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 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 experiencing positive cash flow shocks increase their land purchases, which results in a reallocation effect. Examining purchases across areas, I find that farmers in high-productivity areas who receive cash flow shocks buy farmland in low-productivity areas, but farmers in low-productivity areas receiving positive cash flow shocks do not. Moreover, farmers increase their purchases of vacant (undeveloped) land. Average output, productivity, equipment investment, and profits all increase significantly 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, leading to depressed aggregate outcomes, such as lower productivity and asset values.[1] Financing frictions are an important class of frictions causing such misallocation.[2] For example, the "inalienability" of human capital as in Hart and Moore (1994), limits how much external financing can be raised, and may cause underinvestment in the sense that value-enhancing projects that would be taken if the firm had internal funds would be forsaken if external financing was needed (see also Holmstrom and Tirole (1997)). Thus, in an industry in which assets are not in the hands of the most productive users, this friction may impede the most productive users of assets from obtaining financing to acquire those assets, leaving them with less-productive users. If so, then relaxing these financial constraints may undo some of the misallocation and result in an efficient *reallocation* of assets. Another financial friction is moral hazard—managers may engage in empire building (which includes overinvesting and excessive perks), in which case a financial constraint (like that introduced by a hard claim like debt, as in Hart and Moore (1995)) can reduce overinvestment and relaxing it can worsen outcomes. Thus, depending on which friction dominates, relaxing financial constraints can either increase or decrease industry allocative efficiency. The question of how relaxing financial constraints affects allocative efficiency thus needs empirical analysis, particularly to understand the size and significance of the effects.

The goal of this paper is to empirically address this question. A major challenge in this exercise is that a shock that relaxes financial constraints will typically also affect the

[1] A large literature has argued that such misallocation may account for differences in total factor productivity (TFP) and wealth across nations. 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] 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. I develop a simple theoretical model to demonstrate how this would operate in my setting and generate the results I hypothesize.

firm's fundamentals, making it difficult to isolate the effect of relaxing financial constraints. To overcome this challenge, I consider a setting with a shock that relaxes firms' financial constraints, but *not* their future investment opportunities. I empirically examine whether this leads to a reallocation of assets, and its effect on productivity, output, profitability, and asset values.

The setting I use is the agricultural land market in Oklahoma. For identification, I exploit the exogenous cash windfalls starting in the mid-2000s that farmers received from signing hydraulic fracturing (fracking) leases. I combine these cash flow shocks with a unique institutional feature that helps to overcome the challenge of disentangling the effect of liquidity shocks from changes in fundamental values. 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 farm the land. However, a fracking lease can be signed only with the owner of the *mineral* rights. Thus, the productivity and value of *farmland* will not be directly affected by the discovery of underground oil and gas, as oil/gas-related cash flows accrue *only* to the mineral right owner.[3]

As some farmers own the mineral rights and others do not, there is heterogeneity that I am able to exploit in my tests, namely that any effect on asset transfers, productivity, and prices should be driven by a liquidity effect from relaxing financial constraints.[4] I use a differences-in-differences methodology to examine areas where many farmers received cash payments when fracking arrived—due to their ownership of both the surface and mineral rights—to areas where there was fracking but farmers did not own mineral rights, thereby not receiving cash windfalls. My tests involve county-level, zip code-level, and farm-level data.

I find that farmers who enter into fracking leases subsequently purchase more land on

[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 B.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.

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 these farmers overinvesting or empire-building, as in Jensen (1986)).[5] These two motivations for land purchases have very different implications for economic efficiency.

To further understand the underlying mechanism, I examine in detail the reallocation of farmland. Specifically, farmers in high-productivity areas who receive mineral-lease-related cash flow shocks after fracking arrives purchase more farmland from farmers in low-farm-productivity areas. However, in low-productivity areas, similarly-affected farmers do not exhibit this post-fracking purchasing behavior. These effects are inconsistent with empire-building, since that would require *all* farmers to buy land with cash windfalls. They are, however, consistent with a reallocation of farmland from less- to more-productive farmers. I also find no significant increase in farmland purchases in the areas where relatively few farmers have mineral rights, and thus associated windfalls post-fracking are also relatively few. This means that the effects are driven by heterogeneity in mineral rights ownership, an essential feature of my identification strategy.

In addition to this reallocation, 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 productively used, and is 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

[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 theoretically shown to be even greater in family-owned firms with family CEOs (Schulz, Labatkin, Dino, and Buccholtz (2001)). Empirical evidence is provided by Bandiera, Lemos, Prat, and Sadun (2017), who 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.

[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.

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. Furthermore, the pattern of these increases when split between high-productivity and low-productivity areas are broadly consistent with an efficient reallocation of assets from less-productive to more-productive users.

Next, I examine the effect of the reallocation on land prices. First, 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. Second, segmenting the effects by area productivity reveals that the increases in land values cluster in the low-productivity areas, in line with other (high-productivity) farmers purchasing land in those areas. These effects are again in line with the reallocation of land to more-efficient users whose asset valuation is higher due to the higher surplus they can extract from it. Since this reallocation is caused by a liquidity influx, it also provides novel evidence of a "cash-in-the-market" pricing effect (e.g. Allen and Gale (2005)).[7]

Finally, I show that farmers also use these cash windfalls to increase farm equipment purchases, with farmers in areas with higher farm mineral ownership making about 10% more equipment purchases compared to farmers in other areas. This is consistent with higher capital investments by farmers aiming to farm the purchased land.

I run numerous checks to provide further evidence of the channels at play, and to rule

[7]These prices only reflect the value of surface rights, and so are not a result of the discovery of oil or gas 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).

out alternative channels that may drive the results. I begin by providing evidence that the liquidity shock resulted in a reduction in credit constraints, as measured by loan-to-value ratios. I additionally show that the main results I find are stronger in areas where farmers were ex ante more financially constrained. I then conduct a number of robustness checks. First I examine whether the results are caused by a wealth effect. If agents hold an "idiosyncratic" asset—whose value depends on user-specific skills—then a large positive wealth shock could cause these agents to purchase more of the asset. To check this, I conduct a placebo test using non-farm vacant landholders. If a wealth effect is the driver, *both* farmers and non-farm vacant landholders should purchase additional land. I find, however, that 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.

This paper is related to the literature on the factors driving within-industry reallocation of assets. Maksimovic and Philips (2001) provide evidence of productivity gains from asset reallocation due to M&A activity. Bertrand, Schoar, and Thesmar (2007) study how banking deregulation in France improved allocative efficiency through an effect on credit supply.[8] Almeida and Wolfenzon (2005) develop a model (with supporting empirical evidence) in which limited pledgeability creates a misallocation of capital, but high external financing needs can improve allocative efficiency via liquidation of low-productivity projects.

My incremental contribution to this literature is documenting that relaxing the financial

[8] 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 (2018) document that the financial crisis induced a reallocation of liquidity from low-capital to higher-capital banks.

constraints of small firms (i.e. farms), through channels other than credit supply or product demand effects, can lead to real effects through a reallocation of capital that improves productivity and profitability.[9] Gilje, Loutskina and Strahan (2011) and Gilje (2019) show that fracking increased bank deposits, and in turn increased credit supply. This potentially contributes to relaxing the financial constraints of farmers. However, all the counties in my sample experienced fracking and hence increased credit supply from banks, so the results I document on the reallocation effect that are based on productivity-based heterogeneity across farmers are likely not affected by this augmentation of credit supply in all counties.[10] 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 on how frictions lead to capital misallocation and lower productivity—Restuccia and Rogerson (2013) provide a review. These papers focus on empirically identifying a misallocation of resources and the resulting heterogeneity in total factor productivity. Hsieh and Klenow (2009) use manufacturing establishment data from China, India, and the U.S., and show how resource misallocation lowers aggregate productivity. Subsequent papers have explored how different frictions impact misallocation, often by calibrating equilibrium models or using data across countries or industries. For

[9] 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 delineates the effect on financially-constrained firms when their constraints are relaxed, and I further discuss later on how the results are unlikely to be driven by any potential changes in credit supply.

[10] One interesting aspect of the increased credit supply is that farmers in low-yield counties also had additional options for raising liquidity besides selling their farmland post-fracking. This means that the low-productivity farmers had a diminished need to sell their farmland after fracking arrived, which works against finding a reallocation effect. Nonetheless, I find evidence that low-productivity farmers are selling farmland to high-productivity farmers.

example, Midrigan and Xu (2014) create a model in which financial frictions lead to misallocation, and provide supporting plant-level evidence.[11] In contrast, I provide direct evidence of how *alleviating* the constraints can lead to a reallocation of assets that improves efficiency, and examining the channels through which this reallocation operates.

A third related literature addresses how financial constraints and liquidity affect investment (e.g. Fazzari, Hubbard, and Petersen (1988)), and consumption (e.g. Agarwal, Liu, and Souleles (2007), and Agarwal and Qian (2014)). While my analysis also adds to this literature by showing how an exogenous cash flow shock impacts investment via agricultural land purchases by small firms (farms), I additionally show how this investment behavior affects output, productivity, and asset prices. Importantly, I provide new evidence of a specific channel—efficient asset reallocation—through which financial constraints affect these outcomes.

Finally, this paper is connected to the large literature on the effect of liquidity on asset prices. For theories, see Allen and Gale (1994) and Shleifer and Vishny (2011).[12] Allen and Gale (2005) call this "cash-in-the-market pricing". My empirical results are consistent with these theories, and also provide novel support for their underlying mechanisms.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical motivation, and provides institutional background on farming in Oklahoma, the financial constraints of farmers, and fracking and mineral rights. Section 3 describes the empirical

[11] 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. Butler and Cornaggia (2011) explore 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.

[12] 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.

strategy, data sources, and summary statistics. Section 4 contains the main results. Section 5 describes numerous robustness tests. Section 6 discusses external validity, and concludes.

2 Theoretical Setting and Institutional Background

In this section, in order to motivate the empirical hypotheses and the mechanisms that drive the results, I first provide an overview of a theoretical model which describes the frictions that may cause a misallocation and how liquidity shocks may produce an efficient reallocation. The model is formally presented in Appendix A. After the model overview, I describe the specific institutional details related to fracking and farming in Oklahoma that makes it ideal to empirically test this reallocation.

2.1 Theoretical Framework

I develop a theoretical model which is built upon the idea that when the provision of human capital (effort) to a productive enterprise is discretionary and cannot be contracted upon in raising external finance, the borrower can pledge only a fraction of future output as repayment to financiers (e.g. Hart and Moore (1994) and Holmstrom and Tirole (1997)). This limits the amount of financing the borrower can raise, which implies that an efficient investment that would be made when the borrower can self-finance may not be possible with external finance. In these situations, borrowers can increase their debt capacity by pledging tangible, redeployable assets as collateral (e.g. Campello and Giambona (2013)). And lacking these, there would be underinvestment, relative to the first best, that may be partially attenuated if the borrower receives a liquidity windfall that can be used for investment.

More specifically, consider an economy where a farmer can be one of two types: high productivity (h) and low productivity (l). Each farmer knows her type privately, and there is a commonly-held prior on the type. There are two dates in the model. At the first date, the farmer can choose to make either a large or small investment in farming (equipment, grain, and fertilizer purchase, working capital, and so on), with a larger investment costing more. Farm output is random, but is more likely to be higher based on two factors: the scale of the capital investment and the farmer's costly but unobservable effort input. Each farmer has redeployable tangible capital, and there is observable heterogeneity across farmers as to the amount of capital they have. While this capital cannot be liquidated for investment because it is essential for farming (i.e. land, buildings, machinery, etc.), it can be used as collateral for bank borrowing. All of the financing the farmer needs to invest must be borrowed from a bank that cannot observe the farmer's choice of effort.

With this setup, the formal model generates the following main results. First, cross-sectional variation in debt between farmers depends primarily on differences in their tangible redeployable assets, and not on differences in productivity. This result is driven in part by the assumption that farmers' productivities are privately known to the farmers and not external financiers, so the equilibrium is pooling in farm productivity and separating in the pledgeable collateral offered by the farmer. In other words, all farmers borrow, but farmers with more tangible redeployable assets borrow more, and controlling for this source of collateral, higher (pre-shock) productivity does not lead to higher borrowing in a Bayesian Perfect Nash Equilibrium. Second, the pledgeability constraint—not all future cash flows can be pledged as repayment to financiers—is binding in equilibrium, and it diminishes each farmer's borrowing capacity, due to the inability of financiers to contract on the farmer's discretionary effort input. Thus, the farmer is unable to invest at the optimal level with external debt financing. Put together, this implies even high-productivity farmers can be financially constrained, which leads to a misallocation in which high-productivity farmers cannot invest in projects. Third, a high-productivity farmer can generate a positive surplus by acquiring assets (farmland) from a low-productivity farmer, and would do so if he had sufficient internal funds; low-productivity farmers do not experience the same gains from trade. However, there are circumstances in which such an acquisition would not be possible with external financing, due to the pledgeability friction.

The model thus predicts how farmers should respond to the fracking cash shock, which not only provides funds for self-financing, but also relaxes the pledgeability constraint.[13] In particular, due to pledgeability frictions, prior to the fracking liquidity shock, farm debt usage is independent of farm productivity but varies based on tangible farm assets.[14] After the fracking liquidity shock, these debt constraints are no longer binding, allowing farmers to increase their investment and high-productivity farmers to acquire farmland from low-productivity farmers.

2.2 Institutional Background

Farmers: For many reasons, the agricultural sector is ideal for examining asset reallocation. First, farmers are small business owners who own and invest in farmland—a specialized asset which they are the expert (most-efficient) users of. In particular, the market for farmland is localized, and local farmers are the most knowledgeable about cultivation and land properties, like soil quality. Consequently, local farmers are typically the most productive users of farmland, and value it more than "outside" users. Furthermore, the agricultural sector permits a straightforward measurement of outcomes like production and productivity without requiring models or estimation of measures like TFP.

Second, farmers are often financially constrained—most are small family farmers lacking access to equity markets, and have operating profit margins around 6% and frequently negative.[15] The agricultural economics literature suggests that these aspects of farming lead to limited liquidity and low net worth, thus causing farmers to be either denied credit or to not

[13]In the model, the more inside equity the borrower can provide, the higher is the debt capacity because the pledgeability constraint becomes less tight.

[14]As empirical evidence of this result, in *Table C1* I provide evidence at the county-level that farm debt usage prior to the arrival of fracking was not significantly correlated with farm productivity, measured by wheat yields, but was significantly correlated with asset value, measured by farmland value. While these county-level results are suggestive due to data limitations (such as the need to use call report data to measure debt), in untabulated results using confidential microdata from the USDA, I also confirm that this result holds at the individual farm level.

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

seek it (e.g. Turvey and Weersink (1997), Briggeman, Towe, and Morehart (2009), Hartarska and Nadolnyak (2012)). For example, 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, consistent with binding financial constraints. Bierlan and Featherstone (1998) and O'Toole and Hennessy (2013) quantify the extent of financial constraints using a 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.[16] The participants unanimously noted that the majority of farmers are cash-constrained and that these constraints are a first-order factor 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,[17] and include the inability to increase borrowing from relationship lenders (e.g. Uchida, Udell, and Yamori (2012)). Thus, a cash infusion to a farmer can be interpreted, on average, as relaxing a binding financial constraint. One advantage of focusing on farmers, therefore, is that reliance on specific measures of financial constraints is avoided, given the substantial disagreement about these measures (e.g. Farre-Mensa and Ljundqvist (2016)).

Oklahoma, Fracking, and Mineral Rights: The agricultural sector further 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 drilling: hydraulic fracturing ("fracking" henceforth). Fracking is the process of extracting oil and gas from deep underground shale rock, by injecting high-pressure liquid agents into rock formations to

[16] 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.

[17] There is no evidence of any pre-2005 deterioration in overall bank credit in Oklahoma and elsewhere. For example, Berger, Saunders, Scalise, and Udell (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 contrary to what I find. Furthermore, as I show later, proxies for creditworthiness prior to the influx of fracking are uncorrelated with mineral rights ownership.

create cracks and release oil and gas. While fracking has existed 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 due to a law change in 2005—the Energy Policy Act of 2005, which reduced regulatory uncertainty for drillers—attracted a flood of producers to start fracking in states rich in oil and gas, including Oklahoma.

