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The Impact of Natural Resource Booms on Local Economic Conditions

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Abstract

My research examines the impacts of natural resource booms on local economic conditions. Each chapter relies upon evidence from the three-state region of Montana, North Dakota, and South Dakota. A combination of rising prices and advancements in extraction technologies led to a boom in oil production in the region. This boom represents an exogenous shock to local economic conditions.

The first and second chapters of my dissertation examine the impact of this exogenous labor demand shock that increased earnings in the three-state region. The first chapter analyzes the impact of earnings growth on net migration rates. My estimates suggest that a 10 percent increase in earnings will increase the net migration rate by nearly 3 percentage points in oil counties, consistent with theoretical models of local labor markets and migration. The second chapter examines the extent to which labor force participation and Disability Insurance (DI) are substitutes, since DI becomes more attractive as outside employment options decline. Consistent with evidence from previous studies, my estimates indicate a higher degree of substitutability for current workers. I find that a 10 percent increase in earnings will reduce DI payments by 10 percent and DI participation by nearly 7 percent.

The third chapter studies the impact of local economic conditions on the sales and income tax bases. I find that increases in the value of oil produced substantially increase the sales and income tax bases. More specifically, during the boom, a doubling in the value of oil produced led to an 18 percent increase in the sales tax base and a 16 percent increase in the income tax base for oil counties in North Dakota.
The Impact of Natural Resource Booms on Local Economic Conditions

By

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DISSEPTION

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Chapter 1

The Impact of Local Labor Market Conditions on Migration: Evidence from the Bakken Oil Boom

I. Introduction

A central question in labor economics has been the extent to which local economic conditions impact labor migration. This question is of particular importance given that migration is a fundamental outcome of local economic growth and decline, as well as a primary mechanism of regional labor market adjustment (Blanchard and Katz, 1992; Saks and Wozniak, 2011). Somewhat surprisingly, the existing literature in this area provides relatively few causal estimates of the relationship between local labor market conditions and migration.

In this paper, I provide new estimates of the effect of local labor market conditions, as measured by earnings, on permanent migration. I exploit exogenous variation in earnings growth over time across counties in Montana, North Dakota, and South Dakota (henceforth known as “the three-state region”) due to a boom in oil production in the Bakken formation of the Williston Basin. From 2000 through 2010, oil production in these states more than quintupled from nearly 50 to 250 million barrels of oil per year. This increase is part of a larger boom in oil and natural gas production in the United States that was made possible by a combination of rising oil prices and advancements in extraction technologies, including horizontal drilling and hydraulic fracturing, colloquially known as fracking. As extractive industries increasingly rely on technological advancements and boom and bust cycles become a common feature of the industry, it is important to understand the impacts of these cycles on local labor markets and labor migration.
As there are several potential sources of bias in estimating the relationship between local labor market conditions and migration using ordinary least squares (OLS), I develop an instrumental variable (IV) estimation strategy that isolates the shocks to labor demand from factors that also directly affect labor supply and migration. I implement this strategy using a county-level panel dataset of administrative earnings and migration data from the Internal Revenue Service (IRS) for 1993 through 2010. To estimate the causal relationship between earnings and net migration, I use the value of county oil reserves as an instrument for earnings. I construct the instrument using oil reserves data and West Texas Intermediate (WTI) crude oil prices from the United States Department of Energy’s Energy Information Administration (EIA). This methodology allows me to exploit natural variation in oil reserves across counties and time series variation in oil prices. In particular, the oil-rich counties in the three-state region experienced an exogenous shock to labor demand and earnings. Much of the oil activity and, by extension, economic activity takes place around the Bakken formation, where there are large amounts of proven reserves.

My IV estimates suggest a substantial, statistically significant, positive relationship between county-level earnings growth and net migration. I estimate a semi-elasticity of net migration with respect to earnings for North Dakota, which accounted for nearly 70 percent of the oil production in the three-state region since 2000. I find a semi-elasticity of 0.2. This estimate implies that if earnings increase by 10 percent, the net migration rate increases by 2 percentage points. Expanding the analysis to the three-state region, I find a semi-elasticity of migration with respect to county earnings of 0.4. This estimate suggests that if earnings increase by 10 percent, the net migration rate increases by 4 percentage points. Compared to the mean net migration rate of -0.8 percent (i.e. net out-migration), these estimates suggest a large impact of
earnings growth on net migration. Although somewhat speculative, the net migration semi-elasticities suggest that the premium to earnings to compensate for the costs of moving to North Dakota is 64 percent.

These relatively large elasticities of migration with respect to local earnings that I find are consistent with the Blanchard and Katz (1992) findings that migration is a primary mechanism for labor market adjustment. Beyond providing these new estimates, this paper contributes to a growing body of literature that explores the impact of natural resources on various labor market outcomes, such as employment, earnings, and federal disability insurance. This literature includes studies by Acemoglu et al. (2013), Aldy (2014), Allcott and Keniston (2014), Black et al. (2002), Black et al. (2005), and Vachon (2015a), among others.

The paper is organized as follows. Section II reviews the literature. Section III outlines the basic theoretical framework. Section IV provides an overview of the recent oil boom. Section V describes the data and econometric specifications. Section VI illustrates the identification strategy. Section VII presents the estimation and results. Finally, Section VIII summarizes the results, describes caveats, and offers areas of future research.

II. Previous Literature

The local labor markets literature has examined the extent to which local labor supply and demand shocks impact labor market outcomes, including earnings, employment, migration, and the spatial equilibrium of labor. Bartik (2014) and Moretti (2011) provide reviews of the literature. Bartik (1991) and Blanchard and Katz (1992), among others, examine the general features of regional economic cycles by looking at the response of employment, wages, and migration to economic conditions. Blanchard and Katz (1992) study supply and demand and then
simulate the impact of shocks on employment and wages. They find that labor migration is an important mechanism for interregional adjustment to labor demand shocks. While Blanchard and Katz (1992) find that a local labor market generally returns to equilibrium less than a decade after a shock, Bartik (1991) finds a slightly slower adjustment. Topel (1986) examines a spatial equilibrium model in a dynamic setting. He finds that positive shocks to local labor demand increase nominal wages in that market, consistent with Bartik (1991) and Blanchard and Katz (1992). Partridge and Rickman (2006) estimate models of employment, migration, and wages and find that positive labor demand shocks increase employment-to-population ratios in both the short- and long-run, with stronger effects in Rustbelt and Farmbelt states. Gallin (2004) and Saks and Wozniak (2011) build upon these structural models of local labor markets, examining the impact of aggregate national economic conditions and business cycle fluctuations on internal migration.

More recently, a growing empirical literature examines the impact of local demand and supply shocks on county-level economic conditions. Aldy (2014), Allcott and Keniston (2014), Black et al. (2002), Black et al. (2005), Carrington (1996) and Vachon (2015a) examine the impact of natural resource-induced shocks on local economic conditions. Aldy (2014) studies the 2010 Deepwater Horizon oil spill, spill response, and drilling moratorium. Using a difference-in-differences strategy, he finds increases in employment in the oil-intensive parishes in Louisiana as well as coastal Alabama, but decreases in employment in certain Gulf Coast Florida counties. Allcott and Keniston (2014) use a national, county-level panel dataset to estimate how resource booms and busts impact the manufacturing sector, finding that total manufacturing employment increases during booms and decreases during busts in natural resource-rich counties. Black et al. (2002) and Vachon (2015a) study the impact of natural resource shocks on Disability Insurance
(DI) payments and participation in the Appalachian and Bakken regions, respectively. Both studies find a negative relationship between a natural resource price-induced change in earnings and DI payments and participation. Carrington (1996) studies the impact of construction of the Trans-Alaska Pipeline during the 1970s on wages and employment at the state level, finding employment spillovers to non-construction industries and a fairly elastic labor supply on both the intensive and extensive margins. In particular, he finds that a 10 percent increase in earnings increases labor supply by approximately 7 percent. Black et al. (2005) examine the local labor market impacts of the coal boom and bust in Appalachia in the 1970s and 1980s, primarily focusing on spillovers from coal to no coal counties. They also examine the impact of the boom and bust on cohort-level migration by gender, finding increases in the in-migration of working-age men during the coal boom, while other populations generally experienced increased out-migration.

III. Basic Theoretical Framework

The migration decision is commonly viewed as a utility maximization problem in which individuals choose the location that provides the highest utility, typically modeled as a function of local earnings, amenities, and the cost of moving.\(^1\) Figure 1 illustrates the basic market-level predictions of a change in demand for labor in a model of two labor markets, Region A and Region B, for which other inputs to production, such as land and capital, are perfectly elastic in supply. In particular, in equilibrium, individuals should be indifferent between locating in

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\(^1\) This model of income maximization closely follows Roy’s (1951) framework, which is the foundation for a large portion of the migration literature. The Roy Model generally posits that workers will migrate to the regions which offer the best relative return to their skill, taking into consideration the costs of migrating from the origin to destination. Borjas (1999) and Greenwood (1975) provide reviews of the literature; see also Blanchard and Katz (1992), Borjas (1987), Dahl (2002), Davies, Greenwood, and Li (2001), Gallin (2004), Grogger and Hanson (2011), Saks and Wozniak (2011), and Topel (1986).
Region A or Region B. This requires that earnings plus the money-metric value of amenities minus the cost of moving are equal in the two locations.

