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Rational but Not Prescient: Borrowing during the Fracking Boom[*]

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Abstract

Following the arrival of news that fracking technology was commercially viable, leaseholders of gas rights in Texas' Barnett Shale borrowed $12,800 more than non-leaseholders during 2003-2008. Ninety percent of leaseholders' borrowing occurred before they signed a lease. Expected royalties from fracking leases could not be collateralized, suggesting that expectations of increased permanent income rather than relaxed credit constraints drove leaseholder borrowing. We show that leaseholder borrowing is consistent with plausible expectations of gas prices and royalties. When natural gas prices unexpectedly crashed during 2009-2019, bankruptcy rates of leaseholders and non-leaseholders were no different, suggesting leaseholder borrowing 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, they faced a potentially large windfall when hydraulic fracturing (fracking) unexpectedly made large natural gas fields 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 that depended on natural gas prices and drilling outcomes. While signing bonuses were generally modest, expected royalties represented a substantial permanent income shock because of a bullish outlook for domestic natural gas prices.

Because royalties from fracking leases could not be collateralized, the setting provides an opportunity to answer broad questions about how increased expected income affects behavior apart from any loosening of credit constraints. Do people respond rationally and use the best available information when deciding how to borrow from their expected future income streams (Lucas and Lucas, 1987; Sargent, 2013)? Or are they over-confident and impulsive, borrowing off of what appears to be implausibly large future income gains? Or, because the diffusion and associated general equilibrium effects of technological innovations such as fracking are hard to predict, do they delay plans to increase consumption until the windfalls are in hand? Finally, if people are rational but not prescient, does their consumption smoothing behavior force them to engage in painful deleveraging or to file for bankruptcy when it becomes clear that their initial permanent income forecasts need to be revised?

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 suburbs 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 shock to expected permanent income for people owning gas rights and who eventually secured fracking leases. To estimate how they responded, we construct a dataset that tracks financial outcomes from 2000:Q1 to 2019:Q4 for more than 10,000 people who eventually signed leases with energy companies. Thus, our dataset spans a period before, during and after the arrival of news that fracking was commercially viable. 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 Klauw, 2010). To construct a credible counterfactual, we follow Imbens (2015) and match leaseholders with non-leaseholders drawn from a pool of more than five million observations in the Consumer Credit Panel. With about 470 potential control observations for each leaseholder, we obtain close to exact matches.

We find leaseholders were forward looking because 90 percent of their borrowing occurred before the first lease payment. They also borrowed an economically important amount, taking on $12,800 more debt than non-leaseholders during 2003-2008, a period of generally rising natural gas prices. Moreover, 80 percent of the debt was in mortgage debt as opposed to higher interest home equity loans or credit cards.

To assess whether this borrowing response was rational, we use the canonical model of consumption smoothing and permanent income (Jappelli and Pistaferri, 2010) to derive the average leaseholder's optimal borrowing over the 2003-2008 period. A simple calibration using median household income in Tarrant County Texas and a rational (and not impatient) discount factor shows the average leaseholder's borrowing was consistent with expectations of plausible royalty payouts over the course of a twenty-year lease. Specifically, we use market prices and well production parameters from the Powell Barnett Newsletter, which reflects the type of talk swirling around the Barnett circa 2008 when natural gas prices were high and when the average leaseholder signed a lease.[1]

While leaseholders had rational borrowing behavior during 2003-2008, they could not foresee the future general equilibrium effects of the rapid diffusion of fracking technology. This spurred a surge in production, causing natural gas prices to crash in 2009 and to remain

[1] See `www.latax.state.la.us/Menu_RulesRegulations/Rules%20and%20Regs%20Changes/Proposals/2010/LMOGA/Exhibit%208.3%20-%202009%20Tarrant%20County%20Barnett%20Shale%20revenue%20estimate.pdf`

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 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 bankruptcy rate over the 2009-2019 period was similar to that of non-leaseholders (6.3 vs 6.1 percent). The similarity in rates 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 impulsive or excessive borrowing. Credit markets can allow borrowers to smooth consumption, but excessive borrowing can have the opposite effect, causing painful deleveraging. Prior research has documented how increased credit availability through rising home values and low interest rates can spur borrowing and later defaults, especially for those with low credit scores (Mian and Sufi, 2011; Bhutta and Keys, 2016). Because rising home values and lower interest rates increase permanent income and also reduce credit constraints, increased borrowing and defaults could have two very different interpretations. The borrowing 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 could not be collateralized, our study enables us to shut down the credit constraint channel and focus on whether leaseholders were rational or over-confident when they borrowed from their expected permanent income. In a related study, Agarwal et al. (2023) also shuts down the credit constraint channel and documents how a U.S. federal program increased refinancing activity and durable goods spending among eligible borrowers.

Looking at the same context and many of the same individuals, Cookson et al. (2022) find that actual receipt of payments causes individuals to reduce debt payments by about $900 per year, which, they note, is inconsistent with a forward-looking, consumption smoothing model. Their result comes from matching leaseholders and non-leaseholders in 2005. By then owners of gas rights had adjusted to the news of fracking and most were waiting to sign leases and get a signing bonus which happened in 2008 on average. Even though our source of credit bureau data and our sample is different than what Cookson et al. (2022) use, we obtain a similar result when applying their methods (e.g. matching in 2005 instead of during 2000-2002), finding that annual debt payments decline by $811 after receiving the first payment. 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.

Our findings regarding leaseholders can provide insight into behavior in similar situations. The average sample leaseholder has an expected permanent income gain of roughly $60,000 over a 20-year period. Our setting shows how people might respond to obtaining a raise of roughly $3,000 per year that may or may not persist. This could happen, for example, if someone takes a new job that initially has a higher salary but the future pay is uncertain because it is based largely on the stock price of the company.

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 local aggregate measures of consumer debt (Brown, 2021; Cunningham et al., 2021). Most studies estimate effects on places rather than people (Marchand and Weber, 2018). Some 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 shale development on people thought to be one of its major beneficiaries–those who own the resources in the ground.

The focus on leaseholder also 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 the land for their farm 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 oil and gas right owners. 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. Archival work indicates a shift in expectations 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.[2] 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, 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.[3] 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 (0.61 acres). For prices, we take the average spot market price in 2008 and, in line with Hotelling (1931), assume that it grows at the real interest rate. This roughly fits the futures price curve in January of 2008, which showed a price of $9 per Mcf two years into the future.[4] The parameters imply that over 20-years, the expected lease duration at the time, the average leaseholder would receive a 2008 present value of royalties ranging from roughly $30,000 to $60,000 (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

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

[3] 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.

[4] Natural gas futures prices are based on Bloomberg data for the Nymex price.

