Liquidity Windfalls and Reallocation: Evidence from Farming and Fracking*

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Abstract

Financing frictions may create a misallocation of assets in a market, thus depressing output, productivity, and asset values. This paper empirically explores how liquidity shocks generate a reallocation effect that diminishes this misallocation. Using a unique dataset of agricultural outcomes, I explore how farmers respond to a relaxation of financial constraints through a liquidity shock unrelated to farming fundamentals, namely exogenous cash inflows caused by an expansion of hydraulic fracturing (fracking) leases. Farmers who receive positive cash flow shocks increase their land purchases, which results in a reallocation effect. Examining cross-county purchases, I find that farmers in high-productivity counties who receive cash flow shocks buy farmland in low-productivity counties. In contrast, farmers in low-productivity areas who receive positive cash flow shocks do not engage in similar behavior. Moreover, farmers increase their purchases of vacant (undeveloped) land. Average output, productivity, equipment investment, and profits all increase substantially following these positive cash flow shocks. Farmland prices also rise significantly, consistent with a cash-in-the-market pricing effect. These effects are consistent with an efficient reallocation of land towards more productive users.

Keywords: Misallocation, Reallocation, Production, Productivity, Liquidity, Financial Constraints, Fracking, Agriculture, Asset Values

JEL Classification: D24, E22, G12, G31, G32, O16, Q15

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1 Introduction

Absent significant frictions, assets in an industry will be allocated to the most efficient users. However, frictions can cause assets to be allocated to less-efficient users. This misallocation may lead to depressed aggregate outcomes, such as lower productivity and asset values.[1] Financing frictions represent an important class of frictions that may induce such misallocation. These frictions can generate financial constraints (e.g. Bolton and Scharfstein (1990)) that impede the most productive users of assets from obtaining financing to invest in those assets, leaving them with less-productive users.[2] If so, then relaxing these financial constraints may undo some of the misallocation and result in an efficient *reallocation* of assets. Alternatively, it is also possible that financial constraints discipline managers and induce less wasteful spending, the way debt contracts might (e.g. Hart and Moore (1994)). In this case, relaxing these constraints may worsen outcomes. Thus, we lack an unambiguous theoretical answer to the question of how relaxing financial constraints will impact the allocative efficiency in an industry; these hypotheses need to be confronted with the data, particularly to understand the size and significance of the effects.

The goal of this paper is to empirically examine how alleviating financial constraints affects misallocation and aggregate economic outcomes. This issue is important for determining the extent of misallocation in a given marketplace as well as understanding potential mechanisms, including policy interventions, that may reduce such misallocation. A major challenge in such an empirical analysis is that a shock that relaxes financial constraints will typically also affect the firm's fundamentals, making it difficult to isolate the effect of relaxing financial constraints. To overcome this challenge, I consider a setting in which there is a

[1]A large literature has argued that such misallocation may account for differences in total factor productivity (TFP) and wealth across nations. Banerjee and Duflo (2005) and Restuccia and Rogerson (2013) summarize the macroeconomic evidence on this. While these effects may be potentially mitigated through contracting, frictions that lead to incomplete contracts often play an important role in sustaining their effects.

[2]Why firms are financially constrained and why creditors do not lift these constraints are issues that have been explored in various theories. For example, Holmstrom and Tirole (2011), who view financial constraints as ubiquitous, show that a single deviation from the Arrow-Debreu paradigm, namely limited pledgeability of future income, can generate financial constraints.

shock that relaxes firms' financial constraints, but *not* their future investment opportunities. I empirically examine whether the relaxation of financial constraints leads to a reallocation of assets, and the effect this has on productivity, output, profitability, and asset values.

The setting I use is the market for agricultural land in Oklahoma. For identification, I exploit the exogenous cash windfalls that Oklahoma farmers received starting in the mid-2000s from signing hydraulic fracturing (fracking) leases. I use these cash flow shocks in conjunction with a unique institutional feature that helps to overcome the empirical challenge of disentangling the effect of liquidity shocks from changes in the fundamental value of the asset. By law, there is a separation of ownership between the "surface land rights" (i.e. farmland) and subsurface "mineral rights"—the two are traded as distinct assets. Surface rights entitle the owner to use the land for farming. However, a fracking lease can be entered into only with the owner of the *mineral* rights of the land. This feature means that the productivity and value of *farmland* will be directly unaffected by the discovery of oil underneath the ground, as the owner of *only* the surface rights cannot capture the cash flows from the oil beneath that land.[3]

As some farmers own the mineral rights beneath their land and others do not, there is heterogeneity that I am able to exploit in my empirical tests, relying on the idea that any effect on asset transfers, productivity, and prices should be driven by a liquidity effect operating through a lessening of financial constraints.[4] I use a differences-in-differences methodology to examine areas where many farmers received cash payments following the arrival of fracking—due to their ownership of both the surface and mineral rights—to areas where there was fracking but farmers did not own mineral rights and thus did not receive cash payments. My tests involve both county-level and farm-level data.

I find that farmers who enter into fracking leases (and thus receive large cash windfalls)

[3]It may be the case that fracking *adversely* affects farmland values through channels such as earthquakes, pollution or groundwater contamination. These types of channels would bias me *against* finding an effect. I address these more fully in Section A.4 of the Appendix. Also see Bartik, Currie, Greenstone, and Knittel (2016), who examine a fairly broad set of economic consequences of fracking.

[4]This pattern of mineral rights ownership amongst farmers was established well before the sample period that I examine. See the discussion on the selection issue later in Section 2.2.

subsequently purchase more land on average than farmers who do not enter into these leases. While consistent with an efficient reallocation of assets when financial constraints are relaxed, these results could also be driven by farmers receiving cash windfalls and buying farmland to "park" the cash (similar to overinvestment or empire-building, as in Stein (2003)).[5] These two motivations for land purchases have very different implications for economic efficiency.

To further understand the mechanism at play, I examine in detail the reallocation of farmland. Specifically, after fracking arrives in high-farm-productivity counties, farmers who receive mineral-lease-related cash flow shocks in these areas purchase more farmland from farmers in low-farm-productivity counties. However, when fracking arrives in low-productivity counties, similarly-affected farmers do not exhibit the same purchasing behavior. Exploiting more granular productivity data, I additionally provide evidence that the general purchasing behavior within counties is driven by farmers who reside in high-productivity zip codes, rather than farmers who reside in low-productivity zip codes. These effects are inconsistent with empire-building, since that would require *all* farmers who received cash windfalls to buy land. It is, however, consistent with a reallocation of farmland from less-productive to more-productive farmers. I also find that there is no significant increase in farmland purchases in the areas where relatively few farmers have mineral rights, and thus few experience fracking-related cash windfalls. This means that the effects I document are driven by heterogeneity in mineral rights ownership, an essential feature of my identification strategy.

In addition to this reallocation of land between farmers, I provide evidence of a second channel—a reallocation of land from *non-farm* users to farmers. In particular, farmers who receive fracking-related cash flow shocks also increase their purchases of non-farm vacant (undeveloped) land. Since this vacant land was previously not put to productive use, and is

[5]While these agency problems are typically thought of as occurring in large firms with a separation of ownership and control, moral hazard has been documented to be even greater in family-owned firms with family CEOs. Bandiera, Lemos, Prat, and Sadun (2017) document that family CEOs work 9% fewer hours than professional CEOs, and this accounts for 18% of the relative underperformance of firms run by family CEOs. Levinson (1971) describes many inefficiencies in family businesses, including misguided investments.

transferred to a user who can extract higher cash flows through its conversion into farmland, this effect also suggests a reallocation of land from "outside" users to "expert" users.[6]

I then turn to how this reallocation affects farm output, productivity, and profitability. I find that areas where farmers enter into a large number of fracking leases experience increases in their crop area under cultivation and in crop production, and also enjoy greater crop-growing productivity enhancements than do other areas, leading to higher farm profits. These outcomes are also economically significant, with areas where many farmers enter into fracking leases experiencing increases of roughly 19% in crop production, 8% in productivity, and 6% in farm profits compared to other areas. Broadly speaking, these effects are more consistent with the hypothesis that there is an efficient reallocation of assets from less-productive to more-productive users than with alternative hypotheses.

Next, I examine the effect of the reallocation on land prices. I find larger farmland price increases in areas where many farmers own mineral rights and enter into fracking leases, compared to areas where only a few farmers enter into fracking leases. These price increases are sizable in magnitude and highly significant—areas where many farmers entered into fracking leases experienced increases in farmland prices of roughly 13% more than other areas. This effect is again in line with the reallocation of land to more-efficient users whose valuation of the asset is higher, since they are able to extract a higher surplus from it. Since this reallocation is caused by an influx of liquidity, it also provides novel evidence of a "cash-in-the-market" pricing effect (e.g. Allen and Gale (1994, 2005)).[7]

Finally, I explore the effects on equipment investment. I show that farmers also use these cash windfalls to increase their purchases of farm equipment, with farmers in areas with

[6] In a sense, this is the reverse of the effect in Shleifer and Vishny (1992), where a fire sale leads to a reallocation of the asset from "expert" to "outside" users.

[7] These prices only reflect the value of surface rights, and so are not a result of the discovery of oil underneath the land. One possible reason why farmland prices rose so much more than productivity and output is that prior to the liquidity shock, land prices were depressed due to binding financial constraints. For example, if farmers were only willing to pay an amount well below the value of farmland even in the hands of less-productive users, then that lower amount would represent the pre-fracking land price and only farmers with a significant liquidity need or desire to get out of farming would sell at that price (similar to a fire sales setting).

higher farm mineral ownership making about 10% more equipment purchases compared to farmers in other areas. This is in line with farmers investing in additional capital in order to farm the land that they purchased.

I run a number of robustness checks in order to rule out alternative channels that may drive the results. First, I examine whether the results may be due to a wealth effect. If agents hold an "idiosyncratic" asset—one whose value depends on user-specific skills—then a large positive shock to wealth could cause these agents to purchase more of the asset. To check this channel, I conduct a placebo test using non-farm vacant landholders. If a wealth effect is driving the results, then *both* farmers and non-farm vacant landholders should purchase additional land. I find, however, that the non-farm landholders do not purchase additional land, consistent with the reallocation effect.

Second, I examine whether the results are driven by a long-term trend in the relationships between the outcome variables in the high- and low-mineral-rights counties. This involves a falsification test in which I examine land purchases, farm output, productivity, and land prices during the sample period, falsely specifying the year of fracking arrival as 1999. I find no statistical difference between the high-mineral-rights and low-mineral-rights counties based on the diff-in-diff estimator, thereby ruling out the long-term trend hypothesis.

Finally, I check whether the results are driven by a boost in local economic activity due to the arrival of fracking. For example, an increase in local economic activity could increase farmland values and output through demand channels that are unrelated to a reallocation effect. If this effect is indeed at work, then counties with the most oil and fracking should experience the largest effects, irrespective of the mineral rights ownership patterns of farmers. I find, however, that this is not the case—conditioning simply on fracking activity does not deliver my results. Rather, what matters is the pattern of mineral rights ownership. This rules out a fracking-related boost in local economic activity as the driver of the results.[8]

This paper is directly related to papers that examine how different factors may drive a

[8]This also rules out the possibility of my results being driven by other factors, such as changes in commodity prices.

reallocation of assets in an industry. Maksimovic and Philips (2001) analyze reallocation arising from M&A activity and asset sales, and provide evidence of productivity gains. Bertrand, Schoar, and Thesmar (2007) study how banking deregulation in France can improve banking efficiency, leading to an improvement in allocative efficiency across firms (borrowers) through an effect on credit supply.[9] Almeida and Wolfenzon (2005) develop a model in which limited pledgeability (driven by low investor protection) creates a misallocation of capital, but high external financing needs can create an efficient reallocation by forcing the liquidation of low-productivity projects; they also provide empirical evidence using cross-country data.[10]

My incremental contribution to this literature is documenting that relaxing the financial constraints of small firms (i.e. farms), independently of any changes in credit supply or product demand, can lead to real effects through a reallocation of capital that improves productivity and profitability.[11] In contrast to the approach in previous papers, I examine an exogenous shock to financial constraints that is *unrelated* to the future productivity or prospects of the business. As a result, I provide direct evidence of reallocation effects at a more micro level and for particular assets in a market, including a reduction in cross-sectional productivity dispersion, which permits an assessment of some of the specific channels through which the effects arise. Moreover, I provide novel additional evidence that such a reallocation effect also significantly affects asset prices, which also has not been previously shown.

This paper is also related to the literature that explores how frictions lead to capital misallocation, and lower productivity as a result—see Restuccia and Rogerson (2013) for a

[9]Also related is Jayaratne and Strahan (1996). These papers examine a different phenomenon from what I focus on in this paper, in that they are concerned with constraints on the supply of credit due to factors that affect lenders. My focus is therefore distinct from how shocks to bank capital can reduce lending (e.g. Peek and Rosengren (2000)). Recently, Perignon, Thesmar, and Vuillemey (2017) document that the financial crisis induced a reallocation of liquidity from low-capital to higher-capital banks.

[10]Other papers show how different frictions can affect the reallocation of labor and capital. Giroud and Mueller (2015) examine how a positive shock to a plant at a financially-constrained firm can induce a reallocation of labor and capital from low-TFP to high-TFP plants. Ai, Li, and Yang (2016) develop and estimate a model where frictions in financial intermediaries can affect the efficiency of capital reallocation.

[11]A change in credit supply often has fairly broad effects and will affect both financially-constrained firms as well as unconstrained firms, even though constrained firms may be affected more. My analysis is able to empirically sharply delineate the effect on financially-constrained firms when their constraints are relaxed, and I further discuss later on in the paper how the results are unlikely to be driven by any potential changes in credit supply.

review. These papers focus mainly on empirically identifying a misallocation of resources and the resulting heterogeneity in total factor productivity. An important paper in this area is Hsieh and Klenow (2009), which provides evidence from manufacturing establishments in China and India compared to the U.S., and shows how resource misallocation can lower aggregate productivity. Subsequent papers have explored how different frictions can contribute to misallocation, often by calibrating equilibrium models or using data across countries or industries. For example, Midrigan and Xu (2014) create a model in which they examine how financial frictions can lead to misallocation, and provide plant-level evidence in support of the predictions.[12] In contrast to this literature, I focus on providing direct evidence of how *alleviating* the constraints generated by financial frictions can lead to a reallocation of assets between users that improves efficiency, and examining the various channels through which this reallocation operates.

A third related literature is that on the effect of financial constraints and liquidity on investment (e.g. Fazzari, Hubbard, and Petersen (1988)),[13] and consumption (e.g. Agarwal, Liu, and Souleles (2007), Aaronson, Agarwal, and French (2012), and Agarwal and Qian (2014)).[14] While my analysis also adds to this literature by showing the effect of an exogenous cash flow shock on investment via agricultural land investment by small firms (farms), I additionally show how this investment behavior affects other real outcomes such as output, productivity, and asset prices. Importantly, I provide new evidence of a specific channel—an

[12]Gilchrist, Sim, and Zakrajsek (2013) propose an empirical framework to estimate how resource misallocation, caused by financial frictions, creates a loss in productivity. Sraer and Thesmar (2018) create a GE model where aggregate financing shocks to constrained firms can create a reallocation effect, and use their framework to show how firm-level effects can be mapped to aggregate effects. In terms of evidence of misallocation in the agricultural sector, Adamopoulos and Restuccia (2014) provide evidence of how the misallocation of resources across farms can explain productivity and farm size differences between rich and poor countries. Another related paper is Butler and Cornaggia (2011), which explores the effect of access to financing on productivity. It shows that corn farmers experienced larger increases in productivity in areas with greater access to local finance, following an increase in demand for corn. In contrast, I show evidence of reallocation effects as an important extensive-margin (reallocation) channel through which financial constraints (isolated from other channels such as product demand or credit supply) can affect real outcomes.

[13]See also Blanchard, Lopez de Silanes, and Shleifer (1994), Rauh (2006), and Hadlock, and Pierce (2010), among others.

[14]These papers document that consumers increase consumption in response to exogenous unanticipated income shocks, similar to farmers in my sample increasing investment. Unlike these papers, however, I focus on reallocation, productivity, and price effects of small firms.

efficient reallocation of assets—through which financial constraints affect these outcomes.

Finally, this paper is connected to the large literature on the effect of liquidity on asset prices. A number of theoretical models have shown how the amount of liquidity held by market participants may affect the prices of assets purchased by those participants (e.g. Allen and Gale (1994, 2004), Holmstrom and Tirole (2001), and Shleifer and Vishny (1992, 1997)).[15] Allen and Gale (1994, 2005) call this "cash-in-the-market pricing". My empirical results are consistent with the predictions of these theories, and also provide novel support for some of the underlying mechanisms that drive the results.[16]

The remainder of this paper is organized as follows. Section 2 provides a discussion of the institutional background on farming in Oklahoma, the financial constraints of farmers, and fracking and mineral rights. It also contains a description of the empirical strategy, data sources, and summary statistics. Section 3 contains the main results of the analysis. Section 4 conducts numerous robustness tests of the main results. Section 5 discusses the external validity of the results, and concludes.

2 Institutional Background, Empirical Methodology and Data

In this section, I describe the institutional setting in Oklahoma and empirical methodology. I also describe the dataset that I construct and provide summary statistics.