At the initial labor market equilibrium \((E_A)\) in Region A, earnings equal \(Y_A\) and the labor force participation is \(N_A\). In Region B, at the initial labor market equilibrium \((E_B)\), earnings equal \(Y_B\), and labor force participation is \(N_B\). For Region B, earnings \(Y_B\) are equal to \(Y_A\) minus the cost, \(C\), of moving from Region B to Region A:

\[
(1) \quad Y_A - C = Y_B.
\]

To simplify, I assume that moving costs, \(C\), are net of the value of the amenity differential between the two regions. In this model, workers migrate from Region B to Region A when \(Y_A > Y_B + C\). In equilibrium, labor supply equals labor demand in each region:

\[
(2) \quad D_A(Y_A) = S_A(Y_A)
\]

and

\[
(3) \quad D_B(Y_B) = S_B(Y_B).
\]

Now, assume Region A experiences an exogenous shock to labor demand. This shifts the labor demand curve outward from \(D_A\) to \(D_A'\). The new Region A labor market equilibrium is at \(E_A'\), with increases in earnings and labor force participation to \(Y_A'\) and \(N_A'\), respectively. The increase in earnings from \(Y_A\) to \(Y_A'\) in Region A induces a migration response from workers in Region B, and the Region B labor supply curve shifts inward from \(S_B\) to \(S_B'\). This shift, in turn, shifts the Region A labor supply curve outward to \(S_A'\), resulting in the new equilibrium level of earnings \(Y_A''\) and labor force participation \(N_A''\). The initial increase in labor force participation from \(N_A\) to \(N_A'\) (movement along the labor supply curve) in Region A is due an increase in
participation of current residents. In contrast, the increase from $N_A'$ to $N_A''$ (outward shift of the supply curve to $S_A''$) is the result of net migration from Region $B$. \(^2\)

As illustrated, the labor market response in Region $A$ depends on the labor supply and demand elasticities in both regions and the moving cost. The goal of this paper is to estimate the migration response in Region $B$ ($N_B$ to $N_B'$) to an exogenous increase in earnings in Region $A$ ($Y_A$ to $Y_A'$). The migration response from Region $B$, $dD_B/dY_A$, is out-migration from Region $B$ to $A$ in response to the increase in Region $A$ earnings. So, this migration response represents net in-migration to Region $A$, expressed as $-dD_B/dY_A$. From equations (1) through (3), it can be shown that this migration response can be written in terms of the elasticity and cost parameters as

\[
\beta = \frac{-dD_B}{S_A} \frac{1}{dY_A} = \eta_A^s - \eta_A^d - \eta_B^s \left(\frac{S_B}{S_A}\right) \left(1 + \frac{C}{Y_B}\right).
\]

Here, I have expressed $\beta$ as a semi-elasticity, where $-dD_B/S_A$ is the migration rate, $m$, and $dY_A/Y_A$ is the percent change in earnings for Region $A$.

To understand what drives changes in $\beta$, I display the partial derivatives from (4) below. First, there is a negative relationship between $\beta$ and the cost of migration:

\[
\frac{\partial \beta}{\partial C} = -\eta_s \left(\frac{S_B}{S_A}\right) \left(\frac{1}{Y_B}\right) < 0.
\]

Second, the relationship between $\beta$ and the elasticity of labor supply for Region $A$ is positive. As $\eta_A^s$ increases, a shock to demand will lead to larger increases in $Y_A$ and thus increase the migration response from Region $B$:

\[
\frac{\partial \beta}{\partial \eta_A^s} = 1 > 0.
\]

\(^2\) From Figure 1, the reduction in Region $B$ labor force participation, $N_B' - N_B$, is equal to the increase in Region $A$ labor force participation due to in-migration, $N_A' - N_A'$. 

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Third, the relationship between $\beta$ and the elasticity of labor supply for Region $B$ is negative. As $\eta^S_B$ increases, there will be a smaller migration response from Region $B$ to a given increase in Region $A$ earnings:

$$\frac{\partial \beta}{\partial \eta^S} = -\left(\frac{s_B}{s_A}\right) \left(1 + \frac{c}{y_B}\right) < 0.$$  

Finally, there is a negative relationship between $\beta$ and the elasticity of labor demand. As $\eta^D_A$ increases (becomes less negative), a shock to demand will lead to smaller increases in $Y_A$, reducing the migration response from Region $B$:

$$\frac{\partial \beta}{\partial \eta^D_A} = -1 < 0.$$  

The goal of the empirical analysis in Section VII is to estimate $\beta$.

IV. Oil Boom Background

The source of oil is organic matter that is preserved and buried in some sedimentary rocks. For an oil deposit to be considered for commercial production, three important geological criteria must be met (Hyne, 2012). First, there must be a subsurface source rock that generated the oil (see Figure 2). The most common source rock is black shale. Shale originated as organic matter-rich mud on ancient seafloors.\(^3\) As it was covered with more and more sediments and buried further below the Earth’s surface, the heat from geological pressure turned the organic matter into oil. Second, there must be a separate subsurface reservoir rock that holds the oil. Reservoir rocks are sedimentary rock layers that contain billions of tiny spaces, or pores. Sandstone (composed of compressed grains of sand) and limestone (composed of broken down

\(^3\) The shale oil extracted from the Bakken was formed approximately 350 million years ago during the late Devonian and early Mississippian geologic periods (Hyne, 2012).
seashells and corals) are common reservoir rocks. Oil is able to flow through sandstone, limestone, and other reservoir rocks through the pore spaces between the sediments. Third, there must be a geological trap and cap rock to concentrate the oil into commercially extractable quantities. The trap is a geological high point in the formation that prevents the oil from flowing upward; the cap rock is a seal that prevents oil from flowing through it, concentrating the oil in the reservoir rock.

In “conventional” oil extraction, a well is drilled into the reservoir rock. Such methods characterized oil production in the United States, including North Dakota, for much of the previous century. In contrast, the recent oil boom uses “unconventional” oil extraction because it involves drilling into and extracting resources from the shale source rock, which is less porous and permeable than typical reservoir rocks (i.e. sandstone and limestone, among others) (Maugeri, 2012). In particular, shale oil is extracted using the combined application of horizontal drilling and fracking techniques. Horizontal drilling is particularly effective in these formations because more well surface area is exposed to the oil-rich rock as compared to traditional vertical drilling. Hydraulic fracturing is the process of injecting large volumes of fluids into a well to fracture the rock. The fluid used is generally combined with sand before it is injected. The sand particles, known as propping agents, hold open the fractures, allowing oil to flow into the well (Hyne, 2012).

Figure 3 presents the time-series price and production data for North Dakota. Geologists and petroleum experts have been aware of North Dakota’s reserves since the middle of the previous century when Amerada Petroleum Corporation drilled the area’s first commercial oil

---

4 While the focus of this paper is on the Bakken formation, the explanations of the geology of fossil fuels and extraction technologies can generally be applied to other regions with shale oil and gas reserves and extraction (i.e. Marcellus and Utica in the Appalachian region, Eagle Ford and Barnett in Texas, and Woodford in Oklahoma, among others).
well at the Clarence Iversen farm in Tioga, North Dakota in 1951. However, later that year Amerada made another important discovery at the Henry O. Bakken farm, also in Tioga. The Bakken well is important because it was the first in the area drilled into the older (deeper) geologic formation that became known as the Bakken formation. From 1951 through the 1970s, oil production averaged a modest 20 million to 25 million barrels per year. Beginning in 1973 with the OPEC embargo and continuing through the oil crisis of 1979, rising oil prices led to a boom in production in North Dakota in the 1980s. Even with record-high oil prices, annual production peaked at approximately 50 million barrels in 1984, compared to nearly 900 million barrels produced in Texas that year (U.S. Energy Information Administration, 2014).

While oil companies have had access to horizontal drilling and fracking technologies for some time, their combined application was not successful until 2000, when Mitchell Energy extracted natural gas from the Barnett shale in Texas (Maugeri, 2012). In North Dakota’s Bakken, Continental Resources is credited with the first commercially successful combined horizontal drilling and fracking oil well in 2004 (Continental Resources, 2014). North Dakota oil production hit nearly 250 million barrels in 2012 and continues to increase. Production resulting from this most recent boom dwarfs that of the 1980s.

V. Econometric Specifications and Data

The basic prediction of the model in Section III is that a labor demand shock increases earnings in the destination region and, ultimately, induces an in-migration response, increasing the supply of labor in the destination (and reducing labor supply in the origination region). Following the literature and treating the county as the local labor market, I present the reduced-form relationship between net migration and local earnings below:
where $m_{ist}$ represents the net migration rate for county $i$ in state $s$ in year $t$, and $\varepsilon_{ist}$ is the error term. Specifically, a migrant is someone who moves to or from county $i$ between year $t$ and year $t+1$. The migration rate is defined as the number of in-migrants minus the number of out-migrants from a county divided by the beginning-of-period number of inhabitants of the county. The explanatory variable is $ln(y_{ist})$, the natural logarithm of real earnings. The focal parameter $\beta$ represents the semi-elasticity of migration with respect to local earnings and is the reduced-form of the four parameters ($\eta^S_A$, $\eta^P_A$, $\eta^S_B$, and $C$) as shown in equation (4).

I model $\varepsilon$ as

$$\varepsilon_{ist} = \pi_t + \tau_t + \phi_{st} + \mu_{ist},$$

where $\pi$ represents a county-specific fixed effect, and $\tau$ represents a linear time trend. To account for this fixed effect, I first-difference equation (9) to yield:

$$\Delta m_{ist} = \delta + \beta \Delta ln(y_{ist}) + \omega_{ist},$$

where $\Delta$ indicates a first difference, and $\omega$ is the differenced error term from equation (10):

$$\omega_{ist} = \gamma_{st} + u_{ist},$$

where $\gamma_{st} \equiv \Delta \phi_{st}$ is a state-by-year effect, and $\delta$ is the new intercept, where $\delta \equiv \Delta \tau_t$. As described below, consistent estimates of $\beta$ from equation (11) are identified by within state, over time, across county differences in earnings.

The dataset used in this analysis is based on county-level administrative data from IRS Statistics of Income (SOI), based on federal income tax returns. Migration status is based on year-over-year address changes on federal individual income tax returns. I use the number of returns, rather than exemptions, as the primary measure of migration, as they approximate households; exemptions declared on those returns approximate the population and include
children and other non-participants in the labor market. I calculate county-level net migration by subtracting total out-migration from total in-migration. Dividing net migration by the total number of returns filed in the county gives the rate, \( m_{ist} \). The net migration rate will be negative if outflows are greater than inflows in a given year. I measure real earnings in 2010 dollars as county mean wage and salary income reported on federal income tax returns, adjusted for inflation using the Consumer Price Index (CPI). Dividing real earnings by the number of returns filed in the county gives the earnings per household, \( y_{ist} \).

Panel A of Table 1 presents summary statistics for the entire sample period. Column 1 of Panel A presents sample means. Montana, North Dakota, and South Dakota are small states; according to the 1990 Census, their respective populations were 799,000, 639,000, and 696,000. The average number of households per county is 5,500, and average household earnings are approximately $27,000. Average annual earnings growth is 0.9 percent. Throughout the period of interest, the three-state region experienced, on average, net migration rates of approximately -0.8 percent.

