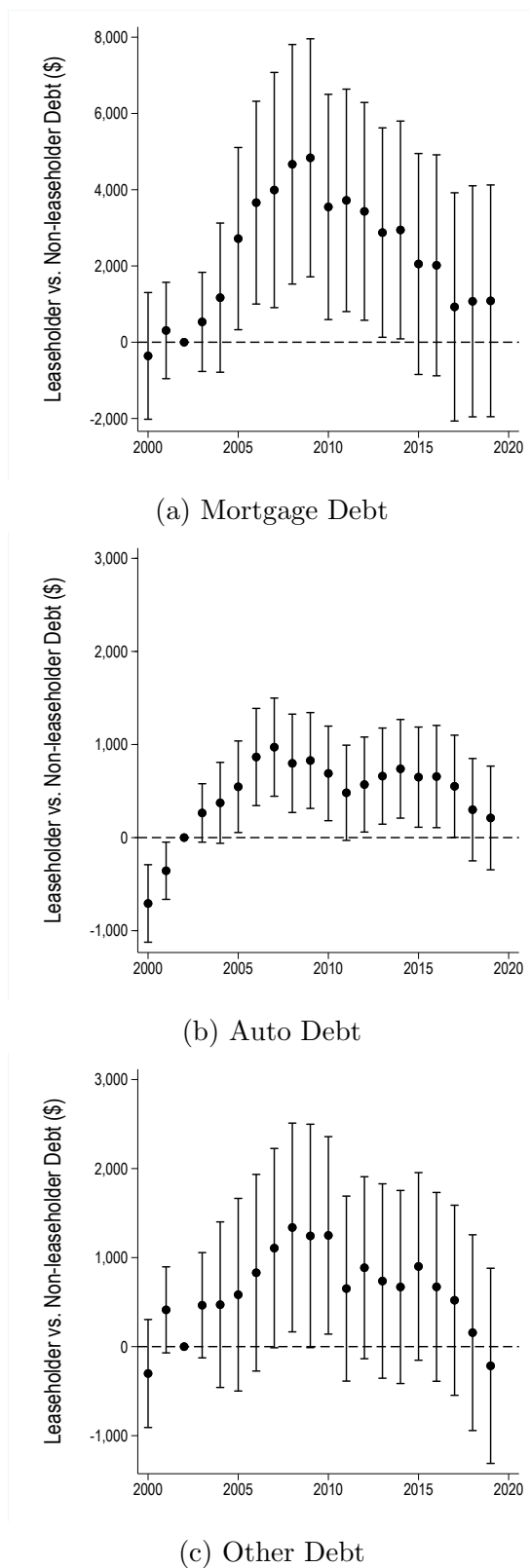
(a) Mortgage Debt

(b) Auto Debt

(c) Other Debt

Figure 5: Estimated Differences in Debt by Category, Leaseholders versus Matched Non-Leaseholders