[15] In frictionless, complete markets, agents are able to replicate any claim in the economy, so there should be no misallocation of resources and the amount of cash held by market participants should not affect equilibrium prices. However, when agents are liquidity-constrained, they may not be able to fully participate in the marketplace for an asset. This can push the price of the asset below its fundamental level, especially if outside agents (i.e. ones that value the asset less than the normal users) are the ones that step in to purchase the asset in place of the first-best, most efficient users. This latter effect is the channel through which fire sales have an impact on prices, as argued by Shleifer and Vishny (1992, 1997). Consequently, when the financial constraints of agents are loosened, prices should rise.

[16] Tirole (2008) provides a review.

2.1 Institutional Background: Farmers in Oklahoma

For many reasons, the agricultural sector provides an ideal setting for examining asset reallocation.

First, farmers are small business owners who own and invest in a specialized asset which they are the expert (most-efficient) users of: farmland. In particular, the market for farmland is localized, with local farmers being the most knowledgeable about cultivating the land and understanding its properties, such as soil quality. As a result, local farmers are typically the most productive users of farmland, and value it more than "outside" users. This allows one to examine the reallocation of land between different types of users. Furthermore, the agricultural sector permits a straightforward measurement of important outcomes, like production and productivity, without requiring models or estimation (in contrast to measures such as TFP).

Second, farmers are generally financially constrained for various reasons—most are small family farmers who do not have access to equity markets, and have operating profit margins on the order of 6% and frequently negative.[17] For example, Hartarska and Nadolnyak (2012) use survey data and provide evidence that farmers in Alabama are financially constrained. Hartarska and Mai (2008) show that farmers use off-farm income for investments in farm assets, and that farm investment is sensitive to off-farm income, which they note is consistent with binding financial constraints. Internationally, O'Toole and Hennessy (2013) use Irish data and quantify the extent of financial constraints using a neoclassical Q model. As further evidence that farmers are financially constrained, I obtained interview data of directors and senior executives of lending institutions (many of whom are farmers themselves) providing credit to U.S. farmers.[18] The participants noted that the majority of farmers are cash-constrained, and they unanimously stated that these constraints are a first-order factor

[17]From the USDA Economic Research Service and the USDA Economic information bulletin, May 2006.

[18]I obtained interview data for 26 directors and senior executives of lending associations of the Farm Credit System—a $248 billion nationwide network of agricultural lending institutions in the United States. This credit system serves as one of the most important sources of credit to farmers, providing more than one third of total agricultural credit in the U.S.

affecting farm investment. These financial constraints are specific to farmers themselves, as opposed to being caused by marketwide credit supply contractions prior to my sample period.[19] As a result, a cash infusion to a farmer can be interpreted, on average, as a relaxation of a binding financial constraint caused by financial frictions.[20] One advantage of focusing on farmers, therefore, is that it allows one to avoid reliance on specific measures of financial constraints, given the substantial disagreement about these measures in the literature (e.g. Farre-Mensa and Ljundqvist (2016)).

Finally, the agricultural sector provides an ideal empirical setting for my purposes because farmers experienced exogenous liquidity shocks in the 2000s due to the entry of a new technology of oil drilling: hydraulic fracturing (referred to as fracking henceforth). Fracking is the process of extracting oil from deep underground shale rock formations, by injecting high-pressure liquid agents into rock formations to create cracks and release oil and gas. While fracking has existed as a technology since the 1950s, a technological innovation in the early- to mid-2000s combined fracking with horizontal drilling, to make fracking much more economical. A reduction in legal uncertainty provided by a law change in 2005 allowed a flood of oil producers to enter into oil-rich states (particularly Texas, Oklahoma, and North Dakota) with this new technology and set up fracking drills.

[19] There is no evidence of any pre-2005 deterioration in overall bank credit in Oklahoma and elsewhere. For example, Berger, Saunders, Udell, and Scalise (1998) find no negative effect of bank consolidation on credit supply during this time. More broadly, it is also important to note that the results in this paper cannot be explained by fracking-induced deposit flows at local banks causing credit supply to increase. If this were the case, then it would affect all farmers, regardless of pre-liquidity-shock productivity or minerals rights ownership, which is not what I find. Furthermore, as I show later, proxies for creditworthiness prior to the influx of fracking are uncorrelated with mineral rights ownership.

[20] An alternative way to relax this cash constraint would be by borrowing from relationship lenders (e.g. Berger and Udell (2002) and Uchida, Udell, and Yamori (2012)), as most farmers are small private businesses that cannot raise equity financing. However, this constraint can be interpreted as a binding borrowing constraint—that farmers are unable to borrow more funds because they are at their debt capacity, with no additional unpledged assets to offer as collateral (e.g. Berger, Frame, and Ioannidou (2011)) and no ability to service additional debt due to their low profit margins. This is especially important for farmers who have long enjoyed substantial protection under U.S. bankruptcy law, which limits what can be pledged to creditors (see Tremper (1988) for a review). Additionally, farmers may face a borrowing limit due to their inability to pledge their future human capital (e.g. Hart and Moore (1994)). The children of many family farmers show a lack of interest in continuing to work on the farm.

2.2 Institutional Background: Fracking and Mineral Rights

In order to drill underground, fracking operators must sign a lease agreement. This agreement involves a large upfront payment to the mineral rights owner as well as subsequent royalties that depend on the amount of oil produced. For farmers in oil-rich states in particular, this payment represents a significant source of income—the average upfront payment typically ranges from \$500 to \$10,000 per acre in Oklahoma.[21] With an average farm size in Oklahoma of roughly 450 acres, these payments can range from tens of thousands of dollars to a few million dollars. Given a median U.S. farm household income of roughly \$52,000 in the late 2000s, these payments represent a large cash infusion on average.[22]

However, importantly for my purposes, not every farmer receives these payments even if there is oil underneath the farmer's land. In Oklahoma and most other states there is a "split-estate" law system—the ownership of the surface land and the ownership of the mineral rights underneath that land are legally separated, and thus the two are separate assets. By law, the mineral rights have legal superiority, so fracking operators must sign a lease agreement with the owners of the *mineral rights* in order to drill on a parcel of land. This is crucial to my empirical analysis for two reasons. First, the fact that the *mineral* rights are the asset that confers drilling rights means that oil drilling in a given area will not directly affect the value of the *surface* land rights, since the owner of just the surface rights is not able to capture the cash flows from oil payments.[23] This allows me to isolate and identify the channel through which liquidity affects the price of the farmland. Second, this

[21] This is based upon conversations with farmers in Oklahoma. These numbers are consistent with those in other studies. For example, Andrews (2010) reports that the average upfront payments in Texas can reach up to \$10,000 to \$20,000 per acre.

[22] Data are taken from the USDA Economic Research Service. This large cash infusion related to fracking leases is also in line with the results of Gilje, Loutskina, and Strahan (2016), Gilje (2017), and Plosser (2014), who use fracking discoveries in a different context, as an instrument for exogenous deposit inflows to banks.

[23] There are potentially negative externalities to fracking moving into an area, such as wellwater pollution or disruption of farm operations, which may affect productivity and farmland values. However, these potential externalities will negatively affect production and farmland values, and thus bias me *against* finding positive effects. Furthermore, since my treatment is based on farm mineral ownership and not fracking intensity, any negative externalities are unlikely to vary with my treatment intensity. This issue is discussed further in the Appendix.

ownership split means that some farmers own the mineral rights underneath their land as a result of inheritance within their families over the years, while other farmers do not—the mineral rights to their land had been sold off generations ago. Furthermore, this pattern of mineral rights ownership was established well before my sample period, and can be taken as exogenous.[24] This fact means that there is heterogeneity amongst farmers in terms of who owns mineral rights, and therefore who can enter into a fracking lease and reap the cash flows. I exploit this heterogeneity in my empirical tests, to compare farmland purchases by farmers who own mineral rights and enter fracking leases to farmers who do not.

In Appendix A, I provide further institutional details on how fracking in conducted. There are two key takeaways from these details. First, the actual fracking drilling on a farm occupies very little of the farm's surface area, so farming can proceed more or less as usual once the infrastructure for fracking is set up. Second, due to "forced pooling" laws in Oklahoma, an individual farmer with mineral rights has virtually no ability to hold out and refuse to permit fracking on his or her land.

2.3 Empirical Specification

I now describe my empirical strategy. I focus my tests on the state of Oklahoma for a number of reasons. First, agricultural production is significant in Oklahoma, and data on farmers and agricultural land are available at a detailed level. Second, Oklahoma is an oil-rich state due to a number of shale oil formations, which attracted companies interested in drilling to the state, resulting in a large spike in oil production. Finally, Oklahoma has a legal

[24] As further evidence of this fact, I show in the Appendix that the market for mineral rights is thin, with few sales and transferences. The initial split between mineral rights and surface rights occurred as a result of Homestead Acts in the late 1800s and early 1900s, with some parcels of mineral rights sold to individuals interested in mining for precious minerals such as gold and other resources. For example, once laws in Texas in the late 1800s allowed surface owners to sell their mineral rights, many mineral owners sold their rights because salt deposit harvesting was a lucrative trade at the time. In the late 19th and early 20th centuries as well, railroad companies actively bought much of the mineral rights of the land that they laid tracks over. Mineral rights that were not sold off during this time tended to be transferred across generations of farmers, along with the surface rights (and thus the farmland). However, in a number of instances, mineral rights were also sold off or lost during the inheritance process. See Brown, Fitzgerald, and Weber (2016), for example, for details on mineral ownership patterns.

system that is advantageous for my empirical analysis, including a split-estate law system where surface rights and mineral rights are separate assets, as described earlier, and "forced pooling", as will be explained later.

2.3.1 Empirical Approach

I employ a differences-in-differences (diff-in-diff) methodology in order to examine the impact of fracking on the outcome variables of interest. The ideal strategy involves comparing areas where farmers own both land and mineral rights to areas where farmers do not own mineral rights, and examining the differential impact between the areas after fracking operators enter and sign leases with mineral owners. As the actual mineral rights ownership pattern is not observable in my data, I identify these ownership patterns through an examination of whether farm landowners signed mineral leases (and therefore owned the mineral rights underneath the land).[25] By doing so, I am able to infer which areas have a large number of farmers who own both surface and mineral rights, and which areas have relatively few farmers who own both. The logic behind this strategy is that the opportunity for a farmer to enter into a mineral lease is exogenous—it depends on whether the farmer owns the mineral rights to the farmland, and whether there is oil underneath the land. There are two potential endogeneity concerns with this assumption. First, a farmer may decide to strategically buy or sell mineral rights in anticipation of fracking operators entering an area, thus raising the possibility of self-selection into the treatment or control groups. Second, the decision to enter into a fracking lease may be endogenous for the farmer; the farmer may decide to turn down a fracking lease when approached by an oil company.

The setting specific to Oklahoma suggests that these endogeneity concerns are not an issue for my analysis. Regarding the first concern, I am able to examine the number of

[25] For an agent to sign a mineral lease, it must be the case that the agent owns some portion of the mineral rights underneath a plot of land (even if he or she does not own the land itself). The reason why actual mineral rights ownership is not observable in my data is because mineral rights, in many cases, were transferred to farm families when the farm was originally established generations ago. While in some cases mineral rights may have been sold or transferred over time, the timeframe of the original granting of rights or tranference of rights pre-dates the courthouse data that I have access to.

mineral deed transferences during my sample period. The data show that the number of mineral deed transferences amongst farmers is extremely low for all counties during my sample period, indicating that mineral rights are illiquid assets with sparse trading on the part of farmers.[26] In addition, following the arrival of fracking, there is no significant change in terms of mineral deed transferences between areas with many farmers who own mineral rights compared to other areas—this indicates that farmers who own mineral rights did not strategically buy/sell them following the arrival of fracking.[27]

Regarding the second concern, while there is no formal dataset on the number of farmers who turn down fracking leases, I interviewed a director of a Farm Credit Association in Oklahoma. The director noted that the percentage of farmers who own mineral rights but turn down fracking leases when offered is essentially zero. The reasons for this are twofold. First, the amount of money offered by oil companies for mineral leases is typically very substantial and thus attractive for farmers. Second, the "forced pooling" law in Oklahoma that was discussed earlier makes it difficult for farmers to hold out or refuse to lease minerals that they own. The law stipulates that recalcitrant farmers can be forced into signing mineral leases when the majority of mineral acreage around them has already been leased. As a result,

[26] *Figure B1* of the Appendix shows the total proportion of farmers over time who either transfer their mineral deeds to different owners or who take ownership of mineral deeds. The proportion of farmers who transfer mineral deeds is low, and there is no significant change in the pattern of transferences after the arrival of fracking. Moreover, this proportion is likely overstated in the graph since a number of these transferences are not due to buying/selling, but rather due to estate inheritance transfers within the family. The reason why mineral rights are illiquid is because purchasing them in the marketplace is usually not optimal. For oil companies, leasing the right to drill for the minerals is typically more efficient than taking ownership of the mineral rights, and the majority of U.S. production occurs via leases for this reason (see Fitzgerald and Rucker (2014)). For farmers, the minerals underneath their farmland serve no purpose that is useful to farming, and thus they have no desire to purchase the mineral rights. While a farmer may want to purchase mineral rights in anticipation of being approached by an oil company for a lease, the farmer's relative lack of expertise in assessing the likelihood and profitability of a future lease (these depend on the oil potential of the minerals) makes such a purchase expensive and prone to adverse-selection problems for the farmer. After the arrival of fracking, when mineral rights increase in value, a farmer may choose to sell his mineral rights instead of entering into a fracking lease. In that case, the farmer would receive a cash inflow from the sale, but would not be identified as a mineral rights owner since he never entered into a lease. However, such a situation would bias me against finding an effect, since these farmers would contribute towards an effect for the control group.

[27] *Figure B2* graphs transferences of mineral deeds for counties with a high proportion of farm mineral ownership, compared to counties with a low proportion of farm mineral ownership, following the arrival of fracking. *Table B1* of the Appendix shows, through a differences-in-differences regression, that the difference between the two groups does not significantly change when fracking arrives.

refusing to enter into a fracking lease when approached by an oil company is impractical or infeasible (see Eubanks and Mueller (1986) and Baca (2011), for example, for details).

2.3.2 Arrival of Fracking

For the diff-in-diff specification, I use the year 2005 to denote when fracking entered Oklahoma.[28] Fracking operators flooded Oklahoma starting in 2005, thereby dramatically increasing oil production from that point in time, for two reasons. First, a new technique developed by oil operators in Texas in 2003 combined fracking with horizontal drilling. This allowed drill operators to penetrate shale deposits that were previously difficult to access, and made fracking wells much more economical to develop; the technology became more widely adopted in the next few years. Second, the Energy Policy Act of 2005 exempted fluids used in fracking from federal clean water laws, thereby greatly reducing regulatory uncertainty for well operators. This Act is often cited as a key contributing factor to the surge of fracking after 2005 (see, for example, Krauss and Lipton (2012)).

Figure 1 depicts the entry of fracking into Oklahoma in the 2000s, and the large influx subsequent to 2005. The graph shows how the number of Underground Injection Control wells (UIC), which fracking wells are classified as, increased exponentially after 2005.[29] *Figure 2* shows the number of oil and gas wells in Oklahoma that were active prior to the arrival of fracking, compared with the number of wells that are currently active (as of the end of 2015). As can be seen from the figures, while there were oil and gas wells prior to the entry of

[28]This is the same period identified by Covert (2014) for the entry of fracking operators into North Dakota. 2005 is also the year that oil companies drilled their first modern horizontal wells in the Woodford Shale in Oklahoma, which is the major shale formation in Oklahoma (e.g. see Appendix sections E.9.13 and E.9.14 in Bartik, Currie, Greenstone, and Knittel (2016); also see Cardott (2013) for evidence of the increase in the number of wells in the Woodford Shale from 2005). Fracking wells expanded throughout the state in the following years, which comprise my treatment period. Defining the treatment period broadly in this way accomodates any small differences in entry timing between counties; moreover any such differences will bias me *against* finding an effect.

[29]According to the EPA, UIC wells include wells that "are used to inject fluids associated with oil and natural gas production" and wells that "are used to inject fluids to dissolve and extract minerals", which comprise the techniques used in fracking. The number of wells starts to increase after 2006, a delay which represents the fact that the figure depicts wells that have actually been constructed. Construction in many instances will take a year, or possibly more. However, mineral owners are compensated with upfront payments when they first sign leases, and thus the cash inflows to farmers will begin in 2005.

fracking, most counties in Oklahoma were inundated with a massive increase in the number of wells.[30] This increase in activity caused by the arrival of fracking allowed mineral owners to sign leases with drilling companies, and thus receive large cash payments.

[Insert Figure 1 Here]

[Insert Figure 2 Here]

2.3.3 Regression Specification

More specifically, I run the following main regression specification:

$$Y_{i,t} = \beta_0 + \beta_1 \left(Farm\,Minerals_i \times Fracking\,Entry_t \right) + \theta \left(Controls \right)_{i,t} + \gamma_i + \eta_t + \varepsilon_{i,t}. \tag{1}$$

Regression (1) is estimated for the period from 2000 to 2010, and is at the county-year level for the main specifications (thus, i indexes counties and t indexes years).[31] For robustness, I also estimate (1) at the farm-year level using farm micro data where possible, and including county-by-year fixed effects. $Y_{i,t}$ is the outcome variable of interest, which includes land purchases in area i at time t, production and productivity measures, the value of farmland, investment, and debt. $Farm\,Minerals_i$ is a continuous variable which estimates the proportion of agricultural landowners in county i which own mineral rights.[32] This mineral rights

[30] The white spaces in Panel B—i.e. the counties with a small number of wells (for example, in the southeast portion of the state)—are areas where geographically there is less oil potential underneath the ground due to how the shale formations have formed. As explained below, I exclude these counties from my analysis in order to form a more consistent treatment group. The one exception is Osage county in northern Oklahoma, which has some wells in Panel A but very few wells in Panel B. This is due to lawsuits involving Native American land that halted drilling after 2010 (and thus after my sample period), and therefore is reflected in the 2015 map in Panel B.