VI. Identification Strategy

Because earnings and migration are jointly determined, I estimate the parameters in equation (11) using an instrumental variables strategy following Black et al. (2002) and Vachon (2015a). This strategy is based on natural variation in county-level oil reserves. The oil reserve data come from the 2004 EIA assessment of the Bakken formation of the Williston Basin and the 2001 assessments of Montana Thrust Belt and Powder River Basin. I calculate oil reserves using EIA shape files and MapInfo software. I use midpoint estimates for each oil field, as the reserves are listed in ranges, then aggregate to the county level. Based on this method, there are 32
counties in the three-state region that have oil reserves, and 143 counties that have no reserves. From Column 2 of Table 1, the average oil county has nearly forty-four million barrels of oil reserves. I calculate the value of oil reserves by multiplying county-level reserves by the price of WTI crude oil. From Panels B and C of Table 1, the average price per barrel of West Texas Intermediate (WTI) crude oil increased from $31 to $76 between the early and later years of the oil boom. I use the value of oil reserves and that value interacted with a dummy variable for the presence of horizontal drilling and fracking extraction technologies as instruments for earnings to econometrically capture the impact of the oil price-generated increase in local labor market earnings on migration.

Figures 4 through 6b present a visual depiction of my identification strategy. Figure 4 shows the level of county oil reserves for the Bakken formation of the Williston Basin (eastern Montana, western North Dakota, and northwest South Dakota), Montana Thrust Belt (northwestern Montana), and Powder River Basin (southeast Montana and southwest South Dakota). The darkest shaded counties have the highest levels of oil reserves, and those areas shaded white have no oil reserves. The darkest shaded counties have between 50 and 217 million barrels of oil. The counties shaded in dark gray have between 5 and 50 million barrels of oil. The counties shaded in the lightest gray have less than less than 5 million barrels of oil (but more than zero). The most oil-rich part of the region is the Bakken formation of the Williston Basin.

Figures 5a and 5b present quartiles of average annual earnings growth rates for the pre-boom (1993-2004) and boom (2005-2010) periods, respectively. The areas with the darkest shading have the greatest increases in average annual earnings growth over the timeframe. During the pre-boom period in Figure 5a, the first through fourth quartiles represent earnings growth below 0.75 percent, between 0.75 percent and 1.6 percent, between 1.6 percent and 2.5
percent, and above 2.5 percent, respectively. During the early period, the lowest growth county experienced a 1.3 percent decrease in earnings; the highest growth county experienced an 8.2 percent increase in earnings.

For the boom period in Figure 5b, the first through fourth quartiles represent earnings growth below 1.51 percent, between 1.52 percent and 2.29 percent, between 2.3 percent and 3.3 percent, and above 3.4 percent, respectively. The lowest growth county experienced a 4.9 percent decrease in average annual earnings; the highest growth county experienced a 10.8 percent increase. The average annual earnings growth was 2.9 percent greater in oil counties than no oil counties during the boom.

Figures 6a and 6b present quartiles of average changes in net migration for the pre-boom and boom periods, respectively. The areas with the darkest shading have the greatest change in average net migration over the timeframe. During the pre-boom period in Figure 6a, the first through fourth quartiles represent changes in net migration below -0.12 percentage points, between -0.12 percentage points and -0.025 percentage points, between -0.025 percentage points and 0.09 percentage points, and above 0.09 percentage points, respectively. From Figure 6b, the first through fourth quartiles represent changes in net migration below -0.02 percentage points, between -0.02 percentage points and 0.132 percentage points, between 0.132 percentage points and 0.29 percentage points, and above 0.29 percentage points, respectively. During the oil boom, the lowest growth county experienced a 0.5 percentage point decrease in its net migration rate; the highest growth county experienced a 1.3 percentage point increase.

Figures 4, 5a, and 5b represent the first-stage relationship between oil reserves and earnings growth. Those counties with high earnings growth have the highest levels of oil reserves, as evidenced by the dark shading on both maps. The reverse is also true; areas with low
earnings growth have little to no oil reserves. Figures 4, 6a, and 6b represent the reduced-form relationship between oil reserves and net migration. There is a positive relationship between oil reserves and changes in net migration. Those areas with high levels of oil reserves have high changes in net migration.

VII. Estimation and Results

The first-stage of the IV estimation is:

\[
\Delta \ln(y_{ist}) = \alpha_0 + \alpha_1 \Delta \ln(v_{ist}) + \alpha_2 D_{2004}^{Post} \cdot \Delta \ln(v_{ist}) + \gamma_{st} + u_{ist},
\]

where the instruments are \( \Delta \ln(v_{ist}) \) and \( D_{2004}^{Post} \cdot \Delta \ln(v_{ist}) \). \( \ln(v_{ist}) \) represents the natural logarithm of the value of county oil reserves for each year in 2010 dollars; \( D_{2004}^{Post} \) is a dummy variable with value 1 for years 2005 through 2010, when the combination of horizontal drilling and fracking was available in the three-state region, and 0 otherwise.

Table 2 presents estimates of \( \alpha_1 \) and \( \alpha_2 \) from equation (13). These estimates illustrate the relationship between growth in the value of oil reserves, the presence of new extraction technologies, and earnings growth. Column 1 presents the estimates for North Dakota. The estimate for \( \alpha_1 \) implies that a doubling in the value of oil reserves leads to a 2.5 percent increase in earnings. The coefficient on the interaction term, \( \alpha_2 \), suggests that if the value of oil reserves doubles during this period, earnings increases by an additional 4 percent. I find a strong positive relationship between earnings growth and value of oil reserves; the \( F \)-statistic from the test on excluded instruments is 12.6 for North Dakota, suggesting that these are strong instruments.

Column 2 presents the first-stage relationship for the three-state region. The estimate for \( \alpha_1 \) implies that a doubling in the value of oil reserves leads to a 0.4 percent increase in earnings. The coefficient on the interaction term suggests that if the value of oil reserves doubles during
this period, earnings increases by an additional 3.2 percent. For the three-state region, the $F$-statistic from the test on excluded instruments is 3.8, suggesting the instruments are relatively weak in this case.

Table 3 presents OLS and IV estimates of $\beta$, the impact of earnings growth on net migration for North Dakota as well as the three-state region. Column 1 presents OLS estimates for North Dakota. I find a semi-elasticity of net migration with respect to county earnings of 0.04. This estimate suggests that a 10 percent increase in earnings will increase the net migration rate 0.4 percentage points. Compared to the mean net migration rate of -0.8 percent for the three-state region, this is a large impact. However, OLS does not isolate shocks to labor demand from important factors that directly influence both labor supply and migration.

Column 2 of Table 3 presents IV estimates of $\beta$ for North Dakota. I find a semi-elasticity of net migration with respect to earnings growth of 0.2; if earnings increase by 10 percent, the net migration rate will increase by 2 percentage points.\footnote{There are three potential sources of OLS bias. First, endogeneity suggests OLS estimates would be biased upward. Second, mobility costs may represent an omitted variable that is negatively correlated with migration but positively correlated with wage growth. At the same time, migration is positively correlated with wages. Given that oil counties are generally less populous and more rural than counties without oil, it is plausible that high earnings growth counties also had higher mobility costs, so OLS estimates of $\beta$ will be biased downward. While classical measurement error may also lead to downward biased estimates of $\beta$ using OLS, it is unlikely the source of potential bias given that I use administrative migration and earnings data. As such, the direction of the bias is unclear.} Column 3 of Table 3 presents estimates for the three-state region. I find a semi-elasticity of net migration with respect to earnings growth of 0.4. If earnings increase by 10 percent, the net migration rate will increase by 4 percentage points. In reality, during the oil boom, earnings for oil counties increased by approximately 13 percent in North Dakota and increased by approximately 8 percent in the three-state region. For North Dakota, these estimates suggest the increase in earnings during the oil boom led to a 2.6 percentage point increase in the net migration rate in oil counties; for the three-state region, these estimates suggest the increase in earnings led to a 3.2 percentage point increase in the net
migration rate in oil counties. These estimates imply a large statistically significant, positive impact of earnings growth on net migration.

During the sample period, parts of the United States, including the three-state region, experienced an agricultural boom in addition to the boom in oil production. Since agricultural production varies across counties, such additional sources of county-by-time variation could confound my results. To account for this, I control for the value of agricultural land using land price data from the United States Department of Agriculture (USDA), which are only available for North Dakota during the entire period of interest.6

Table 4 presents OLS and IV estimates of the relationship between earnings and net migration rates, controlling for land values. The OLS estimates in Column 1 suggest a positive relationship between earnings growth and net migration. I find a semi-elasticity of migration with respect to earnings of 0.04. The semi-elasticity of net migration with respect to cropland value is -0.005. These estimates suggest a positive, significant relationship between earnings growth and net migration and a negative, insignificant relationship between cropland value and net migration. Column 2 presents IV estimates of the relationship, suggesting a semi-elasticity of net migration with respect to earnings of 0.2. I find a semi-elasticity of net migration with respect to cropland value of -0.008. While the large earnings growth estimates are consistent with my previous results, the land value estimates are quite small, suggesting that land value growth has little impact on net migration.

In Column 3, I treat cropland value as an endogenous regressor, as in Rosen (1979) and Roback (1982). Because I have two instruments, this specification is just identified. From Table 2, the F-statistic from the test of excluded instruments from the first-stage regression of oil

---

6 Data for Montana and South Dakota are only available sporadically for the period of interest.
reserves on cropland values is 9.1. I find a semi-elasticity of net migration with respect to local earnings of 0.2; the semi-elasticity of net migration with respect to cropland value is 0.005.

As a final robustness check, I use an estimator that follows Cliff and Ord’s seminal work (1973 and 1981) to provide IV estimates of the relationship between local economic conditions and net migration that account for spatial autocorrelation. I generate an inverse-distance spatial weighting matrix (spatial correlation decreases with the distance between two counties), where distance is measured between the geographic center of one county and another. Table 5 presents IV estimates from the spatial error model of the relationship between local labor market conditions and net migration rates for North Dakota.7 Estimates from the spatial error model in column 1 suggest a semi-elasticity of 0.24, implying that a 10 percent increase in earnings will increase the net migration rate by between 2.4 percentage points. The estimate of the semi-elasticity of net migration with respect to earnings growth is quantitatively similar to my primary estimate from column 2 of Table 4.