In Appendix B, the institutional details of fracking and mineral rights in Oklahoma are provided. The key takeaways for my analysis are: i) every piece of farmland has two legally distinct claims on it—surface rights that enable underground drilling, with some farmers own both rights and some own only surface rights; ii) fracking lease payments are large and received only by farmers who own the minerals rights; and iii) farmers with mineral rights have virtually no ability to refuse fracking leases if others in their area accept them ("forced pooling"); and iv) fracking equipment occupies very little of the farm's surface area.

3 Empirical Specification and Data

3.1 Empirical Strategy

I employ a differences-in-differences (diff-in-diff) methodology to examine the impact of fracking on the outcome variables. The ideal strategy would be to alleviate financial constraints for two types of buyers—low-productivity and high-productivity—and examine the purchasing behavior of the two groups. As predicted by the theoretical framework described in the previous section, farmers should increase their purchases of farmland, driven by high-productivity farmers buying assets from low-productivity farmers and resulting in productivity and other outcomes improve as a result. To implement this strategy, I compare areas where farmers own both land and mineral rights to areas where farmers do not own mineral rights, further subdividing the areas by productivity, and examine the differential impact between the areas after fracking operators enter and sign leases with mineral owners.

As the actual mineral rights ownership is not observable in my data, I identify this ownership by examining whether farm landowners signed mineral leases. I am thereby able to infer which which areas have many farmers who own *both* surface and mineral rights, and which do not. The logic is that a farmer's opportunity to enter into a lease is exogenous—it depends on whether the farmer owns the mineral rights, and whether there is oil/gas underneath the land. There are two potential endogeneity concerns with this assumption. First, a farmer may decide to strategically trade mineral rights in anticipation of fracking operators entering an area, which raises the possibility of self-selection into the treatment or control groups. Second, the decision to enter into a fracking lease may be endogenous—the farmer may decide to turn down a fracking lease when approached by an oil and gas company.

The Oklahoma setting largely attenuates these endogeneity concerns. Regarding the first concern, I examine mineral deed transferences during my sample period. I find that the number of mineral deed transferences amongst farmers is extremely low for all counties, confirming sparse mineral rights trading.[18] In addition, after fracking arrives, there is no significant change in 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 after fracking arrived.[19]

Regarding the second concern, I interviewed a director of a Farm Credit Association in Oklahoma, who noted that the percentage of farmers who own mineral rights but turn down fracking lease offers is essentially zero. The reasons are twofold. First, the payment for mineral leases is typically substantial and thus attractive for farmers. Second, the "forced pooling" law in Oklahoma stipulates that recalcitrant farmers can be forced into signing leases when the majority of mineral acreage around them has already been leased. Consequently, refusing to enter into a fracking lease when approached by an oil and gas company

[18] *Figure C1* of Appendix C shows the total proportion of farmers over time who either transfer their mineral deeds to different owners or who take ownership of mineral deeds. This figure shows there is no significant change in the pattern of transferences after the arrival of fracking. This issue is discussed in more detail in Appendix C.

[19] See *Figure C2* and *Table C2* of Appendix C.

is impractical or infeasible (see Eubanks and Mueller (1986) and Baca (2011) for details).

3.2 Arrival of Fracking

For the diff-in-diff specification, I use 2005 to denote when fracking entered Oklahoma.[20] Fracking operators flooded Oklahoma starting in 2005, because a new technique that combined fracking with horizontal drilling, was developed by oil and gas operators in Texas in 2003, and regulatory uncertainty for well operators was greatly reduced by the Energy Policy Act of 2005, which exempted fluids used in fracking from federal clean water laws. This Act is often cited as a key to the fracking surge after 2005 (e.g., Krauss and Lipton (2012)).

Figure 1 depicts the entry of fracking into Oklahoma and the large influx subsequent to 2005. It shows how the number of Underground Injection Control wells (UIC), which fracking wells are classified as, increased exponentially after 2005.[21] *Figure 2* shows the number of oil and gas wells in Oklahoma that were active prior to fracking, and active as of the end of 2015; the massive post-2005 increase in the number of wells is apparent. 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 Figures 1 and 2 Here]

[20] 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 and gas 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 accommodates any small differences in entry timing between counties; moreover any such differences will bias me *against* finding an effect.

[21] 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.

3.3 Regression Specification

More specifically, I run the following main regression specification at the county level:

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

Regression (1) is estimated over 2000 to 2010, and i indexes counties and t indexes years.[22] $Y_{i,t}$ is the outcome variable of interest, which includes land purchases in area i at time t, production and productivity measures, the value of farmland, and other outcomes. $Farm\,Minerals_i$ is a continuous variable which estimates the proportion of agricultural landowners in county i which own mineral rights.[23] This mineral rights ownership is inferred through the mean percentage of farmers in each county that signed mineral leases (and therefore both own mineral rights and have oil/gas underneath their land).[24] $Farm\,Minerals_i$ thus serves to measure each county's exposure to the treatment, with a higher value indicating greater treatment intensity when fracking arrives. To make the counties more comparable, I exclude counties that have little oil/gas potential underground (fewer than 20 discovered fields, corresponding to the bottom 20th percentile of the sample), although the results are robust to including these counties.

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

[23]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.

[24]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/gas 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) or just in the post-fracking period (i.e. using realized fracking leases). 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.

$Fracking\,Entry_t$ 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/gas-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.[25]

A potential concern with this specification is the effect of spatial correlation—counties that are closer to each other geographically may have correlated outcomes, perhaps due to clustering of mineral rights ownership or other characteristics. This may bias the standard errors in regression (1). To account for this concern, in addition to robust standard errors clustered by county, I also include coefficient estimates with standard errors corrected for spatial correlation, as well as autocorrelation, following Conley (1999, 2010).[26]

For robustness and to provide further evidence of the effects, I also estimate a version of (1) at the farm-year level using farm micro data where possible. In these specifications, I exploit the heterogenous timing of when individual farmers signed fracking leases to construct a treatment variable, $Fracking\,Mineral\,Lease_{f,t}$, that takes a value of 1 if a farmer f signed a fracking mineral lease in year t or prior, and 0 otherwise. I then run the following regression

[25] These include log county population, amount of cropland, total farm income, farm production expenses, and government subsidy receipts. A concern is that there may be differential fracking growth options in counties, which may cause unobserved heterogeneity if it affects mineral rights payments. I therefore control for this by including the log of the total number of shale wells drilled in each county up to year t, following Gilje (2019). I thank an anonymous referee for this suggestion.

[26] 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. 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).

specification at the farm level:

$$Y_{f,t} \;=\; \beta_0 + \beta_1 Fracking\,Mineral\,Lease_{f,t} + \theta_f + \eta_t + \varepsilon_{i,t}. \tag{2}$$

Equation (2) includes year fixed effects η_t as well as farm fixed effects θ_f; in the most stringent specifications, county-by-year fixed effects are also included in order to compare farmers within counties during the same period.[27]

3.4 Dataset Construction

I construct a novel dataset of agricultural outcomes for Oklahoma counties from many sources. I first identify farm landowners using data taken from County Assessor offices in Oklahoma.[28] 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, over the period 1995 to 2010. This enables me to identify individual farmers who own land, when they purchased their land, and the price each paid. The overall dataset contains information for 25,738 individual farmers.[29] I also obtain this information for non-farm vacant (undeveloped) landholders.

I next obtain Oil, Gas, and Mineral Lease data from County Courthouse records for each Oklahoma county for the period 1990-2014.[30] These data include the identity of each person

[27]Standard errors are clustered at the farm level as well as the county level, in order to adjust for the spatial correlation concern previously mentioned. The results for the farm level regressions are also robust to defining the treatment variable in a parallel way to the county-level regressions, i.e. as a dummy variable which is 1 if a farmer owns mineral rights (i.e. has signed a mineral lease prior to the arrival of fracking), and 0 otherwise. These results are available upon request.

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

[29]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 farms for which the owners are located out-of-state as well as corporate farms—which are more likely to have access to broader capital markets. In line with this, in *Table C3* of the Appendix, I find that corporate farms do not respond to liquidity windfalls in terms of land purchasing behavior.

[30]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.

who signs a mineral lease (and thus owns mineral rights to a plot of land) in each year and each county. By merging these data with the data on farm landowners, I 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 surface and mineral land rights.

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. These data allow me 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.[31]

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). 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.[32] 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. For an additional control variable, I obtain data from the Oklahoma Geological Survey via the University of Oklahoma, which gives information on all horizontal wells drilled in a county in a given year. To examine investment behavior, I use data on farm machinery purchases by farmers via EDA from 1995 to 2010.

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. The land values in this dataset are calculated on a per-acre basis from cleaned land sales data. In order to

[31]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.

[32]These include sales receipts, expenditures for farming inputs (livestock, seed, feed, and fertilizer purchases), government payments, and other production expenditures. These other production expenditures include repair and machinery operation costs, depreciation, interest, rent, taxes, and other miscellaneous expenses including animal health costs and agricultural chemicals.

construct land value estimates at the zip code level, I supplement this data with individual transaction-level land prices from the Oklahoma County Assessor, which contain information on acreage, sale price, sales date, and buyer/seller information for each plot of land.

Finally, I also obtain a measure of the oil/gas potential of the different counties from the Oklahoma Corporation Commission. These data contain 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 low-potential counties, leaving a total of 60 (out of an original 77) counties in Oklahoma for the data items described above.

3.5 Summary Statistics

[Insert Table 1 Here]

Table 1 presents summary statistics for the main variables. For the average county in a given year, about 32% of farmers had signed mineral leases to their land, indicating mineral rights ownership. 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.[33] The average price of farmland is roughly $1,090 per acre over the sample period, so lease payments of a few thousand dollars per acre can enable the purchase of 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, varies considerably across counties—ranging from 25 bushels/acre in the 25th percentile to 35.5 bushels/acre in the 75th percentile.

[33] *Figure C3* of the Appendix shows a map of mineral ownership across counties according to this measure, underscoring this heterogeneity as well as geographic dispersion.

A potential concern is that the treatment (i.e. measure of mineral ownership) is not randomly assigned, but is correlated with some other attributes. While the validity of the diff-in-diff methodology rests upon the parallel trends assumption (verified later), a correlation between the treatment and other attributes may confound the interpretation of the results. To investigate this, *Table 2* examines differences in the observable characteristics of counties with high and low farm mineral ownership in the pre-period, by running cross-sectional regressions of county characteristics (averaged from 2000 to 2004) on the measure of farm mineral ownership.[34]

[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 these 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.[35] 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, and find they are not. Overall, these tests suggest that the treatment assignment is not correlated with observable characteristics, and that the fracking shock is an exogenous liquidity event.

4 Empirical Results

This section contains the main empirical results. I show that counties where farmers receive cash inflows from signing mineral leases for fracking subsequently purchase more land relative

[34] *Table C4* in the Appendix provides the correlation matrix between these variables in the pre-period.

[35] 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.

to other counties. I show that this drives a reallocation of land from less-efficient to more-efficient users, and productivity, farmland prices, and farm equipment purchases all increase.

4.1 Purchasing Behavior by Farmers

Signing a fracking lease generates a large upfront cash payment that relaxes the farmer's cash constraints, permitting a farmland purchase. *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, a crucial assumption in diff-in-diff analyses. This is the total amount of land purchased by farmers residing in the county, and includes both land purchased within the county as well as land purchased in other counties. In the following section, I break down these purchases by type. The top graph compares the total acreage purchased by farmers in counties above the 50th percentile of farm mineral rights ownership 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 pre-fracking parallel trends. The bottom graph shows the differences between the two groups, including trend lines for the pre- and post-fracking periods.

The purchasing behaviors of counties in the top and bottom halves of mineral rights ownership exhibit a slight upward trend during 1995-2004, but the differences between them are insignificant (as shown below). In the years immediately before 2005, this visual trend also flattens, suggesting that the parallel trends assumption holds. Panel A of *Table 3* statistically confirms this by examining the pre-period growth rates of each group, and testing if they differ significantly. For both the sample pre-period 2000-2004 and the extended pre-period 1995-2004, 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 differences exhibiting a strong increasing trend.

[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). Thus, 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. Interpreting the coefficients shows that farmers in counties with a ten percentage point higher proportion of farm mineral ownership engaged in roughly 3.6% more purchases, on average, post-fracking than farmers in counties with low mineral ownership. Moving from a county at the 25th percentile of mineral ownership to a county at the 75th percentile of mineral ownership implies 18% higher aggregate acres purchased.

Columns (3) and (4) show the results at the individual farm level. The results are consistent with the county-level results, showing that farmers that signed fracking mineral leases increased their purchases of land relative to other farmers.[36] Furthermore, including county-by-year fixed effects in the farm-level specifications allows me to exploit variation in leases across farmers *within* the same county and year. This controls for a variety of potentially confounding effects, such as possible changes in local economic conditions induced by the arrival of fracking; later I provide additional tests to rule out these alternative channels. Overall, these results are consistent with farmers using their cash payments to invest in more farmland, and furthermore demonstrate that the aggregate results documented at the county level translate into average purchasing behavior at the farm level, which may not be the case in all settings (e.g. Garrett (2003)).

[36]The results are also robust to running the regression as a linear probability specification, which examines the overall propensity to purchase land.

4.2 Reallocation Effects

I now examine more closely this purchasing behavior by farmers, and provide evidence that it induces 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.

4.2.1 Cross-area Purchases by Farmers in High- and Low-Yield Counties

I first examine purchases of land between farmers both across and within counties. In particular, I explore *cross-county* purchases of farmland in low-productivity counties by farmers residing in either high- or low-productivity counties.[37]

I examine cross-county purchases by running the following county-level regression:

$$\log\left(1 + Farmland\,Acres\,Purchased\,in\,j \mid j \in \{LP\}, i \in \{HP, LP\}\right)_{i,t}$$
$$= \beta_0 + \beta_1 \left(Farm\,Minerals_i \times Fracking\,Entry_t\right) + \theta \left(Controls\right)_{i,t} + \gamma_i + \eta_t + \varepsilon_{i,t}. \qquad (3)$$

In (3), the dependent variable is the total acres of farmland purchased in county j by farmers residing in county i, where j is a low-productivity (LP) county and $i \neq j$. A county is defined as high- (low-) productivity if its average yield prior to the arrival of fracking is above (below) the median across all counties.[38] Equation (3) is run separately conditional on i being either high productivity (HP) or low productivity (LP); I also run a joint specification that interacts a county-level high-productivity dummy with the treatment variables. All other variables and fixed effects are as defined in (1). I next explore purchases at the farm-level with the

[37] At the county level, the majority of purchases by farmers are within the same county. Nonetheless, these cross-county purchases in low productivity counties still make up a significant proportion of total land purchases by farmers. In my sample at the county level, the median proportion of total purchases that were made up of purchases in other counties was 25.3%. High- and low-yield counties are dispersed throughout the state, and do not all cluster with each other, as indicated by *Figure C4* of the Appendix.

[38] 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.

following specification:

$$\log\left(1 + Farmland\,Acres\,Purchased\,in\,j \mid j \in \{LP\}, i \in \{HP, LP\}\right)_{f,i,t}$$
$$= \beta_0 + \beta_1\left(Fracking\,Mineral\,Lease_{f,t}\right) + \mathbf{\Gamma}_{f,i,t} + \varepsilon_{i,t}. \tag{4}$$

In (4), f indexes individual farms, and i and j are defined at the county level. The dependent variable is the amount of farmland purchased in area j by farmer f residing in area i. $\mathbf{\Gamma}_{f,i,t}$ represents a vector of farm and year or county-by-year fixed effects. If the reallocation channel holds, all the diff-in-diff estimators should be positive and significant for high-yield areas ($i \in \{HP\}$), but not for low-yield areas ($i \in \{LP\}$).