[31] The results are robust to expanding the sample period to 1996 to 2014 (and in general are stronger), which would include the continued expansion of fracking post-2010. However, the downside of expanding the sample window is an increased bias due to autocorrelation in a diff-in-diff setting, as documented by Bertrand and Mullainathan (2004). In addition, for some counties, mineral lease data are not available prior to 2000.

[32] The results are also robust to defining the treatment variable as a binary variable, which take a value of 1 if a county's farm mineral ownership is above the median, and 0 otherwise. When (1) is run at the farm

ownership is inferred through the mean percentage of farmers in each county that signed mineral leases (and therefore both own mineral rights to their land and have oil underneath their land).[33] $Farm\,Minerals_i$ thus serves to measure each county's exposure to the treatment, with a higher value indicating greater treatment intensity when fracking arrives. In order to make the counties more comparable, I exclude counties with Oklahoma that have little oil potential underground, although the results are robust to including these counties.[34] $Fracking\,Entry_t$ is a dummy variable which takes a value of 1 if the year is 2005 and onwards, and 0 otherwise. The coefficient on $Farm\,Minerals_i \times Fracking\,Entry_t$ is therefore the differences-in-differences (diff-in-diff) estimator, which examines whether oil-rich areas where more farmers own mineral rights differed from other areas after fracking arrived in Oklahoma. County fixed effects (given by γ_i) are included to control for unobservable time-invariant heterogeneity between counties, such as differences in soil quality. Year fixed effects (given by η_t) are included to control for time trends over the sample period. $Controls$ is a vector of time-varying county-level control variables which are included to control for observable differences between counties that may create differential trends.[35]

A potential concern with this regression specification is that the estimates may be affected by spatial correlation—counties that are closer to each other geographically may have correlated outcomes, perhaps due to clustering of mineral rights ownership or other charac-

level, $Farm\,Minerals_i$ is a binary variable which takes a value of 1 if the individual farmer owns mineral rights (has signed a mineral lease), and 0 otherwise.

[33] Since all farmers who enter into mineral leases own mineral rights, and there are very few transferences of mineral rights, this measure will give a close approximation to the true proportion of mineral rights owners in the county. To be conservative and in order to avoid using ex-post outcomes to identify ex ante characteristics, I use the mean proportion of farmers in each county that signed leases prior to 2005. Put differently, a county that had relatively more farmers that signed leases for (non-fracking) oil drilling prior to 2005 will also have relatively more farmers that sign leases when fracking drillers arrive. The results are robust to specifying this in a variety of different ways, including using the mean proportion of farmers in each county that signed leases over the entire sample period (including post-2005). The different possible specifications of this variable are highly correlated, thus leading to very similar results, since mineral rights ownership is largely invariant over time. These alternative specifications are available upon request.

[34] This is defined as counties with fewer than 20 discovered oil fields, which corresponds to roughly the bottom 20th percentile of the sample. These counties are ones where, geologically, there is little oil underneath the ground. The results are robust to including these counties.

[35] These include log county population, amount of cropland, total farm income, farm production expenses, and government subsidy receipts.

teristics. This type of correlation may bias the standard errors in regression (1). To account for this concern in the main specifications, in addition to robust standard errors clustered by county, for robustness I also include coefficient estimates with standard errors corrected for spatial correlation, as well as autocorrelation, following Conley (1999, 2010).[36]

2.4 Dataset Construction

I construct a novel dataset of agricultural outcomes for counties in Oklahoma from a variety of sources. I first identify farm landowners using data taken from County Assessor offices in Oklahoma.[37] For each county, I obtain ownership information for each plot of agricultural land, as well as prior sales information, including the sales price, date of purchase, seller of the land, and the size of the parcel of land. Using this information over the period from 1995 to 2010, I am able to identify individual farmers who own land, when those farmers purchased their land, and the price each paid for the land. The overall dataset contains information for 25,738 individual farmers.[38] In addition, I obtain this information for non-farm vacant (undeveloped) land holders.

I next obtain Oil, Gas, and Mineral Lease data from County Courthouse records for each county in Oklahoma for the period from 1990 to 2014.[39] These data include the identity of each person who grants a mineral lease (and thus owns mineral rights to a plot of land) in

[36]In particular, this spatial adjustment assumes that there is heteroscedasticity amongst counties that are geographically close to each other, and this correlation decays as counties become more distant from each other. More specifically, I account for spatial correlation up to 150km, which is approximately three times the diameter of a typical county in Oklahoma. The results are robust to different choices of this cutoff. Distance is measured using the latitude and longitude of the center of each county, taken from the U.S. Census Bureau. The results are also robust to more generalized corrections for spatial correlation, such as the procedure of Driscoll and Kraay (1998). Finally, I also correct for autocorrelation for up to 5 lags, in order to account for the potential bias related to diff-in-diff estimators noted by Bertrand and Mullainathan (2004).

[37]I access the data through OkAssessor.com, which electronically allows access to each individual county's Assessor Office land ownership rolls.

[38]I use the data prior to 2000 in order to examine pre-trends. A potential disadvantage of this dataset is that it includes only currently active farmers, and thus may contain some survivorship bias. As my focus is on small private farms, I drop corporate farms—which are more likely to have access to broader capital markets—as well as farms for which the owners are located out-of-state.

[39]These data are electronically accessible from Okcountyrecords.com. A handful of counties do not post their records electronically to that site; for those counties, I supplement the courthouse records with lease data from DrillingInfo, a database provider of oil and gas drilling records.

each year and each county. By merging these data with the data on farm landowners, I am able to construct a dataset that identifies farmers in each county who own land and have signed mineral leases, indicating that the farmers have ownership of both the land and the mineral rights underneath the land.

To further document reallocation effects at the farm-level, I supplement this data with confidential farm-level micro data from the 1992, 1997, and 2002 USDA Agricultural Censuses. In particular, I use this Agricultural Census data to obtain estimates of farm-level productivity (measured through crop yields) prior to the arrival of fracking. I collapse this data at the 5-digit zip code level in order to conduct an additional analysis of reallocation effects.[40]

In order to examine changes in output, I collect data from the USDA Economic Research Service (ERS) on county-level crop production, acreage, and productivity (crop yields). In order to estimate profits related to crops, I use data on revenue from crop sales and crop input expenses from the USDA Agricultural Census, which is available at five-year intervals from 1997 to 2012. I obtain yearly aggregate data on county-level farm income, crop acreage, government payments, population, and income per capita from the Bureau of Economic Analysis (BEA), for use as control variables. I also use data on purchases of farm machinery via EDA from 1995 to 2010, to further examine investment behavior by farmers.

To examine the effect on the price of farmland, I obtain county-level average farm land value data for the period from 2000 to 2010 from Oklahoma State University. The sales prices in this data include only the price of the *surface rights* of the land.[41] The land values in this dataset are calculated on a per-acre basis from cleaned land sales data.[42]

[40]Because the Agricultural Census microdata is anonymized and does not provide name or specific addresses for the farmers, I am not able to merge this data at the farm-level to my farmland ownership and mineral lease data. For this reason, I am forced to aggregate it to the most granular level that I am able to merge it at, which is the 5-digit zip code level. I discuss this in more detail later on.

[41]Oklahoma State University specifically subtracts the value of minerals in any transactions where these are sold alongside the surface rights. However, these will comprise few of the total land transactions, given the small number of mineral transfers noted in the Appendix.

[42]I use this land data to examine land prices because the County Assessor dataset contains missing sales prices for many farmland transactions. While the dataset is filled in for other information (acreage, sales date, and buyer/seller information), the missing price data prevents me from forming accurate county average

Finally, I also obtain a measure of the oil potential of the different counties in my sample from the Oklahoma Corporation Commission. These data consist of information on exploratory drilling wells that were spudded long before my sample period, and which identify discovered oil fields. I use these data to identify and exclude counties with little oil potential from my dataset, leaving a total of 60 (out of an original 77) counties of data in Oklahoma for the various items described above. I also use this data to construct a measure of oil-rich counties, which I use in robustness checks.

2.5 Summary Statistics

[Insert Table 1 Here]

Table 1 presents summary statistics for the main variables. For the average county in a given year in the sample, about 32% of farmers had signed mineral leases to their land, and thus owned the mineral rights to their land. However, there is significant heterogeneity across counties in the proportion of farmers who sign mineral leases—for example, at the 25th percentile about 13% of farmers signed leases, while 63% of farmers signed leases at the 75th percentile. I exploit this heterogeneity in my empirical tests.[43] The average price of farmland is roughly $1,090 per acre over the sample period. Fracking lease payments of a few thousand dollars per acre can therefore afford a farmer the opportunity to purchase a substantial amount of farmland. Consistent with this, the total amount of land purchased at the county-level is about 5,857 acres on average in any given year.

Wheat is the main production crop in Oklahoma, and the average county devotes 102,096 acres to growing wheat, producing roughly 2.185 million bushels of wheat. Wheat yield, a standard measure of crop productivity in the agricultural sector, also shows considerable variation across counties—ranging from 25 bushels/acre in the 25th percentile to 35.5

prices for a number of counties using the Assessor data. However, the results are qualitatively similar when using the available sales price data from the County Assessor dataset, despite lower power.

[43] *Figure B3* of the Appendix shows a map of mineral ownership across counties according to this measure, which underscores this heterogeneity as well as the fact that counties with high mineral ownership are geographically dispersed.

bushels/acre in the 75th percentile.

A potential concern is that the treatment (i.e. measure of mineral ownership) is not randomly assigned, but rather is correlated with some other variable or attribute. While the validity of the diff-in-diff methdology rests upon the parallel trends assumption, which is verified later in the analysis, a correlation between the treatment and other attributes may obscure the interpretation of the results. To investigate this, I examine whether the observable characteristics of counties with higher farm mineral ownership differ significantly from those with lower farm mineral ownership in the pre-period. *Table 2* provides this comparison, showing how the characteristics are related to the measure of farm mineral ownership, and whether the relation is significant.[44]

[Insert Table 2 Here]

In terms of county-level farm characteristics—total farm acreage, cropland, government payments to farmers, number of farms, and average farm size—there is *no* significant relationship between the characteristics and the proportion of farmers with mineral rights. I also examine the relationship for farming outcome variables which serve as dependent variables in the main analysis, including productivity (wheat yield), wheat production, machine purchases, and farmland prices. There is again no significant relationship between these outcome variables and mineral rights ownership.[45] Finally, I examine two proxies for financial constraints—county-level farm income per acre and loan-to-value (LTV)—to test whether financial constraints are correlated with the treatment assignment. There is no significant relationship with these measures as well. Overall, these tests suggest that the treatment assignment is not correlated with observable characteristics, and therefore provides supporting evidence for the interpretation of the fracking shock as an exogenous liquidity event.

[44] This is accomplished by running a regression at the county-year level, with the characteristic of interest as the dependent variable and $Farm\,Minerals_i$ as the independent variable. Year fixed effects are included in the regression.

[45] This also serves as evidence of the lack of statistically significant pre-trends for the outcome variables, which supports the parallel trends assumption. Further evidence is provided with the main analysis.

3 Empirical Results

This section contains the main empirical results. I begin by showing that counties where farmers enter into mineral leases from fracking—and thus receive large cash inflows—subsequently purchase more land relative to other counties. I then show that this drives a reallocation of land in these counties from less-efficient to more-efficient users, and productivity increases. I finally show how this affects the price of farmland and farm equipment purchases.

3.1 Purchasing Behavior by Farmers

A farmer entering into a mineral lease with a fracking operator receives a large upfront cash payment. This relaxes the farmer's cash constraints, permitting purchase of more farmland. *Figure 3* graphically demonstrates this purchasing behavior at the county level, and also examines whether the outcome variables exhibit parallel trends prior to the entry of fracking, which is a crucial assumption of the diff-in-diff framework. The top graph compares the total acres of land purchased by farmers in counties above the 50th percentile of farm mineral rights ownership (and thus fracking leases) compared to counties below the 50th percentile of farm mineral rights ownership. The graph extends from 1995 (five years prior to the sample period) to 2010 to more fully examine parallel trends prior to the arrival of fracking. The bottom graph shows the differences between the two groups over time, including trend lines for the pre- and post-fracking periods.

From 1995 to 2004, the purchasing behaviors of counties in the top and bottom halves of farm mineral rights ownership visually exhibit a slight upward trend over time when examining differences between them, but this trend is insignificant (as shown below). In the few years immediately prior to 2005, this visual trend also flattens. This suggests that the parallel trends assumption for the diff-in-diff holds. Panel A of *Table 3* statistically confirms this by examining the pre-period growth rates of each group, and testing if they are significantly different from each other. For both the sample pre-period from 2000 to 2004 and the extended pre-period from 1995 to 2004, there is no significant difference between the growth rates of counties in the top and bottom halves of mineral ownership. From the figure, after fracking arrived in 2005, farmers in the counties with a high proportion of mineral rights (the solid blue line) purchased more land than farmers in counties with a low proportion of mineral rights (the dashed red line), with a strong increasing trend when examining differences.

[Insert Figure 3 Here]

[Insert Table 3 Here]

The corresponding regression results are given in Panel B of *Table 3.* Columns (1) and (2) show the results for the total number of acres purchased by farmers aggregated at the county level, while columns (3) and (4) show the results for the total number of acres purchased at the individual farm level. For the county-level results, the coefficients for the diff-in-diff estimator $Farm\,Minerals_i \times Fracking\,Entry_t$ are positive and significant both when clustering at the county-level and when adjusting for spatial heteroscedasticity and autocorrelation (spatial HAC). This indicates that farmers in counties with higher farm mineral rights ownership increased both their number of purchases and acres purchased relative to farmers in counties with lower farm mineral ownership. The interpretation of the coefficients is that farmers in counties with a ten percentage point higher proportion of farm mineral ownership engaged in roughly 3.6% more purchases, on average, following the entry of fracking than farmers in counties with low farm mineral ownership. Put differently, moving from a county at the 25th percentile of mineral ownership to a county at the 75th percentile of mineral ownership implies an increase in acres purchased of 18%.

Columns (3) and (4) show the results at the individual farm level, comparing farmers who own mineral rights to farmers who do not own mineral rights.[46] The results are consistent

[46] As previously noted, for the farm-level regressions, $Farm\,Minerals$ is a dummy variable which takes a value of 1 if a farmer owns mineral rights (i.e. has signed a mineral lease prior to the arrival of fracking), and 0 otherwise. As with the county-level results, the results are robust to defining the treatment variable based on whether the farmer signed a mineral lease at any time during the sample period.

with the county-level results, showing that farmers who own mineral rights increased their purchases of land relative to other farmers following the arrival of fracking.[47] Furthermore, including county-by-year fixed effects in the farm-level specifications allows me to exploit variation in mineral rights across farmers *within* the same county and year. This controls for a variety of potentially confounding effects, such as changes in local economic conditions over time that may also have been induced by the arrival of fracking.[48] Overall, these results are consistent with farmers using their cash payments to invest in more farmland.

3.2 Reallocation Effects

I now examine more closely this purchasing behavior by farmers, and show that it generates a reallocation of land from less-efficient to more-efficient users. I show that this effect operates via two channels: a reallocation of farmland between farmers located in areas of differing productivity, and a reallocation of undeveloped land from "outside" users to farmers.

3.2.1 Cross-county Purchases by Farmers in High- and Low-Yield Counties

I first examine purchases of land between farmers. The intuition is that high-productivity farmers, when they experience a relaxation of their financial constraints, will seek out additional farmland to purchase. These farmers can extract higher cash flows from the land than low-productivity farmers and thus place a higher value on farmland. Thus, higher-productivity farmers will purchase farmland from lower-productivity farmers, something they were unable/unwilling to do prior to their liquidity windfall.

To explore this, I examine cross-county purchases of farmland in low-productivity counties by farmers residing in either high- or low-productivity counties.[49] If the reallocation channel operates, then farmers in high-yield counties (with high farm mineral ownership) should

[47] The results are also robust to running the regression as a linear probability specification, which examines the overall propensity to purchase land. The standard errors in these regressions are clustered at the farm level, however the results are also robust to clustering at the county level.

[48] In subsequent robustness tests, I also provide additional tests to rule out these alternative channels.

[49] I measure productivity at the county-level due to data limitations, since only limited production and productivity data are available at a more granular level. I discuss this issue in more depth below.

increase their purchases of farmland from farmers in low-yield counties, relative to other counties. Specifically, I run regression (1) conditionally for high-yield and low-yield counties, where a county is defined as high- (low-) yield if the buyer's county has an average yield prior to the arrival of fracking that is above (below) the median across all counties.[50] The dependent variable is the total acreage of cross-county farmland purchases in low-productivity counties.[51] If the reallocation channel holds, then the diff-in-diff estimator should be positive and significant for high-yield counties, but not for low-yield counties.