Source: New York Fed Consumer Credit Panel; Envegus. *Notes*: "Other Debt" includes all debt other than mortgage and auto debt. The bars show 95 percent confidence intervals.
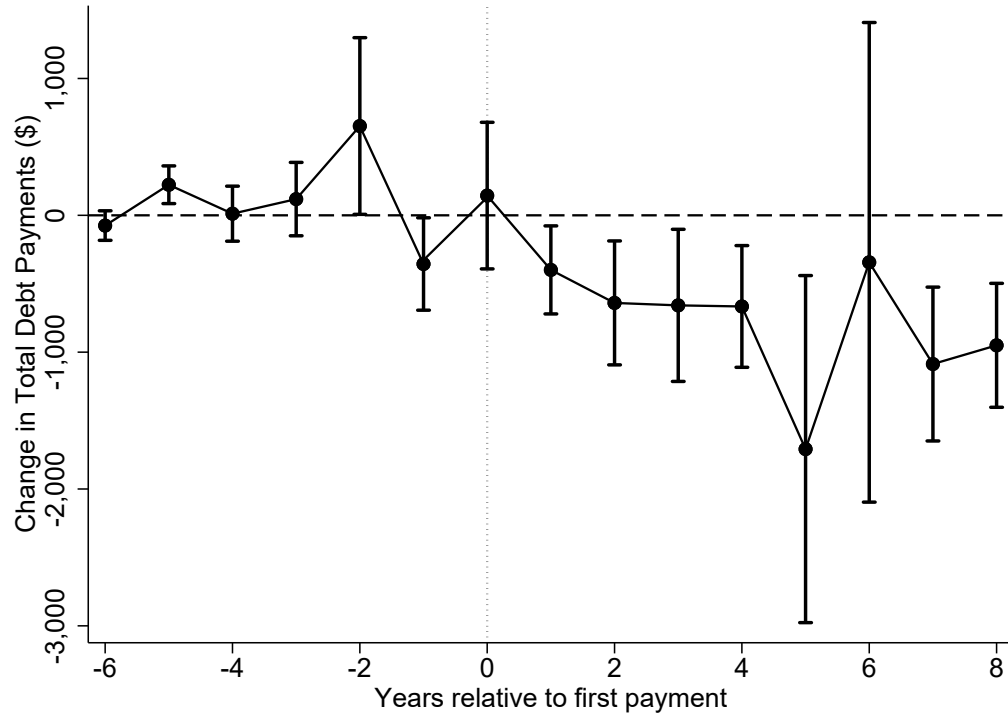
Figure 6: Event Study Estimates of the Effect of Lease Payments on Debt Payments

Notes: The figure shows the coefficients from an event study following the specification used by Cookson et al. (2022). The event is the receipt of the first payment, which is the bonus payment made upon signing a lease.

Table 1: Predicted Debt ($) by Scenario (natural gas base price year/real interest rate)

Year	2003 price/2%	2003 price/3%	2006 price/2%	2006 price/3%
2003	1,494	1,669	1,660	1,769
2006	6,158	6,984	6,842	7,400

Note: The values are from the consumption smoothing model described in Section 3.

Table 2: Balance Table of Matching Sample

	Leaseholder=0		Leaseholder=1		Mean		Normalized
	Mean	SD	Mean	SD	Difference	t-stat	Difference
Credit Score$_{00-02}$	665.24	104.95	695.36	91.74	-30.12***	-20.67	-0.31
Credit Length$_{00-02}$ (Months)	196.99	111.61	234.12	111.15	-37.13***	-23.75	-0.33
Age$_{00-02}$	43.63	14.51	46.16	12.31	-2.53***	-12.57	-0.19
Total Debt$_{00-02}$ (Thous. $)	45.58	64.93	57.58	68.61	-12.00***	-13.13	-0.18
Δ Total Debt$_{00-02}$ (Thous. $)	6.82	60.70	5.34	47.95	1.48*	1.76	0.03
Mortgage Debt$_{00-02}$	0.46	0.50	0.65	0.48	-0.19***	-26.90	-0.39
Auto Debt$_{00-02}$	0.56	0.50	0.67	0.47	-0.11***	-15.62	-0.23
Bankruptcy$_{00-02}$	0.04	0.20	0.04	0.19	0.01**	2.15	0.05
N	66,307		5,516				

Notes: All monetary values are in 2010 dollars. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: New York Fed Consumer Credit Panel/Equifax; Enverus.

Table 3: Balance Table of Matched Sample

	Leaseholder=0		Leaseholder=1		Mean		Normalized
	Mean	SD	Mean	SD	Difference	t-stat	Difference
Credit Score$_{00-02}$	694.79	92.04	695.36	91.74	-0.57	-0.32	-0.01
Credit Length$_{00-02}$ (Months)	233.53	110.77	234.12	111.15	-0.59	-0.28	-0.01
Age$_{00-02}$	45.89	12.19	46.16	12.31	-0.27	-1.16	-0.02
Total Debt$_{00-02}$ (Thous. $)	58.77	70.83	57.58	68.61	0.70	0.59	0.01
Δ Total Debt$_{00-02}$ (Thous. $)	5.74	59.84	5.34	47.95	1.19	0.90	0.02
Mortgage Debt$_{00-02}$	0.66	0.47	0.65	0.48	0.007	0.74	0.01
Auto Debt$_{00-02}$	0.68	0.47	0.67	0.47	0.01	1.47	0.02
Bankruptcy$_{00-02}$	0.04	0.19	0.04	0.19	0.001	0.40	0.01
N	5,516		5,516				

Notes: All monetary values are in 2010 dollars. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: New York Fed Consumer Credit Panel/Equifax; Enverus.