2008 with occasional spikes (Figure 1). In general the public had bullish expectations for energy prices circa 2008. 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. In 2008, gasoline and other energy prices had spiked, and 78 percent of people expected the rise to be permanent, the highest of the 15 times the question has been asked. The Gallup survey also asked whether people thought the United States was likely to face a critical energy shortage in the next five years. In 2008, 62 percent expected a shortage, also the highest recorded percentage.[5]

The Gallup surveys are themselves 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 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

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

40 trillion cubic feet.[6] 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.[7]

3 Fracking, Permanent Income, and Consumption Smoothing

How would owners of oil and gas rights in the Barnett Shale rationally respond to the news in 2002-2003 that fracking had become commercially viable? The average owner signed a lease in 2008 and received a small signing bonus. On average she would get a royalty stream starting in 2010 and a common view was that wells would have economical production for roughly twenty years, covering 2010-2029. We focus on borrowing during 2003-2008 because it is a period of bullish natural gas price expectations that ended with the 2009 price crash that marked the beginning of a decade of dramatically lower prices.

Consider a leaseholder who maximizes her utility function over current and future con-

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

[7] 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.

sumption for a time horizon that includes her expected royalty stream:

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

where $t = 2003, 2004, ..., T = 2029$, c_i 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, $u_i(c_i) = ln(c_i)$, which implies that the elasticity of substitution between current and future consumption is unitary.[8] In this setup consumption includes payments for housing debt, auto loans and other debt. This assumption enables us to sharply predict how the news of fracking drove borrowing patterns of leaseholders versus non-leaseholders.

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 period, $T = 2029$, she pays off her remaining debts or consumes her remain savings. This implies that she has an intertemporal budget constraint:

$$\sum_{t}^{T} \beta^{t-2003} \frac{c_i}{(1+r)^{t-2003}} = \sum_{t}^{T} \beta^{t-2003} \frac{Q_i}{(1+r)^{t-2003}} \equiv PI. \tag{2}$$

The variable PI in equation (2) denotes permanent income. It is the present discounted value of income during the period running from t=2003 to T=2029, where Q_i is expected income in each year, and r is the discount rate.

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

$$u'(c^*_{2003}) = u'(c^*_{2004}) = ... = u'(c^*_{T=2029}). \tag{3}$$

where $u'(c^*_i)$ denotes the marginal utility of consumption in year t. Solving equation (3),

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

consumption in any year t is:

$$c_i^* = \frac{PI * (1 + r)^{t-2003}}{T - t_0}, \text{where } t_0 = 2002 \text{ and } t = 2003...2029. \quad (4)$$

Suppose that the eventual leaseholder has an income of $56,900 (in 2010 dollars) in 2003, roughly the median household income in Tarrant County at the time.[9] She expects this to grow in real terms by 2 percent per year through 2029 and expects a real interest rate of 2 percent through 2029. In this scenario, before the arrival of fracking news, her present discounted value of income is $1,536,300. Following the arrival of the fracking news, her expected permanent income increases by $59,515 under the assumption that natural gas price is $8.86 per Mcf (average price in 2008) and rises at the real interest rate. Under this scenario, the leaseholder's cumulative borrowing as of 2008 is $13,600.[10] In the appendix we report additional borrowing simulation results under different income growth, interest rate, lease horizon, and leaseholder's horizon scenarios (Table A1). For example, a more pessimistic view of the lease horizon (a well life of only 15 years), reduces optimal borrowing in the 2003-2008 period to $12,100. Later, we estimate that the average eventual leaseholder borrowed $12,800 more than a non-leaseholder. This suggests that the average leaseholder was forward-looking, had plausible price expectations for the time period and, given the price expectations, fully expected that her lease would be drilled and produce royalties.

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

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

[10] 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.

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. Arguably, there are three channels through which valuable gas rights could do this, all of which are unlikely. First, the leaseholder might attempt to use future leased rights as collateral for a loan. This is unlikely because from the standpoint of a lender, it is uncertain whether a lease will be signed or, if signed, how much royalties it will generate, if any. Anecdotally, we spoke with several people involved in lending in the region, and no one knew of cases where someone collateralized an anticipated lease for a loan.

Second, after fracking becomes news and the lease is signed, the cash from the initial bonus payment might loosen borrowing constraints, affecting borrowing limits or the interest rate charged. For example, payments in pocket could allow leaseholders to afford a down payment. This is also unlikely for mortgages because Cookson et al. (2022) estimate that the average leaseholder in the Barnett Shale received about $2,300 upon signing a lease, and an industry report (the U.S. Lease Price Report) suggests modal payments of about $900 or $1,200 for Tarrant and Johnson Counties, key Barnett Shale counties, for the years 2006 to 2008.[11] Such a modest payment is unlikely to be decisive for reaching a down payment for a home, though it might help for smaller purchases such as a vehicle.

Third, the presence of valuable gas rights might increase the appraised value of a home, increasing the equity that the owner could borrow against. Appraised values are determined by sales prices observed for nearby comparable homes. If gas rights are capitalized in the sales price of comparable homes because the rights conveyed with the property, they could affect the appraised value of the home in question. That said, the noise, air pollution, and other dis-amenities from shale drilling have generally reduced the sales value of nearby homes (Muehlenbachs et al., 2015; Weber et al., 2016; Balthrop and Hawley, 2017).[12]

[11] The Report gives a modal bonus payment per acre of $1,500 and $2,000 for Tarrant and Johnson County but our average–and the average leaseholder in Cookson et al. (2022)–has about 0.6 acres.

[12] Weber et al. (2016) finds that the property tax base expansion and resulting tax rate reductions in the Barnett Shale led to higher home values relative to areas outside the Shale. However, it also shows that

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.[13] 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 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

within the shale, a greater density of wells nearby lowers home values.

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

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 also focus on leaseholders whose first leasing event occurred in 2005 or later. The restrictions yield a sample of 10,660 leaseholders observed over the full 2000:Q1-2019:Q4 period. To be clear, leaseholders need not live in any of the study counties; they only need to own a lease in one of the counties. Slightly more than 7 percent of leaseholders live outside the six study counties.

5 Empirical Approach and Identification

The core of our empirical approach is to match leaseholders with observationally similar non-leaseholders selected from a massive pool of non-leaseholders. Our identifying assumption is that of unconfoundedness, also known as selection on observables: conditional on similar pre-treatment observed values, any post-treatment differences between treatment and control groups can be interpreted as the causal effect of treatment (Imbens, 2015).

The matching approach and its unconfoundedness assumption fit our situation well. Fracking news affected the expected income of some people and not others based on ownership of gas rights that previously would have been nearly worthless. Many owners would have acquired their rights incidentally when they purchased their home or inherited property in the Fort-Worth area. Thus, we expect owners to potentially differ from a randomly selected person but in observable ways. Moreover, our massive pool of potential matches allows us to find high quality matches under which the unconfoundedness assumption likely holds.

5.1 Matching Strategy

Our matching strategy builds on the Cookson et al. (2022) study of leaseholder finances in the Barnett Shale. Using data from the 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 age and geography 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.

In our first step, we trim our massive pool of potential matches to 1) only include people who live in a three-digit ZIP code where at least one leaseholder also lives, and 2) excludes people whose ages are outside the range of ages observed for the leaseholders in the same three-digit ZIP code. Trimming is helpful because the Equifax Consumer Credit Panel contains tens of millions of people.

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 along with three-digit ZIP code fixed effects. 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. Some variation in these variables is captured by location, which we cover by requiring an exact match on three digit ZIP Code, of which there are more than 900 in the United States.

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 A2 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 and an exact match on location at the three-digit ZIP code. We require the matches to have common support.