Table 4 provides the regression results and confirms this. Columns (1)-(4) run regression (1) conditional on low-yield counties and show that, at both the county-year and farm-year levels, the diff-in-diff estimator is insignificant. This suggests that farmers who own mineral rights and reside in low-yield counties do not purchase land in other low-yield counties when fracking arrives. In contrast, in columns (5)-(8) the diff-in-diff estimator is positive and significant at *both* the county and farm levels when the regression is run for high-yield counties. This indicates that farmers who own mineral rights and reside in high-yield counties increase their purchases of farmland in low-yield counties when fracking arrives, suggesting that higher-productivity farmers are the ones who purchase farmland from lower-productivity farmers when they receive the fracking-related cash windfall.[52]

[Insert Table 4 Here]

As additional evidence of this effect, I also exploit more detailed data from the USDA Agricultural Census. In particular, I use farm-level yield data from the Agricultural Census to construct estimates of farm productivity at a more granular level—the 5-digit *zip code* level—prior to the arrival of fracking. I then re-run regression (1) examining purchases of

[50]This is measured based on the 15-year period prior to the arrival of fracking, from 1990 to 2004. The results are robust to a variety of alternate measurement periods.

[51]For the low-yield counties, only purchases in other low-yield counties outside the buyer's county are included.

[52]The effect is also significant at the county-level when structuring the regression as a triple-differences. Furthermore, in untabulated results, as a placebo test I examine whether farmers also increase their cross-county purchases of land in *high-yield* counties. Such purchasing behavior would be inconsistent with an efficient reallocation effect. I find insignificant results for this test—in particular, farmers residing in either high-yield or low-yield counties do *not* increase their purchases of land in other high-yield counties.

farmland at the farm level conditionally for farmers residing in high-yield and low-yield zip codes, where (similar to above) a zip code is defined as high- (low-) yield if the buyer's zip code has an average yield prior to the arrival of fracking that is above (below) the median across all zip codes.[53] This allows a *within-county* examination of whether farmers in high- or low-productivity zip codes respond differently to the arrival of fracking.[54] The results are provided in *Table 5*. The first two columns indicate that, following the arrival of fracking, farmers residing in low-yield zip codes do not respond in terms of their purchases of farmland from other farmers. In contrast, the last two columns show that it was the farmers residing in high-yield zip codes (and own mineral rights) that increased their purchases of farmland from other farmers following the arrival of fracking. Specifically, with the inclusion of county-by-year fixed effects, the interpretation is that even *within* counties in a given year, farmers with mineral rights in high-yield areas increased their purchases of farmland relative to other farmers after fracking arrived, whereas similar farmers in low-yield areas did not. This provides additional evidence in line with the interpretation of the effects in *Table 4*.

[Insert Table 5 Here]

Overall, these findings are consistent with a reallocation effect from less-efficient to more-efficient farmers. Moreover, these results suggest that the effects are not being driven by a distorted-incentives problem, such as empire building (e.g. Jensen (1986)). Such incentives can arise from farmers deriving utility from simply expanding their farms using the excess money they receive, even though such investment may not be productively efficient. As indi-

[53]Specifically, in line with the procedure at the county level, I first calculate average farm yields at the 5-digit zip code level using the 1992, 1997, and 2002 USDA Agricultural Censuses, and then take the average yield for each zip code across these period.

[54]The ideal specification would be to examine purchases by high-yield farmers from low-yield farmers at the farm level. However, data limitations prevent me from running this specification. First, as previously mentioned, while the Agricultural Census data provides yields at the farm level, the censored personally identifiable information does not enable me to merge this data with the county assessor and mineral lease data. Second, for many of the sales transactions in the county assessor dataset, there is not detailed enough address information to accurately assign the seller to a particular 5-digit zip code. Nonetheless, the specification using zip code-level yield data allows an improvement in the identification of farmer productivity, given the size of typical farms relative to 5-digit zip codes, and shines further light on the within-county purchasing that farmers are engaging in.

cated earlier, these problems are not limited to public firms with a separation of ownership and control—for example, Schulze, Lubatkin, Dino, and Buchholtz (2001) present a theory of agency problems of various sorts that are worse in privately-held owner-managed firms than in public firms, due to the lack of public shareholder discipline, and provide supporting empirical evidence based on family firms. If these types of distorted incentives are driving farm purchases, then *both* high-yield and low-yield farmers with liquidity windfalls should increase their purchases (purchasing whatever land they are able to), which is not what I find. However, if the purchasing behavior is part of an efficient reallocation effect, then high-yield farmers—the more effiicent users of farmland—should be expected to increase their purchases and purchase from low-yield farmers, which is what I find.[55]

3.2.2 Purchases of Vacant Land

A second reallocation channel is a reallocation of land from non-farm users to farmers. More specifically, farmers who are interested in purchasing additional land primarily demand open land that is suitable for either crop production or livestock grazing. While farmers may specifically purchase land that is already used as farmland, they may also purchase vacant (undeveloped) land. Such a purchase can be viewed as a transfer from a less-efficient user of the land to a more-efficient user—the vacant land, previously not put to any productive use in the hands of an "outside" user, is transferred to an "expert" user (in a Shleifer and Vishny (1992) sense) who is able to extract cash flows by converting the land into farmland. Indeed, since most farmers live in remote or rural areas, farming is often the most efficient

[55]Another question that arises is whether the counties are high- or low-productivity because of skill-based differences on the part of farmers, or due to endowed characteristics of the land itself (such as soil quality). The results are consistent with skill-based differences between farmers driving the results, thus facilitating the interpretation as an efficient reallocation effect. It is an empirical fact that skill differences among farmers translate into productivity differences (see Laajaj and Macours (2017) and Lockheed, Jamison, and Lau (1979)). If innate characteristics of the land were the main driver behind the differences in productivity, then one would expect that farmers in low-productivity counties to purchase land from farmers in high-productivity counties (which would have better soil quality), which as previously noted is not what I observe in the data. In addition, the zip code-level analysis exploits variation in yields within counties, at a small enough geographical level that heterogeneity in land characteristics such as soil quality are likely less of a concern. For example, a zip code may be small enough that only one farmer resides in it.

use of land that has little alternative commercial applicability.

Figure 4 examines total acres of vacant land purchased by farmers from 1995 to 2010. Before the arrival of fracking from 1995 to 2004, the amount of vacant land purchased by farmers in high-farm-mineral-ownership counties runs in parallel to the amount of vacant land purchased by farmers in low-farm-mineral-ownership counties, with no differential trend. After the arrival of fracking, the purchases by the high-farm-mineral-ownership counties increase by more than the purchases by the low-farm-mineral-ownership counties, with a clear increasing trend. Panel A of *Table 5* statistically tests the parallel trends assumption, and shows that there is no significant difference in growth rates between the two groups during the pre-period.

[Insert Figure 4 Here]

[Insert Table 6 Here]

Panel B of *Table 6* shows the diff-in-diff estimation results. The coefficient on the diff-in-diff estimator positive and significant, and is robust to spatial correlation and autocorrelation (columns (1) and (2)). It is also positive and significant at the farm level (columns (3) and (4)). The point estimate at the county level implies that farmers in counties at the 75th percentile of mineral ownership increased their purchases of vacant land by roughly 33% more than farmers in counties at the 25th percentile of mineral ownership following the arrival of fracking. Overall, the results indicate a reallocation of land to the users who are able to make more productive use of the land.

3.3 Production and Productivity

3.3.1 Effect on Wheat Production, Acres under Cultivation, and Productivity

An important implication of this reallocation of assets is that it should be reflected in agricultural crop production and productivity. In other words, given that land is transferred from vacant landholders (who do not have a productive use of the asset) to farmers (who are able to use the asset for farming), areas that experience more of these transfers should also show expanded agricultural crop acreage under cultivation, as well as higher production and productivity. Moreover, to the extent that farmland is reallocated from lower-productivity farmers to higher-productivity farmers within counties when farmers are given a cash flow shock that relaxes their constraints, this effect is likely to be amplified.

Figure 5 examines crop production, acres under cultivation, and productivity before and after the arrival of fracking. I examine these outcomes for wheat, as it is the primary crop grown in Oklahoma. Average wheat production for counties in the top and bottom halves of farm mineral ownership follow parallel trends from 1995 to before the arrival of fracking, with high-farm-mineral-ownership counties having slightly higher production on average. However, after the arrival of fracking, the gap between the two types of counties widens, and from 2008 and onward the production of the high-farm-mineral-ownership counties substantially overtakes that of the low-farm-mineral-ownership counties. For wheat acres under cultivation, counties above and below the 50th percentile of farm mineral ownership move in parallel before the entry of fracking, but then the high-farm-mineral-ownership counties surpass the other counties by substantially increasing their acreage under cultivation following the entry of fracking. When examining productivity, the pre-trends stay relatively flat and do not exhibit a discernible pattern. After fracking arrives, productivity for the top farm-mineral counties increases relative to that of the bottom farm-mineral counties—the average wheat yield for the high-farm-mineral-ownership counties is generally below that for other counties prior to the entry of fracking, but then subsequently increases to slightly above the level of the other counties. Panel A of *Table 7* tests the difference in pre-period growth rates between the top and bottom quartiles for these variables, and shows that there is no significant difference in growth rates for any of the variables during either the 1995-2004 or 2000-2004 pre-periods.

[Insert Figure 5 Here]

[Insert Table 7 Here]

Panel B of *Table 7* provides the diff-in-diff regression results. The diff-in-diff estimator for wheat production is positive and significant, both with robust standard errors as well as after correcting for spatial correlation and autocorrelation. The coefficient indicates that a ten percentage point higher proportion of farm mineral ownership implies an increase in wheat production of 3.8%—this translates into an increase in production of 19% when moving from the 25th to 75th percentile of farm mineral ownership. The diff-in-diff estimator for wheat acres is positive and significant with both robust and spatial HAC standard errors. The magnitude indicates that counties at the 75th percentile of farm mineral ownership increased their wheat acres under cultivation by 13% compared to counties at the 25th percentile after the entry of fracking. Finally, the diff-in-diff estimator for wheat yields is positive and significant across all specifications. The magnitude indicates that a ten percentage point increase in mineral ownership leads to a 1.6% increase in productivity following the arrival of fracking, which translates to an increase in yields of 8% after the arrival of fracking for counties at the 75th percentile of farm mineral ownership compared to counties at the 25th percentile.[56]

3.3.2 Dispersion of Productivity

A further implication of the reallocation effects of the previous sections is that the cross-sectional *dispersion* of productivity between high- and low-yield areas should decrease once fracking arrives. The intuition is that, with the reallocation of land from less-productive to more-productive users, land will be in the hands of more skilled users on average, resulting in a smaller spread in productivity. *Figure 6* presents results on the yields of counties over time ranked according to the quartile of productivity that they are in (measured from 1990 to

[56]This increase in productivity is not likely to be the result of increasing returns to scale on the part of farmers, given the documented inverse relationship between farm size and productivity (see, for example, Carletto, Savastano, and Zezza (2013)). The dis-economies of scale experienced by farmers would bias me *against* finding the increase in productivity that I do.

2000). Consistent with the productivity dispersion declining over time, the spread between the higher- and lower-productivity counties tightens substantially following the arrival of fracking, with the dispersion narrowing to almost zero by 2007.

[Insert Figure 6 Here]

3.3.3 Crop Profits

Finally, these effects for production and productivity should also translate into higher crop profits, a hypothesis that I now examine.[57] Columns (7) and (8) in Panel B of *Table 7* show the diff-in-diff regression results for farm crop profits, which is defined as crop sales revenue minus production input expenses. Since data for crop sales revenues are available only at five-year intervals at the county-level from the USDA Agricultural Census, the regression is run for the years 1997, 2002, 2007, and 2012. The diff-in-diff estimator is positive and significant in both columns, showing that profits increased for counties with higher farm mineral ownership relative to other counties following the arrival of fracking. For a ten percentage point increase in farm mineral ownership, profits increased by about 1% after fracking arrived, which represents a roughly 5.5% increase in profits on average for counties at the 75th percentile of mineral ownership relative to counties at the 25th percentile.

Overall, these increases in production, acreage under cultivation, productivity, and profits as well as the reduced productivity dispersion are all consistent with an efficient reallocation of assets following the relaxation of financial constraints.

3.4 Effect on Land Prices

I now explore how the positive liquidity shock provided by fracking affects asset prices, by estimating regression (1) using county farmland values as the dependent variable. Farmland values are measured in terms of the dollar price per acre of farmland, a standard scaling to

[57] Note that fracking by itself has no direct effect on farming profitability, so if there is a detectable profitability effect, it must come from the reallocation induced by fracking.

account for size, and only include the value of *surface* rights. As a result, these values do *not* include any of the expected cash flows from fracking lease payments. *Figure 7* explores graphical evidence of the effect.[58] Overall, from 2000 to 2004, the counties above and below the median of farm mineral ownership move in parallel, with a slight downward trend when looking at differences (that is insignficant, as shown below). However, starting in 2005, the price of farmland for counties with numerous farm mineral leases jumps substantially compared to the other counties. Panel A of *Table 8* statistically confirms that there is no significant difference in growth rates between the two groups during the pre-periods.

[Insert Figure 7 Here]

[Insert Table 8 Here]

Panel B of *Table 8* provides the regression results for (1). The diff-in-diff estimator is positive and highly significant across all specifications. The magnitudes indicate that the farmland prices of areas with a ten percentage point higher farm mineral ownership increased on average by 2.7% more than land prices in other areas after the arrival of fracking. This implies an increase in prices of 13.4% following the arrival of fracking when going from counties at the 25th percentile of farm mineral ownership to counties at the 75th percentile.

This price effect is consistent with asset reallocation following a relaxation of financial constraints—land is being transferred from less-efficient users to more-efficient users, who are able to generate higher cash flows. Since the market for farmland is localized and farmers have expertise on local growing conditions as well as a network of local relationships that may enhance farm productivity, the price of farmland is driven up once financial constraints are relaxed. And to the extent that the pre-liquidity-shock farmland prices were depressed due to binding financial constraints, these prices rise by a greater percentage than the productivity gain from asset reallocation, as explained earlier. This is also consistent with a "cash-in-the-market" pricing effect (e.g. Allen and Gale (1994)), as well as the underlying mechanisms of

[58] The land value data are only available from 2000 and onwards.

fire sales (e.g. Shleifer and Vishny (1992, 1997)).[59]

3.5 Other Investment: Farm Equipment

It is economically sensible to posit that farmers use their liquidity windfall to purchase farm machinery in addition to acquiring more farmland. So I next look at farm machinery purchases. *Figure 8* graphs new farm equipment purchases for counties in the top quartile of farm mineral rights ownership compared to counties where at the bottom quartile of farm mineral rights ownership, around the arrival of fracking. The figure shows that, prior to fracking, the farmers in the high-farm-mineral-ownership counties purchased less farm equipment than farmers in the low-farm-mineral-ownership counties. While visually the two groups run roughly in parallel, when examining differences, the pattern is noisy and there is a slight downward trend. Thus, inference may be less clean in this particular setting. However, panel B of *Table 9* shows that the pre-period growth rates of the two groups are not statistically different. Following the arrival of fracking, the purchases of farmers in the high-farm-mineral-ownership counties increased relative to those in the low-farm-mineral-ownership counties, reducing the gap between the two groups.

[Insert Figure 8 Here]

Table 9 provides diff-in-diff regression results that confirm that this difference is significant. In particular, the coefficients indicate that counties with a ten percentage point higher farm mineral ownership increased their number of farm equipment purchases by roughly 1.9% compared to other counties after the entry of fracking, implying a 9.6% difference between counties at the 75th versus 25th percentile of farm mineral ownership. These results indicate that farmers whose financial constraints are relaxed due to the fracking shock subsequently

[59] This result is also consistent with Weber and Hitaj (2014), who document that self-reported farmland value estimates increased in areas with fracking in Texas and Pennsylvania. My analysis differs as I use yearly farmland sales data, rather than self-reported Agricultural Census data (which are only available at 5-year intervals), and I also exploit cross-sectional variation in mineral rights ownership. In addition, my results illuminate a specific channel for the increase in farmland value, namely the reallocation of farmland across users with different productivities.

increase investment in additional new farm machinery. This is consistent with the results on land purchases previously shown—since farmers are expanding their land holdings, it is economically intuitive that they are also investing more in farm equipment in order to farm the new land. Additionally, this increase in machinery purchases provides further evidence that the increase in productivity documented earlier is likely the result of a reallocation channel rather than economies of scale, given the documented inverse relationship between farm scale and productivity (e.g. Carletto et al. (2013)).

[Insert Table 9 Here]

4 Robustness

In this section, I present a number of robustness checks for the main results.

4.1 Effects Amongst Non-farm Vacant Landholders: Checking for Wealth Effects

While the results that have been presented are consistent with an efficient reallocation of assets, they may also be driven by a wealth effect. In particular, a wealth effect would predict that, if agents held some idiosyncratic asset, a large shock to wealth would induce them to purchase more of the asset because they are richer. While the output and productivity results presented earlier are inconsistent with this effect, I attempt to explicitly rule this channel out by examining the effects for non-farm vacant landholders as a placebo test.

More specifically, while farmers are the specialist, most efficient users of farmland, vacant landholders (who are not farmers) are simply holding an asset that is currently not in productive use.[60] Consequently, while a wealth effect would predict that *both* farmers and non-farm vacant landholders will purchase additional land following a cash windfall, a

[60] Farmers being specialist users of the land implies a participation/entry cost related to acquiring these skills and entering farming.

reallocation effect would predict that the effects documented for farmers should *not* hold for vacant landholders.