Table 4: Descriptive Statistics of Matched Sample

(a) Non-Leaseholders

	Mean	SD	25th	50th	75th	90th
Credit Score$_{00-02}$	694.79	92.04	631.21	718.29	772.04	795.50
Credit Length$_{00-02}$ (Months)	233.53	110.77	151.00	216.00	303.00	388.00
Age$_{00-02}$	45.89	12.19	37.00	45.00	54.00	62.00
Total Debt$_{00-02}$ (Thous. \$)	58.77	70.83	14.74	44.23	79.83	125.76
Δ Total Debt$_{00-02}$ (Thous. \$)	5.74	59.84	-10.83	0.00	16.27	60.68
Mortgage Debt$_{00-02}$	0.66	0.47	0.00	1.00	1.00	1.00
Auto Debt$_{00-02}$	0.68	0.47	0.00	1.00	1.00	1.00
Bankruptcy$_{00-02}$	0.04	0.19	0.00	0.00	0.00	0.00
N	5,516					

(b) Leaseholders

	Mean	SD	25th	50th	75th	90th
Credit Score$_{00-02}$	695.36	91.74	631.83	719.29	771.62	794.17
Credit Length$_{00-02}$ (Months)	234.12	111.15	153.00	215.00	307.00	394.00
Age$_{00-02}$	46.16	12.31	37.00	45.00	54.00	63.00
Total Debt$_{00-02}$ (Thous. \$)	57.58	68.61	15.27	44.87	80.06	121.03
Δ Total Debt$_{00-02}$ (Thous. \$)	5.34	47.95	-10.06	-0.10	14.71	51.00
Mortgage Deb$_{00-02}$t	0.65	0.48	0.00	1.00	1.00	1.00
Auto Debt$_{00-02}$	0.67	0.47	0.00	1.00	1.00	1.00
Bankruptcy$_{00-02}$	0.04	0.19	0.00	0.00	0.00	0.00
Lease Acreage	0.40	1.00	0.09	0.20	0.33	0.64
Lease Year	2008.27	1.37	2007	2008	2009	2010
N	5,516					

Sources: New York Fed Consumer Credit Panel/Equifax; Enverus. *Notes*: All measures are an average of the pre-treatment period 2000 to 2002, except for the change in total debt, which is the change in debt between 2000 and 2002. All monetary variables are in 2010 dollars.

Table 5: Heterogeneity in Debt Response

	Total Debt$_{2003}$	Total Debt$_{2006}$
Age$_{q1}$	12402***	26174***
	(2468)	(4208)
Age$_{q2}$	6000**	16547***
	(2373)	(4235)
Age$_{q3}$	4372*	10229***
	(2258)	(3840)
Credit Score$_{q1}$	9749***	20432***
	(3741)	(6708)
Credit Score$_{q2}$	16049***	24203***
	(3001)	(5423)
Credit Score$_{q3}$	10150***	17934***
	(2539)	(4318)
Credit Card Utilization$_{q1}$	4177	9353
	(3396)	(6623)
Credit Card Utilization$_{q2}$	6453**	6285
	(3232)	(6452)
Credit Card Utilization$_{q3}$	6754**	8324
	(2926)	(5476)
Acreage$_{q1}$	-4279*	-8241*
	(2596)	(4758)
Acreage$_{q2}$	-5971**	-11338**
	(2716)	(4654)
Acreage$_{q3}$	-6777***	-14338***
	(2615)	(4674)
Intercept	-12841***	-20076**
	(4104)	(7880)
Adjusted R^2	0.016	0.015
N	5,516	5,516