Table 4 provides the regression results for the cross-county purchases. Columns (1)-(4) show results conditional on low-yield counties and show that, at both the county-year and farm-year levels, 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) and (6), at the county level farmers in high-yield counties significantly increase their purchases of farmland in low-yield counties when they receive cash windfalls. The magnitude of the effect is large, implying that a high-yield county at the 25th percentile of mineral ownership will increase its cross-county purchases of low-yield land by roughly 98% compared to a high-yield county at the 75th percentile of mineral ownership. Columns (7) and (8) examine cross-county purchases in low-yield counties at the farm level, and the results are broadly consistent—farmers residing in high-yield counties significantly increase their purchases of land from farmers in low-yield counties after receiving fracking windfalls (column (7)); the results when controlling for county-by-year fixed effects are similar but marginally insignificant (p-value of 0.13).

Column (9) statistically tests the difference between the effects in low- and high-yield counties at the county level by running a triple-differences specification—interacting a dummy variable for whether county i is a high-yield county with the diff-in-diff estimator. Column

(10) does the same to statistically test the difference between coefficients at the farm level. The interaction effects are positive and significant, indicating that the differences between the high- and low-yield counties are significant. Overall, these results indicate 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.[39]

[Insert Table 4 Here]

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. The estimates are provided in *Table 5.* 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. In fact, the negative coefficients suggest, if anything, farmers are *less* likely to purchase farmland from high-yield counties, which is in line with the prediction of the theory, that farmers are reacting in an efficient manner to the liquidity windfall[40]

[Insert Table 5 Here]

As a robustness check, in *Table B5* of Appendix B, I provide farm-level regressions for (4) exploring farmland purchases in low-yield zip codes by farmers in other high- or low-yield zip codes.[41] The results are broadly consistent with those in *Table 4*, and provide additional

[39]One reason for this effect may be because low-yield farmers see a large increase in cash they could get from selling land, and deduce that the price they could receive from selling the land is higher than the present value of the cash flows they would get from keeping the land. Alternatively, low-yield farmers were not willing to sell previously (because they relied on farming for a living), but now are willing to let go of their low-yielding asset after receiving the windfall.

[40]The theory model predicts that there are gains from trade for high-yield farmers to purchase from low-yield farmers, but not vice versa. The point estimates suggest that farmers cut their aggregate purchases of cross-county high-yield farmland by about half when going from the 25th to 75th percentile of mineral ownership, although the point estimates are not significant.

[41]Specifically, in line with the procedure at the county level, I first calculate average farm yields at the

evidence suggesting a reallocation high- and low-productivity farmers both across counties and within counties.[42]

Overall, these findings are consistent with a reallocation of farmland from less-efficient to more-efficient farmers. A competing hypothesis is that the effects are driven by a distorted-incentives problem, such as empire building (e.g. Jensen (1986)). However, my results suggest that this is not what is going on. First, if distorted incentives were driving the results, then *both* high-yield and low-yield farms with liquidity windfalls would be increasing their purchases, which is not what I find. Second, these purchases are followed by increases in productivity in both high- yield and low-yield counties, but the increase in low-yield counties' exceeds that in high-yield counties, consistent with the farmland being more productive in the hands of the purchasers. Moreover, while the increases in productivity in both high-yield and low-yield counties may reflect relaxation of financial constraints, most purchases are within counties, so the yield increases provide another indication that the reallocation induced by the purchase transactions is productivity enhancing. Collectively, this evidence strongly suggests a reallocation of land that improves productivity.[43]

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

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. 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—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. Nonetheless, the specification using zip code-level yield data shines further light on the within-county purchasing that farmers are engaging in.

[42]In this specification, 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 in low-yield areas relative to other farmers after fracking arrived, whereas similar farmers residing in low-yield areas did not. However, I note that the difference between the coefficients for the low- and high-yield zip code farmers is not statistically difference when running a triple-interaction, owing to the relatively large standard errors for the low-yield group.

[43]Having said this, one cannot rule out the possibility that even though the purchasers are engaging in transactions that boost farm productivity in the aggregate—which is socially beneficial—they may be over-investing in farmland from the standpoint of maximizing their own (private) utility. Ideally, one would calculate the NPV of these investments; however, NPV estimation requires having access to a rational forecast of future cash flows or a stock market reaction that can be interpreted as an assessment of NPV. These data are not available for these privately-owned farms.

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 regressions utilizing zip code-level data 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.

4.2.2 Purchases of Vacant Land

A second channel is a reallocation of land from non-farm users to farmers. More specifically, purchasing farmers primarily demand open land suitable for either crop production or livestock grazing. This includes existing farmland, as well as vacant (undeveloped) land. Purchase of vacant land is a transfer from less-efficient users of the land to more-efficient users, where low productivity is replaced by no productivity—the vacant land, previously not put to any productive use in the hands of an "outside" user, is transferred to an "expert" user (in the Shleifer and Vishny (1992) sense) who extracts higher cash flows from the land. Indeed, since most farmers live in remote or rural areas, farming is often the most efficient use of land that has little alternative commercial applicability.

I examine this channel by exploring purchases by farmers of vacant land within counties. The idea is that, even within counties, such purchases between farmers and vacant land owners constitutes a reallocation of land. *Figure 4* examines total acres of vacant land purchased by farmers from 1995 to 2010. In the 1995-2004 pre-fracking period, the amount of vacant land purchased by farmers in high-farm-mineral-ownership counties runs parallel to the amount of vacant land purchased by farmers in low-farm-mineral-ownership counties.

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 6* 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 34% more than farmers in counties at the 25th percentile of mineral ownership following the arrival of fracking. At the farm level, farmers that signed fracking mineral leases tended to increase their land purchases by 7.2% compared to those that did not. Overall, the results provide additional within-county evidence of a reallocation of land to more productive users.

4.3 Production, Productivity, and Profits

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

An efficient reallocation of assets should be reflected in crop production and productivity. The purchasing behavior documented previously suggests within-county land reallocation from low-productivity farmers and vacant landholders to high-productivity farmers. These within-county transfers imply that counties experiencing *more* of them should also show greater agricultural crop acreage under cultivation, and higher production and productivity.

Figure 5 examines within-county crop production, acres under cultivation, and productivity pre- and post-fracking. I examine these outcomes for wheat, the primary crop in

Oklahoma. Average wheat production for counties in the top and bottom halves of farm mineral ownership follow parallel trends during the pre-fracking 1995-2004 period, with high-farm-mineral-ownership counties exhibiting 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-period.

[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 3.7%—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 fracking arrived. Finally, the diff-in-diff estimator for wheat yields is positive and significant across all specifications. A ten percentage point increase in mineral ownership leads to a 1.6% increase in productivity following the arrival of fracking, which translates into 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.[44]

4.3.2 Crop Profits

These effects on production and productivity should also translate into higher crop profits, a hypothesis that I now examine.[45] 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 5.6% increase in profits on average for counties at the 75th percentile of mineral ownership relative to counties at the 25th percentile.

4.3.3 Dispersion of Productivity

A further implication of the documented reallocation effects is that the cross-sectional *dispersion* of productivity between high- and low-yield areas should decrease once fracking arrives.

[44]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.

[45]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.

The intuition is that land reallocation leads to land being in the hands of more skilled users on average, resulting in smaller productivity differences across farmers. *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 2000). Consistent with efficient reallocation, the spread between the higher- and lower-productivity counties decreases substantially after fracking arrives, with the dispersion narrowing to almost zero by 2007. Column (1) of *Table 8* Panel A in the next section confirms this statistically by showing that counties in the bottom two quartiles of productivity moved significantly closer (increasing by more) in terms of yields to counties in the bottom two quartiles of productivity following the arrival of fracking.

[Insert Figure 6 Here]

4.3.4 Further Evidence of a Reallocation Channel

I now examine whether the results I find could be generated by forces other than the efficient reallocation of resources. For example, the relaxed financial constraints may lead farmers to improve their existing land (e.g. Butler and Cornaggia (2011)). While this mechanism may operate, I now build upon the previous results to provide additional evidence for the reallocation effect.

First, I explore whether the within-county increase in productivity documented in *Table 7* differs across high- and low-productivity counties. I do so by interacting a dummy variable, $Low\,Yield_i$—which takes a value of 1 if county i is below the median in terms of wheat yield prior to the arrival of fracking—with $Fracking\,Entry_t$. The idea is twofold. First, as noted in Section 4.3.2, the reallocation of land implies an increase in the fraction of more-productive users, resulting in a smaller cross-sectional difference in productivity. Second, the cross-county purchases documented in Section 4.2.1 provided evidence that farmers residing in high-yield counties increased their purchases of farmland in low-yield counties. Therefore, with more land in low-yield counties now in the hands of high-yield farmers, the low-yield counties should experience a greater increase in productivity than high-yield counties. Column (1) of *Table 8* Panel A provides this test, and confirms this to be the case.

[Insert Table 8 Here]

Second, in columns (2)-(3) of *Table 8* Panel A, I explore the differential increase in productivity between high- and low-productivity counties. Both high- and low-productivity counties experienced significant increases in wheat yields (while the coefficient estimate is higher for the low-yield counties, the difference is not statistically significant). Since most land purchases are within-county, the productivity increases in both low-productivity and high-productivity counties are due to land being transferred from low- to high-yield farmers.[46]

Finally, I provide evidence consistent with an efficient reallocation channel by showing the effect of cross-county purchases. In particular, I examine whether the counties that had a relatively greater portion of land acquired by farmers in high-yield counties experienced a greater improvement in productivity and profits, which would be consistent with those high-productivity acquiring farmers subsequently improving outcomes on the land they acquired. To do so, I construct a dummy variable, $High\, Purchases\, by\, HY_i$, that takes a value of 1 if county i had an above-median proportion of post-fracking farmland purchases that were made by farmers residing in high-yield counties, and 0 otherwise. I then interact this dummy with the diff-in-diff estimator and examine wheat yields and profits as outcome variables. The results are provided in Panel B of *Table 8*, and confirm that the counties that experienced more purchases by high-yield farmers had relatively greater improvements in yields and profits.

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

[46] In untabulated results, I find that the effect for wheat production, acres under cultivation, and profits is positive and significant for high-yield counties, but not for low-yield counties. These results are also consistent with most of the purchases by high-yield farmers being within-county. This also indicates that within the most productive counties, the high-yield farmers choose to expand their operations (such as by turning vacant land into new farmland, expanding production), in line with the previous results in *Table 4* that farmers in low-yield counties did not increase their purchases in other areas. Furthermore, if farmers were increasing their activities due to empire building or primarily making improvements upon their existing land with the cash windfalls, we would observe significant effects in the low-yield counties as well.

of assets following the relaxation of financial constraints.

4.4 Effect on Land Prices

I now explore how the fracking-related liquidity shock affects asset prices, by estimating regression (1) using county farmland values as the dependent variable. Farmland values are measured as the dollar price per acre of farmland, a standard scaling to 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* provides graphical evidence of the effect. During 2000-2004, the counties above and below the median of farm mineral ownership move in parallel, with a slight (insignificant) downward trend in differences. 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 9* 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 9 Here]

Panel B of *Table 9* provides the regression results for (1). The diff-in-diff estimator is positive and highly significant across all specifications (columns (1) to (3)). The magnitudes indicate that the farmland prices of counties with a ten percentage point higher farm mineral ownership increased on average by 2.4% more post-fracking than land prices in other counties (the more localized estimate of relative increase at the zip code level is 3.7%). This implies a post-fracking price increase of 12.2% when going from counties at the 25th percentile of farm mineral ownership to counties at the 75th percentile. Furthermore, columns (4) and (5) split the sample between high- and low-productivity zip codes—the increase in land values is significant for low-productivity zip codes, but not for high-productivity zip codes. This is consistent with higher-productivity farmers purchasing land in lower-productivity areas—as shown by the evidence in Section 4.2.1—thus raising prices in these areas. However, these results based on the productivity split should only be taken as suggestive, as the difference between the coefficients is insignificant.

These price effects are consistent with relaxed financial constraints leading to efficiency-enhancing land reallocation, with the land purchasers being able to generate higher cash flows. Since the market for farmland is localized, and local farmers have the best expertise on local growing conditions and a network of productivity-enhancing local relationships. Thus, farmland value is highest with the most efficient local users. Once these users are able to buy the land, prices increase to reflect this, specifically where the more-efficient users are buying. And given 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. This is also consistent with a "cash-in-the-market" pricing effect (Allen and Gale (1994)), as well as the underlying mechanism of fire sales (Shleifer and Vishny (2011)).[47]

4.5 Other Investment: Farm Equipment

A liquidity windfall should also permit farmers to purchase farm machinery in addition to acquiring more farmland. *Figure 8* graphs new farm equipment purchases for counties in the top quartile of farm mineral rights ownership compared to those in the bottom quartile, around the arrival of fracking. 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, but panel A of *Table 10* shows that the pre-period growth rates of the two groups are not statistically different. Following the arrival of fracking,

[47]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.

the purchases of farmers in the high-farm-mineral-ownership counties increased significantly relative to those in the low-farm-mineral-ownership counties.

[Insert Figure 8 Here]

Table 10 provides within-county diff-in-diff regression results that confirm that this difference is significant. The coefficients indicate that counties with a ten percentage point higher farm mineral ownership increased their farm equipment purchases by roughly 1.9% compared to other counties after fracking arrived, implying a 9.5% difference between counties at the 75th versus 25th percentile of farm mineral ownership. These results indicate that farmers whose financial constraints are relaxed invest more in new farm machinery. This is consistent with the scaling effect associated with the previously-documented land purchases—since farmers are expanding their land holdings, more equipment is needed to farm the new land.[48] Another reason for the extra spending on equipment is that these farmers in high-yield counties are also upgrading their farms and improving their capital-labor ratio. However, I find that the farmers in low-yield counties who receive the cash windfall do not significantly increase machinery purchases.[49] This suggests that the previously-documented increase in yields is not due to increased capex by the incumbent low-yield farmers on their existing land. Rather, it is primarily due to the high-yield farmers purchasing the land and subsequently increasing productivity. Additionally, this increase in machinery purchases provides further evidence that the post-fracking increase in productivity results from reallocation and farm upgrades rather than economies of scale, given the documented inverse relationship between farm scale and productivity (e.g. Carletto et al. (2013)).

[Insert Table 10 Here]

[48]In line with this, the equipment purchased includes loaders, tractors, harvesters, planters, and seeders, among other types of equipment.

[49]This is shown in *Table C6* of the Appendix.

4.6 Financial Constraints

As discussed in the theoretical framework in Section 2, farmers respond to fracking liquidity windfalls because they are financially constrained—they lack sufficient internal funds to have made investments before fracking, and faced credit constraints. In this sub-section, I provide some additional evidence of this.

First, in *Table 11* Panel A, I show at the county-level that loan-to-value (LTV) ratios significantly fell for counties that experienced the greatest fracking windfalls. This provides evidence that the fracking shock relieved credit constraints for farmers.[50] Second, in Panel B of *Table 11*, I show that the counties with farmers that had ex ante lower income (and thus were more constrained leading up to the fracking shock) exhibited the greatest response in terms of the main outcome variables.

[Insert Table 11 Here]

5 Robustness

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

5.1 Non-farm Vacant Landholders: Checking for Wealth Effects

An alternative possibility is that the results may be driven by a wealth effect. 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.

Specifically, unlike farmers who are specialized, first-best users of farmland, vacant (non-farm) landholders are simply holding an asset currently not in productive use. Consequently,

[50] LTV is calculated at the county level as the total amount of farm real estate debt divided by the total value of farmland. The data for debt come from the call reports, which requires the assumption that farm loans made by a bank headquartered in a county are primarily extended to farmers in that county.

while a wealth effect would predict that *both* farmers and non-farm vacant landholders will purchase additional land following a cash windfall, a 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. *Table 12* 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 12 Here]

5.2 Falsification Test

Another concern is that the results may be driven by some sort of long-term trend in the relationships between the variables in the counties with higher and lower farm mineral rights ownerships. If so, then the effects on productivity and prices that I document are not unique to the sample period corresponding to the arrival of fracking. 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.[51] This captures the immediate pre-period before the arrival of fracking.