VIII. Summary, Caveats, and Implications

In this paper, I exploit exogenous variation in local labor market conditions to estimate the impact of economic growth on net migration. The boom in oil production in the Bakken formation covering parts of Montana, North Dakota, and South Dakota created an unexpected labor demand shock that increased earnings, particularly for oil counties. Overall, my estimates suggest a statistically significant, positive impact of earnings growth on net migration rates. I

7 These specifications use only the first difference of the natural logarithm of oil reserves as an instrument for earnings. The spatial regression analysis used requires that panel data be strongly balanced. Observations prior to 1998 were dropped due to missing values. For the same reason, one county with missing data after 1998 was also dropped from the sample. Column 2 provides estimates from the specification in Table 4 that rely on the same sample as the spatial error model. The estimates in column 2 suggest that a 10 percent increase in earnings will increase the net migration rate by 2.8 percentage points.
find semi-elasticities of net migration with respect to earnings of 0.2 and 0.4 for North Dakota and the three-state region, respectively. During the oil boom, earnings for oil counties increased by approximately 13 percent in North Dakota, and this earnings growth led to a 2.6 percentage point increase in the net migration rate. For the same period, earnings growth in the three-state region increased by approximately 8 percent, and this suggests the earnings growth led to a 3.2 percentage point increase in the net migration rate in oil counties in the three-state region.

More recently, however, between June 2014 and February 2015, oil prices fell by just over 50 percent from $106 to $51 per barrel. This decrease in prices represents a negative shock to local economic conditions. The new estimates that I present in this paper can provide insight into how changes in the price of oil will impact net migration rates. Based on my first-stage estimates, this decrease in prices will reduce earnings by nearly 3.25 percent. From my IV estimates, a 50 percent decrease in prices will reduce net migration rates by 0.65 percentage points. These somewhat speculative estimates assume a symmetric response of economic conditions to increases and decreases in the price of oil.

In addition, I use the estimates of $\beta$ to estimate migration costs. From (4), it follows that

$$\theta = \frac{c}{y_B} = \frac{-\beta - \eta^B_A + \eta^S_B}{\eta^S_B \left( \frac{s_B}{s_A} \right)} - 1,$$

where $\theta$ is the earnings premium paid to workers to compensate them for the cost of migrating from Region B to Region A. To calibrate this, I make reasonable assumptions about the elasticities of labor supply and demand as well as the population ratio between the two regions, $\frac{s_B}{s_A}$. Consistent with the literature, I assume the uncompensated elasticity of labor supply is 0.1. I calculate a weighted average of the elasticity of labor demand. This estimate is based on Slaughter’s (2001) elasticities of -1.3 and -0.8 for production and nonproduction labor,
respectively. Production labor makes up approximately 24 percent of the total labor force in North Dakota’s oil counties. From these estimates,

\[ \eta_A^D = (-1.3)(0.24) + (-0.8)(0.76) = -0.92 \]

is the industry-weighted labor demand elasticity. Finally, in this calibration, I assume oil counties in North Dakota comprise Region \( A \) and Montana and South Dakota make up Region \( B \), which implies \( \frac{s_B}{s_A} = 5 \). With these assumptions, \( \theta \) is equal to 0.64, or workers require a 64 percent increase in earnings if they are to migrate to North Dakota.

My research contributes to the literature in three ways. First, the use of a natural experiment is a novel approach that provides new causal evidence of the impact of economic booms on county-level internal migration within the United States. Despite an extensive body of research examining migration, we know little about the impact of natural resource booms on migration in impacted localities. Second, my large elasticity estimates are consistent the Blanchard and Katz (1992) finding that migration is an important mechanism of labor market adjustment in the presence of a shock to local economic conditions. The local labor markets literature explains that a positive demand shock, such as an oil boom, should increase wages, employment, and in-migration. Finally, this paper contributes to the growing literature examining impact of natural resources on labor market outcomes (Acemoglu et al., 2013; Aldy, 2014; Allcott and Keniston, 2014; Black et al., 2002; Black et al., 2005; Vachon, 2015a).

While my findings suggest large impacts of earnings on net migration, there are two primary limitations to this study. First, this paper examines permanent rather than temporary

\[ \text{While largely based on Slaughter’s (2001) estimates, these demand elasticities are consistent with those in the literature, including Hammermesh (1996).} \]
Permanent migrants should be less elastic in their response to changes in earnings than temporary migrants as the fixed costs associated with a permanent move are relatively high. Anecdotal evidence suggests large increases in temporary in-migration, especially in oil-rich counties. In addition, the focus of the current paper on permanent migration implies that these migrants viewed the shock as permanent rather than transitory.

Finally, the three-state region I examine in this paper is less populous and more rural than the rest of the United States. As such, caution should be taken when attempting to generalize these estimates beyond the three-state region. These caveats provide natural avenues for future research. Estimating temporary migration into the region and expanding this analysis beyond the three-state region to other areas impacted by the national shale boom are important extensions, as they may shed new light on this relationship between earnings growth and migration.

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9 The IRS data used in this paper measures those who filed federal income tax returns as residents of the three-state region.
10 I am currently working to procure North Dakota state income tax return data, which measures those who earn money in the state, including both permanent and temporary workers.
Figure 1 – Local Labor Markets and Migration
Figure 2 – Petroleum Geology and Extraction
Figure 3 – Historical North Dakota Oil Production and Prices

North Dakota Oil Production and the Real Price of Oil: 1952-2012

2000: First combined use of horizontal drilling and hydraulic fracturing in TX
2004: First successful horizontal/fracturing well in Bakken

Thousands of Barrels of Oil Produced

Real Price of Oil (2010$)

- ND Production
- Real Price of Oil (2010$)
Figure 4 – Oil Reserves in Montana, North Dakota, and South Dakota
Figure 5a – Quartile of Average Annual Earnings Growth:
Montana, North Dakota, and South Dakota, 1993-2004

Figure 5b – Quartile of Average Annual Earnings Growth:
Montana, North Dakota, and South Dakota, 2005-2010

Legend:
- First Quartile
- Second Quartile
- Third Quartile
- Fourth Quartile
Figure 6a – Quartile of Average Change in Net Migration: Montana, North Dakota, and South Dakota, 1993-2004

Figure 6b – Quartile of Average Change in Net Migration: Montana, North Dakota, and South Dakota, 2005-2010
Table 1 - Sample Means by Period: Montana, North Dakota, and South Dakota, 1993-2004 and 2005-2010

<table>
<thead>
<tr>
<th>Panel A: Sample Means (1993-2010)</th>
<th>All Counties (1)</th>
<th>Oil Counties (2)</th>
<th>No Oil Counties (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Returns In</td>
<td>385.3</td>
<td>196.0</td>
<td>427.7</td>
</tr>
<tr>
<td>Returns Out</td>
<td>388.3</td>
<td>215.8</td>
<td>426.9</td>
</tr>
<tr>
<td>Net Migration</td>
<td>-2.9</td>
<td>-19.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Total Returns (Households)</td>
<td>5556.1</td>
<td>3206.1</td>
<td>6131.9</td>
</tr>
<tr>
<td>Net Migration Rate</td>
<td>-0.008</td>
<td>-0.010</td>
<td>-0.008</td>
</tr>
<tr>
<td>Total Exemptions (Population)</td>
<td>11798.9</td>
<td>7048.1</td>
<td>12963.0</td>
</tr>
<tr>
<td>County Earnings per Return (Thousands of 2010$)</td>
<td>27.03</td>
<td>26.1</td>
<td>27.3</td>
</tr>
<tr>
<td>Logarithmic Difference in Earnings</td>
<td>0.009</td>
<td>0.016</td>
<td>0.007</td>
</tr>
<tr>
<td>Oil Reserves (Thousands of Barrels)</td>
<td>43,993.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Texas Intermediate Crude Oil Price per Barrel (2010$)</td>
<td>45.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logarithmic Difference in the Value of Oil Reserves</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Panel B: Pre-Boom (1993-2004)

| Returns In                        | 372.0596         | 182.9            | 414.3             |
| Returns Out                       | 382.9537         | 218.5            | 419.7             |
| Net Migration                     | -10.9            | -35.6            | -5.4              |
| Total Returns (Households)        | 5,282.8          | 3,109.2          | 5,842.6           |
| Net Migration Rate                | -0.01            | -0.015           | -0.009            |
| Total Exemptions (Population)     | 11,551.2         | 7,065.9          | 12,706.4          |
| County Earnings per Return (Thousands of 2010$) | 26.2          | 24.5             | 26.7              |
| Logarithmic Difference in Earnings| 0.016            | 0.017            | 0.015             |
| Oil Reserves (Thousands of Barrels) | 43,993.7       |                 |                   |
| West Texas Intermediate Crude Oil Price per Barrel (2010$) | 30.8        |                 |                   |
| Logarithmic Difference in the Value of Oil Reserves | 0.049              |                 |                   |

Panel C: Oil Boom (2005-2010)

| Returns In                        | 411.8            | 222.0            | 454.6             |
| Returns Out                       | 399.0            | 210.4            | 441.5             |
| Net Migration                     | 12.9             | 11.6             | 13.2              |
| Total Returns (Households)        | 6034.0           | 3395.9           | 6624.3            |
| Net Migration Rate                | -0.0045          | -0.0013          | -0.005            |
| Total Exemptions (Population)     | 12,231.9         | 7,013.2          | 13,399.7          |
| County Earnings per Return (Thousands of 2010$) | 28.4          | 29.3             | 28.2              |
| Logarithmic Difference in Earnings| -0.002           | 0.015            | -0.005            |
| Oil Reserves (Thousands of Barrels) | 43,993.7       |                 |                   |
| West Texas Intermediate Crude Oil Price per Barrel (2010$) | 75.7        |                 |                   |
| Logarithmic Difference in the Value of Oil Reserves | 0.084              |                 |                   |
| Number of Counties                | 175              | 32               | 143               |
Table 2 - First-Stage Relationship between Oil Reserve Instruments and Earnings Growth and Land Value Growth:
Montana, North Dakota, and South Dakota, 1993-2010