In order to test this channel, I examine purchases of land by non-farm vacant landholders, as well as the sales prices of these transactions.[61] *Table 10* presents the results at the county and landholder levels for acres of land purchased, and at the county level for the sales prices. For the county-level results in this case, I identify counties based on whether many non-farm *vacant landholders* own mineral rights, as opposed to whether many farmers own mineral rights. Across all of the specifications, the diff-in-diff estimators are insignificant. These results provide evidence that the effects I document are not driven by a wealth effect.

[Insert Table 10 Here]

4.2 Falsification Test

Another concern is that the results may be driven by some sort of long-term trend in the relationships between the variables of interest in the counties with higher farm mineral rights ownership and those variables in the counties with lower mineral rights ownership. If so, then the effects on productivity and prices that I document are not unique to the sample period I consider (i.e. not caused by the entry of fracking). In order to rule out this possibility, I run a falsification test. The test involves examining total and vacant acres purchased by farmers, wheat production, acres under cultivation, wheat yield, and farmland sales prices during the period from 1997 to 2004, while falsely specifying the year of the arrival of fracking as 1999.[62] This captures the immediate pre-period before the arrival of fracking.

Table 11 presents the results. It confirms that the diff-in-diff estimator for each outcome is insignificant. Thus, these results indicate that the reallocation effect is attributable to the

[61] Similar to the concern with using transaction data for farmland, sales prices are missing in a number of transactions. However, there is a relatively large number of vacant land transactions, which makes it feasible to construct estimates for most counties.

[62] I use 1997 as the start of the sample period for this test because it is the first year for which data for the control variables are available. The results are similar using the sample period from 1994 to 2004, but excluding control variables. Along the same lines, the effects are also insignificant when considering an earlier sample period from 1990 to 2000 (excluding controls), and falsely specifying the arrival of fracking as 1995.

arrival of fracking around 2005, and not due to some trends over time between the counties.

[Insert Table 11 Here]

4.3 High versus Low Oil Counties: Possible Effects of Local Economic Activity

Another possible channel which may be driving my results is the stimulation of local economic activity due to the arrival of fracking (see Feyrer, Mansur, and Sacerdote (2015), Bartik et al. (2016), Cunningham, Gerardi, and Shen (2017), and Allcott and Keniston (2017) for example). Among other effects, this can affect labor costs, which may in turn affect production and productivity in farming. In addition, there may be an elevated demand for land from real estate developers, looking to build housing for oil drill workers and others who may move in due to the fracking boom, and this could increase the price of farmland through a channel distinct from reallocation.

This alternative channel has a specific implication: counties with more oil beneath the land (and therefore experiencing higher fracking activity) should experience larger effects, regardless of the mineral rights ownership of farmers. In other words, any effect of farm mineral rights ownership should be driven by an incidental correlation with general fracking activity. To examine this, I run the following diff-in-diff regression:

$$Y_{i,t} \;\; = \;\; \beta_0 + \beta_1 \left(\log\left(Oil_i\right) \times Fracking\,Entry_t\right) + \left(Controls\right)_{i,t} + \gamma_i + \eta_t + \varepsilon_{i,t}. \qquad (2)$$

In (2), $\log\left(Oil_i\right)$ is the log of the number of previously discovered oil fields in the county, as a measure of oil potential.[63] The local economic activity channel implies that the diff-in-diff

[63] Specifically, these oil fields were all discovered prior to (and in almost all cases well prior to) 2000 through discovery wells. The data come from the Oklahoma Geological Survey conducted by the University of Oklahoma, and contains data on 5,227 discovery wells/fields. The idea is that this provides an ex ante measure of the expected oil production in each county once fracking arrives and is able to further tap into the reserves. The results are unchanged if I use a measure of the number of total fracking leases (which is more directly correlated with ex post oil production) in a county instead of oil potential.

estimator β_1 should be positive and significant.

Table 12 gives the results for acres of land purchased by farmers, wheat production, acres under cultivation, yields, and farmland prices. For each variable, the diff-in-diff estimator is insignificant. Overall, this provides evidence against the channel of local economic activity, and suggests that conditioning specifically on farm mineral rights ownership (rather than simply fracking intensity) is critical for my results.

[Insert Table 12 Here]

5 Conclusion

In a frictionless market, assets within an industry should be allocated to the highest-productivity producers. However, financial constraints generated by financial frictions can cause a misallocation of assets across firms that differ in the productivity with which they deploy assets, distorting total factor productivity, output, and asset prices. A positive liquidity shock for some producers can relax their financial constraints, allowing them to increase their investment and reduce misallocation. I examine the effect of such a shock by exploiting a quasi-natural experiment: the arrival of hydraulic fracturing (fracking) into Oklahoma in the mid-2000s, and its effect on farmers. Since farmers who own the mineral rights to their land receive exogenous cash windfalls as a result of fracking leases while others do not, this creates a unique heterogeneity that permits a clean empirical test.

My main results are that areas with more farmers that receive such positive liquidity shocks increase their investment in farmland compared to areas with fewer such farmers. These purchases of farmland generate a reallocation effect that operates through two channels. The first channel is a reallocation between farmers, whereby liquidity-shocked farmers in high-productivity areas purchase more land from farmers in low-productivity areas. The second channel is a reallocation from non-farm users to farmers—liquidity-shocked farmers increase their purchases of vacant (undeveloped) land. Both of these channels are consistent with a reallocation of assets from less-productive to more-productive users. In line with this, I find that crop production, acreage under cultivation, crop growing productivity, and farm crop profits all increase in areas where numerous farmers receive liquidity shocks compared to other areas. In addition, I show that the price of farmland increases in these areas, consistent with various theories and a "cash-in-the-market" pricing effect. Finally, farmers in these areas also use the extra liquidity to increase equipment purchases. I rule out a number of alternative channels that may drive the results.[64] In a nutshell, my results indicate that relaxed financial constraints improve efficiency through industry asset reallocation.

My paper adds to the literature on misallocation, which in turn has broader implications for economic growth. While focusing on a particular sector (agriculture) allows for a cleaner empirical test, it also raises a question about external validity. On this issue, I note that the agricultural sector is also appealing because farms can be viewed as small firms, each with business operations that are analogous to more "traditional" firms that most papers examine. Indeed, U.S. farmers have many characteristics that make the lessons learned from studying them generalizable to a variety of other small (privately-held) family businesses and even households. First, they operate in an industry in which there is a non-trivial difference in productivity between expert users (local farmers) and non-expert (outside-of-the-industry) users (owners of vacant land). Many industries have this feature (e.g. biotechnology), and indeed this feature corresponds to a key assumption in the fire sales model of Shleifer and Vishny (2011). Second, farmers can raise external financing principally by borrowing—they have traditionally not been issuers of (private) equity. This is a ubiquitous feature of private firms and households. Third, there is cross-sectional heterogeneity in productivity across farmers, as well as financial constraints that cause a misallocation of resources. This is quite common in many other industries, including those in other countries (e.g. Hsieh and Klenow (2009)), so it is also relevant for international comparisons. As a result, my results can be

[64] Taken together, my results can be sensibly interpreted only in the context of pre-liquidity-shock financial constraints. Note that absent financial constraints, liquidity shocks are unlikely to have real effects. For example, Mian and Sufi (2012) show that the "cash for clunkers" fiscal stimulus program has a very short-lived effect on automobile purchases, and no effect on employment and house prices.

viewed as having external validity beyond just the agricultural sector.

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Figure 1: Entry of Fracking into Oklahoma in the 2000s: New Fracking Wells
This figure depicts the entry of fracking into Oklahoma around 2005. The graph shows the number of new Underground Injection Control (UIC) wells, which represents the type of well that a hydraulic fractured well is classified as, for each year in Oklahoma. The data are taken from the Oklahoma Corporation Commission, Oil and Gas Division.

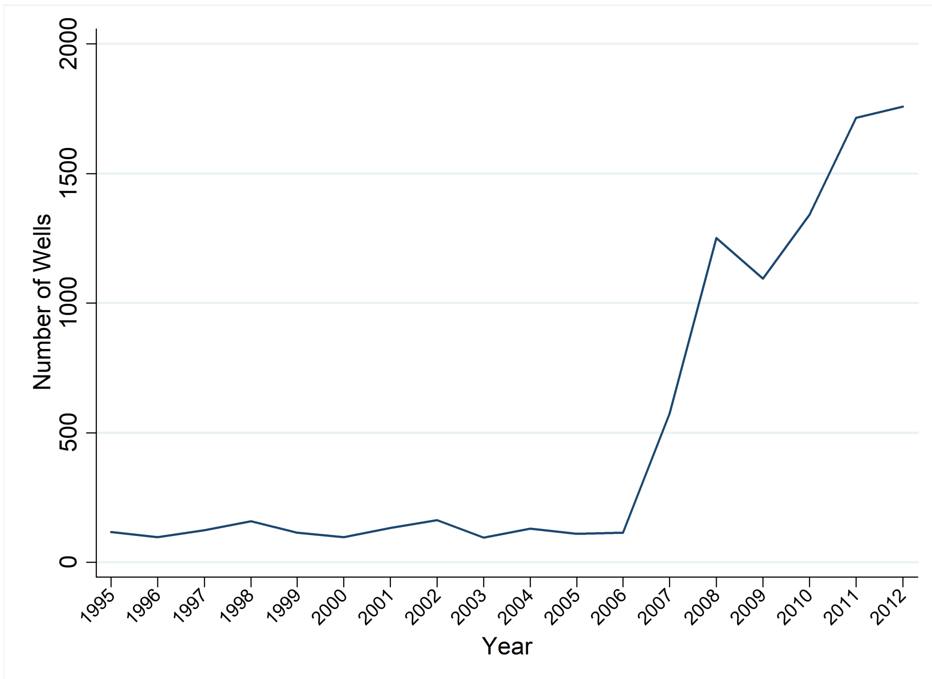
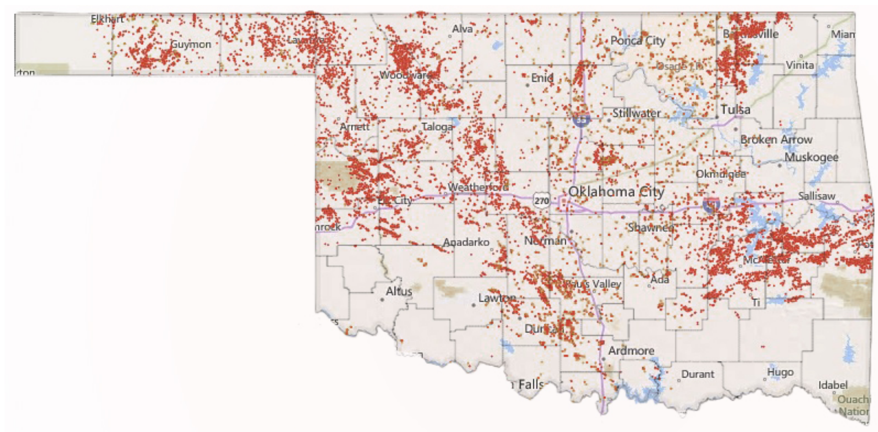


Figure 2: Entry of Fracking into Oklahoma in the 2000s—Active Wells Before and After

This figure shows the active oil and gas wells across Oklahoma, during the period 1995–2004 (panel A) and in 2015 (panel B). Panel A is constructed using data from Drillinginfo.com, and panel B is generated from fractracker.org. Each red dot represents either an oil and gas well or a cluster of wells.

Panel A: Active Wells During 1995–2004



Panel B: Current Active Wells in 2015

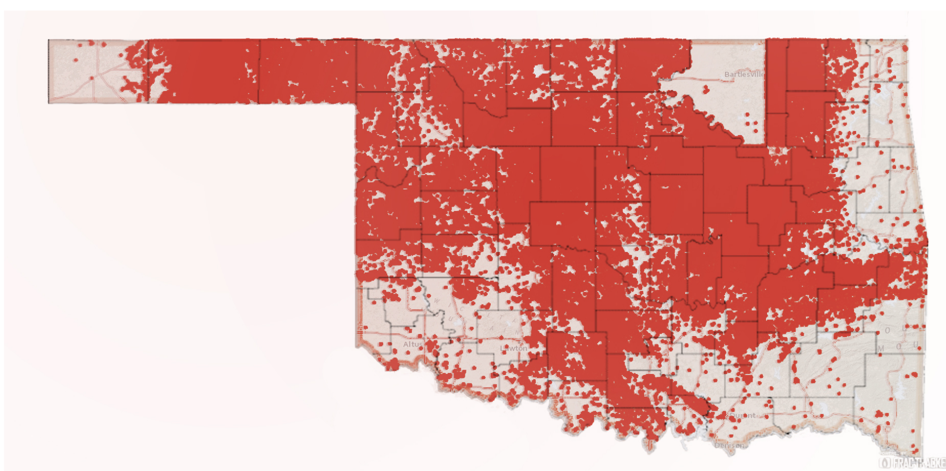
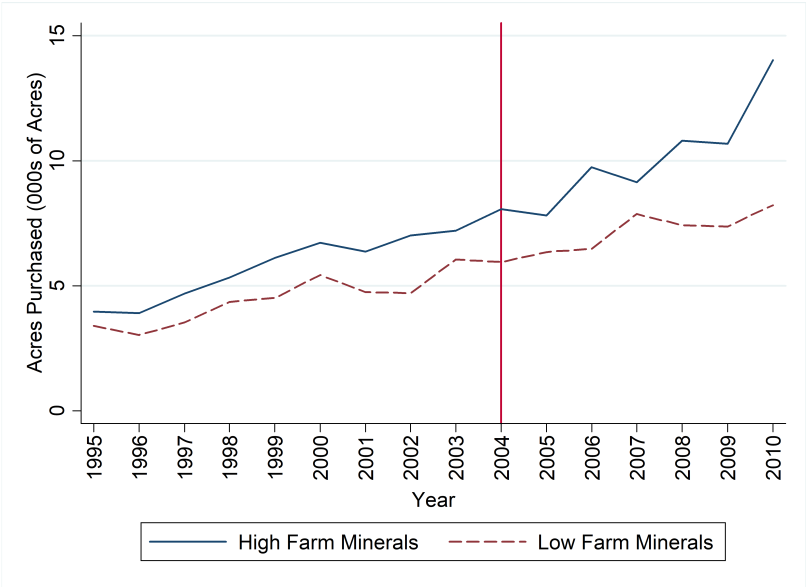


Figure 3: Purchases of Land by Farmers

This figure depicts total acres of land purchased by farmers (in thousands of acres) from 1995 to 2010. In the top graph, the solid blue line represents the mean purchases of counties above the 50th percentile in terms of proportion of farmers that own mineral rights, while the dashed red line represents counties below the 50th percentile in terms of proportion of farmers that own mineral rights. The bottom graph shows the difference over time between the two groups (top minus bottom), with trend lines included in dashes. Counties with low oil potential are excluded.



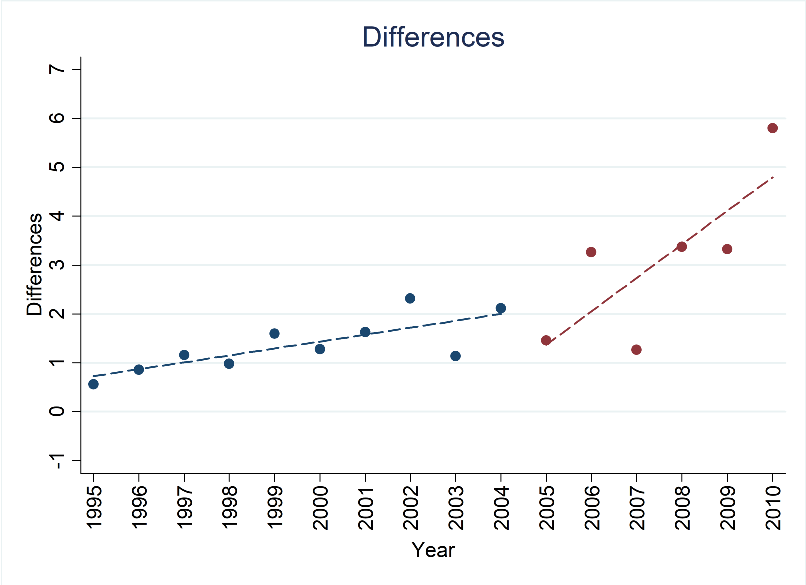


Figure 4: Reallocation of Farmland—Purchases of Vacant Land

This figure depicts total acres of vacant land purchased by farmers (in thousands of acres) from 1995 to 2010. In the top graph, the solid blue line represents the mean aggregate purchases of counties above the 50th percentile in terms of proportion of farmers that own mineral rights, while the dashed red line represents counties below the 50th percentile in terms of proportion of farmers that own mineral rights. The bottom graph shows the difference over time between the two groups (top minus bottom), with trend lines included in dashes. Counties with low oil potential are excluded.