Table 13 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 arrival of fracking around 2005, and not due to some trends over time between the counties.

[51]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.

[Insert Table 13 Here]

6 Conclusion

In a frictionless market, assets within an industry should be allocated to the highest-productivity producers. However, financial constraints generated by financial frictions like adverse selection can cause a misallocation of assets across firms, distorting productivity, output, and asset prices. A positive liquidity shock for some producers can relax their financial constraints, allowing them to increase their investments and reduce misallocation. I examine the effect of such a shock by exploiting a quasi-natural experiment: the arrival of hydraulic fracturing (fracking) to 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 farmland purchases generate a reallocation effect that operates through two channels: (i) a reallocation *between* farmers, whereby liquidity-shocked farmers in high-productivity areas purchase more land from farmers in low-productivity areas, and (ii) a reallocation from *non-farm users* to farmers—liquidity-shocked farmers increase their purchases of vacant (undeveloped) land. Both channels imply 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, the price of farmland increases in these areas, concentrated in the areas with high-productivity purchasers, 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. Numerous alternative channels that may drive the results are ruled out. 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 has broader implications for economic growth. While focusing on agriculture permits a clean empirical test, I note that my results have external validity beyond just the agricultural sector. Farms are small firms, each with business operations analogous to other “traditional” firms. Indeed, U.S. farmers have characteristics that allow generalizability to other small (privately-held) family businesses (or households), such as productivity differences between expert and non-expert users, the need to raise external financing principally by borrowing, and cross-sectional heterogeneity in productivity as well as financial constraints.

References

[1] Adamopoulos, Tasso, and Diego Restuccia. "The size distribution of farms and international productivity differences." *American Economic Review* 104, no. 6 (2014): 1667-97.

[2] Agarwal, Sumit, Chunlin Liu, and Nicholas S. Souleles. "The reaction of consumer spending and debt to tax rebates—evidence from consumer credit data." *Journal of Political Economy* 115, no. 6 (2007): 986-1019.

[3] Agarwal, Sumit, and Wenlan Qian. "Consumption and debt response to unanticipated income shocks: Evidence from a natural experiment in singapore." *American Economic Review* 104, no. 12 (2014): 4205-30.

[4] Allcott, Hunt, and Daniel Keniston. "Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America." *The Review of Economic Studies* 85, no. 2 (2017): 695-731.

[5] Allen, Franklin, and Douglas Gale. "Limited Market Participation and Volatility of Asset Prices." *American Economic Review* 84, no. 4 (1994): 933-955.

[6] Allen, Franklin, and Douglas Gale. "From Cash-In-The-Market Pricing To Financial Fragility." *Journal of the European Economic Association* 3, no. 2-3 (2005): 535-546.

[7] Almeida, Heitor, and Daniel Wolfenzon. "The effect of external finance on the equilibrium allocation of capital." *Journal of Financial Economics* 75, no. 1 (2005): 133-164.

[8] Andrews, Anthony. *Unconventional gas shales: development, technology, and policy issues*. Diane Publishing, 2010.

[9] Baca, Marie C. "Forced Pooling: When Landowners Can't Say No to Drilling." Propublica (May 18. http://www. propublica. org/article/forced-pooling-when-landownerscant-say-no-to-drilling) (2011).

[10] Bandiera, Oriana, Andrea Prat, Renata Lemos, and Raffaella Sadun. "Managing the Family Firm: Evidence from CEOs at Work." *The Review of Financial Studies*, (2017).

[11] Bartik, Alexander W., Janet Currie, Michael Greenstone, and Christopher R. Knittel. "The local economic and welfare consequences of hydraulic fracturing." (2016).

[12] Berger, Allen N., Anthony Saunders, Joseph M. Scalise, and Gregory F. Udell. "The effects of bank mergers and acquisitions on small business lending1." *Journal of Financial Economics* 50, no. 2 (1998): 187-229.

[13] Berger, Allen N., and Gregory F. Udell. "Small business credit availability and relationship lending: The importance of bank organisational structure." *The Economic Journal* 112, no. 477 (2002).

[14] Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan. "How much should we trust differences-in-differences estimates?." *The Quarterly Journal of Economics* 119, no. 1 (2004): 249-275.

[15] Bertrand, Marianne, Antoinette Schoar, and David Thesmar. "Banking deregulation and industry structure: Evidence from the French banking reforms of 1985." *The Journal of Finance* 62, no. 2 (2007): 597-628.

[16] Besanko, David, and Anjan V. Thakor. "Collateral and rationing: sorting equilibria in monopolistic and competitive credit markets." *International economic review* (1987): 671-689.

[17] Bierlen, Ralph, and Allen M. Featherstone. "Fundamental q, cash flow, and investment: Evidence from farm panel data." *Review of Economics and Statistics* 80, no. 3 (1998): 427-435.

[18] Briggeman, Brian C., Charles A. Towe, and Mitchell J. Morehart. "Credit constraints: their existence, determinants, and implications for US farm and nonfarm sole proprietorships." *American Journal of Agricultural Economics* 91, no. 1 (2009): 275-289.

[19] Brown, Jason P., Timothy Fitzgerald, and Jeremy G. Weber. "Capturing rents from natural resource abundance: Private royalties from US onshore oil & gas production." *Resource and Energy Economics* 46 (2016): 23-38.

[20] Butler, Alexander W., and Jess Cornaggia. "Does access to external finance improve productivity? Evidence from a natural experiment." *Journal of Financial Economics* 99, no. 1 (2011): 184-203.

[21] Campello, Murillo, and Erasmo Giambona. "Real assets and capital structure." *Journal of Financial and Quantitative Analysis* 48, no. 5 (2013): 1333-1370.

[22] Cardott, Brian J. "Woodford Shale: from hydrocarbon source rock to reservoir." In *AAPG Woodford Shale Forum.* Tulsa, OK: American Association of Petroleum Geologists (AAPG), 2013.

[23] Carletto, Calogero, Sara Savastano, and Alberto Zezza. "Fact or artifact: The impact of measurement errors on the farm size–productivity relationship." *Journal of Development Economics* 103, no. C (2013): 254-261.

[24] Conley, Timothy G. "GMM estimation with cross sectional dependence." *Journal of Econometrics* 92, no. 1 (1999): 1-45.

[25] Conley, Timothy G. "Spatial econometrics." In *Microeconometrics*, pp. 303-313. Palgrave Macmillan UK, 2010.

[26] Covert, Thomas. "Experiential and social learning in firms: the case of hydraulic fracturing in the Bakken Shale." Available at SSRN 2481321 (2014).

[27] Driscoll, John C., and Aart C. Kraay. "Consistent covariance matrix estimation with spatially dependent panel data." *The Review of Economics and Statistics* 80, no. 4 (1998): 549-560.

[28] Eubanks, Larry S., and Michael J. Mueller. "An economic analysis of Oklahoma's oil and gas forced pooling law." *Natural Resources Journal* 26, no. 3 (1986): 469-491.

[29] Farre-Mensa, Joan, and Alexander Ljungqvist. "Do measures of financial constraints measure financial constraints?." *Review of Financial Studies* 29, no. 2 (2016): 271-308.

[30] Fazzari, Steven M., Robert G. Hubbard, and Bruce C. Petersen. "Financing Constraints and Corporate Investment." *Brookings Papers on Economic Activity* 1988, no. 1 (1988): 141-195.

[31] Garrett, Thomas A. "Aggregated versus disaggregated data in regression analysis: implications for inference." *Economics Letters* 81, no. 1 (2003): 61-65.

[32] Gilje, Erik P. "Does local access to finance matter? Evidence from US oil and natural gas shale booms." *Management Science* 65, no. 1 (2019): 1-18.

[33] Gilje, Erik P., Elena Loutskina, and Philip E. Strahan. "Exporting liquidity: Branch banking and financial integration." *The Journal of Finance* (2016).

[34] Hart, Oliver, and J. Moore. "A Theory of Debt Based on the Inalienability of Human Capital." *The Quarterly Journal of Economics* 109, no. 4 (1994).

[35] Hart, Oliver, and John Moore. "Debt and Seniority: An Analysis of the Role of Hard Claims in Constraining Management." *The American Economic Review* 85, no. 3 (1995): 567.

[36] Hartarska, Valentina M., and Chi Mai. "Financing Constraints and the Family Farm: How do Families React?." No. 6861. Southern Agricultural Economics Association, 2008.

[37] Hartarska, Valentina, and Dennis Nadolnyak. "Financing Constraints and Access to Credit in a Postcrisis Environment: Evidence from New Farmers in Alabama." *Journal of Agricultural and Applied Economics* 44, no. 04 (2012): 607-621.

[38] Holmström, Bengt, and Jean Tirole. *Inside and outside liquidity*. MIT Press, 2011.

[39] Holmstrom, Bengt, and Jean Tirole. "Financial intermediation, loanable funds, and the real sector." *the Quarterly Journal of Economics* 112, no. 3 (1997): 663-691.

[40] Hsieh, Chang-Tai, and Peter J. Klenow. "Misallocation and Manufacturing TFP in China and India." *The Quarterly Journal of Economics* 124, no. 4 (2009): 1403-1448.

[41] Jayaratne, Jith, and Philip E. Strahan. "The finance-growth nexus: Evidence from bank branch deregulation." *The Quarterly Journal of Economics* 111, no. 3 (1996): 639-670.

[42] Jensen, Michael C. "Agency cost of free cash flow, corporate finance, and takeovers." Corporate Finance, and Takeovers. *American Economic Review* 76, no. 2 (1986).

[43] Krauss, Clifford, and Eric Lipton. "U.S. Inches Toward Goal of Energy Independence". *The New York Times*, March 22, 2012.

[44] Laajaj, Rachid, and Karen Macours. "Measuring skills in developing countries." (2017).

[45] Levinson, Harry. "Conflicts that plague family businesses." *Harvard business review* 49, no. 2 (1971): 90-98.

[46] Lockheed, Marlaine E., Dean T. Jamison, and Lawrence J. Lau. "Farmer education and farm efficiency: A survey." *ETS Research Report Series* 1979, no. 2 (1979).

[47] Maksimovic, Vojislav, and Gordon Phillips. "The Market for Corporate Assets: Who Engages in Mergers and Asset Sales and Are There Efficiency Gains?." *The Journal of Finance* 56, no. 6 (2001): 2019-2065.

[48] Midrigan, Virgiliu, and Daniel Yi Xu. "Finance and misallocation: Evidence from plant-level data." *The American Economic Review* 104, no. 2 (2014): 422-458.

[49] Peek, Joe, and Eric S. Rosengren. "Collateral Damage: Effects of the Japanese Bank Crisis on Real Activity in the United States." *The American Economic Review* 90, no. 1 (2000): 30-45.

[50] Pérignon, Christophe, David Thesmar, and Guillaume Vuillemey. "Wholesale funding dry-ups." *The Journal of Finance* 73, no. 2 (2018): 575-617.

[51] Plosser, Matthew C. "Bank Heterogeneity and Capital Allocation: Evidence from 'Fracking' Shocks." Available at SSRN 2362499 (2014).

[52] Restuccia, Diego, and Richard Rogerson. "Misallocation and productivity." *Review of Economic Dynamics* 16, no. 1 (2013): 1-10.

[53] Schulze, William S., Michael H. Lubatkin, Richard N. Dino, and Ann K. Buchholtz. "Agency relationships in family firms: Theory and evidence." *Organization Science* 12, no. 2 (2001): 99-116.

[54] Shleifer, Andrei, and Robert Vishny. "Fire Sales in Finance and Macroeconomics." *Journal of Economic Perspectives* 25, no. 1 (2011): 29-48.

[55] Turvey, Calum G., and Alfons Weersink. "Credit risk and the demand for agricultural loans." *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 45, no. 3 (1997): 201-217.

[56] Uchida, Hirofumi, Gregory F. Udell, and Nobuyoshi Yamori. "Loan officers and relationship lending to SMEs." *Journal of Financial Intermediation* 21, no. 1 (2012): 97-122.

[57] United States Environmental Protection Agency. "Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources". Office of Research and Development, Washington DC (2015).

[58] Weber, Jeremy, and Claudia Hitaj. "Shale Gas Drilling and Farm Real Estate Values." National Agricultural & Rural Development Policy Center. *Policy Brief* 25, June 2014.

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.

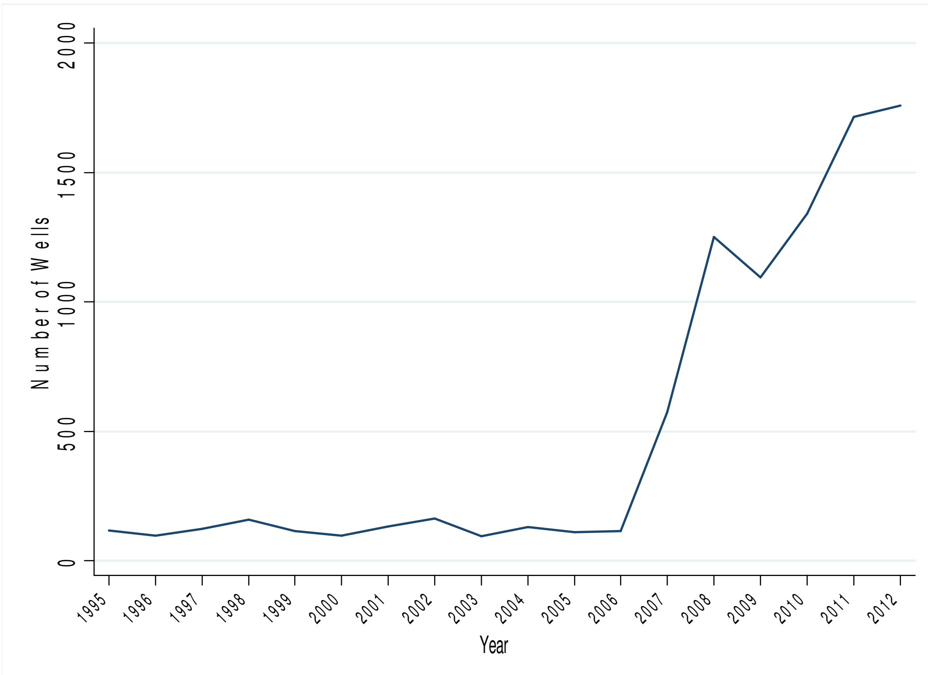
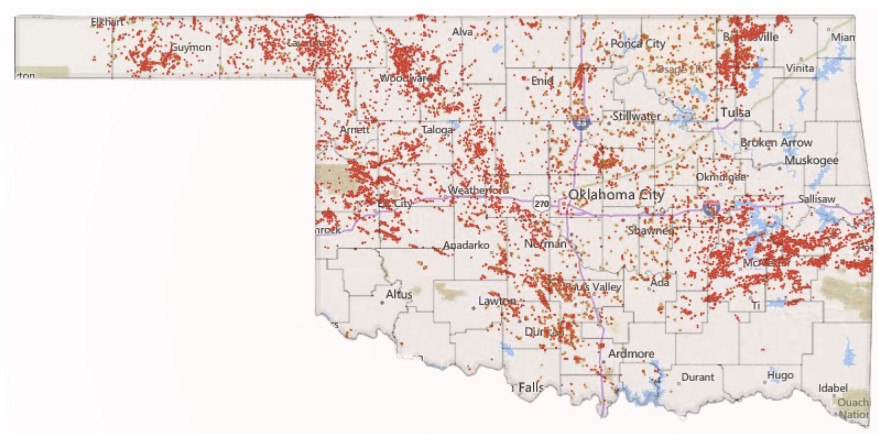


Figure 2: Entry of Fracking into Oklahoma in the 2000s—Active Wells Before and After

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. The white spaces in Panel B are areas where geographically there is less oil potential underneath the ground due to how the shale formations have formed. These counties are excluded from the 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 the sample period), and therefore is reflected in the 2015 map in Panel B.