<table>
<thead>
<tr>
<th></th>
<th>Earnings North Dakota (1)</th>
<th>Earnings Three-State Region (2)</th>
<th>Cropland Value North Dakota (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in the Value of Oil Reserves ($a_1$)</td>
<td>0.025</td>
<td>0.004</td>
<td>-0.087</td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.007)</td>
<td>(0.024)</td>
</tr>
<tr>
<td>Dummy Variable for Post-2004 x Change in the Value of Oil Reserves ($a_2$)</td>
<td>0.041</td>
<td>0.032</td>
<td>0.140</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.013)</td>
<td>(0.043)</td>
</tr>
<tr>
<td>F-Statistic</td>
<td>12.6</td>
<td>3.8</td>
<td>9.1</td>
</tr>
<tr>
<td>Observations</td>
<td>884</td>
<td>2,669</td>
<td>884</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.
Table 3 - Estimates of the Impact of Earnings Growth on Net Migration:
Montana, North Dakota, and South Dakota, 1993-2010

<table>
<thead>
<tr>
<th></th>
<th>North Dakota</th>
<th>Three-State Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLS (1)</td>
<td>IV (2)</td>
</tr>
<tr>
<td>Earnings Growth</td>
<td>0.043 (0.025)</td>
<td>0.214 (0.115)</td>
</tr>
<tr>
<td>Observations</td>
<td>884</td>
<td>884</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.
### Table 4 - Estimates of the Impact of Earnings and Land Value Growth on Net Migration: North Dakota, 1993-2010

<table>
<thead>
<tr>
<th></th>
<th>OLS (1)</th>
<th>IV (2)</th>
<th>IV (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earnings Growth</td>
<td>0.042</td>
<td>0.215</td>
<td>0.213</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.115)</td>
<td>(0.112)</td>
</tr>
<tr>
<td>Cropland Value Growth</td>
<td>-0.005</td>
<td>-0.008</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.007)</td>
<td>(0.059)</td>
</tr>
<tr>
<td>Cropland Value as Endogenous Regressor</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>899</td>
<td>884</td>
<td>884</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.
Table 5 - Spatial IV Estimates of the Impact of Earnings Growth on Net Migration:
North Dakota, 1998-2010

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earnings Growth</td>
<td>0.237</td>
<td>0.281</td>
</tr>
<tr>
<td></td>
<td>(0.134)</td>
<td>(0.115)</td>
</tr>
<tr>
<td>Spatial Error Model</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Observations</td>
<td>673</td>
<td>673</td>
</tr>
</tbody>
</table>

Notes: Standard errors are in parentheses. All models include state-by-year fixed effects. The spatial regression analysis used requires that panel data be strongly balanced. Observations prior to 1998 were dropped due to missing values. For the same reason, one county with missing data after 1998 was also dropped from the sample.
Chapter 2

Local Labor Market Conditions and the Federal Disability Insurance Program: New Evidence from the Bakken Oil Boom

I. Introduction

The Social Security Disability Insurance (DI) program is the largest income replacement program in the United States for non-elderly adults (Autor and Duggan, 2003; Black et al., 2002). Furthermore, the DI program has been growing in real terms since the 1970s. In 2013, there were approximately 9 million individuals in the United States receiving nearly $120 billion in DI benefits. This represents an increase from nearly 5 million beneficiaries receiving about $50 billion in benefits in 2000.¹ This decades-long expansion of DI expenditures coincided with a well-documented decline in wages and labor force participation of low-skilled workers. Various explanations for this secular change in labor force participation include skill-biased technological change, the increase in import penetration and labor outsourcing, and the decline in unionization, among others.² Since DI is more attractive as outside options decline, a key question is the extent to which secular changes in the labor market have led to increases in DI program participation.³

A fundamental empirical challenge in this literature is that, in equilibrium, earnings, employment, and DI participation are jointly determined, making it difficult to estimate a causal

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¹ These estimates come from the Statistical Abstract of the United States, Table 545 (US Census Bureau, 2012).
² See Bound and Johnson (1992).
relationship between labor market conditions and DI payments and participation.\(^4\) In particular, it is difficult to separate the effects of labor demand shocks from labor supply shocks. Positive shocks to labor demand increase the value of labor force participation, thus making employment options seem more attractive. Labor supply shocks, including increases in DI benefit generosity, increase the value of DI participation relative to labor force participation.

The previous literature has attempted to separate the impacts of these two shocks. Black et al. (2002) exploited shocks to labor demand from the coal boom and bust of the 1970s and 1980s in Appalachia (Kentucky, Ohio, Pennsylvania, and West Virginia).\(^5\) In particular, the boom in coal production coincided with a dramatic rise in world coal prices. The coal boom represented a favorable shock to labor demand that increased earnings in coal-producing regions. Following the boom, a steep decline in world coal prices led to a sharp decline in U.S. coal production, resulting in an adverse labor demand shock to coal producing areas. Black et al. (2002) focused on the coal-producing four-state region in Appalachia. Natural endowments of coal varied across counties and the value of coal changed over time, generating county-by-time variation in the value of coal reserves. Therefore, the demand for labor varied across counties, with the value of coal reserves, in a way that was plausibly uncorrelated with changes to labor supply and the DI program. Using an instrumental variable (IV) strategy, they estimated the causal impact of this shock to local economic conditions on DI program participation, finding that, during the coal bust, workers in coal counties saw their earnings fall 13.5 percent relative to

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\(^4\) An increase in county-level earnings will increase both employment and the value of an individual’s potential DI payments. The value of individual DI payments is expected to increase due to the increase in earnings, which increases the level of income replacement from DI.

\(^5\) Other studies have further examined the extent to which economic conditions impact growth in DI participation. Rupp and Stapleton (1995) summarize earlier work exploring the relationship between unemployment rates and DI participation. These works generally find that a 1 percentage point increase in the unemployment rate increases DI awards by between 2 and 6 percentage points, with some studies finding a negligible effect (Hambor, 1975 and 1992; Lando, 1979; Levy and Krute, 1983; Muller, 1982).
those in counties without coal. For the DI program, they found that the elasticity of payments 
with respect to local earnings is approximately -0.4.

In a second influential study, Autor and Duggan (2003) used an IV strategy to identify 
exogenous variation in both the supply and demand of DI benefits. They emphasized the role that 
1984 programmatic changes that increased benefit generosity, as well as rising replacement rates, 
play in the financial incentive to apply for DI. These changes increased the supply of benefits. At 
the same time, the declining demand for less-skilled workers coincided with changes that 
liberalized the DI screening process, increasing the demand for DI benefits. They argued that the 
interaction between the progressive formula used in determining replacement rates and rising 
earnings inequality from the decrease in labor demand resulted in the relative increase of 
replacement rates for low-skilled workers.  
6 This effectively increased the value of participation 
in the DI program, and decreased the value of labor force participation, for low-skilled workers.

In the current paper, I attempt to identify the effect of labor market conditions on DI, 
 focusing on a positive labor demand shock that changes the value of labor force participation. 
This increase in the value of labor force participation, in turn, impacts DI caseloads and 
payments. In an analysis that largely follows Black et al. (2002), I exploit exogenous time-series 
and spatial variation in earnings growth for counties in Montana, North Dakota, and South 
Dakota (henceforth known as “the three-state region”) due to a boom in oil production in the 
Bakken formation of the Williston Basin. In particular, for the oil-rich counties in these states, 
the oil boom led to an exogenous shock to the value of labor force participation that increased 
earnings. Yearly oil production in these states more than quintupled from approximately 50 
million barrels of oil in 2000 to 250 million barrels of oil in 2010. This boom in oil production is

6 According to Autor and Duggan (2003), real weekly earnings of full-time workers with less than a high school 
degree fell by 19.1 percentage points between 1975 and 1999. During the same period, the SSA’s mean wage series 
increased by 21.6 percentage points in real terms.
part of a larger increase in oil and natural gas production in the United States that was made possible by a combination of rising oil prices and advancements in extraction technologies, including horizontal drilling and hydraulic fracturing, colloquially known as fracking. Much of the oil activity and, by extension, economic activity takes place around the Bakken formation, where there are large amounts of proven reserves. The oil boom differentially impacts counties with oil in a way that is plausibly uncorrelated with the DI program.

To circumvent the identification problems discussed above, I estimate a causal relationship between earnings and DI payments and participation using the value of county oil reserves as an instrument for earnings. I implement this IV strategy using a county-level panel dataset of administrative earnings data from the Internal Revenue Service (IRS) and DI payment and participation data from the Social Security Administration (SSA) for 2000 through 2009. I construct the instrument using oil reserves data and West Texas Intermediate (WTI) crude oil prices from the U.S. Department of Energy’s Energy Information Administration (EIA). This methodology allows me to exploit natural variation in oil reserves across counties and time-series variation in oil prices.

This paper differs from the Black et al. (2002) paper in three ways. First, labor market conditions have changed markedly, particularly for low-skilled workers, since the 1970s, impacting labor force attachment. Second, programmatic and systematic changes to DI benefits effectively increased program generosity, increasing the demand for benefits.7 Autor and Duggan (2003) exploit these changes, finding a strong interaction between changes to DI benefits and the secular change in labor force participation of low-skilled workers. This interaction suggests labor force attachment and the relationship between DI and economic

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7 Due to a 1984 eligibility policy change, DI beneficiaries are now younger and suffer from more musculoskeletal conditions and mental impairments (Bound and Waidmann, 2002; Autor and Duggan, 2006; Duggan and Imberman, 2009; von Wachter et al., 2011).
conditions have changed over time. Finally, this analysis of the oil boom in the three-state region is temporally and geographically different from that of Black et al. (2002).

Overall, my IV estimates suggest that there is a substantial, statistically significant negative relationship between local economic conditions and DI payments and participation. I estimate the elasticities of DI payments and participation with respect to local earnings for the three-state region. I find an elasticity of DI payments with respect to local earnings of -1 and an elasticity of participation with respect to local earnings of -0.7. These estimates suggest that the oil boom led to decreases in payments and participation that were 2.5 percent and 1.6 percent greater for oil counties, compared to counties without oil. While qualitatively similar, these estimates are quantitatively larger than those of Black et al. (2002).8 To the extent that the labor demand shock differentially impacted low-skilled workers in the three-state region, these estimates are consistent with both Black et al. (2002) and Autor and Duggan (2003). Beyond providing these new estimates, this paper contributes to a growing body of literature that examines the impact of natural resource booms on various labor market outcomes, such as earnings, employment, migration, and social insurance (Acemoglu et al., 2013; Aldy, 2014; Allcott and Keniston, 2014; Black et al., 2002; Black et al., 2005; Vachon, 2015b).