Notes: The dependent variable is the change in total debt from the 2000-2002 period to 2003/2006 less the change of the matched control individual. * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Robust standard errors are in parentheses.
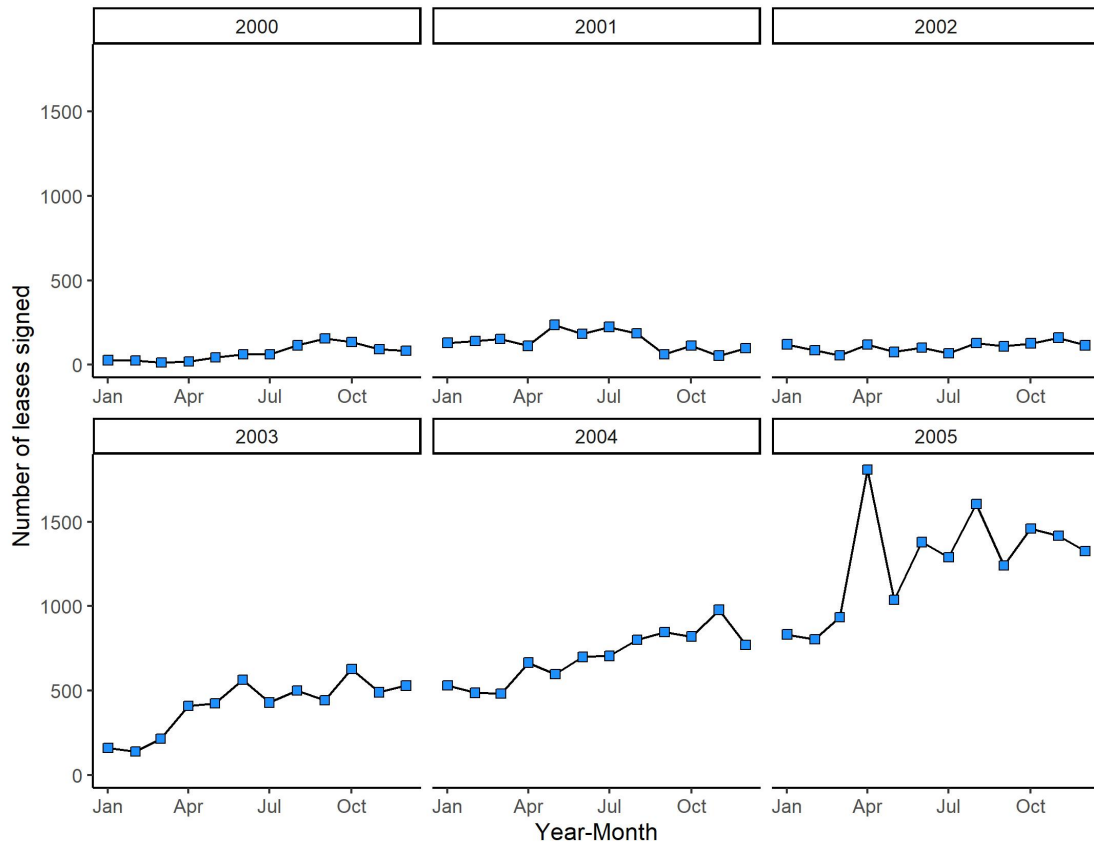
Appendix

Figure A1: Monthly Leasing Activity in Study Counties, 2000-2005

Notes: Calculations by authors. Leasing data are from Enverus (formerly Drillinginfo), which seeks to capture the universe of leases.