Having made credible matches based on the propensity score, we show the evolution of financial outcomes over the study period for leaseholders and matched non-leaseholders. We do this most simply and clearly by graphically showing the mean debt for each group by quarter. We also quantify the difference in means by year and their standard errors using an individual fixed effects regression described in the Appendix.

6 Descriptive Statistics and Balance Tests

Our data bear out the general similarities between future leaseholders and the pool of potential matches, where the only conditions to be in the pool are to live in a three-digit ZIP code of a leaseholder and not have an age outside of the age range of leaseholders. For six of the eight covariates, the difference in means is less than 0.15 standard deviations before matching (Table 1). Leaseholders had an average initial credit score of 691 compared to 685 for non-leaseholders, and the two groups had nearly identical increase in debt over the 2000-2002 period. All but one of the differences in means is highly statistically significant, but this is expected given more than five million observations used. Overall, the pre-matching comparisons support the assertion that people who found themselves in a position to lease out gas rights in the Barnett Shale were fairly representative of the broader population in their three-digit ZIP code.

Our rich propensity score specification, shown in Table A2, leads to good matches, yielding leaseholder and non-leaseholder samples that are nearly perfectly balanced across the eight covariates (Table 2). The largest difference in means is 0.06 standard deviations, with leaseholders having an average age of 46.1 years compared to 45.3 years for non-leaseholders. All other differences are 0.03 standard deviations or less (in absolute terms) and economically small. For example, average values for leaseholders and matched non-leaseholders are 691.6 and 691.3 for credit scores and $57,370 and $57,950 for initial total debt.

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

Our main finding as shown in Figure 3 is that leaseholder and non-leaseholder debt tracked closely from 2000 until 2003, at which point leaseholder debt continued to grow while non-leaseholder debt began to level off. The debt difference between the two groups peaked in 2008 at $12,800 (standard error of about $1,600), the year of peak natural gas prices and payments. This is noteworthy because the median time of leasing was the second quarter of 2008. In fact, looking at the change in borrowing from the initial period (2000-02) until the two quarters before signing a lease gives an average increase in borrowing (relative to the control group) of $12,000. Thus, 90 percent of additional borrowing occurred before any payment had been received, suggesting that it 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. Thus, we provide point estimates and standard errors of annual differences using a difference-in-differences specification in column 1 of Appendix Table A3.

The leveling off of non-leaseholder debt 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, the difference in debt narrowed considerably through 2013 and more slowly through 2019, with the narrowing driven by greater reductions in debt among leaseholders. By 2019, leaseholders held about $3,500 more debt than non-leaseholders. Since there were no differences in borrowing before fracking, this suggests that the borrowing response did not create irreparable damage when the outlook for payments changed.

Our main estimate of the 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 A4). In addition, the alternatives give annual differences in mean borrowing similar to the original matching approach. Across the four approaches, the estimated increase in borrowing as of 2008 ranges from $12,807 to $15,465, with our main approach giving the smallest effect (Appendix Table A5).

To further explore the borrowing response, we breakout debt by three exclusive and exhaustive categories: mortgage, auto, and everything else ("other") (Figure 4). During times of high natural gas prices and payments, leaseholders increased mortgage debt by about $10,300 and auto debt by about $1,100 (see Appendix Table A3 for point estimates). Thus, 89 percent of the borrowing occurred in these two categories, which generally have some of the lowest interest rates because they are secured by an underlying asset. All other forms of borrowing such as student loans, credit cards, and home equity lines of credit accounted for the remaining 11 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 2008 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, 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 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 4). The more muted borrowing response by leaseholders in the first quartile might reflect a higher cost of credit. Those with the highest credit scores, however, 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 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 as of 2008. In the extreme, a person in the first quartile for age, the second quartile for credit score, and the fourth quartile for acreage borrowed \$70,000 (= 52,000 + 36,000 -18,000). Some of the greater borrowing reflects their greater acreage and therefore greater expected royalties, but considering the same person with acreage in the bottom three quartiles gives an average borrowing response of around \$50,000. This suggests irrational expectations about well productivity, natural gas prices, or both.

7.2 The Response to News vs. Payments in Hand

Our finding of leaseholders taking on more debt seems to contradict the results of Cookson et al. (2022) who show that after receiving payments, leaseholders pay down their debt as evidenced by a roughly \$900 per year decrease in debt payments. 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 having payments in hand.

We first compare their sample data with ours. Our sample size is considerably smaller, 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 A8 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 (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 5 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.

7.3 Unmet Expectations 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, a small fraction of the payments plausibly expected at the 2008 peak and well below the 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.[14]

[14] We thank Thomas Covert for sharing code and replication files for this tabulation.

To consider the effect of unmet expectations, we look at the percent of leaseholders and non-leaseholders that ever filed for bankruptcy over the period of lower natural gas prices (2009-2019). Despite the much lower-than-expected royalty payments, leaseholders and non-leaseholders had similar bankruptcy rates over the low-price period (6.3 vs 6.1 percent), a small and statistically insignificant difference (t-statistic of 0.51).

Evidence suggests that small-scale leaseholders in the Fort Worth suburbs were not duped by industry insiders who had better energy price forecasts. 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 and around the time that leaseholders had their highest bankruptcy rate relative to non-leaseholders. 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.[15] 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 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

[15] www.mvis-indices.com/indices/hard-asset/mvis-global-unconventional-oil-gas.

widespread bankruptcies 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 as evidenced by similar bankruptcy rates among leaseholders and non-leaseholders over the low-price period.

References

Agarwal, Sumit, Gene Amromin, Souphala Chomsisengphet, Tim Landvoigt, Tomasz Piskorski, Amit Seru, and Vincent Yao. 2023. "Mortgage refinancing, consumer spending, and competition: Evidence from the home affordable refinance program." *The Review of Economic Studies*, 90(2): 499–537.

Allcott, Hunt, and Daniel Keniston. 2018. "Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America." *The Review of Economic Studies*, 85(2): 695–731.

Balthrop, Andrew T, and Zackary Hawley. 2017. "I can hear my neighbors' fracking: The effect of natural gas production on housing values in Tarrant County, TX." *Energy Economics*, 61 351–362.

Bardi, Ugo. 2019. "Peak oil, 20 years later: Failed prediction or useful insight." *Energy Research & Social Science*, 48 257–261.

Bartik, Alexander W, Janet Currie, Michael Greenstone, and Christopher R Knittel. 2019. "The local economic and welfare consequences of hydraulic fracturing." *American Economic Journal: Applied Economics*, 11(4): 105–55.

Bhutta, Neil, and Benjamin J Keys. 2016. "Interest rates and equity extraction during the housing boom." *American Economic Review*, 106(7): 1742–74.

Binder, Carola, and Christos Makridis. 2022. "Stuck in the seventies: Gas prices and consumer sentiment." *Review of Economics and Statistics*, 104(2): 293–305.

Black, Dan, Terra McKinnish, and Seth Sanders. 2005. "The economic impact of the coal boom and bust." *The Economic Journal*, 115(503): 449–476.

Brown, Jason P. 2021. "Response of consumer debt to income shocks: The case of energy booms and busts." *Journal of Money, Credit and Banking*, 53(7): 1629–1675.