The rest of this paper proceeds as follows. Section II presents a description of the DI program. Section III provides an overview of the oil boom; the exposition of this section largely draws upon that in Vachon (2015b). Section IV describes the econometric specifications. Section V presents the identification strategy. Section VI outlines the results. Section VII describes the impact of the boom on DI caseloads. Section VIII presents possible program interactions between DI and other SSA programs, and Section IX concludes.

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8 For the DI program, Black et al. (2002) find that the elasticity of payments with respect to local earnings is between -0.3 and -0.4. This estimate corresponds to a differential decrease in DI payments of 1.26 percent for Appalachian coal counties, compared to counties without coal.
II. DI Program Background

The DI program provides income replacement for disabled former workers and is part of the Social Security safety net. To qualify for DI benefits, an individual must be deemed disabled by SSA and meet minimum work history and earnings requirements (the “recent work test”). For example, to meet the recent work test, workers 31 years old and older must have worked during 5 years out of the 10-year period (20 out of the past 40 quarters) ending with the quarter the disability began. According to SSA rules, an individual is deemed disabled if he or she is unable “to engage in substantial gainful activity by reason of a physical or mental impairment.” In 2013, “substantial” employment was determined by an individual’s ability to earn more than $1,040 per month. In addition, the impairment must last for at least 12 months or be expected to result in death. While the eligibility criteria for the federal DI program are uniform across states, applicants file their claims to state-appointed boards.

SSA maintains a list of work-limiting impairments that qualify individuals for benefits. If individuals have conditions not on this list, however, they may still qualify for benefits if physicians determine that the conditions result in sufficient impairment. In making the determination of impairment, the applicant's age, education, and work experience are also considered when deciding whether an applicant is able to work. Such work does not need to exist in the area in which the applicant resides, nor does there need to exist a job vacancy for the individual.

DI payments are based on past earnings. The determination of an individual’s DI benefits proceeds in two steps (Autor and Duggan, 2003). First, the beneficiary’s Average Indexed Monthly Earnings (AIME) is calculated as

\[ AIME = \frac{1}{T} \sum_{t=1}^{T} Y_t \]
where \(Y_t\) is real monthly earnings. Second, DI benefits awarded, the Primary Insurance Amount (PIA), are calculated using the following formula:

\[
P\_\text{IA} = \begin{cases} 
0.9 \times AIME & \text{if } AIME \in [0, b_1] \\
0.9 \times b_1 + 0.32 \times (AIME - b_1) & \text{if } AIME \in [b_1, b_2] \\
0.9 \times b_1 + 0.32 \times (b_2 - b_1) + 0.15 \times (AIME - b_2) & \text{if } AIME > b_2
\end{cases}
\]

where \(b_1\) and \(b_2\) are the “bend points,” or kink points, above which the level of income replacement decreases; these bend points are also adjusted each year to reflect growth in wages. As illustrated in (2), the benefits formula is concave. Although high-income individuals receive more benefits from DI than low-income individuals, this concavity means that the program is progressive. Consequently, low-income workers have higher replacement rates (the fraction of one’s income that can be replaced with DI benefits) than high-income workers. Therefore, the relative reduction in income resulting from labor market withdrawal is smaller for disabled, low-wage workers than for disabled, high-wage workers.

This description of the DI benefit calculation further illustrates the identification problem outlined in the introduction. Earnings, employment and DI are jointly determined in the labor market. That is, an increase in earnings will increase both employment and the value of an individual’s potential DI payments.

In 1984, Congress passed legislation that greatly liberalized the DI system. Generally, the 1984 reforms broadened the definition of disability and provided applicants and doctors greater opportunity to influence the decision process.\(^9\) Three core features of the 1984 legislation contributed to the expansion of the DI program. First, mental illness screening guidelines were relaxed, placing more weight on the individual’s ability to function in a workplace. Second, additional weight was placed on general pain in the disability determination process. Finally,

\(^9\) See Autor and Duggan (2003), Goodman and Waidmann (2003), and Burkhauser and Daly (2011) for more detailed discussions of these policy changes.
criteria were relaxed such that an individual would qualify for DI if he or she had numerous impairments, that alone would not qualify him or her for benefits, but together which could prevent the individual from participating in gainful activity. At the same time, Continuing Disability Reviews became much less common. As a result, fewer beneficiaries were terminated for failing to meet eligibility requirements.10

The analysis in this paper provides new estimates that, in a reduced-form sense, reflect these secular changes in the labor market over time as well as the effects of DI liberalization on labor force participation for current workers. Following Black et al. (2002), I exploit an exogenous shock to labor demand from the Bakken oil boom that increases earnings in the three-state region of Montana, North Dakota, and South Dakota. I describe the economic forces behind the boom in the next section.

III. Oil Boom Background

The source of oil is organic matter that is preserved and buried in some sedimentary rocks. Three important geological criteria must be met for an oil deposit to be considered for commercial production (Hyne, 2012). First, a subsurface source rock must have generated the oil (see Figure 1). The most common source rock is black shale. Black shale originated as organic matter-rich mud on ancient seafloors.11 As the black shale source rock was covered with more and more sediments and buried further below the Earth’s surface, the heat from geological pressure turned the organic matter into oil. Second, a separate subsurface reservoir rock must hold the oil. Reservoir rocks are sedimentary rock layers that contain billions of tiny spaces, or

10 Studies on these compositional changes resulting from liberalization find that DI applicants and beneficiaries are now younger and suffer from more musculoskeletal conditions and mental impairments (Autor and Duggan, 2006; Bound and Waidmann, 2002; Duggan and Imberman, 2009; von Wachter et al., 2011).
11 The shale oil extracted from the Bakken was formed approximately 350 million years ago during the late Devonian and early Mississippian geologic periods (Hyne, 2012).
pores. Sandstone (composed of compressed grains of sand) and limestone (composed of broken down seashells and corals) are common reservoir rocks. Oil is able to flow through sandstone, limestone, and other reservoir rocks through the pore spaces between the sediments. Third, a geological trap and cap rock must concentrate the oil into commercially extractable quantities. The trap is a geological high point in the formation which prevents the oil from flowing upward, and the cap rock is a seal that prevents oil from flowing through it, concentrating the oil in the reservoir rock.

In “conventional” oil extraction, a well is drilled into the reservoir rock. Such methods characterized oil production in the United States, including North Dakota, for much of the previous century. In contrast, the recent shale oil boom involves drilling into and extracting resources from the shale source rock. Shale is less porous and permeable than typical reservoir rocks (i.e. sandstone and limestone, among others) (Maugeri, 2012). Shale oil and gas are often referred to as “unconventional” resources because of their geology as well as the techniques used in extraction. Shale oil is extracted using the combined application of horizontal drilling and fracking techniques. Horizontal drilling is effective in shale formations because a greater portion of a well’s surface area is exposed to the oil-rich rock as compared to traditional vertical drilling. Hydraulic fracturing is the process of injecting large volumes of fluids into a well to fracture the rock (shale, in this case). The fluid used is generally combined with sand before it is injected. The sand particles, known as propping agents, hold open the fractures in the shale, allowing oil to flow into the well (Hyne, 2012).

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12 While the focus of this paper is on the Bakken formation, the explanations of the geology of fossil fuels and extraction technologies can generally be applied to other regions with shale oil and gas reserves and extraction (i.e. Marcellus and Utica in the Appalachian region, Eagle Ford and Barnett in Texas, and Woodford in Oklahoma, among others).
Figure 2 presents price and production data for North Dakota, since production began in 1952. Geologists and petroleum experts have been aware of oil reserves in western North Dakota since the middle of the previous century when Amerada Petroleum Corporation drilled the area’s first commercial oil well at the Clarence Iversen farm in Tioga, North Dakota in 1951. However, later that year Amerada made another important discovery at the Henry O. Bakken farm, also in Tioga. The Bakken well is important because it was the first in the area drilled into the older (deeper) geologic formation that became known as the Bakken formation. From 1951 through the 1970s, oil production averaged a modest 20 million to 25 million barrels per year. In the late 1970s and early 1980s, rising oil prices, as a result of the 1973 OPEC embargo and the oil crisis of 1979, led to a boom in oil production in North Dakota. Even with record-high oil prices, annual production peaked at approximately 50 million barrels in 1984, compared to nearly 900 million barrels produced in Texas (EIA, 2014).

While oil companies have had access to the technologies of fracking and horizontal drilling for some time, their combined application was not successful until 2000 when Mitchell Energy extracted natural gas from the Barnett shale in Texas (Maugeri, 2012). In North Dakota’s Bakken, Continental Resources is credited with drilling the first commercially successful combined horizontal drilling and hydraulic fracturing oil well in 2004 (Continental Resources, 2014). North Dakota oil production hit nearly 250 million barrels in 2012 and continues to increase. Production resulting from this most recent boom dwarfs that of the 1980s.

IV. Econometric Specifications

The goal of this paper is to provide evidence of a causal relationship between local labor market conditions and DI program participation. I begin this empirical analysis by examining the
relationship between county-level earnings and DI payments and program participation. Treating the county as the local labor market, I present the relationship between local earnings and DI payments as:

\( \ln(d_{ist}) = \varphi + \beta \ln(y_{ist}) + \varepsilon_{ist}, \)

where \( \ln(d_{ist}) \) represents the natural logarithm of the value of DI payments or the number of DI participants for county \( i \) in state \( s \) in year \( t \), and \( \varepsilon_{ist} \) is the error term. The main explanatory variable is \( \ln(y_{ist}) \), the natural logarithm of real earnings. The focal parameter \( \beta \) represents the elasticity of the value of DI payments or participation with respect to local earnings.

I model \( \varepsilon \) as

\( \varepsilon_{ist} = \pi_i + \tau_t + \phi_{st} + \mu_{ist}, \)

where \( \pi \) represents a county-specific fixed effect, and \( \tau \) represents a linear time trend. To account for this county fixed effect, I first difference (3) to yield:

\( \Delta \ln(d)_{ist} = \delta + \beta \Delta \ln(y_{ist}) + \omega_{ist}, \)

where \( \Delta \) indicates a first difference, and \( \omega \) is the differenced error term from (4):

\( \omega_{ist} = \gamma_{st} + u_{ist}. \)

\( \gamma_{st} \equiv \Delta \phi_{st} \) is a state-by-year fixed effect, and \( \delta \) is the new intercept, where \( \delta \equiv \Delta \tau_t \).