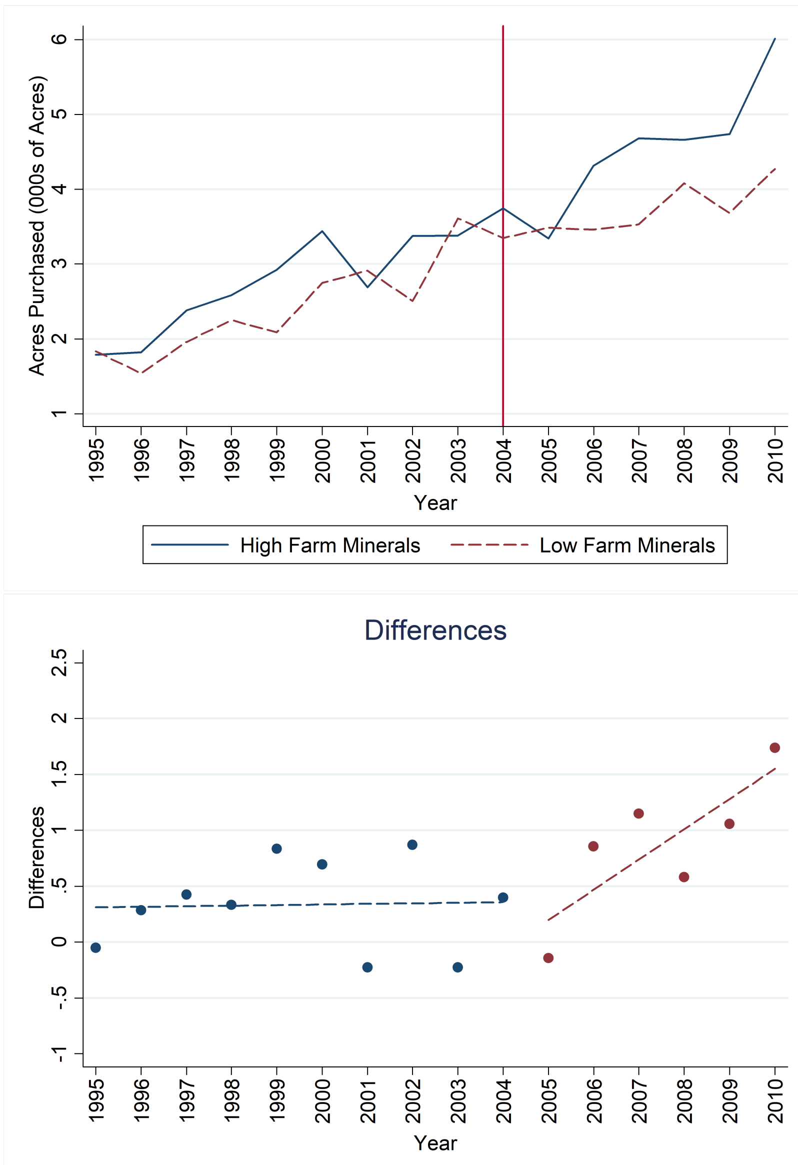


Figure 5: Reallocation—Wheat Production, Wheat Acres Cultivated, and Productivity

This figure depicts wheat production, area under cultivation, and productivity from 1995 and 2010. The left figures show average wheat production, the middle figures show average wheat acres under cultivation, and the right figures show the average wheat growing productivity. The top graphs show the mean outcomes for counties above the 50th percentile of farmer mineral rights ownership (solid blue lines) and below the 50th percentile of farm mineral rights ownership (dashed red lines). The bottom graphs show the differences between these groups (top minus bottom) for the above graphs, with trend lines included in dashes. Wheat Production is the total amount of wheat produced in a given year, in bushels. Wheat Acres is the total number of planted acres of wheat in a given year. Wheat productivity is measured by wheat yield, defined as wheat production per acre harvested (measured in bushels per acre). All outcomes are shown in logs. Counties with low oil potential are excluded.

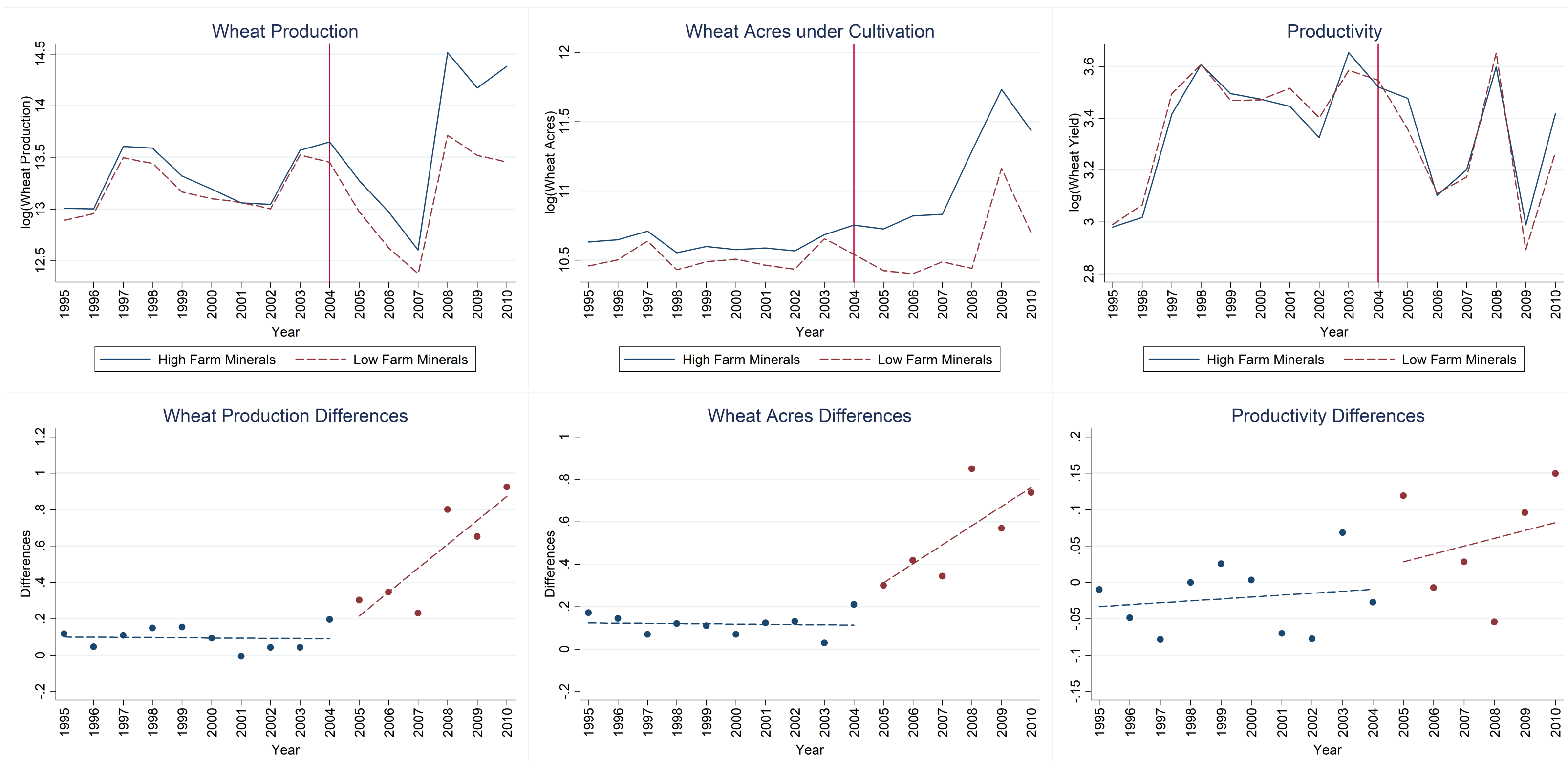


Figure 6: Dispersion of Productivity

The top figure shows the median wheat yields over time for counties in each productivity quartile (measured from 1990 to 2000). The bottom figure shows the difference over time between the 1st quartile and 4th quartile.

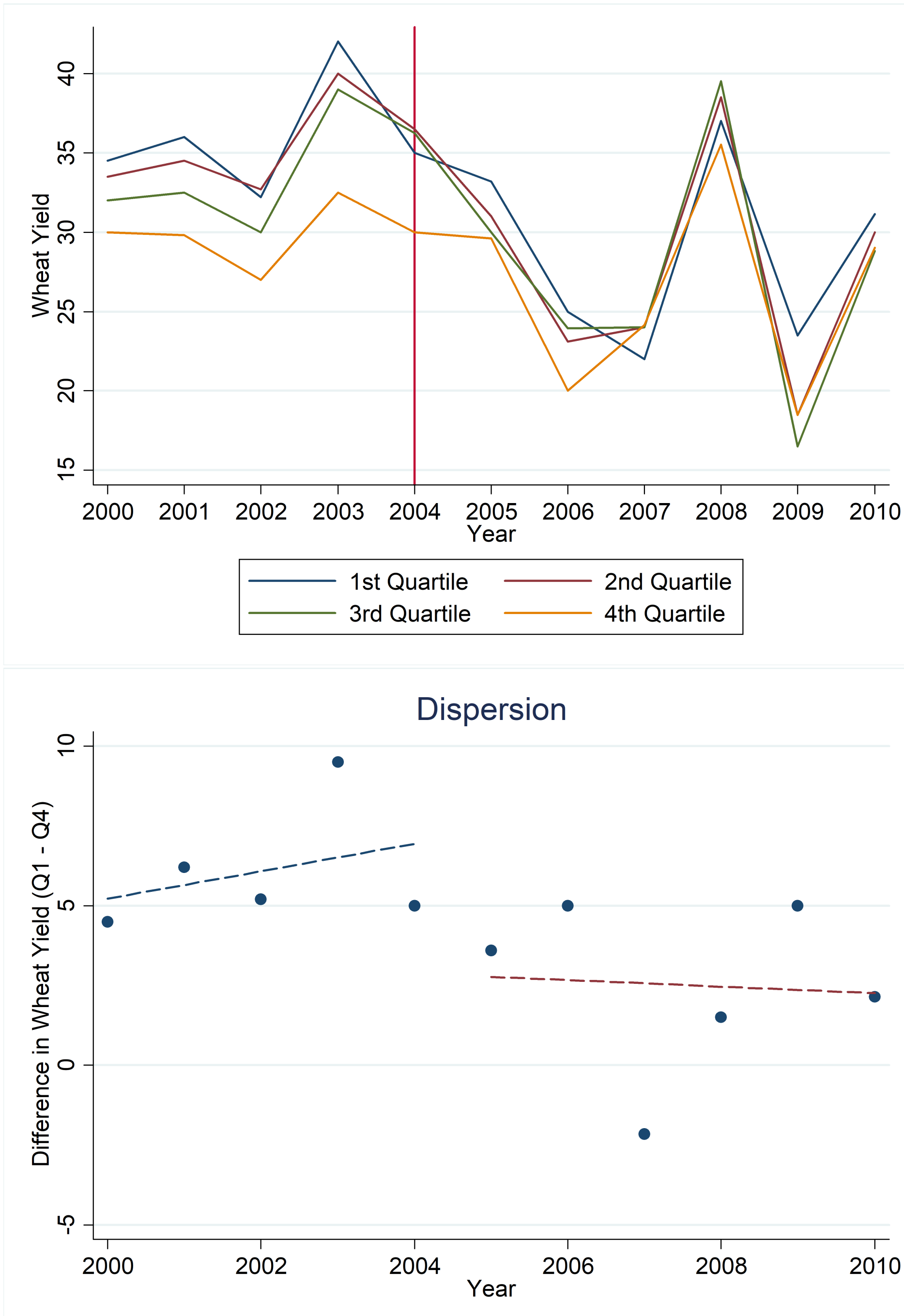


Figure 7: Effect on Farmland Prices

This figure shows the effect on farmland prices from 2000 to 2010. In the top graph, the solid blue line represents the mean price for counties above the 50th percentile in terms of proportion of farmers that own mineral rights, while the dashed red line represents counties below the 50th percentile in terms of proportion of farmers that own mineral rights. The bottom graph shows the difference over time between the two groups (top quartile minus bottom quartile). Counties with low oil potential are excluded. Prices are measured as log sales price per acre.

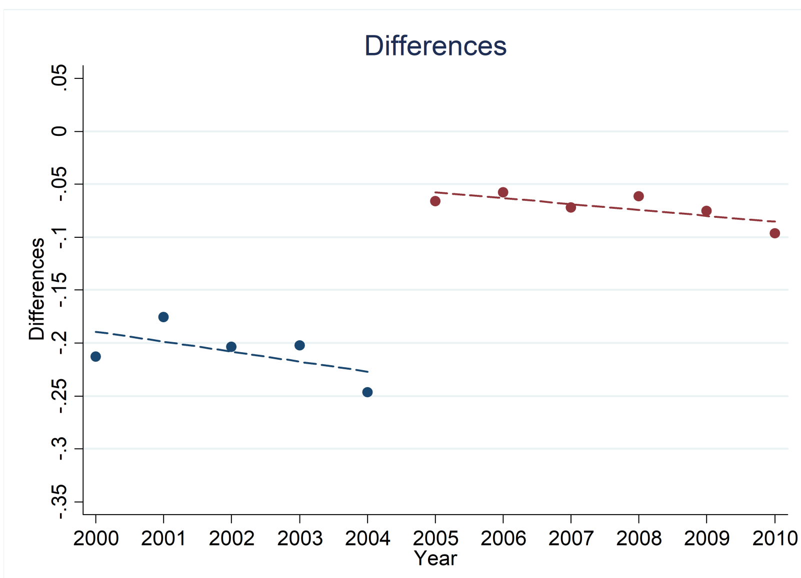


Figure 8: Investment in Farm Machinery

This figure shows the log total number of purchases of new farm machinery from 1995 to 2010. In the top graph, the solid blue line represents purchases for counties above the 50th percentile in terms of proportion of farmers that own mineral rights, while the dashed red line represents counties below the 50th percentile in terms of proportion of farmers that own mineral rights. The bottom graph shows the difference over time between the two groups (top minus bottom). Counties with low oil potential are excluded.

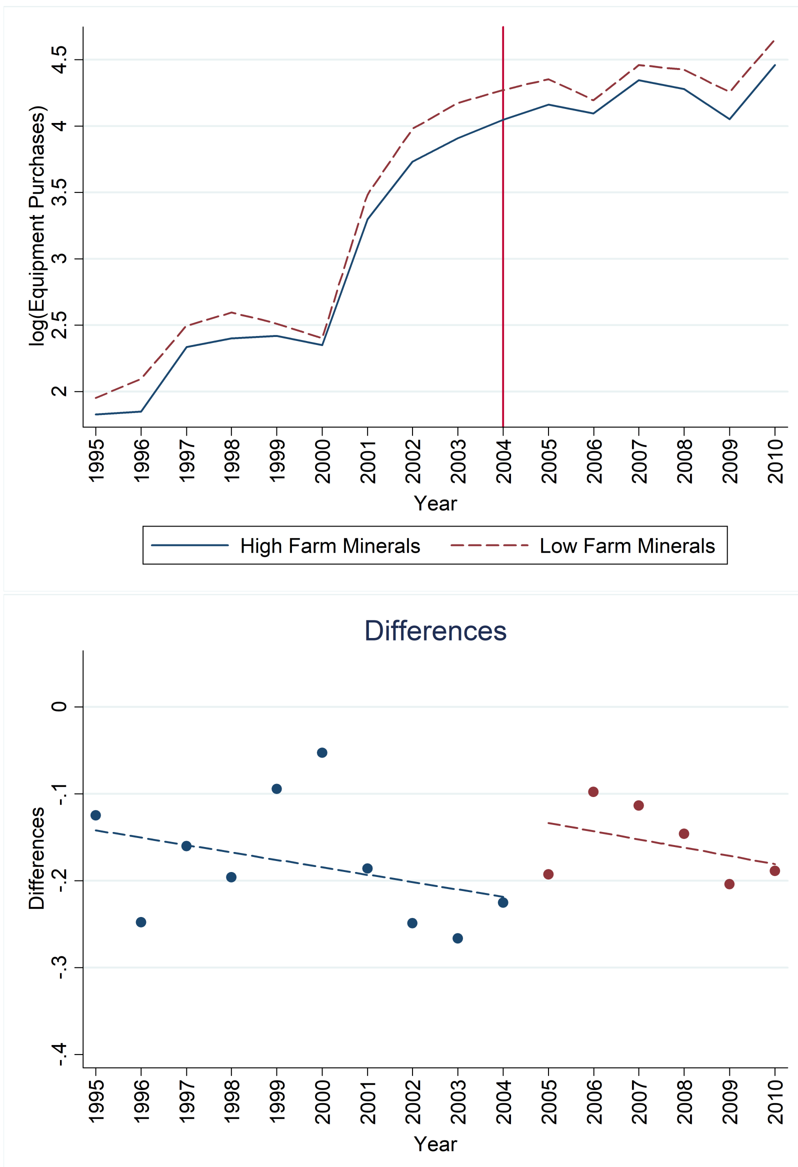


Table 1: Summary Statistics

This table provides summary statistics for the key variables. All other variables are defined at the county or county-year level $Farm\,Minerals$ is the average proportion of farmers in a given county that have entered into a mineral lease, and is defined at the county-level. $Acres\,Purchased$ is the total number of acres of land purchased by farmers. $Wheat\,Yield$ is wheat crop growing productivity, measured in bushels of wheat produced per acre harvested. $Wheat\,Production$ is the total amount of wheat produced in a county for a given year, in millions of bushels. $Wheat\,Acres$ is the total number of cultivated acres of wheat in a county for a given year, in thousands of acres. $Farmland\,Value$ is the average value of agricultural land, in real (2010) dollars per acre. All variables are averages from 2000 to 2010.