Brown, Jason P., Timothy Fitzgerald, and Jeremy G. Weber. 2019. "Does Resource Ownership Matter? Oil and Gas Royalties and the Income Effect of Extraction." *Journal of the Association of Environmental and Resource Economists*, 6(6): 853–878.

Callaway, Brantly, and Pedro HC Sant'Anna. 2021. "Difference-in-differences with multiple time periods." *Journal of Econometrics*, 225(2): 200–230.

Caselli, Francesco, and Guy Michaels. 2013. "Do oil windfalls improve living standards? Evidence from Brazil." *American Economic Journal: Applied Economics*, 5(1): 208–38.

CEA. 2019. "The Value of U.S. Energy Innovation and Policies Supporting the Shale Revolution." working paper, White House Council of Economic Advisers.

Chuan, Amanda. 2022. "The impact of oil and gas job opportunities during youth on human capital." *Southern Economic Journal*, 89(2): 406–439.

Cookson, J Anthony, Erik P Gilje, and Rawley Z Heimer. 2022. "Shale shocked: Cash windfalls and household debt repayment." *Journal of Financial Economics*, 146(3): 905–931.

Covert, Thomas R, and Richard L Sweeney. 2023. "Relinquishing Riches: Auctions versus Informal Negotiations in Texas Oil and Gas Leasing." *American Economic Review*, 113(3): 628–663.

Cunningham, Chris, Kristopher Gerardi, and Lily Shen. 2021. "The double trigger for mortgage default: Evidence from the fracking boom." *Management Science*, 67(6): 3943–3964.

Dehejia, Rajeev H, and Sadek Wahba. 1999. "Causal effects in nonexperimental studies: Reevaluating the evaluation of training programs." *Journal of the American Statistical Association*, 94(448): 1053–1062.

Durham, Louise S. 2006. "Barnett Shale a Stimulating Play." *AAPG Explorer*, URL: https://explorer.aapg.org/story/articleid/37143/barnett-shale-a-stimulating-play.

Feyrer, James, Erin T Mansur, and Bruce Sacerdote. 2017. "Geographic dispersion of economic shocks: Evidence from the fracking revolution." *American Economic Review*, 107(4): 1313–34.

Fuster, Andreas, David Laibson, and Brock Mendel. 2010. "Natural expectations and macroeconomic fluctuations." *Journal of Economic Perspectives*, 24(4): 67–84.

Goetzmann, William N, Dasol Kim, and Robert J Shiller. 2022. "Crash Narratives." Working Paper 30195, National Bureau of Economic Research.

Gülen, Gürcan, John Browning, Svetlana Ikonnikova, and Scott W Tinker. 2013. "Well economics across ten tiers in low and high Btu (British thermal unit) areas, Barnett Shale, Texas." *Energy*, 60 302–315.

Haynes Boone. 2022. "Oil Patch Bankruptcy Monitor." January, URL: https://www.haynesboone.com/-/media/project/haynesboone/haynesboone/pdfs/energy_bankruptcy_reports/oil_patch_bankruptcy_monitor.pdf?rev=e57d3129b7504ea190df5d33dbacae44&hash=F461E4FE13446BE821B8AE9080C349E6.

Hinton, Diana Davids. 2012. "The seventeen-year overnight wonder: George Mitchell and unlocking the Barnett Shale." *The Journal of American History*, 99(1): 229–235.

Hotelling, Harold. 1931. "The economics of exhaustible resources." *Journal of Political Economy*, 39(2): 137–175.

Imbens, Guido W. 2015. "Matching methods in practice: Three examples." *Journal of Human Resources*, 50(2): 373–419.

Imbens, Guido W, Donald B Rubin, and Bruce I Sacerdote. 2001. "Estimating the effect of unearned income on labor earnings, savings, and consumption: Evidence from a survey of lottery players." *American Economic Review* 778–794.

Jacks, David S. 2019. "From boom to bust: A typology of real commodity prices in the long run." *Cliometrica*, 13(2): 201–220.

Jacobsen, Grant D, and Dominic P Parker. 2016. "The economic aftermath of resource booms: evidence from boomtowns in the American West." *The Economic Journal*, 126(593): 1092–1128.

Jacobsen, Grant D, Dominic P Parker, and Justin B Winikoff. 2021. "Are resource booms a blessing or a curse? Evidence from people (not places)." *Journal of Human Resources* 0320–10761R1.

Jappelli, Tullio, and Luigi Pistaferri. 2010. "The consumption response to income changes." *Annual Review of Economics*, 2(1): 479–506.

Lee, Donghoon, and Wilbert van der Klaauw. 2010. "An Introduction to the FRBNY Consumer Credit Panel." Staff Reports 479, Federal Reserve Bank of New York.

Lucas, Robert E, and Lucas. 1987. *Models of business cycles.* 26: Basil Blackwell Oxford.

Marchand, Joseph, and Jeremy Weber. 2018. "Local labor markets and natural resources: A synthesis of the literature." *Journal of Economic Surveys*, 32(2): 469–490.

Mian, Atif, and Amir Sufi. 2011. "House Prices, Home Equity–Based Borrowing, and the US Household Leverage Crisis." *American Economic Review*, 101(5): 2132–2156.

Michaels, Guy. 2011. "The Long Term Consequences of Resource-Based Specialisation." *The Economic Journal*, 121(551): 31–57.

Muehlenbachs, Lucija, Elisheba Spiller, and Christopher Timmins. 2015. "The housing market impacts of shale gas development." *American Economic Review*, 105(12): 3633–3659.

Patzek, Tad W, Frank Male, and Michael Marder. 2013. "Gas production in the Barnett Shale obeys a simple scaling theory." *Proceedings of the National Academy of Sciences*, 110(49): 19731–19736.

Sargent, Thomas J. 2013. "Rational expectations and inflation." In *Rational Expectations and Inflation.*: Princeton University Press.

Weber, Jeremy G, J Wesley Burnett, and Irene M Xiarchos. 2016. "Broadening benefits from natural resource extraction: Housing values and taxation of natural gas wells as property." *Journal of Policy Analysis and Management*, 35(3): 587–614.

Zou, Hui, and Trevor Hastie. 2005. "Regularization and variable selection via the elastic net." *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 67(2): 301–320.