Panel A: Active Wells During 1995–2004



Panel B: Current Active Wells in 2015

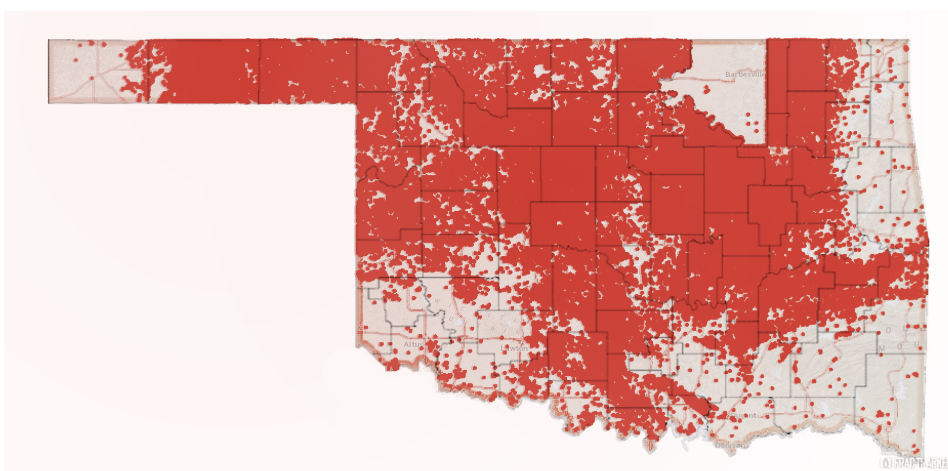


Figure 3: Purchases of Land by Farmers

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/gas potential are excluded.

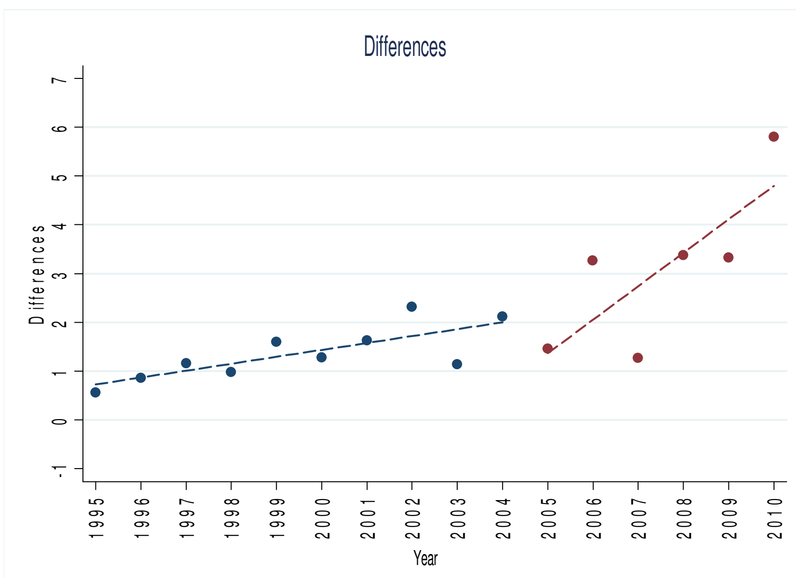


Figure 4: Reallocation of Farmland—Purchases of Vacant Land

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/gas potential are excluded.

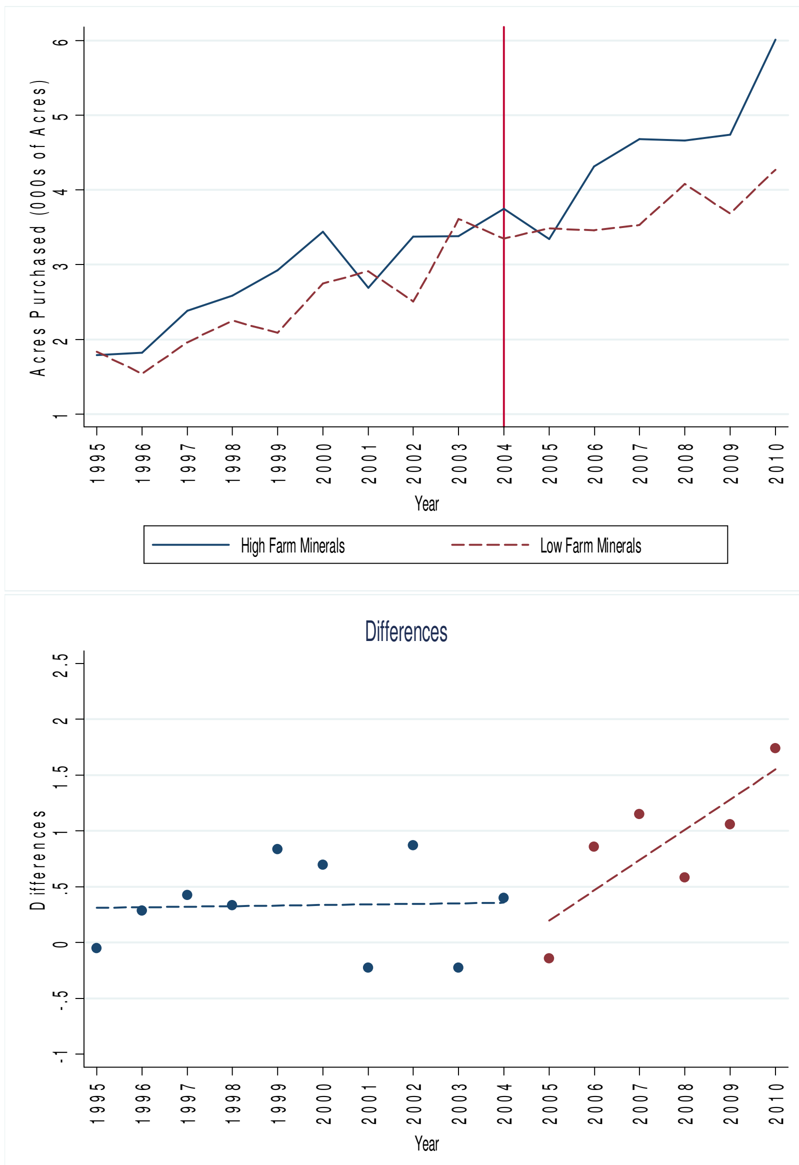


Figure 5: Reallocation—Wheat Production, Wheat Acres Cultivated, and Productivity

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/gas potential are excluded.

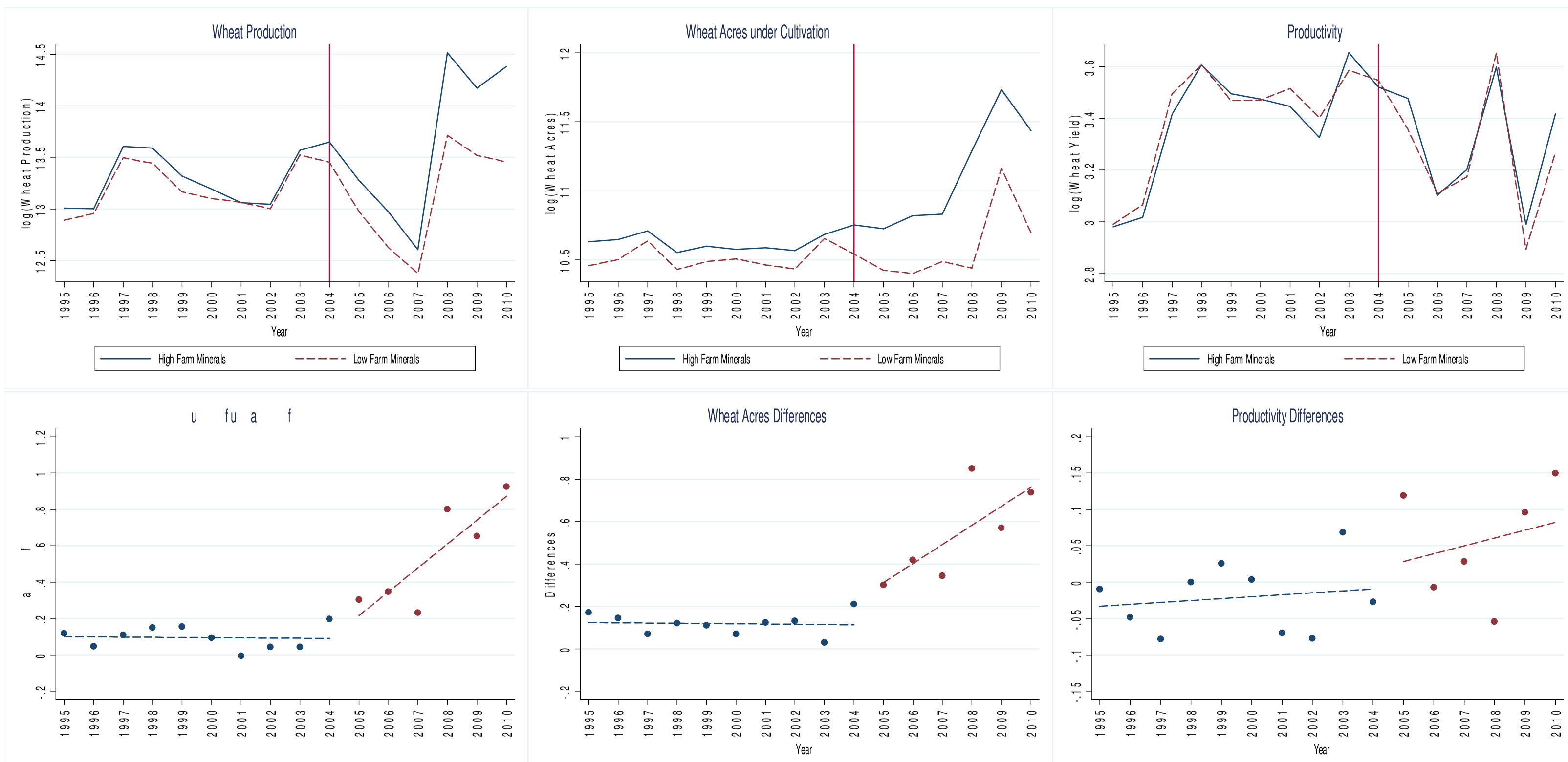
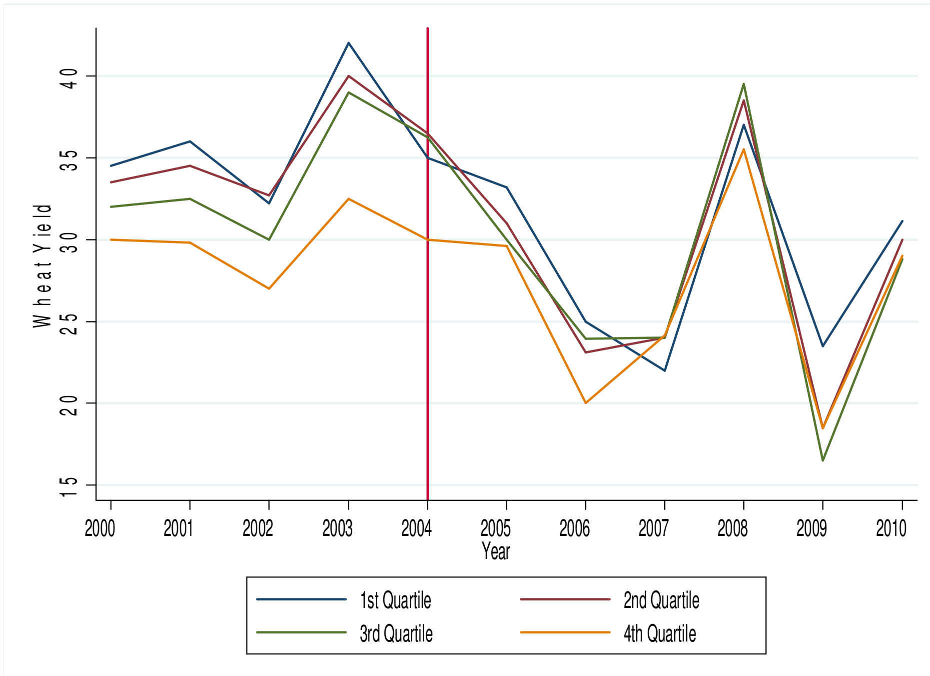


Figure 6: Dispersion of Productivity

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.



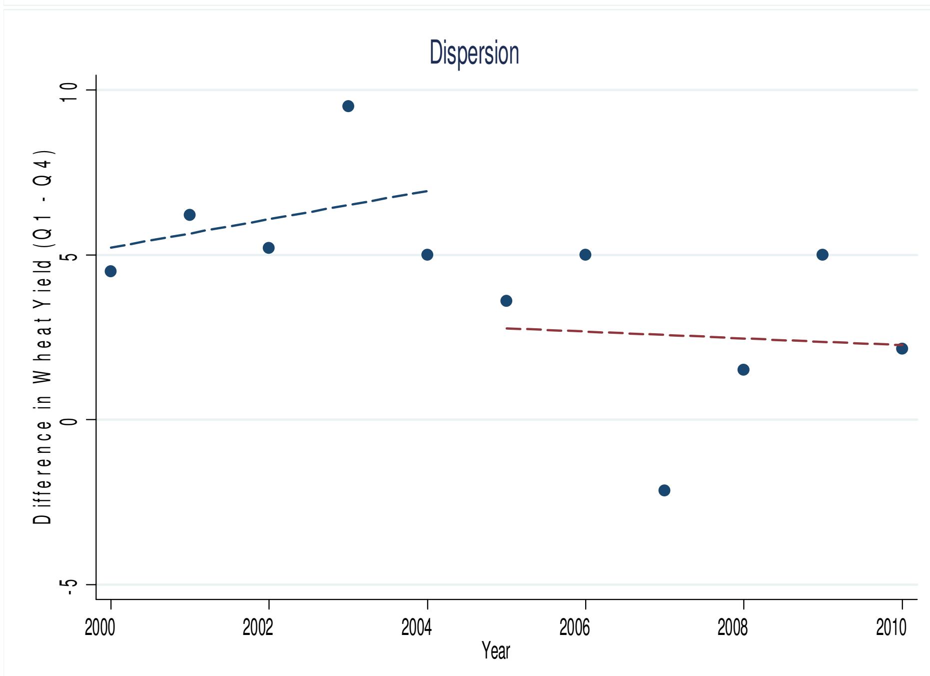


Figure 7: Effect on Farmland Prices

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/gas potential are excluded. Prices are measured as log sales price per acre.

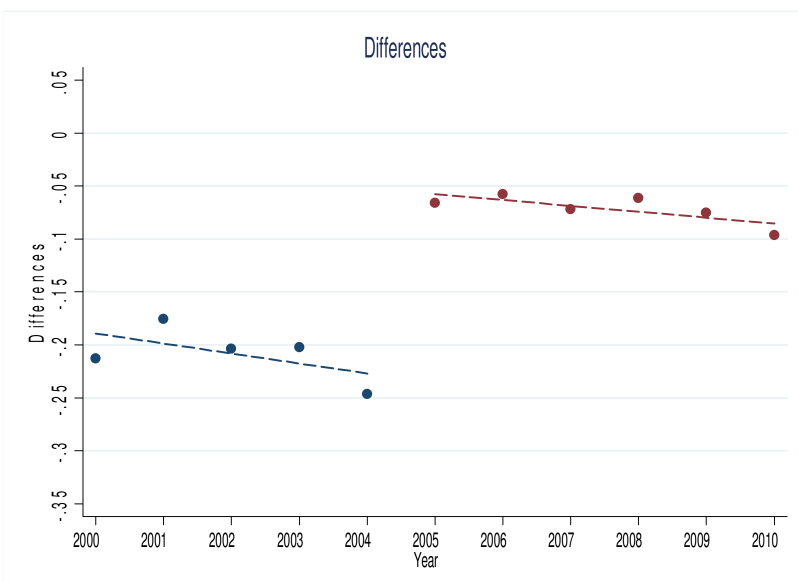


Figure 8: Investment in Farm Machinery

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/gas potential are excluded.