Table A1: Probability of Being a Leaseholder

	$\text{Pr}(\text{Recipient}_{07-16})$
Credit Score$_{00-02}$	0.00503***
	(0.00102)
Credit Length$_{00-02}$ (Months)	0.00117***
	(0.00030)
Age$_{00-02}$	0.03925***
	(0.00521)
Total Debt$_{00-02}$	0.00199***
	(0.00057)
Δ Total Debt$_{00-02}$	-0.00031**
	(0.00012)
Mortgage Debt$_{00-02}$	1.11730***
	(0.11029)
Auto Debt$_{00-02}$	0.19139***
	(0.01582)
Bankruptcy$_{00-02}$	-0.02646
	(0.03783)
Credit Length$^2_{00-02}$	-0.0000001
	(0.0000001)
Credit Score$^2_{00-02}$	-0.000003***
	(0.000001)
Age$^2_{00-02}$	-0.00048***
	(0.00004)
Credit Score$_{00-02}$ × Mortgage Debt$_{00-02}$	-0.00115***
	(0.00016)
Total Debt$^2_{00-02}$	0.000001***
	(0.0000002)
Total Debt$_{00-02}$ × Mortgage Debt$_{00-02}$	-0.00226***
	(0.00048)
Credit Length$_{00-02}$ × Total Debt$_{00-02}$	-0.000004***
	(0.000001)
Credit Score$_{00-02}$ × Age$_{00-02}$	0.00001
	(0.00001)
Intercept	-4.90459***
	(0.34124)
Pseudo R^2	0.045
LL	-18,582
N	71,823

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

Annual Average Effects

Table A2: Average Treatment Effects - Debt Levels

	Total Debt	Mortgage	Auto	Other Debt
Leaseholder × 2000	-1368	-359	-708***	-302
	(919)	(848)	(212)	(309)
Leaseholder × 2001	365	308	-356**	413*
	(678)	(645)	(157)	(247)
Leaseholder × 2003	1263*	533	265*	465
	(741)	(663)	(160)	(301)
Leaseholder × 2004	2014*	1169	373*	471
	(1130)	(998)	(222)	(474)
Leaseholder × 2005	3847***	2717**	546**	583
	(1397)	(1219)	(251)	(552)
Leaseholder × 2006	5356***	3660***	866***	830
	(1542)	(1357)	(266)	(563)
Leaseholder × 2007	6069***	3991**	972***	1107*
	(1758)	(1574)	(269)	(571)
Leaseholder × 2008	6803***	4667***	798***	1338**
	(1800)	(1602)	(270)	(598)
Leaseholder × 2009	6908***	4836***	828***	1244*
	(1789)	(1593)	(263)	(640)
Leaseholder × 2010	5487***	3547**	690***	1250**
	(1686)	(1507)	(259)	(566)
Leaseholder × 2011	4854***	3721**	481*	652
	(1661)	(1488)	(261)	(530)
Leaseholder × 2012	4888***	3432**	570**	886*
	(1632)	(1457)	(260)	(521)
Leaseholder × 2013	4273***	2875**	661**	737
	(1608)	(1401)	(263)	(557)
Leaseholder × 2014	4353***	2944**	739***	670
	(1654)	(1457)	(270)	(553)
Leaseholder × 2015	3602**	2052	650**	901*
	(1677)	(1478)	(275)	(538)
Leaseholder × 2016	3345**	2017	656**	671
	(1675)	(1478)	(280)	(541)
Leaseholder × 2017	1998	926	551**	521
	(1727)	(1527)	(280)	(545)
Leaseholder × 2018	1529	1073	300	157
	(1754)	(1546)	(280)	(561)
Leaseholder × 2019	1081	1085	211	-216
	(1769)	(1551)	(284)	(559)
R-squared	0.592	0.557	0.393	0.445
N	882,560	882,560	882,560	882,560

Notes: * p<0.05, ** p<0.01, *** p<0.001. Robust standard errors clustered by individual are in parentheses. All regressions include individual and quarter fixed effects.

Matching Estimator and Specification Robustness Checks

In our main specification, we used a variable selection procedure proposed by Imbens (2015) to estimate propensity scores. Once propensity scores were estimated, we required an exact match on location at the three-digit zip code level. We matched one-to-one without replacement and required common support. We also considered other matching options to test the robustness of our main results. We report normalized differences between the treated and control portion of the dataset across these matching options in Table A3. We required common support between the treated and control throughout. First, we estimated the same propensity scores, but matched with replacement. Next, using the same propensity score, we matched on three nearest neighbors with replacement. The second and third columns of Table A3 show similar normalized differences to our base specification, indicating that our results are robust to changes in the matching procedure.