I construct a county-level dataset of aggregate earnings and DI payments and participation for the three-state region from 2000 through 2009. I use administrative earnings data from the IRS Statistics of Income (SOI) based on federal income tax returns. The IRS data contain information regarding wage and salary income. SSA Old-Age, Survivors, and Disability Insurance (OASDI) administrative data contain DI recipient count and benefit information. I measure real earnings and real values of payments at the county level in 2009 dollars, adjusted for inflation using the Consumer Price Index (CPI).
Table 1 presents summary statistics for the entire sample period. Montana, North Dakota, and South Dakota are small states; according to the 2000 Census, their respective populations were 902,000, 642,000, and 755,000. From column 1, the average population per county is 13,500. Average annual earnings growth is 1.5 percent. Throughout the period of interest, the three-state region experienced average annual increases in DI payments and participation of 4.4 percent and 3.5 percent, respectively.

The OLS estimates of $\beta$ in column 1 of Table 2 indicate a fairly weak link between earnings growth and DI payment growth. I find an elasticity of DI payments with respect to county earnings of -0.15. In addition, following Black et al. (2002), I add to (5) a vector of control variables, $x_{ist}$, that includes county Metropolitan Statistical Area (MSA) status and the logarithm and log difference of county population as well as the share of workers in manufacturing in 1999. These results are presented in column 2 of Table 2. Again, I find an elasticity of DI payments with respect to county earnings of -0.15. These OLS estimates suggest that a 10 percent increase in county earnings would result in an approximately 1.5 percent decrease in the value of DI payments in the county. The estimates also show a small, statistically insignificant negative relationship between DI payments and county earnings growth. In columns 3 and 4 of Table 2, I repeat the analysis for DI beneficiaries rather than payments. Again, OLS estimates indicate a small, negative relationship between earnings growth and growth in the number of DI beneficiaries. I find an elasticity of approximately -0.16. Based on these OLS estimates, a 10 percent increase in county earnings would result in an approximately 1.6 percent

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13 I control for whether or not the county is in a Metropolitan Statistical Area for the 2000 Census due to the concern that persons with disabilities may move to a metropolitan area for better access to health care. Controls for population serve as a proxy for access to medical care and the provision of public services, amenities which may attract individuals with disabilities.
decrease in the number of DI beneficiaries in the county. In both cases, the estimates do not appear sensitive to the inclusion of control variables.

V. Identification Strategy

In the previous sections, I outlined the central challenge of estimating the relationship between earnings growth and DI payments and participation. As employment, earnings, and DI are jointly determined at the labor market level, increases in earnings at the county level will increase employment and the value of individual DI payments. Consequently, I expect OLS estimates of the focal parameter, $\beta$, to be biased upward to zero. To surmount this challenge, I estimate the parameters in (5) using an IV strategy following Black et al. (2002) and Vachon (2015b). This strategy is based on natural variation in county-level oil reserves. The oil reserve data used in this analysis come from the 2004 EIA assessment of the Bakken formation of the Williston Basin and the 2001 assessments of Montana Thrust Belt and Powder River Basin. I calculate oil reserves using EIA shape files and MapInfo software. I use midpoint estimates for each oil field, as the reserves are listed in ranges, then aggregate to the county level. Based on this method, there are 32 counties in the three-state region that have oil reserves, and 143 counties that have no reserves. From column 2 of Table 3, the average oil county has nearly forty-four million barrels of oil reserves. I calculate the value of oil reserves by multiplying county-level reserves by the price of West Texas Intermediate (WTI) crude oil, also obtained from the EIA. From Panels A and B of Table 3, the average price per barrel of WTI crude oil increased from $38 to $75 between the early and later years of the oil boom. I use the value of oil
reserves as an instrument for earnings to econometrically capture the impact of the oil price-generated increase in local labor market earnings on DI.14

Figures 3 through 5 present a visual depiction of my identification strategy. Estimates are based on data from 2000-2009. Figure 3 shows the level of oil reserves for the Bakken formation of the Williston Basin (eastern Montana, western North Dakota, and northwest South Dakota), Montana Thrust Belt (northwestern Montana), and Powder River Basin (southeast Montana and southwest South Dakota). The counties with the darkest shading have the highest levels of oil reserves; those areas that are white have no oil reserves. The darkest shaded counties have between 50 and 217 million barrels of oil. The counties shaded in dark gray have between 5 and 50 million barrels of oil. The counties shaded in the light gray have less than less than 5 million barrels of oil (but more than zero). The most oil-rich part of the region is the Bakken formation of the Williston Basin.

Figure 4 represents quartiles of average annual earnings growth rates. The areas with the darkest shading have the greatest increases in average annual earnings growth over the timeframe. The first through fourth quartiles represent income growth below 0.6 percent, between 0.6 percent and 1.4 percent, between 1.4 percent and 2.2 percent, and above 2.3 percent, respectively. The lowest growth county experienced a 1.7 percent decrease in average annual earnings; the highest growth county experienced a 7.5 percent increase.

Figure 5 depicts quartiles of average annual DI payment growth rates at the county level. Areas with the darkest shading have the highest growth in DI payments. The first through fourth quartiles represent DI payment growth below 3 percent, between 3.1 percent and 4.4 percent,

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14 During the late part of the oil boom from 2005 through 2009, oil production in the Bakken increased from 1 million to 5 million barrels per month. In 2009, oil production in the Bakken was approximately 3 percent of the US total monthly oil production. From 2009 to 2012, oil production in the Bakken increased from 5 million to 22 million barrels per month. In 2012, oil production in the Bakken represented approximately 10 percent of the US total monthly oil production (Federal Reserve Bank of Minneapolis, 2012).
between 4.9 percent and 5.5 percent, and above 5.5 percent, respectively. The county with the lowest DI payment growth experienced a 4.7 percent decrease in payments; the county with the highest payment growth experienced a 12.7 percent increase in payments.

Figures 3 and 4 represent the first-stage relationship between oil reserves and earnings growth. Those counties with high earnings growth have the highest levels of oil reserves, as evidenced by the dark shading on both maps. The reverse is also true; areas with low earnings growth have little to no oil reserves. Figures 3 and 5 represent the reduced-form relationship between oil reserves and DI payments. There is a negative relationship between oil reserves and growth in DI payments. Those areas with high levels of oil reserves have low levels of DI payment growth. This is evidenced by the fact that high oil reserve counties are more darkly shaded while low DI payment growth counties are lightly shaded.

VI. Estimation and Results

I move beyond the graphical analysis to IV estimation. The first-stage of the IV estimation is:

\[(7) \quad \Delta ln(y_{ist}) = \rho + \alpha Z_{ist} + \gamma_{st} + u_{ist},\]

where \(Z\) is a vector of instruments. The key instrument is the log difference of oil reserve value, \(\Delta ln(v_{ist})\).\(^{15}\) The value of county oil reserves, \(v\), is measured in 2009 dollars, adjusted for inflation using the CPI. This varies over time with oil prices, generating county-by-time variation in the value of oil reserves that is plausibly exogenous. The value of oil reserves changes earnings through the increased demand for labor.

\(^{15}\) Following Black et al. (2002), the log difference in the value of oil reserves and two of its lags are the elements of the vector of instruments, \(Z\). Estimates from specifications relying on the complete instrument set are presented in this paper and do not differ quantitatively from those in specifications where only the key instrument (log difference in the value of oil reserves) is used.
Table 4 presents estimates of $\alpha$ from (7). These estimates illustrate the relationship between growth in the value of oil reserves and earnings growth. The estimate in column 1 implies that a doubling in the value of oil reserves leads to a 4.5 percent increase in county-level earnings. The associated F-statistic is 9.03, suggesting that the value of oil reserves is a relatively strong instrument. From column 2, adding a vector of control variables, $x_{ist}$, increases the point estimate to 4.8 and the F-statistic to 9.8. Following Black et al. (2002), columns 3 and 4 show additional first-stage estimates that add two lags of the log difference of the value of oil reserves to the instrument set, where the estimates in column 4 reflect the addition of the vector of control variables. In principle, expanding the instrument set should increase the power of the first stage. In practice, the F-statistic increases to 10.4 for the model without a vector of control variables and 11.4 for the model with control variables, suggesting that the value of oil reserves and two lagged values make a stronger instrument set. The estimates in column 4 suggest that a doubling in the value of oil reserves in the current year leads to a 4.9 percent increase in county-level earnings. The estimates for the lagged value of oil reserves suggest a doubling in the value of oil reserves in the previous year increases earnings by 6.7 percent while a doubling two years prior increases earnings by 2.1 percent.

Columns 1 and 2 of Table 5 present the IV estimates of $\beta$ using the broader instrument set with and without control variables. These estimates suggest a strong, statistically significant impact of earnings growth on DI expenditures. The point estimate in column 2 shows an elasticity of DI payments with respect to earnings growth of -1. This estimate implies that a 10 percent increase in a county’s earnings would result in a decrease in DI payments within the

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16 Estimates of $\beta$ using only the value of oil reserves (and no lagged values) are both qualitatively and quantitatively similar to those using the more robust instrument set.
county of nearly 10 percent. Clearly, increases in county earnings substantially decrease DI payments.

In columns 3 and 4 of Table 5, I provide the IV estimates of $\beta$ with the logarithmic difference in the number of county DI beneficiaries as the dependent variable. Again, these estimates are presented with and without the control variables, and the addition of controls does not seem to impact the results. The point estimate of -0.7 in column 4 represents the elasticity of DI payments with respect to earnings growth. This estimate implies that a 10 percent increase in a county’s earnings would result in a decrease in DI participation within the county by nearly 7 percent. This represents a substantial and statistically significant inverse relationship between county earnings growth and growth in the number of DI beneficiaries in the county. During the oil boom, oil counties experienced annual earnings growth that was 2.4 percent greater than counties without oil. This growth differential combined with the point estimates from Table 5 suggest the oil boom led to a 2.5 percent decrease in DI payments and a 1.6 percent decrease in participation in oil counties relative to counties without oil.

As a final robustness check, I use an estimator that follows Cliff and Ord’s seminal work (1973 and 1981) to provide IV estimates of the relationship between local economic conditions and net migration that account for spatial autocorrelation. I generate an inverse-distance spatial weighting matrix (spatial correlation decreases with the distance between two counties), where distance is measured between the geographic center of one county and another. Table 6 presents IV estimates from the spatial error model of the relationship between local labor market conditions and net migration rates for North Dakota. The estimates from the spatial error model in Table 6 suggest that a 10 percent increase in earnings will reduce DI payments by 13 percent and DI participation by 12 percent. The estimates of the elasticities of DI payments and

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17 These specifications use only the first difference of the natural logarithm of oil reserves as an instrument.
participation with respect to earnings growth are quantitatively similar to my primary estimates from Table 5.