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

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

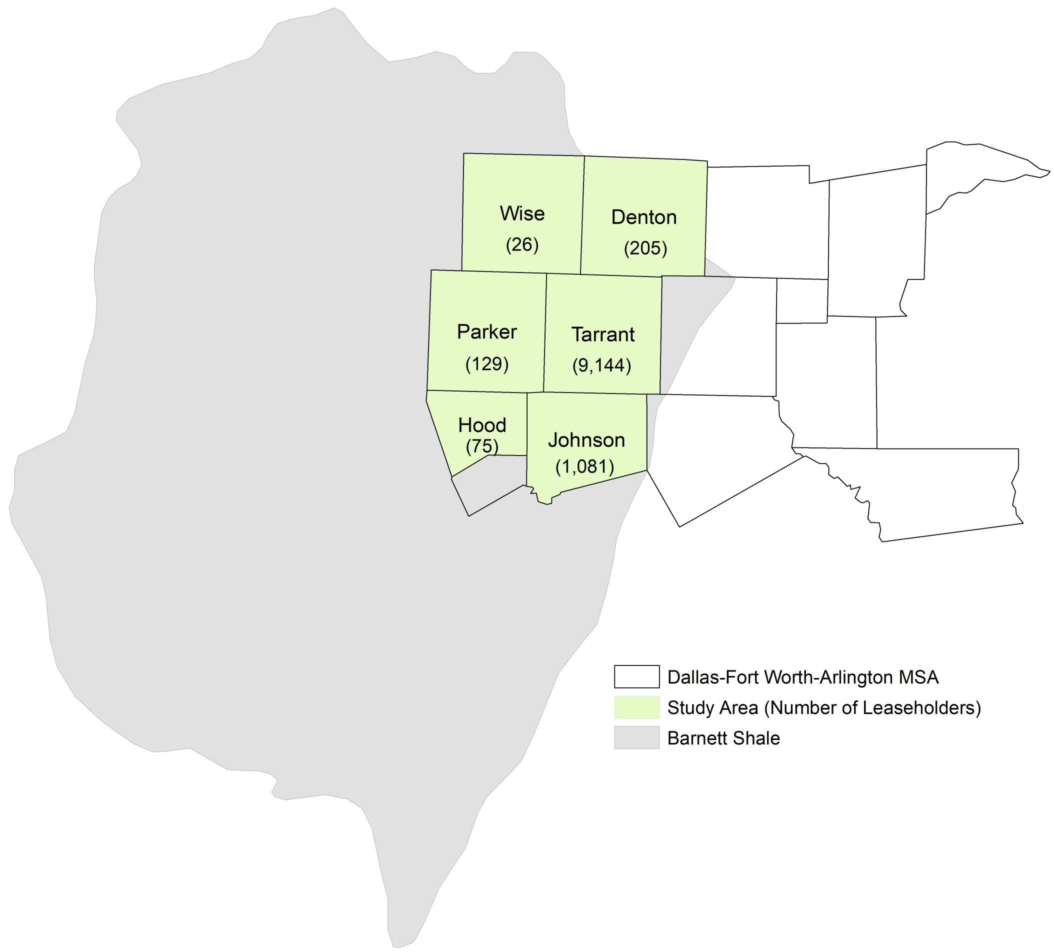


Figure 2: Barnett Shale in Dallas-Forth Worth-Arlington MSA

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.

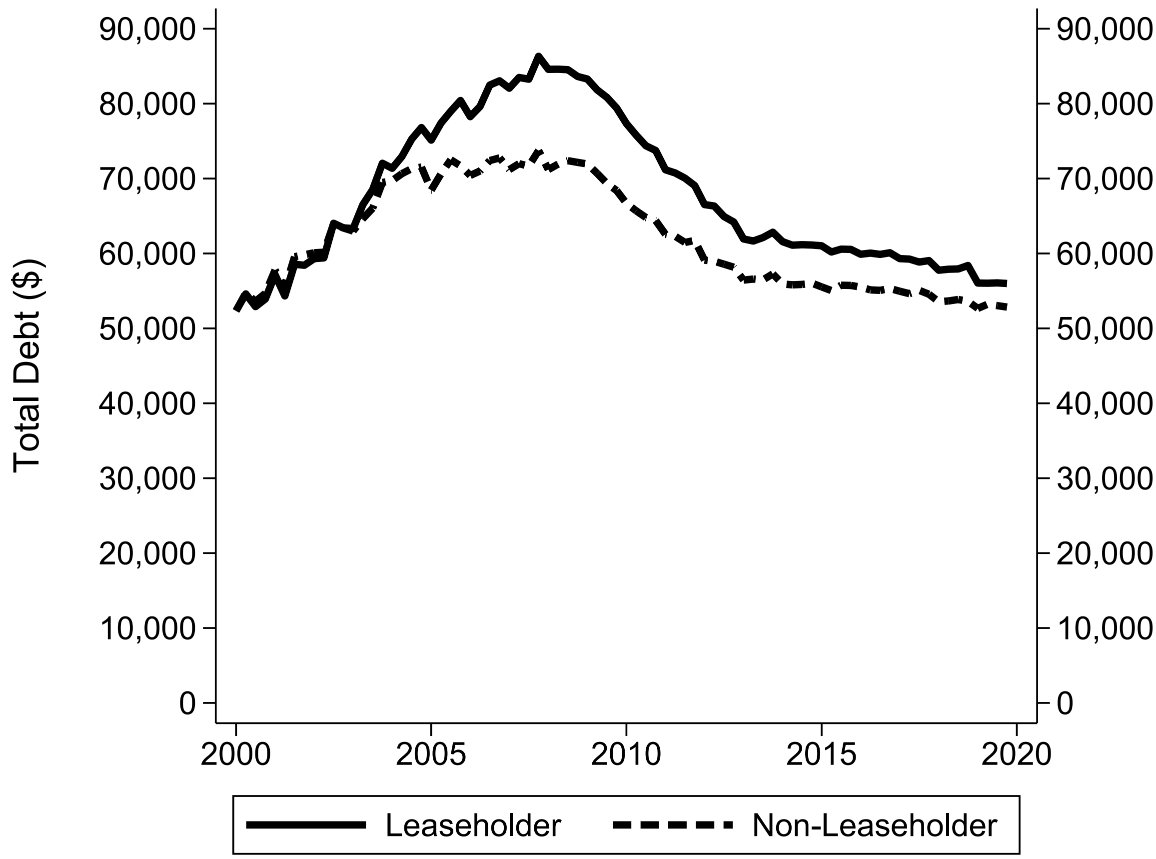
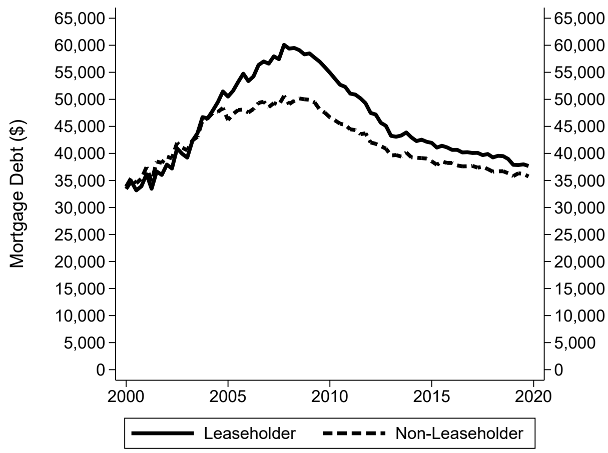
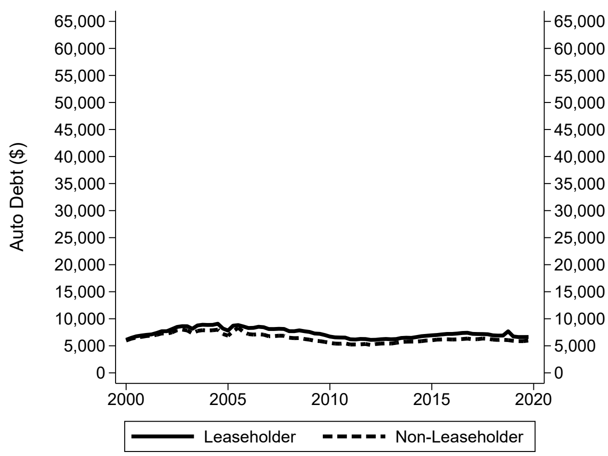