To test the robustness of the specification search algorithm we estimated a linear elastic net probability model. Elastic net is an extension of lasso and ridge regression, two common regularization techniques. Coefficient estimates from elastic net are more robust to high levels of collinearity compared to lasso (Zou and Hastie, 2005). The penalized objective function for elastic net is:

$$Q = \frac{1}{2N} \sum_{i=1}^{N} \left(y_i - \beta_0 - \boldsymbol{x_i}\boldsymbol{\beta'} \right)^2 + \lambda \sum_{j=1}^{p} \left(\frac{1-\alpha}{2}\beta_j^2 + \alpha|\beta_j| \right),$$

where $\boldsymbol{\beta}$ is the p-dimensional vector of coefficients on covariates $\boldsymbol{x}$. The estimated $\boldsymbol{\beta}$ minimize Q for given values of α and λ. When $\alpha = 1$, elastic net reduces to lasso and to ridge regression when $\alpha = 0$. When $\alpha > 0$, elastic net generates sparse solutions in which many of the coefficient estimates are exactly zero. None of the ridge regression estimates ($\alpha = 0$) are exactly zero because the squared penalty causes a smooth tradeoff around 0 instead of the kinked-corner trade-off in lasso. By mixing the two penalties, elastic net keeps the sparse solution nature of lasso, but is less variable than lasso in the presence of high collinearity.

While estimating probit elastic net regressions is possible, the size of our data and inclusion of hundreds of fixed effects made this impractical with respect to computation time. As result, we used a linear elastic net regression to determine variable selection for the propensity score model. Similar to our implementation of the Imbens (2015) matching procedure, we required that all linear terms shown in Table A3 be included in the model as well as three-digit zipcode fixed effects. In doing so, elastic net would help us determine which interaction terms of these variables to include in estimating the propensity score. The model selected with the lowest mean prediction error occurred when $\alpha = 0.5$ and 26 interaction terms were included. From this list of selected interaction terms and the initial base set including three-digit zipcode fixed effects, we estimated a probit model to generate the propensity scores. As before, we matched one-to-one without replacement. Although elastic net selected more (26 vs. 8) interaction terms relative to the Imbens procedure, the last column of the tables shows the normalize differences of the matched leaseholders and non-leaseholders were very similar to our main specification.

We go one step further and test the robustness of our results to matching and variable selection techniques by estimating the average debt effects over time using the same specification in equation 6. Results in Table A4 show very similar leaseholder by year coefficients across the matching and variable selection techniques. We conclude that our implementation of Imbens' procedure is robust to other methods of variable selection and matching.

Table A3: Matching Robustness Checks on Normalized Differences

	One-to-One* No Replacement	One-to-One Replacement	Three Nearest Replacement	Elastic Net No Replacement
Credit Score$_{00-02}$	-0.01	-0.02	-0.001	-0.01
Credit Length$_{00-02}$ (Months)	-0.01	-0.01	0.01	0.003
Age$_{00-02}$	-0.02	-0.03	-0.003	0.01
Total Debt$_{00-02}$ (Thous. \$)	0.01	0.01	-0.01	0.01
Δ Total Debt$_{00-02}$ (Thous. \$)	-0.01	0.01	-0.01	-0.01
Mortgage Debt$_{00-02}$	0.01	0.01	-0.002	0.000
Auto Debt$_{00-02}$	0.02	0.03	0.02	0.03
Bankruptcy$_{00-02}$	0.01	0.01	0.01	-0.01

Note: *Main results are based on one-to-one matching without replacement.