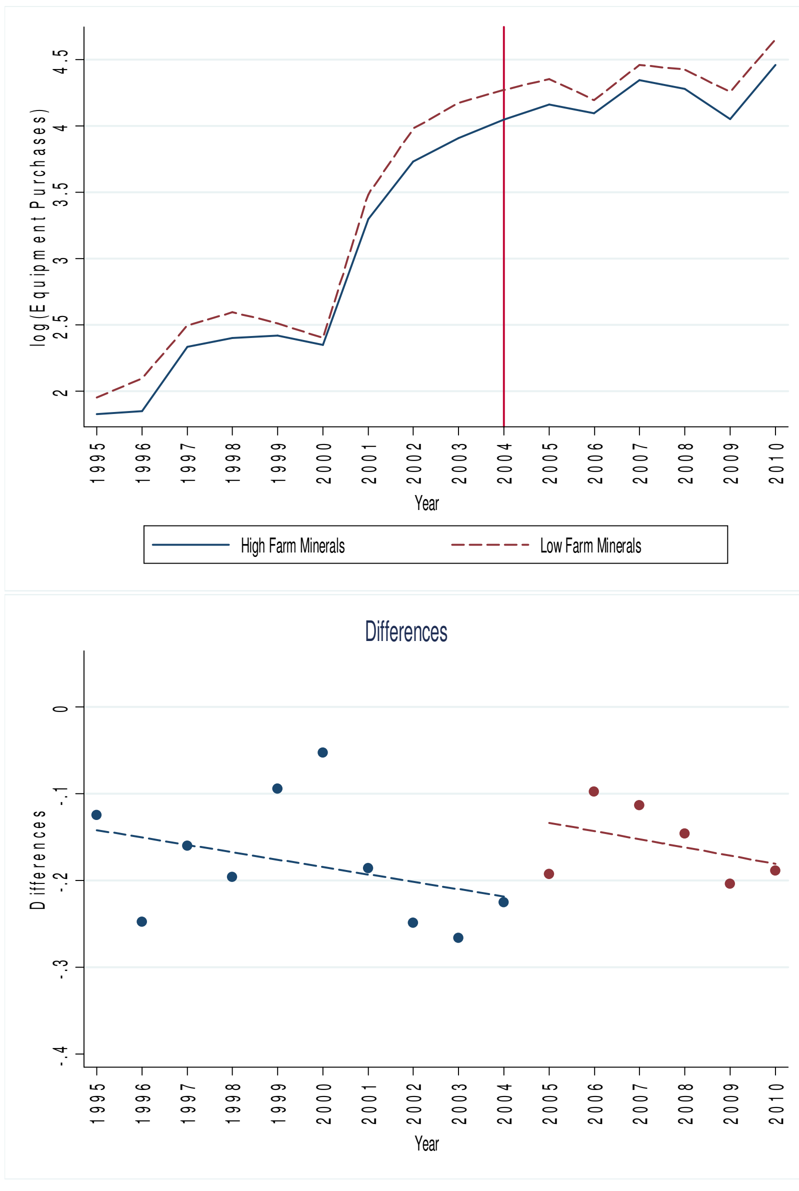


Table 1: Summary Statistics

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. *Farm Minerals* is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. All dependent variables are county-level averages from 2000 to 2004. *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.

Dep Variable:	log(*Cropland Acres*)	log(*Farmland Acres*)	*Govt Payments*	log(*Number Farms*)	log(*Avg Farmsize*)	log(*Wheat Yield*)	log(*Wheat Prod*)	log(1+*Machine Purchase*)	log(*Farmland Price/Acre*)	*Total Income*	*LTV*
$Farm\,Minerals_i$	0.164	0.355	0.002	0.167	−0.058	−0.043	−0.032	−0.471	−0.362	0.056	0.026
	(0.278)	(0.243)	(0.005)	(0.199)	(0.227)	(0.063)	(0.947)	(0.427)	(0.227)	(0.083)	(0.060)
Obs	60	60	60	60	60	60	60	60	60	60	58
R^2	0.005	0.150	0.003	0.013	0.001	0.010	0.000	0.029	0.056	0.007	0.006

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, $Farm\,Minerals_i$ is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. For the farm-level regressions, $Fracking\,Mineral\,Lease_{f,t}$ takes a value of 1 if farmer f has signed a fracking mineral lease in year t or previously, and 0 otherwise. $Fracking\,Entry_t$ 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, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2010, and all regressions exclude counties with low oil/gas 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 and county levels in columns (3)-(4)). *, **, 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)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.363*	0.363**		
	(0.203)	(0.152)		
$Fracking\,Mineral\,Lease_{f,t}$			0.064***	0.066***
			(0.015)	(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	633	633	227,667	227,667
Standard Errors	Robust	Spatial HAC	Robust	Robust
R^2	0.857	0.857	0.223	0.227

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, log population, and the log total number of shale wells drilled in the county. 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/gas 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)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.372*	0.372***	0.265***	0.265***	0.161*	0.161***	0.112*	0.112***
	(0.196)	(0.132)	(0.111)	(0.061)	(0.087)	(0.062)	(0.059)	(0.037)
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	0.577	0.577

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 (Panel A) or farm level (Panel B). The dependent variable is the log total acreage of purchases in other low-yield counties by farmers. For the county-level regressions, $Farm\,Minerals_i$ is a continuous variable which estimates the proportion of farmers in county i who own mineral rights. For the farm-level regressions, $Fracking\,Mineral\,Lease_{f,t}$ takes a value of 1 if farmer f has signed a fracking mineral lease in year t or previously, and 0 otherwise. $Fracking\,Entry_t$ is a dummy variable which takes a value of 1 if the year t is 2005 or later. $High\,Yield$ is a dummy variable that takes a value of 1 if county i has an above-median average yield (defined between 1990 and 2004), and 0 otherwise. In Columns (1) and (2) are run conditionally for counties where the purchasing farmer resides in a county that has a below-median average yield, while columns (3) and (4) 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, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2010, and exclude counties with low oil/gas potential. Standard errors (in parentheses) are clustered at the county level and adjusted for spatial correlation and autocorrelation at the county level following Conley (1999) for the county level regressions, or are clustered at the farm and county levels for the farm level regressions, as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

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

	Low-yield Counties				High-yield Counties				Nested Specification	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$High\,Yield_i \times Farm\,Minerals_i \times Fracking\,Entry_t$									1.909***	
									(0.712)	
$High\,Yield_i \times Fracking\,Mineral\,Lease_{f,t}$										0.009*
										(0.005)
$Farm\,Minerals_i \times Fracking\,Entry_t$	−0.691	−0.691			1.936***	1.936***			−0.237	
	(1.199)	(0.615)			(0.588)	(0.620)			(0.576)	
$Fracking\,Mineral\,Lease_{f,t}$			−0.005	−0.003			0.007*	0.005		−0.003
			(0.004)	(0.004)			(0.004)	(0.003)		(0.004)
$High\,Yield_i \times Fracking\,Entry_t$									−0.932**	
									(0.372)	
Level of Analysis	County	County	Farm	Farm	County	County	Farm	Farm	County	Farm
Controls	Yes	Yes			Yes	Yes			Yes	
Year Fixed Effects	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
County Fixed Effects	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No
Farm Fixed Effects			Yes	Yes			Yes	Yes		Yes
County×Year Fixed Effects			No	Yes			No	Yes		Yes
Observations	171	171	85,452	85,452	147	147	142,290	142,290	318	227,742
Standard Errors	Robust	Spatial HAC	Robust	Robust	Robust	Spatial HAC	Robust	Robust	Spatial HAC	Robust
R^2	0.464	0.464	0.108	0.114	0.658	0.658	0.117	0.122	0.528	0.113

Table 5: Reallocation Placebo—Purchases of Land in High Productivity Counties

This table presents the total amount of cross-county farmland purchases in low-productivity counties. Regressions are run at the county level (Panel A) or farm level (Panel B). The dependent variable is the log total acreage of purchases in other low-yield counties by farmers. For the county-level regressions, $Farm\,Minerals_i$ is a continuous variable which estimates the proportion of farmers in county i who own mineral rights. For the farm-level regressions, $Fracking\,Mineral\,Lease_{f,t}$ takes a value of 1 if farmer f has signed a fracking mineral lease in year t or previously, and 0 otherwise. $Fracking\,Entry_t$ is a dummy variable which takes a value of 1 if the year t is 2005 or later. $High\,Yield$ is a dummy variable that takes a value of 1 if county i has an above-median average yield (defined between 1990 and 2004), and 0 otherwise. In Columns (1) and (2) are run conditionally for counties where the purchasing farmer resides in a county that has a below-median average yield, while columns (3) and (4) 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, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2010, and exclude counties with low oil/gas potential. Standard errors (in parentheses) are clustered at the county level and adjusted for spatial correlation and autocorrelation at the county level following Conley (1999) for the county level regressions, or are clustered at the farm and county levels for the farm level regressions, as indicated. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

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

	Low-yield Counties				High-yield Counties				Nested Specification	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$High\,Yield_i \times Farm\,Minerals_i \times Fracking\,Entry_t$									−0.145	
									(1.072)	
$High\,Yield_i \times Fracking\,Mineral\,Lease_{f,t}$										−0.004
										(0.005)
$Farm\,Minerals_i \times Fracking\,Entry_t$	−0.935	−0.935			−1.291	−1.291			−1.035	
	(1.129)	(0.799)			(1.004)	(0.780)			(0.681)	
$Fracking\,Mineral\,Lease_{f,t}$			0.0004	0.004			−0.001	−0.001		0.004
			(0.005)	(0.004)			(0.0034)	(0.003)		(0.004)
$High\,Yield_i \times Fracking\,Entry_t$									−0.004	
									(0.933)	
Level of Analysis	County	County	Farm	Farm	County	County	Farm	Farm	County	Farm
Controls	Yes	Yes			Yes	Yes			Yes	
Year Fixed Effects	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
County Fixed Effects	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No
Farm Fixed Effects			Yes	Yes			Yes	Yes		Yes
County×Year Fixed Effects			No	Yes			No	Yes		No
Observations	193	193	85,452	85,452	201	201	142,290	142,290	394	227,742
Standard Errors	Robust	Spatial HAC	Robust	Robust	Robust	Spatial HAC	Robust	Robust	Spatial HAC	Robust
R^2	0.552	0.581	0.108	0.112	0.552	0.552	0.119	0.123	0.555	0.113

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, $Fracking\,Mineral\,Lease_{f,t}$ takes a value of 1 if farmer f has signed a fracking mineral lease in year t or previously, 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, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2010, and all regressions exclude counties with low oil/gas 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 county and farm levels 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)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.683***	0.683***		
	(0.222)	(0.165)		
$Fracking\,Mineral\,Lease_{f,t}$			0.070***	0.072***
			(0.012)	(0.011)
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 8: Reallocation Effects

This table provides the estimation results providing evidence of reallocation effects. Panel A examines the effect on crop productivity, split by high- or low-productivity counties. Column (1) examines whether wheat yields increased more in high- or low-yield counties, while columns (2) and (3) split by productivity. Panel B examines whether the improvement in productivity and profits are stronger for counties that experienced more land purchases from farmers in high-yield counties. $Wheat\,Yield$ is wheat growing productivity, defined as wheat production per acre harvested (measured in bushels per acre). $Low\,Yield$ is a dummy variable that takes a value of 1 if a county is below-median average yield (defined between 1990 and 2004), and zero otherwise. $High\,Purchases\,by\,HY$ is a dummy variable that takes a value of 1 if the county is above-median in terms of the proportion of post-fracking land purchases that were made by farmers in other high-yield counties, and 0otherwise. $Farm\,Minerals$ 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, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2010 in Panel A and column (1) of Panel B, and are run from 1997 to 2012 in column (2) of Panel B. Regressions exclude counties with no oil/gas potential. Standard errors (in parentheses) are adjusted for spatial correlation and autocorrelation at the county-level following Conley (1999). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A: Productivity, High- vs. Low-productivity

Dependent Variable: $\log(Wheat\,Yield)$

Pre-period Yield:		High Yield	Low Yield
	(1)	(2)	(3)
$Low\,Yield_i \times Fracking\,Entry_t$	0.093***		
	(0.034)		
$Farm\,Minerals_i \times Fracking\,Entry_t$		0.126**	0.183*
		(0.060)	(0.098)
Controls	Y	Y	Y
County Fixed Effects	Y	Y	Y
Year Fixed Effects	Y	Y	Y
Observations	559	287	272
R^2	0.623	0.708	0.593

Panel B: Proportion of Land Purchased by High-Yield Farmers

Dependent Variable:	$\log(Wheat\,Yield)$	$Profits$
	(1)	(2)
$High\,Purchases\,by\,HY_i \times Farm\,Minerals_i \times Fracking\,Entry_t$	0.141***	0.107**
	(0.046)	(0.047)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.064	−0.003
	(0.060)	(0.023)
$High\,Purchases\,by\,HY_i \times Fracking\,Entry_t$	−0.092**	−0.047**
	(0.042)	(0.020)
Controls	Y	Y
County Fixed Effects	Y	Y
Year Fixed Effects	Y	Y
Observations	559	239
R^2	0.623	0.689

Table 9: 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, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2010, and exclude counties with low oil/gas potential. Standard errors (in parentheses) are clustered at the county level or zip code 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($Farmland\,Price/Acre$)

				Low-yield Zip Codes	High-yield Zip Codes
	(1)	(2)	(3)	(4)	(5)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.243***	0.243***	0.373***	0.205**	0.311
	(0.080)	(0.042)	(0.158)	(0.094)	(0.232)
Level of Analysis	County	County	Zip Code	Zip Code	Zip Code
Controls	Yes	Yes			
County Fixed Effects	Yes	Yes	No	No	No
Zip Code Fixed Effects			Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	No	No	No
County×Year Fixed Effects			Yes	Yes	Yes
Observations	642	642	1,842	671	1,041
Standard Errors	Robust	Spatial HAC	Robust	Robust	Robust
R^2	0.881	0.881	0.652	0.628	0.617

Table 10: 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/gas 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 11: Financial Constraints

This table provides regression estimates related to financial constraints. Panel A provides regressions using loan-to-value as the dependent variable, while Panel B provides evidence on heterogeneous effects based on pre-fracking income. LTV is loan-to-value, calculated as the total amount of farm real estate debt divided by the total value of farmland. $Farm\,Minerals$ 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. $Low\,Income$ takes a value of 1 if the county has below-median net farm income (measured from 1990 to 2004), and 0 if it is above-median. $Acres\,Purchased$ 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. Control variables include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2010, and exclude counties with low oil/gas potential. Standard errors (in parentheses) are 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: Effect on LTV

Dependent Variable: LTV

	(1)	(2)
$Farm\,Minerals_i \times Fracking\,Entry_t$	−0.044***	−0.044***
	(0.014)	(0.014)
Controls	Yes	Yes
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Observations	617	617
Standard Errors	Robust	Spatial HAC
R^2	0.872	0.872

Panel B: Heterogeneity of Effects Based on Income

Dependent Variable:	$\log(1 + Total\,Acres\,Purchased)$	$\log(Wheat\,Production)$	$\log(Wheat\,Acres)$	$\log(Wheat\,Yield)$	$\log(Farmland\,Price/Acre)$
	(1)	(2)	(3)	(4)	(5)
$Low\,Income_i \times Farm\,Minerals_i \times Fracking\,Entry_t$	0.738***	0.430***	0.190***	0.101**	0.191***
	(0.237)	(0.119)	(0.065)	(0.046)	(0.037)
$Low\,Income_i \times Fracking\,Entry_t$	−0.570***	−0.744***	−0.378***	−0.149***	−0.044
	(0.219)	(0.099)	(0.050)	(0.047)	(0.034)
$Farm\,Minerals_i \times Fracking\,Entry_t$	−0.534***	−0.057	−0.028	−0.022	0.003
	(0.219)	(0.062)	(0.027)	(0.029)	(0.029)
Controls	Yes	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	656	563	559	559	642
R^2	0.848	0.964	0.987	0.628	0.881

Table 12: 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/gas 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 13: 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 oil/gas 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

Appendix A: Theoretical Model

A.1 Model Setup

Consider an economy where all agents are risk neutral and the riskless rate is zero. A farmer can be one of two types: high productivity (h) and low productivity (l). Let $\theta \in \{l, h\}$ denote farmer productivity. In the cross section, the commonly-known probability is $\gamma_h \in (0, 1)$ that a randomly-chosen farmer has high productivity, and $1 - \gamma_h$ that she has low productivity. Each farmer knows her θ privately.