Figure 3: Mean Total Debt, 2000 to 2019

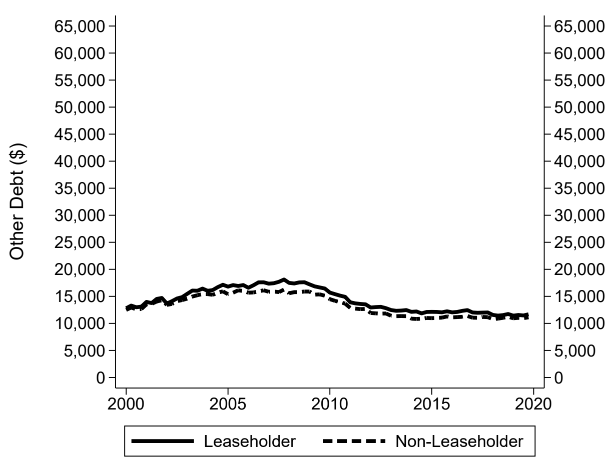
Source: New York Fed Consumer Credit Panel, Enverus. *Notes*: The figure shows the mean total debt for 10,660 leaseholders and the same number of matched non-leaseholders.



(a) Mortgage Debt



(b) Auto Debt



(c) Other Debt

Figure 4: Mean Debt By Category, Leaseholders versus Non-Leaseholders

Source: New York Fed Consumer Credit Panel; Enverus. *Notes*: "Other Debt" includes all debt other than mortgage and auto debt.

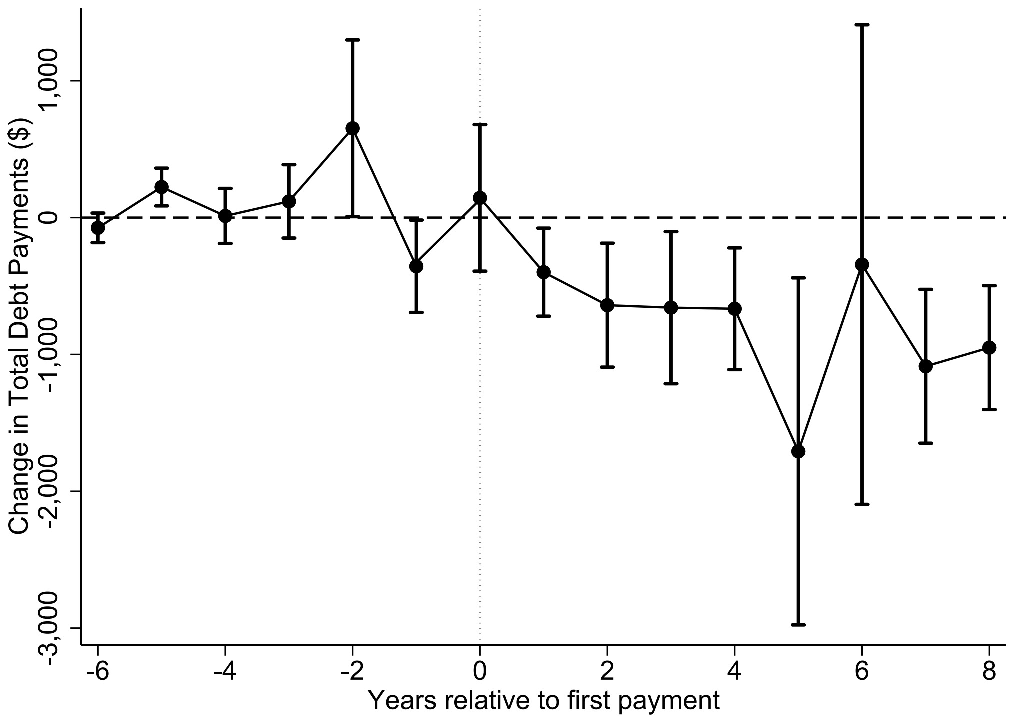


Figure 5: Event Study Estimates of the Effect of Lease Payments on Debt Payments

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: Balance Table of Matching Sample

	Leaseholder=0 Mean	SD	Leaseholder=1 Mean	SD	Mean Difference	t-stat	Normalized Difference
Credit Score$_{00-02}$	684.60	102.02	691.25	92.55	-6.65***	-6.73	-0.70
Credit Length$_{00-02}$ (Months)	206.73	279.61	228.40	148.30	-21.67***	-8.00	-0.10
Age$_{00-02}$	44.14	15.24	46.13	13.59	-1.99***	-13.49	-0.14
Total Debt$_{00-02}$ (Thous. $)	48.06	72.96	57.46	73.70	-9.39***	-13.28	0.13
Δ Total Debt$_{00-02}$ (Thous. $)	7.09	62.74	7.00	58.06	0.090	0.15	0.001
Mortgage Debt$_{00-02}$	0.47	0.50	0.60	0.49	-0.13***	-26.88	-0.26
Auto Debt$_{00-02}$	0.49	0.50	0.64	0.48	-0.15***	-31.11	-0.31
Bankruptcy$_{00-02}$	0.05	0.22	0.04	0.20	0.01***	4.67	0.05
N	5,189,340		10,663				

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

Table 2: Balance Table of Matched Sample

	Leaseholder=0 Mean	SD	Leaseholder=1 Mean	SD	Mean Difference	t-stat	Normalized Difference
Credit Score$_{00-02}$	691.07	90.66	691.26	92.56	-0.18	-0.15	-0.002
Credit Length$_{00-02}$ (Months)	224.92	173.49	228.39	148.30	-3.47	-1.57	-0.02
Age$_{00-02}$	45.26	13.70	46.13	13.59	-0.86***	4.62	-0.06
Total Debt$_{00-02}$ (Thous. $)	57.95	67.79	57.37	73.46	0.58	0.60	0.01
Δ Total Debt$_{00-02}$ (Thous. $)	7.75	59.66	6.97	58.00	0.79	0.98	0.01
Mortgage Debt$_{00-02}$	0.62	0.49	0.60	0.49	0.01**	2.08	0.04
Auto Debt$_{00-02}$	0.65	0.48	0.64	0.48	0.01*	1.69	0.02
Bankruptcy$_{00-02}$	0.04	0.21	0.04	0.20	0.004	1.33	0.02
N	10,660		10,660				

Notes: Three recipients lived in ZIP codes with no control observations and were therefore dropped from the sample. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: New York Fed Consumer Credit Panel; Enverus. All monetary values are in 2010 dollars.