Table A4: Matching Robustness Checks on Average Treatment Effects, Total Debt Levels

	One-to-One[a] No Replacement	One-to-One Replacement	Three Nearest Replacement	Elastic Net No Replacement
Leaseholder × 2000	-1368	-2291**	-1703**	-810
	(919)	(935)	(741)	(806)
Leaseholder × 2001	365	41	380	1090*
	(678)	(688)	(564)	(636)
Leaseholder × 2003	1263*	1343*	241	129
	(741)	(758)	(646)	(734)
Leaseholder × 2004	2014*	2039*	576	1609
	(1130)	(1159)	(958)	(1048)
Leaseholder × 2005	3847***	3756***	2387**	3192**
	(1397)	(1441)	(1207)	(1335)
Leaseholder × 2006	5356***	5154***	4210***	4558***
	(1542)	(1574)	(1365)	(1482)
Leaseholder × 2007	6069***	6079***	4288***	4830***
	(1758)	(1693)	(1492)	(1604)
Leaseholder × 2008	6803***	6832***	5135***	5318***
	(1800)	(1798)	(1538)	(1682)
Leaseholder × 2009	6908***	6946***	5183***	5257***
	(1789)	(1813)	(1527)	(1715)
Leaseholder × 2010	5487***	5206***	4050***	3090*
	(1686)	(1739)	(1462)	(1694)
Leaseholder × 2011	4854***	4256**	3523**	2696
	(1661)	(1707)	(1422)	(1661)
Leaseholder × 2012	4888***	4231**	3419**	2983*
	(1632)	(1671)	(1406)	(1556)
Leaseholder × 2013	4273***	3505**	1974	1331
	(1608)	(1659)	(1351)	(1570)
Leaseholder × 2014	4353***	3228*	2495*	927
	(1654)	(1722)	(1405)	(1620)
Leaseholder × 2015	3602**	2533	1649	728
	(1677)	(1741)	(1397)	(1633)
Leaseholder × 2016	3345**	2219	946	577
	(1675)	(1735)	(1373)	(1656)
Leaseholder × 2017	1998	676	210	392
	(1727)	(1803)	(1457)	(1690)
Leaseholder × 2018	1529	421	-396	234
	(1754)	(1820)	(1456)	(1750)
Leaseholder × 2019	1081	-166	-639	-11
	(1769)	(1838)	(1468)	(1778)
R-squared	0.592	0.594	0.578	0.609
N	882,560	820,640	1,545,200	882,400

Notes: [a]Main results are based on one-to-one matching without replacement. * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Robust standard errors clustered by individual are in parentheses. All regressions include individual and quarter fixed effects.

A8. Sample Comparison with Cookson et al. (2022)

Our sample reflects the same population as that studied by Cookson et al. but is much smaller for two reasons that can be explained by comparing their sequence of sample development to ours. Cookson et al. start with roughly 500,000 leaseholders identified in county tax appraisal records, which they match with Experian records with an 80 percent match rate, leaving 400,000 leaseholders. Further restrictions (e.g., observed for the full study period) leave 216,000 leaseholders.

The first reason for a smaller sample is because we start with a smaller number of raw records. For the same counties, we start with 312,000 lease-owner pairs that we identified from digitized leases recorded in County land offices. The smaller starting number in part reflects the inability to parse out all names in some leases. For example, a lease where the lessor is "John Doe et ux." reveals only one owner (John Doe) when another clearly exists but whose name cannot be identified.

The second reason for a smaller sample is not in matching leaseholder names and addresses to credit bureau records. There, we have a similar match rate to (77 percent vs 80 percent). Rather, it is because we conduct an additional match to find leaseholders also in the Consumer Credit Panel, which itself is a sample. The Panel is a 5 percent anonymous, random sample in its initial draw but also grabs records for related individuals (e.g., those living at the same address). In the end, about 13 percent of matches with credit bureau data were also in the Consumer Credit Panel.

Taking these steps into account leaves roughly 31,000 records (= 312,000 initial records $\times$ 77 percent general match $\times$ 13 percent Credit Panel match rate) compared to the 400,000 of Cookson et al. Further data cleaning (removing any duplicates) and sample restrictions (observed in all quarters of the study period) reduces our sample to roughly 10,000 leaseholders for four Barnett counties studied by Cookson et al. compared to their 216,000 leaseholders.