	#Obs	Mean	Std. Dev.	p25	Median	p75
$Farm\,Minerals$	60	0.316	0.267	0.128	0.316	0.633
$Acres\,Purchased$	629	5,857.018	6,128.249	1,717.00	3,368.80	8,388.064
$Wheat\,Yield$	559	30.515	7.588	25.0	30.8	35.5
$Wheat\,Production$	563	2.185	2.802	0.120	0.770	3.620
$Wheat\,Acres$	559	102.096	101.404	11.000	70.000	190.000
$Farmland\,Value$	646	1,089.890	455.931	771.79	1,015.01	1,350.14

Table 2: Relationship Between Treatment and Observable Variables

This table examines whether the treatment variable is correlated with observable variables. It presents the results of a regression with the indicated variable as the dependent variable, and $Farm\,Minerals$ as the independent variable, $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. Year fixed effects are included, and robust standard errors clustered at the county level are in parentheses. All independent variables are county-level totals. $Cropland\,Acres$ is the total number of acres of cropland planted, and $Farmland\,Acres$ is the total number of acres of all types of farmland. $Govt\,Payments$ is the total amount of payments per acre of farmland by the government to farmers. $Number\,Farms$ is the total number of farms. $Avg\,Farmsize$ is the average size of a farm, in acres. $Wheat\,Yield$ is wheat crop growing productivity, measured in bushels of wheat produced per acre harvested. $Wheat\,Production$ is the total amount of wheat produced in the county in a given year, in bushels. $Machine\,Purchases$ is the total number of new farm equipment purchases in the county. $Farmland\,Price/Acre$ is the average value of farmland per acre, in thousands of real (2010) dollars. $Total\,Income$ is the total amount of money per acre of farmland earned by farmers. LTV is loan-to-value, calculated as the total amount of farm real estate debt divided by the total value of farmland. Regressions are run from 2000 to 2004. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Independent Variable: $Farm\,Minerals_i$	
Dependent Variable	Treatment Effect
$\log\left(Cropland\,Acres\right)_{i,t}$	0.179
	(0.268)
$\log\left(Farmland\,Acres\right)_{i,t}$	0.345
	(0.243)
$Govt\ Payments_{i,t}$	0.003
	(0.005)
$\log(Number\ Farms)_{i,t}$	0.157
	(0.197)
$\log(Avg\,Farmsize)_{i,t}$	−0.079
	(0.220)
$\log(Wheat\,Yield)_{i,t}$	−0.048
	(0.063)
$\log(Wheat\,Prod)_{i,t}$	−0.096
	(0.919)
$\log\left(1 + Machine\,Purchases\right)$	−0.471
	(0.427)
$\log(Farmland\,Price/Acre)$	−0.328
	(0.210)
$Total\,Income_{i,t}$	0.056
	(0.083)
$LTV_{i,t}$	0.034
	(0.060)

Table 3: Purchases of Land by Farmers

This table provides the estimation results for purchases of land by farmers. Panel A statistically examines the parallel trends assumption by testing the difference in mean growth rates over the pre-period for the outcome variable between counties above and below the median of farm mineral ownership. Panel B runs the diff-in-diff regressions. *Total Acres Purchased* is the total number of acres purchased by farmers, at the county level in columns (1) and (2) and at the farm level in columns (3) and (4). For the county-level regressions, $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. For the farm-level regressions, $Farm\,Minerals$ is a dummy variable which takes a value of 1 if a farmer owns mineral rights, and 0 otherwise. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables in the county-level specifications include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010, and all regressions exclude counties with low oil potential. Standard errors (in parentheses) are clustered at the county level in column (1), are adjusted for spatial correlation and autocorrelation at the county level following Conley (1999) in column (2), and are clustered at the farm level in columns (3)-(4)), as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A: Test of Parallel Trends in the Pre-period

Growth Rate, *Total Acres Purchased*		
Pre-period:	2000-2004	1995-2004
Above-median, $Farm\,Minerals$	0.049	0.085
	(0.040)	(0.027)
Below-median, $Farm\,Minerals$	0.034	0.074
	(0.089)	(0.051)
Difference	0.016	0.011
	(0.093)	(0.045)
T-stat of Difference	0.169	0.247

Panel B: Diff-in-Diff Regressions

Dependent Variable: $\log(1 + Total\,Acres\,Purchased)$				
	(1)	(2)	(3)	(4)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.362*	0.362**	0.064***	0.078***
	(0.203)	(0.149)	(0.013)	(0.015)
Level of Analysis	County	County	Farm	Farm
Controls	Yes	Yes		
Year Fixed Effects	Yes	Yes	Yes	No
County Fixed Effects	Yes	Yes	No	No
Farm Fixed Effects			Yes	Yes
County×Year Fixed Effects			No	Yes
Observations	633	633	227,667	227,667
Standard Errors	Robust	Spatial HAC	Robust	Robust
R^2	0.857	0.853	0.223	0.227

Table 4: Reallocation—Purchases of Land in Low Productivity Counties

This table presents the total amount of cross-county farmland purchases in low-productivity counties. Regressions are run at the county level or farm level, as indicated. The dependent variable is the log total acreage of purchases in low-yield counties by farmers in other counties. For the county-level regressions, $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. For the farm-level regressions, $Farm\,Minerals$ is a dummy variable which takes a value of 1 if a farmer owns mineral rights, and 0 otherwise. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Columns (1)-(4) are run conditionally for counties where the purchasing farmer resides in a county that has a below-median average yield (defined between 1990 and 2004), while columns (5)-(8) are run conditionally for counties where the purchasing farmer resides in a county that has an above-median average yield. Control variables include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010, and exclude counties with low oil potential. Standard errors (in parentheses) are clustered at the county level in columns (1) and (5), are adjusted for spatial correlation and autocorrelation at the county level following Conley (1999) in columns (2) and (6), and are clustered at the farm level in columns (3)-(4)) and (7)-(8), as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Dependent Variable: $\log(1 + Acres\,Purchased\,of\,Farmland\,in\,Low\,yield\,Counties)$

	Low-yield Counties				High-yield Counties			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Farm\,Minerals_i \times Fracking\,Entry_t$	−0.255	−0.255	−0.002	0.005	1.904***	1.904***	0.006**	0.006*
	(1.067)	(0.577)	(0.005)	(0.007)	(0.531)	(0.710)	(0.003)	(0.003)
Level of Analysis	County	County	Farm	Farm	County	County	Farm	Farm
Controls	Yes	Yes			Yes	Yes		
Year Fixed Effects	Yes	Yes	Yes	No	Yes	Yes	Yes	No
County Fixed Effects	Yes	Yes	No	No	Yes	Yes	No	No
Farm Fixed Effects			Yes	Yes			Yes	Yes
County×Year Fixed Effects			No	Yes			No	Yes
Observations	171	171	85,452	85,452	147	147	142,290	142,290
Standard Errors	Robust	Spatial HAC	Robust	Robust	Robust	Spatial HAC	Robust	Robust
R^2	0.455	0.455	0.108	0.114	0.657	0.657	0.117	0.122

Table 5: Reallocation—Purchases of Farmland by Farmers in High Productivity Zip Codes

This table presents the total amount of farmland purchases in low-productivity counties. Regressions are run at the farm level. The dependent variable is the log total acreage of farmland purchased by farmers. $Farm\,Minerals$ is a dummy variable which takes a value of 1 if a farmer owns mineral rights, and 0 otherwise. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Columns (1) and (2) are run conditionally for zip codes where the purchasing farmer resides in a 5-digit zip code that has a below-median average yield (defined based on 1992, 1997, and 2002), while columns (3) and (4) are run conditionally for zip codes where the purchasing farmer resides in a 5-digit zip code that has an above-median average yield. Regressions are run from 2000 to 2010, and exclude counties with low oil potential. Standard errors (in parentheses) are clustered at the farm level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Dependent Variable: $\log(1 + Total\,Acres\,Purchased\,of\,Farmland)$

	Low-yield Zip Codes		High-yield Zip Codes	
	(1)	(2)	(3)	(4)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.012	0.013	0.024***	0.020*
	(0.013)	(0.014)	(0.009)	(0.011)
Level of Analysis	Farm	Farm	Farm	Farm
Year Fixed Effects	Yes	No	Yes	No
Farm Fixed Effects	Yes	Yes	Yes	Yes
County×Year Fixed Effects	No	Yes	No	Yes
Observations	47,838	47,838	75,467	75,467
R^2	0.132	0.158	0.154	0.162

Table 6: Reallocation—Purchases of Vacant Land by Farmers

This table provides the estimation results for purchases of vacant land by farmers. Panel A statistically examines the parallel trends assumption by testing the difference in mean growth rates over the pre-period for the outcome variable between counties in the top and bottom quartiles of farm mineral ownership. Panel B runs the diff-in-diff regressions. *Total Vacant Acres Purchased* is the total number of acres purchased by farmers, at the county level in columns (1)-(2) and at the farm level in columns (3) and (4). For the county-level regressions, $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. For the farm-level regressions, $Farm\,Minerals$ is a dummy variable which takes a value of 1 if a farmer owns mineral rights, and 0 otherwise. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables in the county-level specifications include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010, and all regressions exclude counties with low oil potential. Standard errors (in parentheses) are clustered at the county level in column (1), are adjusted for spatial correlation and autocorrelation at the county level following Conley (1999) in column (2), and are clustered at the farm level in columns (3)-(4)), as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A: Test of Parallel Trends in the Pre-period

Growth Rate, *Total Acres Purchased*		
Pre-period:	2000-2004	1995-2004
Above-median, $Farm\,Minerals$	0.037	0.096*
	(0.100)	(0.052)
Below-median, $Farm\,Minerals$	0.072	0.088
	(0.130)	(0.073)
Difference	−0.036	0.008
	(0.195)	(0.088)
T-stat of Difference	−0.183	0.095

Panel B: Diff-in-Diff Regressions

Dependent Variable: $\log(1 + Total\,Vacant\,Acres\,Purchased)$				
	(1)	(2)	(3)	(4)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.661***	0.661***	0.064***	0.072***
	(0.221)	(0.157)	(0.011)	(0.013)
Level of Analysis	County	County	Farm	Farm
Controls	Yes	Yes		
Year Fixed Effects	Yes	Yes	Yes	No
County Fixed Effects	Yes	Yes	No	No
Farm Fixed Effects			Yes	Yes
County×Year Fixed Effects			No	Yes
Observations	620	620	227,667	227,667
Standard Errors	Robust	Spatial HAC	Robust	Robust
R^2	0.828	0.828	0.242	0.246

Table 7: Reallocation—Wheat Production, Wheat Acres under Cultivation, Productivity, and Profits

This table provides the estimation results for wheat production, wheat acres under cultivation, crop productivity, and profits. Panel A statistically examines the parallel trends assumption by testing the difference in mean growth rates over the pre-period for the outcome variable between counties in the top and bottom quartiles of farm mineral ownership. Panel B runs the diff-in-diff regressions. $Wheat\,Production$ is the total amount of wheat produced in the county in a given year, in bushels. $Wheat\,Acres$ is the total number of acres of wheat under cultivation in the county. $Wheat\,Yield$ is wheat growing productivity, defined as wheat production per acre harvested (measured in bushels per acre). $Profits$ is county farm profits (in \$000s), defined as crop sales income less expenses, per acre of cropland. $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables include log amount of cropland (except in columns (3)-(4)), total farm income per acre (except for columns (7)-(8)), government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010 for columns (1)-(6) and for 1997, 2002, 2007, and 2012 for columns (7)-(8). Regressions exclude counties with no oil potential. Standard errors (in parentheses) are clustered at the county level or adjusted for spatial correlation and autocorrelation at the county-level following Conley (1999), as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A: Test of Parallel Trends in the Pre-period

Growth Rate:	$Wheat\,Production$		$Wheat\,Acres$		$Wheat\,Yield$	
Pre-period:	2000-2004	1995-2004	2000-2004	1995-2004	2000-2004	1995-2004
	(1)	(2)	(3)	(4)	(5)	(6)
Above-median, $Farm\,Minerals$	0.147	0.087	0.058	0.031	0.015	0.062
	(0.164)	(0.105)	(0.057)	(0.032)	(0.109)	(0.067)
Below-median, $Farm\,Minerals$	0.055	0.047	−0.005	−0.007	0.016	0.060
	(0.122)	(0.088)	(0.054)	(0.039)	(0.059)	(0.057)
Difference	0.092	0.039	0.064	0.037	−0.0005	0.002
	(0.060)	(0.036)	(0.052)	(0.027)	(0.056)	(0.025)
T-stat of Difference	1.541	1.089	1.234	1.393	−0.008	0.081

Panel B: Diff-in-Diff Regressions

Dependent Variable:	log($Wheat\,Production$)		log($Wheat\,Acres$)		log($Wheat\,Yield$)		$Profits$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.379*	0.379***	0.266***	0.266***	0.162*	0.162***	0.109*	0.109***
	(0.198)	(0.133)	(0.084)	(0.062)	(0.086)	(0.061)	(0.057)	(0.033)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	563	563	559	559	559	559	239	239
Standard Errors	Robust	Spatial HAC	Robust	Spatial HAC	Robust	Spatial HAC	Robust	Spatial HAC
R^2	0.961	0.961	0.986	0.986	0.621	0.621	0.576	0.576

Table 8: Effect on Farmland Prices

This table provides regression estimates for the effect on farmland prices. Panel A statistically examines the parallel trends assumption by testing the difference in mean growth rates over the pre-period for the outcome variable between counties in the top and bottom quartiles of farm mineral ownership. Panel B runs the diff-in-diff regressions. $Farmland\,Price/Acre$ is the average value of farmland per acre, in thousands of real (2010) dollars. $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010, and exclude counties with low oil potential. Standard errors (in parentheses) are clustered at the county level or adjusted for spatial correlation and autocorrelation at the county-level following Conley (1999), as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A: Test of Parallel Trends in the Pre-period

Growth Rate, $Farmland\,Price/Acre$	
Pre-period:	2000-2004
Above-median, $Farm\,Minerals$	0.040
	(0.018)
Below-median, $Farm\,Minerals$	0.041
	(0.015)
Difference	−0.001
	(0.012)
T-stat of Difference	−0.067

Panel B: Diff-in-Diff Regressions

Dependent Variable: log($Farmland\,Price/Acre$)	(1)	(2)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.266***	0.266***
	(0.084)	(0.042)
Controls	Yes	Yes
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Observations	642	642
Standard Errors	Robust	Spatial HAC
R^2	0.877	0.877

Table 9: Investment in Farm Equipment

This table provides regression estimates for investment in farm machinery. The dependent variable is $\log(1 + Machine\,Purchases)$, which is the logarithm of the total number of new farm equipment purchases in the county. $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010, and exclude counties with low oil potential. Standard errors (in parentheses) are clustered at the county level or adjusted for spatial correlation and autocorrelation at the county-level following Conley (1999), as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A: Test of Parallel Trends in the Pre-period

Growth Rate, $Machine\,Purchases$		
Pre-period:	2000-2004	1995-2004
Top Quartile	0.431	0.252**
	(0.183)	(0.108)
Bottom Quartile	0.464	0.254*
	(0.227)	(0.124)
Difference	−0.033	−0.002
	(0.044)	(0.038)
T-stat of Difference	−0.738	−0.057

Panel B: Diff-in-Diff Regressions

Dependent Variable: $\log(1 + Machine\,Purchases)$		
	(1)	(2)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.190*	0.190***
	(0.110)	(0.058)
Controls	Yes	Yes
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Observations	645	645
Standard Errors	Robust	Spatial HAC
R^2	0.941	0.941

Table 10: Placebo Test—Purchasing Behavior and Price Effect for Vacant Land Holders

This table conducts a placebo test for the effect on purchasing behavior and land prices, by examining the effect on vacant landholders. *Acres Purchased* is the total number of acres of vacant land purchased by vacant landholders at the county level or at the landholder level, as indicated. $Land\,Sales\,Price/Acre$ is the average sales price at the county level for vacant land sales amongst vacant landholders. For the county-level regressions, $Vacant\,Minerals$ is a continuous variable which estimates the proportion of vacant landholders in a county who own mineral rights. For the landholder-level regressions, $Vacant\,Minerals$ is a dummy variable which takes a value of 1 if a landholder owns mineral rights, and 0 otherwise. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables in the county-level specifications include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010, and counties with no oil potential are excluded. Standard errors (in parentheses) are clustered at the county level in columns (1) and (4), and clustered at the landholder level in column (2) and (3). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Dependent Variable:	$\log(1 + Acres\,Purchased)$	$\log(1 + Acres\,Purchased)$		$\log(Land\,Sales\,Price/Acre)$
	(1)	(2)	(3)	(4)
$Vacant\,Minerals_i \times Fracking\,Entry_t$	0.510	0.021	0.002	−0.002
	(0.390)	(0.013)	(0.015)	(0.225)
Level of Analysis	County	Landholder	Landholder	County
Controls	Yes			No
County Fixed Effects	Yes	No	No	No
Year Fixed Effects	Yes	Yes	Yes	No
Landholder Fixed Effects		Yes	Yes	
County×Year Fixed Effects		No	Yes	
Observations	644	242,528	242,528	639
R^2	0.777	0.114	0.119	0.643