Table 3: Descriptive Statistics of Matched Sample

(a) Non-Leaseholders

	Mean	SD	25th	50th	75th	90th
Credit Score$_{00-02}$	691.07	90.66	628.92	710.38	767.92	792.67
Credit Length$_{00-02}$ (Months)	224.92	173.49	143.00	205.00	293.00	381.00
Age$_{00-02}$	45.26	13.70	35.00	44.00	53.00	64.00
Total Debt$_{00-02}$ (Thous. $)	57.95	67.79	11.61	40.39	82.13	131.27
Δ Total Debt$_{00-02}$ (Thous. $)	7.75	59.66	-8.95	0.00	16.80	61.23
Mortgage Debt$_{00-02}$	0.62	0.49	0.00	1.00	1.00	1.00
Auto Debt$_{00-02}$	0.65	0.48	0.00	1.00	1.00	1.00
Bankruptcy$_{00-02}$	0.04	0.21	0.00	0.00	0.00	0.00
N	10,660					

(b) Leaseholders

	Mean	SD	25th	50th	75th	90th
Credit Score$_{00-02}$	691.27	92.54	626.75	713.08	769.75	793.58
Credit Length$_{00-02}$ (Months)	228.38	148.30	142.00	205.00	302.00	395.00
Age$_{00-02}$	46.13	13.59	36.00	45.00	55.00	65.00
Total Debt$_{00-02}$ (Thous. $)	57.37	73.47	11.73	40.28	79.53	126.87
Δ Total Debt$_{00-02}$ (Thous. $)	6.97	58.01	-9.32	0.00	15.98	57.64
Mortgage Debt$_{00-02}$	0.60	0.49	0.00	1.00	1.00	1.00
Auto Debt$_{00-02}$	0.64	0.48	0.00	1.00	1.00	1.00
Bankruptcy$_{00-02}$	0.04	0.20	0.00	0.00	0.00	0.00
Lease Acreage	0.61	1.52	0.09	0.21	0.39	1.15
Lease Year	2007.99	1.60	2007	2008	2008	2010
N	10,660					

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 4: Heterogeneity in Debt Response

	Total Debt
Age_{q1}	51861***
	(4004)
Age_{q2}	31325***
	(4130)
Age_{q3}	12882***
	(4068)
Credit $Score_{q1}$	18502***
	(6897)
Credit $Score_{q2}$	36332***
	(5964)
Credit $Score_{q3}$	20225***
	(4698)
Credit Card $Utilization_{q1}$	5610
	(6886)
Credit Card $Utilization_{q2}$	9627
	(6665)
Credit Card $Utilization_{q3}$	768
	(5198)
$Acreage_{q1}$	-20445***
	(4638)
$Acreage_{q2}$	-17093***
	(4664)
$Acreage_{q3}$	-22439***
	(4897)
Intercept	-18104**
	(7869)
Adjusted R^2	0.027
N	10,659

Notes: The dependent variable is the change in total debt from the 2000-2002 period to 2008 less the change of the matched control individual. * p<0.05, ** p<0.01, *** p<0.001. Robust standard errors are in parentheses.

Appendix

Table A1: Optimal Borrowing Simulations

Income growth	Interest rate	Lease horizon	Leaseholder's horizon	Borrowing during 2003-2008
2%	2%	2010-2029	2003-2029	$13,600
1%	1%	2010-2029	2003-2029	$13,900
3%	3%	2010-2029	2003-2029	$13,100
2%	2%	2010-2024	2003-2029	$12,100
2%	2%	2010-2029	2003-2034	$11,300

Notes: Values are reported in 2010 dollars and are based on the consumption smoothing model described in Section 3

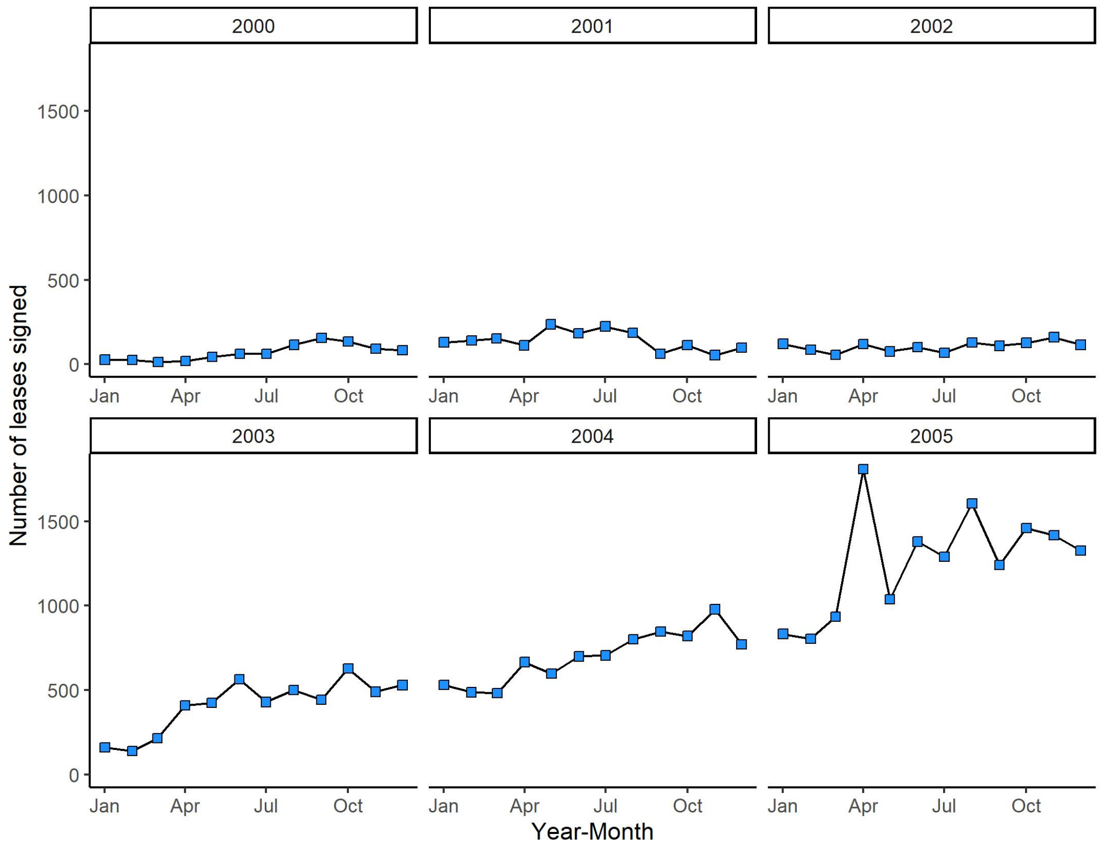


Figure A1: Monthly Leasing Activity in Study Counties, 2000-2005

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

Table A2: Probability of Being a Leaseholder

	Pr($Recipient_{05-16}$)
Credit $Score_{00-02}$	0.00638***
	(0.00067)
Credit $Length_{00-02}$ (Months)	0.00076***
	(0.00015)
Age_{00-02}	0.02482*
	(0.01283)
Total $Debt_{00-02}$	0.00277***
	(0.00049)
Δ Total $Debt_{00-02}$	-0.00011*
	(0.00006)
Mortgage $Debt_{00-02}$	0.65501***
	(0.22011)
Auto $Debt_{00-02}$	0.10501***
	(0.01495)
$Bankruptcy_{00-02}$	-0.03104
	(0.03968)
Credit $Length^2_{00-02}$	-0.0000001***
	(0.00000002)
Credit $Score^2_{00-02}$	-0.000004***
	(0.0000005)
Age^2_{00-02}	-0.00012
	(0.00008)
Credit $Score_{00-02}$ × Mortgage $Debt_{00-02}$	-0.00076***
	(0.00029)
Total $Debt^2_{00-02}$	-0.000001***
	(0.0000002)
Total $Debt_{00-02}$ × Mortgage $Debt_{00-02}$	-0.00114***
	(0.00027)
Credit $Length_{00-02}$ × Total $Debt_{00-02}$	-0.000002**
	(0.000001)
Credit $Score_{00-02}$ × Age_{00-02}	-0.00002**
	(0.00001)
Intercept	-7.12136***
	(0.58053)
Fixed Effects	Yes
Pseudo R^2	0.488
LL	-39,227
N	5,200,003

Notes: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Robust standard errors clustered by three-digit zipcode are in parentheses.