There are two dates in the model: $t = 1$ and $t = 2$. At $t = 1$, the farmer can invest I_1 or I_2 in farming (equipment, grain, and fertilizer purchase, working capital, and so on), where $I_2 > I_1 > 0$. Farm output is a random variable x which depends on two things: the scale of the capital investment I_i ($i \in \{1, 2\}$) and the farmer's effort input, $e \in \{0, 1\}$. This effort input is personally costly to the farmer, imposing a cost of $e\pi_i$, where $\pi_2 > \pi_1 > 0$, and, as in Hart and Moore (1994), the farmer can withhold it. That is, $e = 1$ means the farmer provides this input and $e = 0$ means she does not. If the farmer chooses to provide it, then

$$\Pr\left(x = X_i \mid I = I_i, e = 1\right) = p_\theta, \quad \Pr\left(x = 0 \mid I = I_i, e = 1\right) = 1 - p_\theta \tag{A.1}$$

where $X_i > 0$, $X_2 > X_1$. The marginal cost of effort is π_i when the investment is I_i—the assumption $\pi_2 > \pi_1$ captures the idea that it is more costly for the farmer to operate on a larger scale. If the farmer chooses to withhold her effort, the distribution of x is:

$$\Pr\left(x = X_i \mid I = I_i, e = 0\right) = q_\theta, \quad \Pr\left(x = 0 \mid I = I_i, e = 1\right) = 1 - q_\theta \tag{A.2}$$

where $1 > p_\theta > q_\theta > 0 \ \forall\theta$, $1 > p_h > p_l > 0$, $1 > q_h > q_l > 0$.

I assume that the provision of effort by the farmer is socially efficient, i.e.,

$$p_\theta X_i - \pi_i > q_\theta X_i \quad \forall i \in \{1, 2\},\ \theta \in \{h, l\} \tag{A.3}$$

and that farming on a bigger scale has higher NPV, i.e.,

$$p_\theta X_2 - \pi_2 - I_2 > p_\theta X_1 - \pi_1 - I_1 > 0 \quad \forall \theta \tag{A.4}$$

Finally, the farmer's effort input increases the probability of high farm output by the same amount regardless of productivity, i.e.,

$$p_h - q_h = p_l - q_l \equiv \delta \tag{A.5}$$

Each farmer has redeployable tangible capital, A, which can take one of two values, A_1 or A_2, with $A_2 > A_1 > 0$. This capital cannot be liquidated at $t = 1$ because it is essential for farming (i.e. land, buildings, machinery, etc.), but it can be used as collateral for bank borrowing. Each farmer's A is publicly observable and is valued equally by the bank and the farmer. All of the capital I_1 the farmer needs at $t = 1$ must be borrowed from a bank. A key assumption in the model that we now make is that the farmer's choice of e is unobservable to the bank and cannot be contracted upon.

A.2 Analysis

The model, with the discretionary provision of human capital that cannot be contracted upon, thus captures the incomplete contracting setting in Hart and Moore (1994) and Holmstrom and Tirole (1997). It leads to a pledgeability friction in that the farmer can only pledge a fraction of her future farm output to financiers, which then limits her borrowing capacity. In such an environment, the farmer can enhance this borrowing capacity by offering tangible redeployable capital as collateral (e.g. see the evidence in Campello and Giambona (2011)).

This is a game in which the informed farmer moves first and asks the bank for a loan of either I_1 or I_2 and offers some part of the assets in place as collateral. The bank then responds with an offer of the maximum amount it is willing to lend at $t = 1$ and the repayment obligation of the farmer at $t = 2$. The equilibrium concept is Bayesian Perfect Nash

Equilibrium (BPNE). This means that as long as the farmer chooses equilibrium strategies, all belief revision follows Bayes Rule. If an out-of-equilibrium move is chosen by a famer, the bank assigns a belief to the farmer's type and offers a loan contract commensurate with the belief.

We now make some assumptions on the exogenous parameters to focus on the cases of interest. Define:

$$A^* \equiv I_1 - \overline{p}\left[X_1 - \frac{\pi_1}{\delta}\right] \tag{A.6}$$

$$A^{**} \equiv I_2 - \overline{p}\left[X_2 - \frac{\pi_2}{\delta}\right] \tag{A.7}$$

where

$$\overline{p} = \gamma_h p_h + [1 - \gamma_h]\, p_l \tag{A.8}$$

We further assume:

$$A^* < A_1 < A^{**} < A_2 < I_1 \tag{A.9}$$

Restriction (A9) is essentially an assumption about the sizes of farmers' tangible redeployable assets. This restriction helps to generate tangible-assets-dependent cross-sectional heterogeneity in farmers' capital structures.

We get the following result.

Proposition 1: *In a BPNE, all farmers with $A = A_1$ borrow I_1 from banks, offering A^* of their tangible assets as collateral, regardless of productivity. Farmers with $A = A_2$ borrow I_2 from banks, offering A^{**} of their tangible assets as collateral. Any farmer deviating from these equilibrium offers will be viewed by the bank as a farmer with $\theta \equiv l$ with probability one. The debt repayment obligations of the farmers are independent of farmer productivity and are given by:*

$$D_1^* = X_1 - \frac{\pi_1}{\delta} + A^* \quad \textit{for farmers borrowing } I_1 \tag{A.10}$$

$$D_2^* = X_2 - \frac{\pi_2}{\delta} + A^{**} \quad \textit{for farmers borrowing } I_2 \tag{A.11}$$

Proof: When the farmer offers A of tangible assets as collateral, the maximum amount that the bank is willing to lend has a repayment obligation D_i that solves the incentive compatibility (IC) constraint

$$p_\theta [X_i - D_i] - [1 - p_\theta] A - \pi_i = q_\theta [X_i - D_i] - [1 - q_\theta] A \tag{A.12}$$

Solving this yields

$$D_i = X_i - \frac{\pi_i}{\delta} + A \tag{A.13}$$

Now, the conjectured equilibrium is pooling across the high-productivity and low-productivity farmers for any loan amount requested (I_1 or I_2). The amount the bank lends at $t = 1$ when the repayment obligation at $t = 2$ is D_i is

$$\begin{aligned} B_i(A) &= \overline{p} \left[X_i - \frac{\pi_i}{\delta} + A \right] + [1 - \overline{p}] A \\ &= \overline{p} X_i - \frac{\overline{p}\pi_i}{\delta} + A \end{aligned} \tag{A.14}$$

So if the farmer with $A = A_1$ will be able to offer enough collateral to borrow I_1, but not enough to borrow I_2 since that required collateral of A^{**}, where (using (A.7))

$$B_2 (A^{**}) = I_2 = \overline{p} \left[X_2 - \frac{\pi_2}{\delta} \right] + A^{**} \tag{A.15}$$

However, a farmer with $A = A_2$ will be able to borrow I_2.

From (A.13) it is also straightforward that (A.10) and (A.11) correspond to the equilibrium repayment obligations of farmers borrowing I_1 and I_2, respectively. It follows that no farmers has an incentive to offer any collateral other than A^* or A^{**} since the bank infers the farmer to have $\theta = l$, which then leads to a lower initial loan at $t = 1$ for any repayment obligation at $t = 2$ (see (A.14) and note $p_l < \overline{p}$). ■

It can be shown that the BPNE in this case survives stronger refinements like the Cho and Kreps (1987) Intuitive Criterion; these details are omitted here to save space. There are two important implications of this result. First, farmers' borrowing capacities are constrained by their pledgeable income—the inalienability of human capital friction introduced by Hart and Moore (1994) implies that farmers can pledge only a fraction of farm income to borrow. Second, cross-sectional variations in borrowing by farms are dependent on differences in tangible, redeployable assets, and not from farm productivities. I provide empirical evidence that this implication is supported by the data in my sample.

The equilibrium here is pooling in farm productivity, because collateral is valued equally by the farmer and the bank and thus cannot be used as a (dissipative) signal of productivity. In other words, there is no deadweight loss associated with the used of collateral (see Besanko and Thakor (1987)).

Note that limited pledgeability of future income is a friction that constrains the amount of financing the farmer can raise. If the farmer was self-financing, he would be willing to invest all the way up to $p_\theta [X_i] - \pi_i$, whereas with the pledgeability friction, he can only raise $\overline{p}X_i - \frac{\overline{p}\pi_i}{\delta}$ (see (A.14)) against future income (ignoring collateral). To see that the high-productivity farmer raises less financing than she would in the absence of the pledgeability friction, note that

$$p_h X_i - \pi_i > \overline{p}X_i - \frac{\overline{p}\pi_i}{\delta} \tag{A.16}$$

The reduction in borrowing capacity is coming from both the pledgeability friction and adverse selection (pooling). But even if the high-productivity farmer's type were known to the bank, the pledgeability friction alone lowers her borrowing capacity since

$$p_h X_i - \pi_i > \overline{p}X_i - \frac{\overline{p}\pi_i}{p_h - q_h} \tag{A.17}$$

A.3 Farmland Acquisitions

Suppose that a high-productivity farmer can convert a low-productivity farm into a high-productivity farm by acquiring it, and that the farmer can discover the target farm's productivity at a due diligence cost $C > 0$. If the acquiring farmer offers the target a price P that shares the surplus generated by the acquisition, then there will be gains from trade.

It is straightforward that there will not be gains from trade from a low-productivity farmer being an acquirer, or from a high-productivity farmer acquiring another high-productivity farm. So the focus will be on a high-productivity farm with $A = A_2$ attempting to purchase a low-productivity farm with $A = A_2$. As we know from the previous analysis, the target farm wants to invest I_2. Let P^* be the purchase price. For there to be gains from trade, selling at P^* must make the target farm better off.

Now, the acquirer needs to borrow $2I_2$ to invest in both farms plus the amount needed for the acquisition. How much will the acquirer need to pay? We will see if there exists a price such that: (i) the acquirer is able to borrow the amount needed to finance the acquisition plus $2I_2$ (the amount to be invested in each farm); and (ii) the target is willing to sell.

Note that the pre-acquisition net payoff of the low-productivity farm is:

$$\begin{aligned} p_l \left[X_2 - \left[X_2 - \frac{\pi_2}{\delta} + A^{**}\right] + A_2\right] + [1 - p_l]\,[A_2 - A^{**}] - \pi_2 \\ = p_l \left[\frac{\pi_2}{\delta}\right] + A_2 - A^{**} - \pi_2 \end{aligned} \tag{A.18}$$

Let the expression in (A.18) be represented by P_{min}, the minimum price the seller would accept. The buyer must borrow $P_{min} + 2I_2$. The IC constraint (for debt repayment D) is:

$$\begin{aligned} p_h\,[2X_2 - D] - [1 - p_h]\,[2A_2] - \pi_3 \\ = q_h\,[2X_2 - D] - [1 - q_h]\,2A_2 \end{aligned} \tag{A.19}$$

where I assume, for simplicity, the outputs of the acquirer's farm and the acquired farm are perfectly correlated after the acquisition and that the human-capital cost of operating the two farms at peak efficiency is $\pi_3 > 2\pi_2$, which reflects the usual convexity of the cost of effort in principal-agent models. Solving (A.19) yields

$$D = 2X_2 - \frac{\pi_3}{\delta} + 2A_2 \tag{A.20}$$

Thus, the initial loan amount will be

$$B = p_h \left[2X_2 - \frac{\pi_3}{\delta}\right] + 2A_2 \tag{A.21}$$

We assume that

$$2p_h X_2 > 2I_2 + \pi_3 \tag{A.22}$$

which means that the farmer would acquire if he could self-finance.

This raises the question of whether $B \geq P_{low} + 2I_2$:

Proposition 2: *Assume $q_h > \gamma_h [p_h - p_l]$ and $\overline{p}X_2 - \pi_2 - I_2 > A_2 - C$. Then it is possible that the high-productivity farmer cannot borrow enough to acquire the low-productivity farm, although the acquisition would occur if the high-productivity farmer could self-finance.*

Proof: We want to show that, given the two conditions stated in the proposition, we have

$$B - C < P_{low} + 2I_2$$

or

$$p_h \left[2X_2 - \frac{\pi_3}{\delta}\right] + 2A_2 - C < P_l \left[\frac{\pi_2}{\delta}\right] + A_2 - A^{**} - \pi_2 + 2I_2 \tag{A.23}$$

which simplifies to

$$2p_h X_2 + A_2 - C < 2I_2 + \frac{p_h \pi_3}{\delta} + \psi - \frac{[\overline{p} - p_l]\,\pi_2}{\delta} \tag{A.24}$$

where

$$\psi \equiv \overline{p} X_2 - \pi_2 - I_2 > 0 \tag{A.25}$$

Now

$$\frac{p_h \pi_3}{\delta} - \pi_3 = \frac{q_h \pi_3}{p_h - p_l} \tag{A.26}$$

Substituting (A.26) into (A.24) gives:

$$\begin{aligned} 2p_h X_2 + A_2 - C &< 2I_2 + \pi_3 + \frac{q_h \pi_3}{\delta} + \psi - \frac{[\overline{p} - p_l]\,\pi_2}{\delta} \\ &= 2I_2 + \pi_3 + \psi + \frac{1}{\delta}\left\{q_h \pi_3 - [\overline{p} - p_l]\,\pi_2\right\} \end{aligned} \tag{A.27}$$

In (A.27), we know that $2p_h X_2 > 2I_2 + \pi_3$, which means that the farmer would do the acquisition is she could self-finance. But one condition in the proposition is that $\psi > A_2 - C$. The other condition is $q_h > \gamma_h [p_h - p_l]$, which guarantees that $\left[\frac{1}{\delta}\right]\left\{q_h \pi_3 - [\overline{p} - p_l]\,\pi_2\right\} > 0$. Thus, the inequality in (A.27) will hold for some parameter values. ■

Note that the two conditions in Proposition 2 are essentially statements that the pledgeability friction is severe enough. The inability of the high-productivity farmer to acquire a low-productivity farm with external (debt) financing is what causes the pre-liquidity-shock misallocation. A fracking liquidity shock gives the farmer the internal (equity) financing needed to do the acquisition.

Appendix B: 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.

B.1 Entering into a Fracking Lease and Mineral Rights

In order to drill underground, fracking operators must sign a lease agreement. When an oil and gas 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 and gas company. For farmers in states rich in oil and gas 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, in additional to royalties which are contingent on the production of oil and gas.[52] 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 (USDA ERS), these payments represent a large cash infusion on average. This large cash infusion related to fracking leases is also in line with the results of Gilje, Loutskina, and Strahan (2016), Gilje (2019), and Plosser (2014), who use fracking discoveries in a different context, as an instrument for exogenous deposit inflows to banks.

However, importantly for my purposes, not every farmer receives these payments even if there is oil or gas underneath the farmer's land. In Oklahoma 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. Mineral rights have legal superiority, so fracking

[52]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.

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 or gas drilling in a given area will not directly affect the value of the *surface* land rights. This allows me to isolate the channel through which liquidity affects the price of the farmland. Second, this ownership split means that some farmers own the mineral rights underneath their land due to inheritance, while other farmers do not—their mineral rights were sold off generations ago. Since this pattern of mineral rights ownership was established well before my sample period, it can be taken as exogenous.

As further evidence of this fact, I show in *Figures B1* and *B2* and *Table B2* that the market for mineral rights is thin, with few sales and transferences. Moreover, this activity is likely overstated in the graphs since a number of these transferences are not due to buying/selling, but rather due to estate inheritance transfers within the family. 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. 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.

The reason why mineral rights are illiquid is because purchasing them in the marketplace is usually not optimal. For oil and gas 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 and gas 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/gas 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.