Table 11: Robustness—Falsification Test

This table provides regression results for land purchases, wheat production, acres under cultivation, yields, and farmland values for the years between 1997 and 2004, falsely specifying the entry of fracking as being 1999. *Total Acres Purchased* is the total number of acres purchased by farmers, at the county-level. *Wheat Production* is the total amount of wheat produced in a given year, in bushels. *Wheat Acres* is the total number of harvested acres of wheat in a given year. *Wheat Yield* is the average wheat growing productivity, defined as wheat production per acre harvested (measured in bushels per acre). *Farmland Price/Acre* is the average farmland sales price, in thousands of dollars per acre. *Farm Minerals* is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. $Entry'$ is a dummy variable which takes a value of 1 if the year is 1999 or later. Control variables include log amount of cropland (except in column (4)), total farm income per acre, government payments per acre, county income per capita, and log population. Counties with low potential are excluded. Robust standard errors are in parentheses, and are clustered at the county level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Dependent Variable:	$\log(1 + Total\ Acres\ Purchased)$	$\log(1 + Vacant\ Acres\ Purchased)$	$\log(Wheat\ Production)$	$\log(Wheat\ Acres)$	$\log(Wheat\ Yield)$	$\log(Farmland\ Price/Acre)$
	(1)	(2)	(3)	(4)	(5)	(6)
$Farm\ Minerals_i \times Entry_t^{'}$	0.140	−0.238	0.039	0.097	0.055	−0.050
	(0.256)	(0.345)	(0.166)	(0.131)	(0.065)	(0.093)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	446	432	464	463	463	354
R^2	0.868	0.844	0.972	0.985	0.432	0.899

Table 12: Placebo Test—High vs. Low Oil

This table provides a placebo test for land purchases, wheat production, acres under cultivation, yields, and farmland values, by identifying counties using oil potential rather than mineral rights. $Total\,Acres\,Purchased$ is the total number of acres purchased by farmers, at the county-level. $Wheat\,Production$ is the total amount of wheat produced in a given year, in bushels. $Wheat\,Acres$ is the total number of harvested acres of wheat in a given year. $Wheat\,Yield$ is the average wheat growing productivity, defined as wheat production per acre harvested (measured in bushels per acre). $Farmland\,Price/Acre$ is the average value of farmland, in dollars per acre. Oil is the number of discovered oil fields in the county, as a measure of oil potential. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables include log amount of cropland (except in column (4)), total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010. Robust standard errors are in parentheses, and are clustered at the county level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Dependent Variable:	$\log(1 + Total\,Acres\,Purchased)$	$\log(1 + Vacant\,Acres\,Purchased)$	$\log(Wheat\,Production)$	$\log(Wheat\,Acres)$	$\log(Wheat\,Yield)$	$\log(Farmland\,Price/Acre)$
	(1)	(2)	(3)	(4)	(5)	(6)
$\log(Oil_i) \times Fracking\,Entry_t$	−0.018	−0.040	0.045	0.035	−0.004	−0.010
	(0.047)	(0.073)	(0.059)	(0.025)	(0.025)	(0.033)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	783	770	683	679	679	642
R^2	0.838	0.806	0.956	0.985	0.592	0.871

Appendix A: Institutional Details of Fracking

In this appendix, I provide some useful institutional details related to fracking in Oklahoma. These are gathered from various data sources, including public websites as well as interviews with and surveys of directors and executives of the farm credit system, most of whom are farmers.

A.1 Entering into a Fracking Lease

When an oil company has targeted an area for drilling, it hires an intermediary to locate and contact all owners of mineral rights in that area. The intermediaries then negotiate with the mineral owners, and enter them into a mineral lease with the oil company. The mineral rights owner receives an up-front bonus of \$500–\$10,000 per acre, in additional to royalties which are contingent on the production of oil and gas. The range in the bonuses reflects the fact that oil potential may vary across areas, and also that farmers can opt for a smaller upfront payment in exchange for higher royalties.

There is considerable heterogeneity across farmers in terms of ownership of mineral rights. Some farmers own much of the mineral rights underneath their land, while other farmers own none. While there is a range in terms of the up-front payment, even at the lower end this represents a significant cash inflow to farmers. The average farm size in Oklahoma is roughly 450 acres. Thus, the average farmer that owns even a small portion of the mineral rights underneath his/her land will enjoy an upfront payment of at least tens of thousands of dollars.

Once the oil companies have entered into a lease with the mineral owners, they then negotiate with the surface owners. While owners of surface rights who do not own mineral rights are not able to reap any of the benefits of these contracts nor able to stop any drilling on their property, the oil companies typically will negotiate with the surface owner regarding where to place the drill. In addition, the surface owner is often offered a small inconvenience payment to offset the lack of use of the land during the well construction, as well as a payment for the use of water utilities while the fracking is going on. However, these payments are orders of magnitude smaller than the payments that mineral owners receive.

A.2 Drilling of the Oil Well

Once payments and negotiations have been completed, the oil company then proceeds to build the well. The well is typically constructed at the edge of the property, so as to minimize impact on farming operations. Companies are able to exercise some flexibility with regard to the placement of the drill because of horizontal drilling. The well is part of a drilling pad that is 400 feet by 400 feet (or 3.67 acres). Thus, the area of land that the drilling pad takes up is less than 1% of the total acreage of an average farm.

After constructing the drilling pad, the drill then drills down to 6,000–7,000 feet beneath the surface. After drilling down to that depth, horizontal drilling begins. Once the drilling has been completed, the drilling company brings in a rig and additional equipment that involves roughly 50–100 trucks. At that point, workers then inject chemical fluids at high pressures into the horizontal portion of the drilled minerals, fracturing the rock underground to allow access to stored oil and gas. Once the well is constructed and the infrastructure put in place, the drilling rig is removed and only a small well head that is a few feet tall remains. Oil or gas is then transferred automatically away from the area via constructed pipelines. Thus, once the initial fracking injection and well rig construction is completed, much of the heavy equipment is removed and the used area of the surface land is reduced and able to be restored.

A.3 Forced Pooling

An endogeneity concern in my analysis is that farmers may refuse to sign into fracking leases even if they own mineral rights. While in principle they could, as a practical matter it is virtually impossible for a farmer to do so in the state of Oklahoma. It is one of 40 states that have “compulsory pooling”, also known as “forced pooling”. With this law, the owner of the mineral rights on a piece of land cannot hold out as a non-consenting landowner if a majority of the other mineral rights owners in a given area have agreed to sign leases with the drilling company. All that is required is a “fair and reasonable offer”, and there are pre-determined rules to determine this based on the leases signed by other mineral rights owners. With forced pooling, the percentage of farmers with mineral rights who do *not* sign leases once approached is basically zero. The legal environment in Oklahoma is very favorable to mineral rights owners and drilling companies, and farmers who refuse to sign leases run the risk of protracted and costly legal battles. Eubanks and Mueller (1986) provide an overview of the statutes related to forced pooling and its economic effects in Oklahoma; Baca (2011) provides examples of how forced pooling has been used by drilling companies during the fracking boom.

A.4 Negative Effects of Fracking

There has been much concern over the negative effects of fracking. These effects may manifest themselves in a few different ways for farmers. It is important to note that all of these channels would have a *negative* effect on productivity for a farm, and thus would bias me *against* finding the positive effects that I do in my analysis. Furthermore, areas with high and low farm mineral ownership have similar drilling activity, as shown by *Figure 2* and *Figure B3*, and thus negative externalities associated with fracking should not covary with my treatment effect.

A first potential negative effect of fracking is the possibility of water contamination. Fracking involves the use of toxic chemicals, and so any spillage of such chemicals may adversely affect either livestock of crops on a farm through their use of water. A recent report by the Environmental Protection Agency (EPA, 2015) found no systematic evidence of water contamination by fracking, and concluded that the process does not adversely affect water supplies if undertaken with proper safety measures. Furthermore, conversations with

Farm Credit executives revealed that they know of very few instances of farmers being affected by water contamination as a result of fracking.

A second negative effect of fracking is the disruption of farm operations due to the heavy equipment and trucks needed for fracking. Moreover, the land used for drilling may significantly disrupt farm operations and prevent a farmer from farming. These are of minimal concern for a few reasons. First, oil companies typically drill wells at the edge of any farm property, in order to minimize disruption. Second, the portion of land that is used for fracking is less than 4 acres, which is less than 1% of the acreage of the average farm. Third, once the initial oil drilling rig has been removed, the wellhead that remains is only a few feet tall, and the land around it can be restored for farming.

Appendix B: Additional Figures and Tables

Figure B1: Proportion of Farms that Transfer Mineral Deeds

This figure provides the total proportion of farms that engage in transfers of mineral deeds. These transferences include taking ownership of mineral rights, as well as granting ownership of mineral rights.

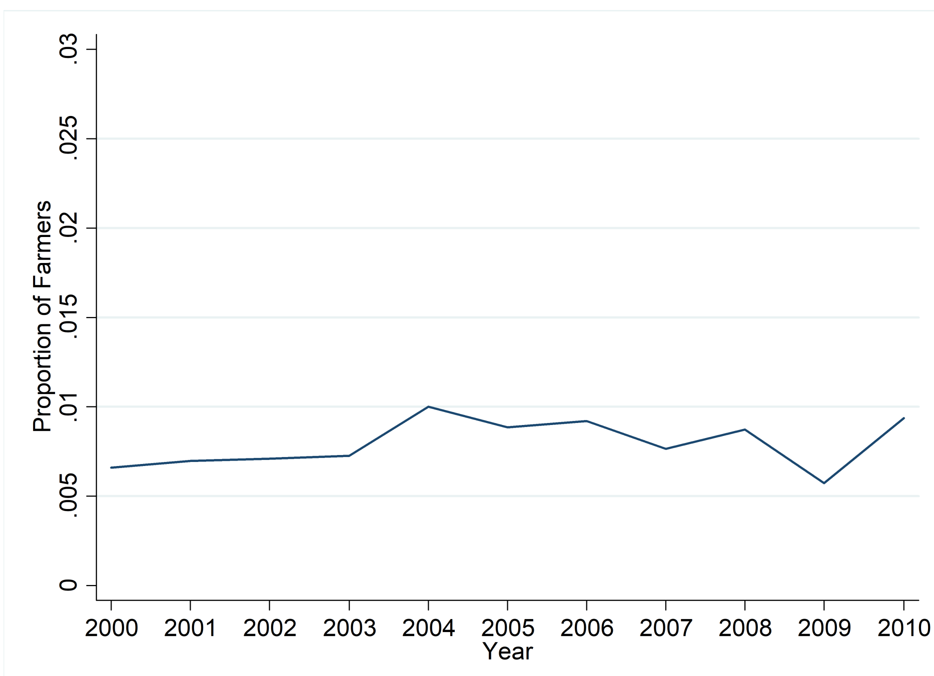
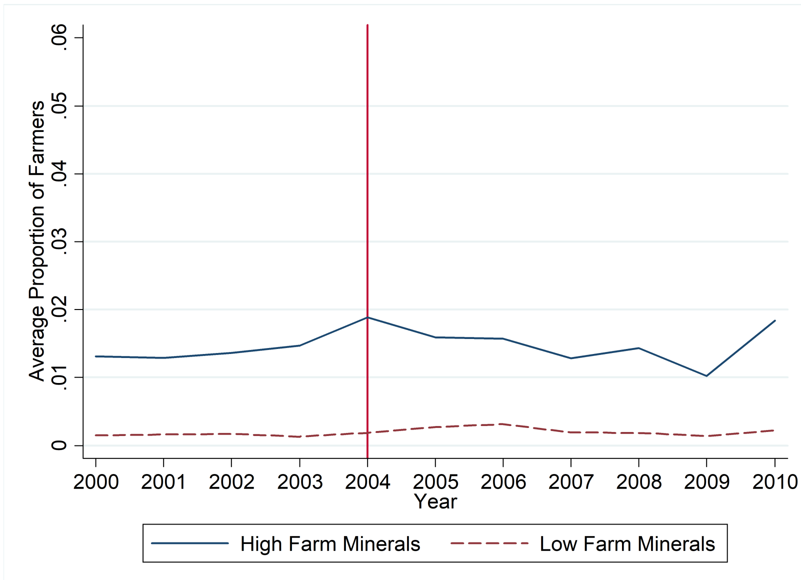


Figure B2: Farm Mineral Deed Transfers, High vs. Low Mineral Ownership Counties

The top figure shows the average proportion of farms that engage in mineral deed transfers, for counties above the median of mineral rights ownership (solid blue line) compared to counties below the median of mineral rights ownership (dashed red line). The bottom figure shows the differences between the two groups (high ownership group minus low ownership group).



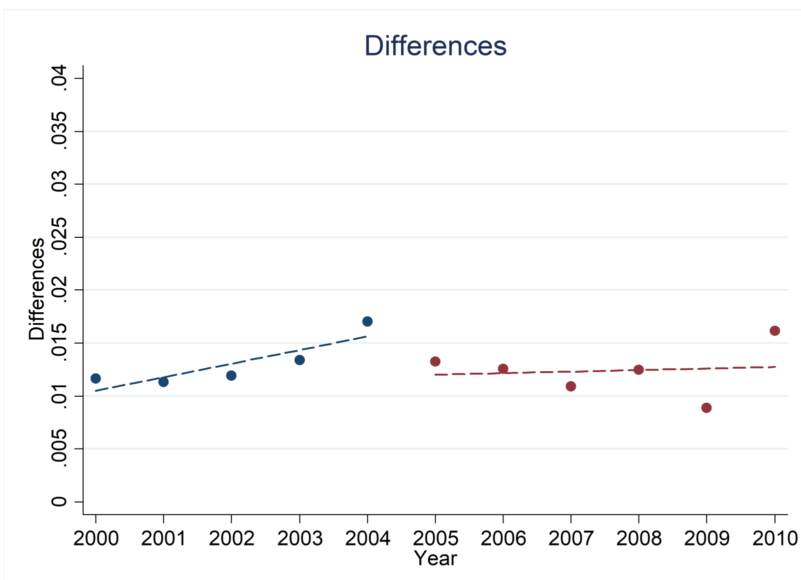


Figure B3: Map of Mineral Ownership across Counties

This figure depicts the values of $Farm\,Minerals$, the estimate of the proportion of farmers who own mineral right, for each county in Oklahoma. The shaded counties represent the indicated proportion of mineral rights ownership, while the unshaded (white) counties represent the excluded counties with no oil potential.

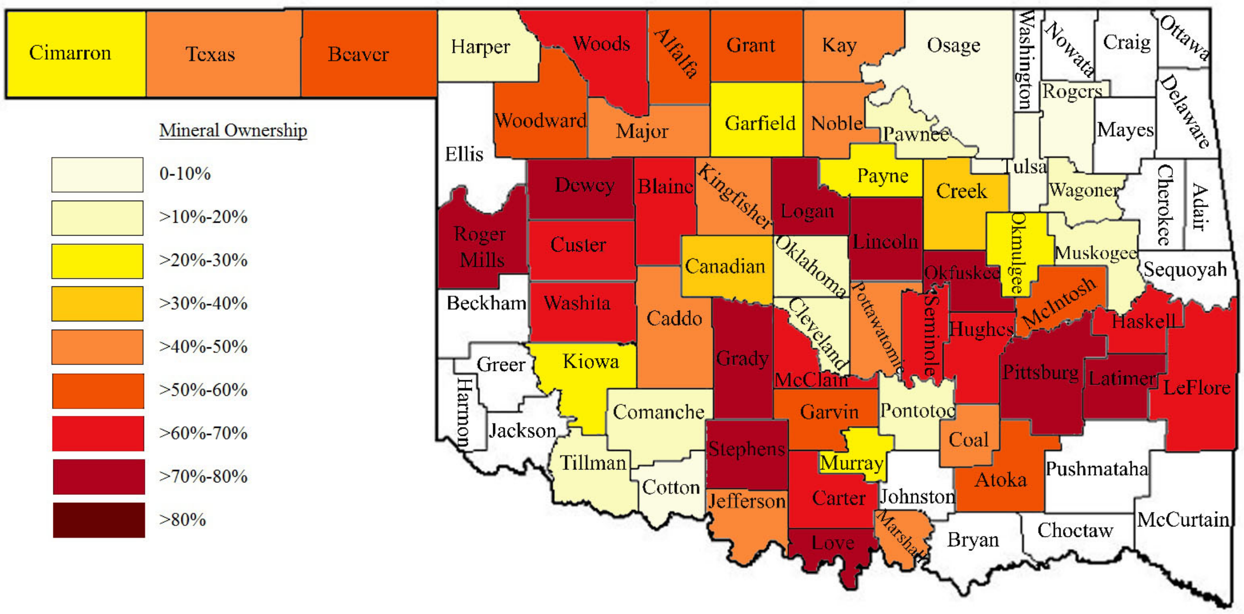


Table B1: Farm Mineral Deed Transfers

This table estimates the change in the proportion of farms engaging in mineral deed transfers following the arrival of fracking, for counties with higher farm mineral ownership compared to counties with lower farm mineral ownership. The dependent variable is the proportion of farms that transfer mineral rights. $Farm\,Minerals$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. $Fracking\,Entry$ is a dummy variable which takes a value of 1 if the year is 2005 or later. Control variables include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, and log population. Regressions are run from 2000 to 2010, and all regressions exclude counties with no oil potential. Robust standard errors are in parentheses, and are clustered at the county level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Dependent Variable: *Percentage of Farms Transferring Mineral Deeds*

	(1)	(2)
$Farm\,Minerals_i \times Fracking\,Entry_t$	−0.005	−0.004
	(0.005)	(0.005)
$Farm\,Minerals_i$	0.031***	
	(0.009)	
$Fracking\,Entry_t$	0.002*	
	(0.001)	
Controls	No	Yes
Year Fixed Effects	No	Yes
County Fixed Effects	No	Yes
Observations	660	656
R^2	0.222	0.820