Annual Average Effects

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. As a result, we quantify the difference in means by year and their standard errors using the following difference-in-differences regression:

$$Debt_{i,t} \;=\; \alpha_i + \sum_{t=2001}^{2019} \delta_y \times Year_{y(t)} + \sum_{t=2001}^{2019} \beta_y (Year_{y(t)} \times Leaseholder_i) + \varepsilon_{it}. \quad (5)$$

where α_i is an individual fixed effect and $Year_{y(t)}$ is a binary variable indicating the observation's year. The β_y coefficients show how the difference in group means in year y differs from the difference in means in the omitted year (2000). To allow for an individual's error term to be correlated over time, we report standard errors clustered at the individual level.

Table A3: Average Treatment Effects - Debt Levels

	Total Debt	Mortgage	Auto	Other Debt
Leaseholder × 2001	-600	-709*	105	4
	(475)	(425)	(104)	(176)
Leaseholder × 2002	29	-427	380**	77
	(701)	(621)	(151)	(279)
Leaseholder × 2003	2200**	898	717***	585*
	(876)	(780)	(171)	(333)
Leaseholder × 2004	3683***	2276**	843***	564
	(1059)	(926)	(185)	(410)
Leaseholder × 2005	7557***	6072***	679***	806*
	(1220)	(1064)	(209)	(443)
Leaseholder × 2006	9598***	7529***	1089***	979**
	(1464)	(1303)	(190)	(468)
Leaseholder × 2007	12033***	9596***	1105***	1332***
	(1556)	(1374)	(188)	(481)
Leaseholder × 2008	12807***	10273***	1145***	1389***
	(1568)	(1385)	(188)	(491)
Leaseholder × 2009	11633***	9477***	1156***	1000*
	(1548)	(1359)	(182)	(533)
Leaseholder × 2010	10311***	8504***	945***	862
	(1474)	(1291)	(177)	(524)
Leaseholder × 2011	8633***	7291***	756***	586
	(1463)	(1296)	(177)	(485)
Leaseholder × 2012	7184***	5808***	644***	732
	(1395)	(1237)	(182)	(454)
Leaseholder × 2013	5835***	4606***	549***	680
	(1401)	(1221)	(194)	(482)
Leaseholder × 2014	5723***	4272***	635***	815*
	(1391)	(1222)	(203)	(456)
Leaseholder × 2015	5456***	4045***	729***	682
	(1418)	(1246)	(210)	(458)
Leaseholder × 2016	5108***	3572***	886***	650
	(1468)	(1279)	(229)	(482)
Leaseholder × 2017	4705***	3469***	713***	523
	(1433)	(1232)	(229)	(490)
Leaseholder × 2018	4715***	3688***	811***	216
	(1428)	(1207)	(298)	(499)
Leaseholder × 2019	3484**	2783**	552***	148
	(1427)	(1214)	(201)	(523)
R-squared	0.593	0.562	0.293	0.449
N	1,705,541	1,705,541	1,705,541	1,705,541

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 A4. 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 A4 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 A4 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 5. Results in Table A5 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 A4: Matching Robustness Checks on Normalized Differences

	One-to-One* No Replacement	One-to-One Replacement	Three Nearest Replacement	Elastic Net No Replacement
Credit Score$_{00-02}$	-0.002	-0.004	-0.02	-0.0001
Credit Length$_{00-02}$ (Months)	-0.02	-0.02	-0.04	-0.03
Age$_{00-02}$	-0.06	-0.07	-0.09	-0.06
Total Debt$_{00-02}$ (Thous. $)	0.01	0.01	0.01	0.002
Δ Total Debt$_{00-02}$ (Thous. $)	0.01	0.02	0.03	0.02
Mortgage Debt$_{00-02}$	0.04	0.03	0.03	0.02
Auto Debt$_{00-02}$	0.02	0.02	0.03	0.02
Bankruptcy$_{00-02}$	0.02	0.01	0.01	0.01

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

Table A5: 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 × 2001	-600	-999	-428	311
	(475)	(609)	(515)	(454)
Leaseholder × 2002	29	-445	-155	285
	(701)	(814)	(672)	(691)
Leaseholder × 2003	2200**	1774*	2578***	3453***
	(876)	(970)	(798)	(851)
Leaseholder × 2004	3683***	3577***	4881***	6316***
	(1059)	(1118)	(952)	(1023)
Leaseholder × 2005	7557***	7514***	8064***	9225***
	(1220)	(1280)	(1099)	(1232)
Leaseholder × 2006	9598***	9339***	10153***	11716***
	(1464)	(1601)	(1281)	(1421)
Leaseholder × 2007	12033***	12045***	12160***	14501***
	(1556)	(1688)	(1404)	(1521)
Leaseholder × 2008	12807***	13051***	13070***	15465***
	(1568)	(1663)	(1403)	(1552)
Leaseholder × 2009	11633***	12093***	11893***	13766***
	(1548)	(1643)	(1381)	(1518)
Leaseholder × 2010	10311***	10946***	10337***	11270***
	(1474)	(1571)	(1304)	(1429)
Leaseholder × 2011	8633***	9146***	8875***	9873***
	(1463)	(1562)	(1279)	(1369)
Leaseholder × 2012	7184***	7447***	7153***	8104***
	(1395)	(1515)	(1191)	(1309)
Leaseholder × 2013	5835***	6029***	6583***	6439***
	(1401)	(1517)	(1273)	(1312)
Leaseholder × 2014	5723***	5851***	6303***	6207***
	(1391)	(1511)	(1188)	(1314)
Leaseholder × 2015	5456***	5982***	6129***	6010***
	(1418)	(1531)	(1221)	(1344)
Leaseholder × 2016	5108***	5421***	6476***	6340***
	(1468)	(1580)	(1247)	(1380)
Leaseholder × 2017	4705***	5048***	5009***	6413***
	(1433)	(1540)	(1259)	(1393)
Leaseholder × 2018	4715***	4924***	4183***	5787***
	(1428)	(1525)	(1300)	(1426)
Leaseholder × 2019	3484**	3673**	3306***	3988***
	(1427)	(1521)	(1278)	(1425)
R-squared	0.593	0.591	0.592	0.600
N	1,705,541	1,705,541	1,705,541	1,705,701

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.

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 × 77 percent general match × 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.