B.2 Drilling of the Well

Once the oil and gas 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 and gas 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.

Once payments and negotiations have been completed, the oil and gas 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.

B.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 predetermined 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.

B.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 co-vary 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 and gas 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 C: Additional Figures and Tables

Figure C1: 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.

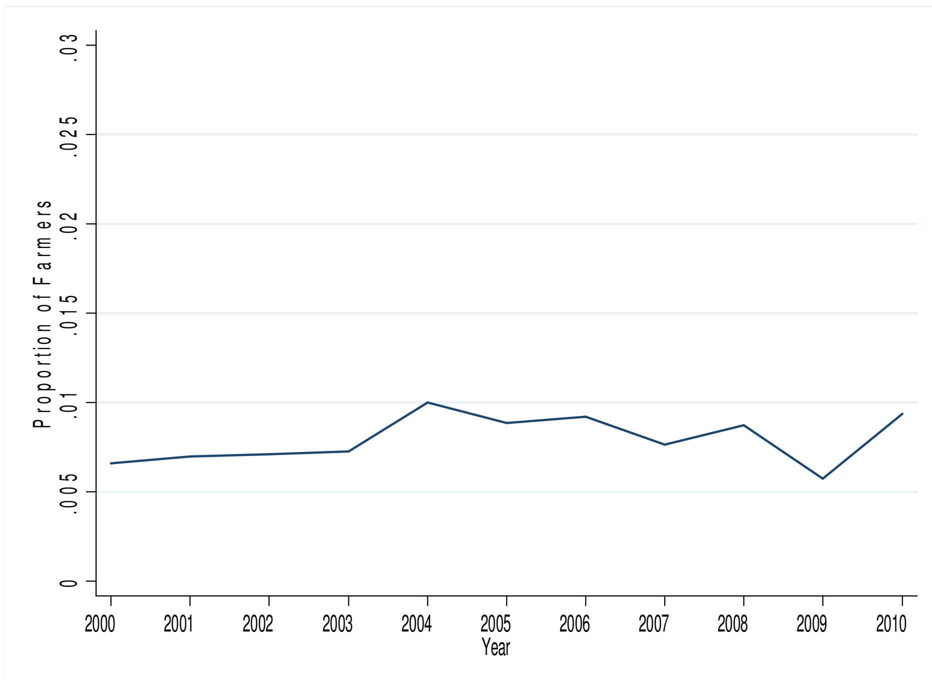


Figure C2: Farm Mineral Deed Transfers, High vs. Low Mineral Ownership Counties

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).

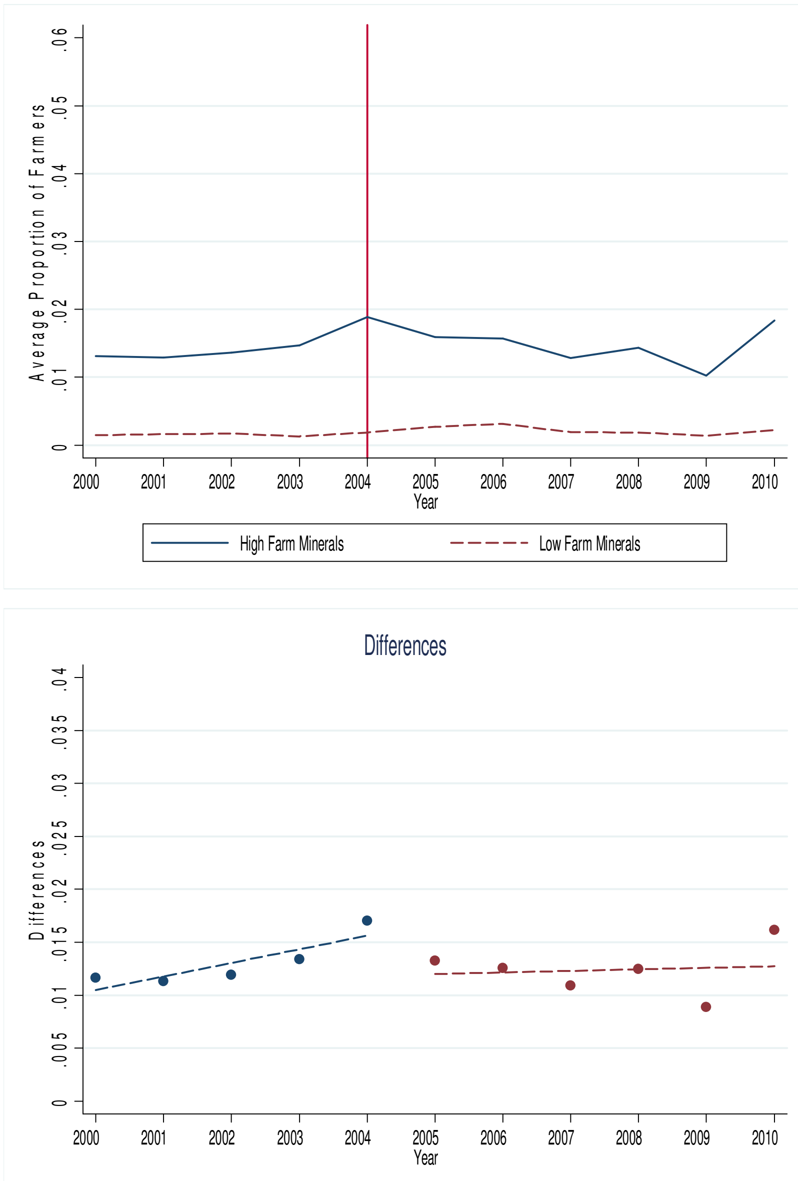


Figure C3: Map of Mineral Ownership across Counties

This figure depicts the values of $Farm\,Minerals$, the estimate of the proportion of farmers who own mineral right, for each county in Oklahoma. Counties with no oil potential are included in the unshaded (white) group.

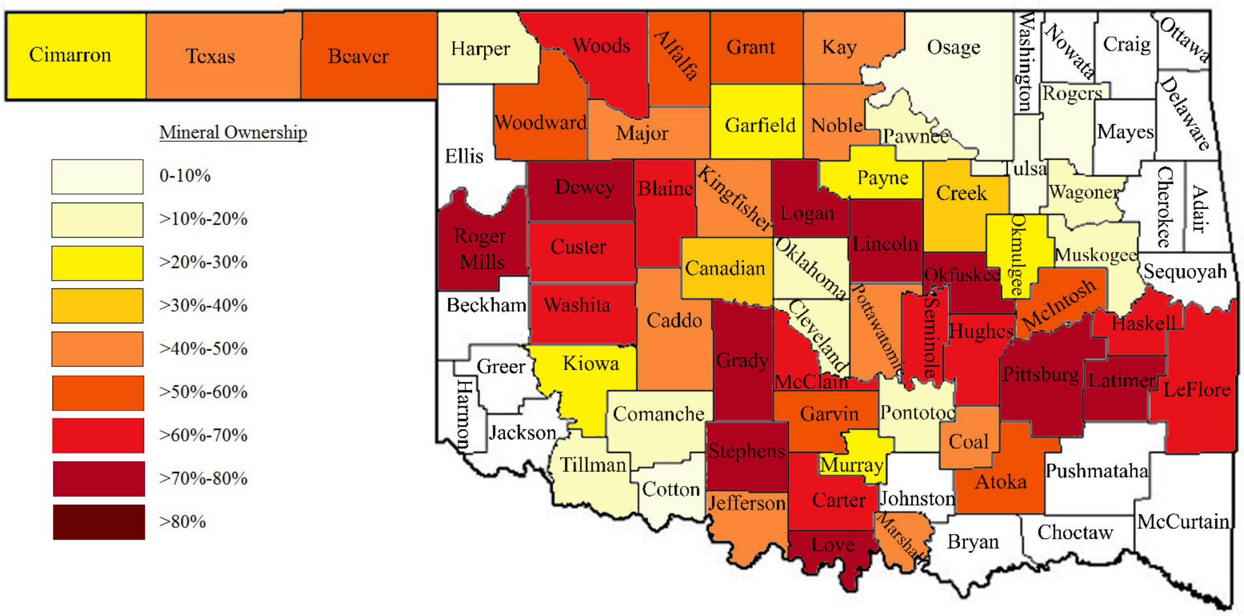


Figure C4: Map of High- and Low-Yield Counties across Oklahoma

This figure depicts whether a county in Oklahoma is classified as high-yield or low-yield. A high-yield county is defined as having an above-median average yield (defined between 1990 and 2004), while a low-yield county is defined as having a below-median average yield. Counties with no oil potential are included in the unshaded (white) group.

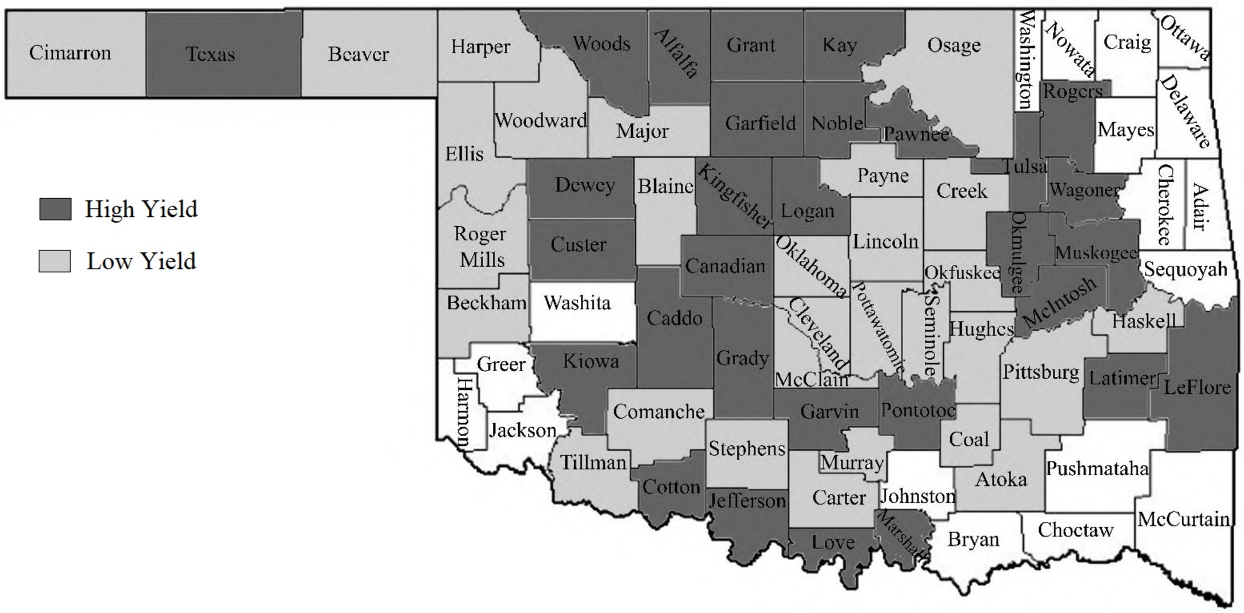


Table C1: Drivers of Farm Debt

This table provides evidence of the drivers of farm debt usage prior to the arrival of fracking. 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. $Farm\,Debt$ is the aggregate amount of farm debt in the county. $Wheat\,Yield$ is wheat crop growing productivity, measured in bushels of wheat produced per acre harvested. $Land\,Value$ is the aggregate value of agricultural land, in real (2010) dollars per acre. Control variables include log amount of cropland, total farm income per acre, government payments per acre, county income per capita, log population, and the log total number of shale wells drilled in the county. Regressions are run from 2000 to 2004, and exclude counties with low oil/gas potential. Standard errors (in parentheses) are adjusted for spatial correlation and autocorrelation at the county-level following Conley (1999). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Dependent Variable: $\log(Farm\,Debt)$		
	(1)	(2)
$\log(Wheat\,Yield)$	-0.040	
	(0.081)	
$\log(Land\,Value)$		0.043*
		(0.022)
Controls	Yes	Yes
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Observations	281	285
R^2	0.931	0.930

Table C2: Correlation Matrix between Variables

This table provides the correlation matrix between the indicated variables from 2000 to 2004. *Farm Minerals* is a continuous variable which estimates the proportion of farmers in a county who own mineral rights. All dependent variables are county-level averages from 2000 to 2004. *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.

	log(*Cropland Acres*)	log(*Farmland Acres*)	*Govt Payments*	log(*Number Farms*)	log(*Avg Farmsize*)	log(*Wheat Yield*)	log(*Wheat Prod*)	log(1+*Machine Purchase*)	log(*Farmland Price/Acre*)	*Total Income*	*LTV*	*Farm Minerals*
log(*Cropland Acres*)	1											
log(*Farmland Acres*)	0.8178	1										
Govt Payments	0.7373	0.5847	1									
log(*Number Farms*)	−0.1648	−0.1454	−0.4555	1								
log(*Avg Farmsize*)	0.0702	0.4403	0.0679	−0.3844	1							
log(*Wheat Yield*)	−0.0116	−0.229	−0.185	0.4717	−0.4274	1						
log(*Wheat Prod*)	0.8401	0.6116	0.7907	−0.2824	−0.0945	−0.0154	1					
log(1+*Machine Purchase*)	−0.3313	−0.4939	−0.4344	0.7583	−0.4915	0.5233	−0.2952	1				
log(*Farmland Price/Acre*)	−0.5275	−0.6954	−0.5343	0.5961	−0.5478	0.4722	−0.3194	0.8189	1			
Total Income	0.209	0.3087	0.222	−0.2408	0.2381	−0.0745	0.1262	−0.1875	-0.2574	1		
LTV	−0.0933	−0.1551	−0.0206	0.0718	−0.0255	−0.0364	−0.0746	0.2445	0.1554	−0.1093	1	
Farm Minerals	0.1395	0.2706	0.1086	0.115	−0.058	−0.1264	0.0157	−0.1487	-0.28	0.0205	0.0518	1

Table C3: 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

Table C4: Land Purchases by Corporate Farms

This table presents purchases by corporate farms. *Total Acres Purchased* is the total number of acres purchased. *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. Regressions are run from 2000 to 2010, and all regressions exclude counties with low oil/gas potential. Standard errors (in parentheses) are clustered at the farm level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

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

	(1)	(2)
$Farm\,Minerals_i \times Fracking\,Entry_t$	-0.098	-0.098
	(0.420)	(0.401)
Level of Analysis	Farm	Farm
Year Fixed Effects	Yes	Yes
Farm Fixed Effects	Yes	Yes
County × Year Fixed Effects	No	Yes
Observations	6,413	6,413
R^2	0.157	0.157

Table C5: Reallocation—Purchases of Land in Low Productivity Zip Codes
This table presents farmland purchases in low-productivity zip codes. Regressions are run at the farm level. The dependent variable is the log total acreage of farmland purchased in other low-yield zip codes by farmers. $Fracking\,Mineral\,Lease_{f,t}$ takes a value of 1 if farmer f has signed a fracking mineral lease in year t or previously, 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/gas potential. Standard errors (in parentheses) are clustered at the farm level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

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

	Low-yield Zip Codes		High-yield Zip Codes	
	(1)	(2)	(3)	(4)
$Fracking\,Mineral\,Lease_{f,t}$	−0.007	−0.003	0.013**	0.011*
	(0.014)	(0.015)	(0.006)	(0.006)
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	50,556	50,534	78,701	78,690
R^2	0.151	0.164	0.141	0.151

Table C6: Machinery Purchases Split by Productivity

This table presents investment in farm machinery, split by county productivity. 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 that estimates the proportion of farmers in a county who own mineral rights. Fracking Entry is a dummy variable that takes a value of 1 if the year is 2005 or later. Columns (1) is 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 column (2) is 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 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.

Dependent Variable: $\log(1 + Machinery\,Purchases)$

	Low-yield Counties	High-yield Counties
	(1)	(2)
$Farm\,Minerals_i \times Fracking\,Entry_t$	0.094	0.133
	(0.108)	(0.094)
Controls	Yes	Yes
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Observations	278	279
R^2	0.934	0.940