**VII. Changes in DI Caseloads**

DI participation changes largely through changes in the number of new DI cases. As such, I use the estimates presented in this paper to provide a back-of-the-envelope calculation of the rate of reduction in new cases as a result of the oil boom. Following Black et al. (2002), if expenditures are equal across cases, changes in expenditures can be expressed as:

\[
\Delta E_t = N_t - \rho E_{t-1}
\]

where \(\Delta E_t\) is the change in expenditures, \(N_t\) is expenditures resulting from new cases, \(\rho\) is the rate at which old cases leave the DI rolls, and \(E_{t-1}\) is the level of expenditures in the previous period. Dividing both sides of (8) by \(E_{t-1}\) yields:

\[
\%\Delta E = \frac{N_t}{E_{t-1}} - \rho.
\]

From the 2000 through 2010 SSA Annual Statistical Supplements, the annual rate of outflows, \(\rho\), appears to be 8 percent of total caseloads. There are three main components to the outflow rate, \(\rho\): “aging out” of DI by reaching the full retirement age, death, and “recovery” from the work-limiting disability.\(^{18}\) Between 2000 and 2009, DI expenditures grew at an annual rate of approximately 6 percent. As \(\%\Delta E = 0.06\), the rate of inflows, \(N_t/E_{t-1}\), must equal 0.14. If the oil boom reduces DI expenditures through changes in the inflow of new cases, for oil counties:

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\(^{18}\) Based on data from the 2000 through 2009 SSA Annual Statistical Supplements, approximately 3.5 percent of caseloads age out by reaching full retirement age, 3 percent die, and less than 1 percent recovers. Full retirement age is the age at which individuals receive 100 percent of the benefits for which they are eligible. For individuals born prior to 1938, full retirement age is 65; the full retirement age gradually increases to 67 for those born in 1960 or later.
(10) \[ \% \Delta E^{oil} = (1 - \theta) \left( \frac{N_t}{E_{t-1}} \right) - \rho \]

where \( \theta < 1 \) represents the reduction in new cases resulting from the coal boom. From (10), it follows that

(11) \[ \% \Delta E - \% \Delta E^{oil} = \theta \times 0.14. \]

Because the boom led to a 2.5 percent decrease in DI payments, \( \theta = 0.25 \), so the increase in earnings reduced new DI entrants by 25 percent. However, this calculation does not take into consideration the impact the boom had on migration, which could potentially affect program outflows. In Vachon (2015b), I find that the boom increased the net migration rate in oil counties by 2.6 percentage points from -1.5 percent to 1.1 percent. Mean net migration rates range from -5.8 percent (out-migration) to 7.2 percent (in-migration). Assuming DI beneficiaries have the same net migration rate as the county, (10) becomes:

(12) \[ \% \Delta E^{oil} = (1 - \theta) \left( \frac{N_t}{E_{t-1}} \right) - \rho - \mu, \]

where \(-0.058 \leq \mu \leq 0.072\) is the net migration rate. Accounting for migration, the rate of reduction of new cases arising from the oil boom, \( \theta \), ranges from 16.5 percent to 42.7 percent. These calculations overestimate the responsiveness of new entrants to changes in earnings if some of the existing DI caseloads did return to work.

VIII. SSA Program Interactions

Applicants and beneficiaries for two other SSA programs – Social Security retirement (OAS) and Supplemental Security Income (SSI) – may be sensitive to changes in local economic conditions. The responsiveness of these programs to changes in earnings and local labor market conditions suggests the possibility of program interactions with DI. As mentioned in the previous
section, aging out of DI into OAS is the primary mechanism for outflows from the DI rolls. SSI is a means-tested welfare program, and beneficiaries may be jointly eligible for SSI and DI. In 2009, nearly 85 percent of SSI beneficiaries were disabled (SSA Annual Statistical Supplement, 2010).

Table 7 presents IV estimates of the impact of earnings growth on OAS and SSI payments and participation. While many of these coefficient estimates are not statistically significant at conventional levels, their magnitudes may shed light on the impact of the boom on other SSA programs as well as their interactions with the DI program. Columns 1 and 2 present estimates of the income elasticity of OAS payments and participation. These estimates suggest that a 10 percent increase in earnings will reduce OAS payments by 2.8 percent and participation by 2 percent. The estimates in column 3 suggest that a 10 percent increase in earnings reduces payments per beneficiary by 0.4 percent. The positive shock to earnings may reduce OAS payments and participation in two ways. First is the out-migration of older residents, who are OAS beneficiaries. However, I examine changes in the age distribution using the American Community Survey (ACS) between the pre-boom and boom periods and find no significant changes, providing suggestive evidence that migration is not likely driving these changes. A second explanation is that older workers may see labor force participation and retirement as substitutes and delay retirement decisions in the presence of strong local labor market conditions.

Columns 4 and 5 of Table 7 present estimates of the income elasticity of SSI payments and participation, respectively. These estimates suggest that a 10 percent increase in earnings will reduce SSI payments by nearly 8 percent and participation by 3 percent. The estimate in column 6 suggests that a 10 percent increase in earnings will reduce payments per beneficiary by 0.8 percent. Higher earnings may reduce SSI payments through relative increases in the value of
labor force participation such that workers become ineligible for benefits as earnings rise; this increase in earnings may also preclude disabled family members from eligibility for SSI benefits.

Given that SSI is a means-tested program designed to provide low-income aged and disabled workers with additional income security, the responsiveness of program payments and participation, including joint participation with DI, to changes in local economic conditions may shed light on changes to the income distribution of DI applicants and beneficiaries between the pre-boom and boom periods. As explained in the previous section, changes in DI payments and participation occur largely through reductions in new entrants. Autor and Duggan (2003) refer to those potential beneficiaries who apply for DI benefits in the presence of adverse economic conditions as “conditional applicants.” Finding little or no relationship between earnings growth and joint SSI and DI participation may suggest that these conditional applicants are from higher in the earnings distribution. Column 1 of Table 8 presents IV estimates of the income elasticity of joint SSI and DI participation. The estimate in column 1 suggests a small and statistically insignificant, albeit positive, relationship between earnings growth and joint SSI and DI participation. In addition, the point estimates in tables 5, 7, and 8 suggest that for both DI and SSI, payments, rather than participation, appear to be more sensitive to changes in earnings. That is, for a given change in earnings, the reduction in program payments is larger than the reduction in participation, suggestive of the idea that the conditional applicants, in this case, may be from higher in the income distribution.

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19 I subtract the number of SSI participants who are over 65 from the total for those who are jointly eligible for SSI and OASDI to provide a coarse measure of those who are jointly eligible for SSI and DI.
IX. **Summary, Caveats, and Implications**

In this paper, I use variation in local labor market conditions to estimate the impact of economic growth on DI program participation. The oil boom created an exogenous shock to local economies. I use data from three oil-producing states and use the oil boom as a natural experiment to identify the causal impact of earnings growth on the DI program. Overall, I find that for the DI program, the elasticity of payments with respect to earnings growth is approximately -1; the elasticity of program with respect to earnings growth is approximately -0.7. These estimates suggest the oil boom led to a 2.5 percent decrease in DI payments and a 1.6 percent decrease in participation in oil counties relative to counties without oil.

My research contributes to the literature in two important ways. First, I provide new causal estimates that suggest current workers may exhibit a higher degree of substitutability between DI and labor force participation. These results are substantially larger than the estimates from Black et al. (2002); but my findings are consistent with Autor and Duggan (2003), who suggest that current workers will be more responsive to changes in economic conditions due to various programmatic and systematic changes to DI. Second, this paper contributes to the growing literature examining impact of natural resources on labor market outcomes (Acemoglu et al., 2013; Aldy, 2014; Allcott and Keniston, 2014; Black et al., 2002; Black et al., 2005; Vachon, 2015b).

In addition, between June 2014 and February 2015, oil prices fell by just over 50 percent from $106 to $51 per barrel. This decrease in prices represents a negative shock to local economic conditions. The new estimates that I present in this paper can provide insight into how changes in the price of oil will impact DI payments and participation. Based on my first stage estimates, this decrease in prices will reduce earnings by nearly 2.5 percent. From my IV
estimates, a 50 percent decrease in prices will increase DI payments by 2.6 percent and DI participation by 1.7 percent at the county level. These somewhat speculative estimates assume a symmetric response of economic conditions to increases and decreases in the price of oil.

However, this study has one primary limitation. The three-state region I examine in this paper is more rural and less populous than the Appalachian region examined by Black et al. (2002). These differences could imply a higher level of DI generosity as well as a higher degree of substitutability between labor force participation and DI participation, especially among low-skilled workers. Additionally, it is possible that the concurrent oil boom and Great Recession have contributed to a unique set of local labor market conditions than has been previously studied during other more mild economic downturns. While these results should be interpreted with caution, the caveats provide avenues for future research. Extending the analysis beyond the three-state region to other areas impacted by the shale boom may broaden our understanding of the relationship between local economic conditions and the DI program.
Figure 1 – Petroleum Geology and Extraction
Figure 2 – Historical North Dakota Oil Production and Prices

North Dakota Oil Production and the Real Price of Oil: 1952-2012

- 2000: First combined use of horizontal drilling and hydraulic fracturing in TX
- 2004: First successful horizontal/fracturing well in Bakken

Thousands of Barrels of Oil Produced

Real Price of Oil (2009$)

0 20 40 60 80 100 120


ND Production
Real Price of Oil (2009$)
Figure 3 – Oil Reserves in Montana, North Dakota, and South Dakota

Oil Reserves

- No oil reserves
- Less than 5 million barrels
- Between 5-50 million barrels
- Greater than 50 million barrels
Figure 4 – Quartile of Average Annual Earnings Growth: Montana, North Dakota, and South Dakota, 2000-2009
Figure 5 – Quartile of Average Annual Growth in DI Payments:
Montana, North Dakota, and South Dakota, 2000-2009
<table>
<thead>
<tr>
<th></th>
<th>All Counties</th>
<th>Oil Counties</th>
<th>No Oil Counties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DI Payments (Thousands of 2009$)</strong></td>
<td>252.5</td>
<td>139.1</td>
<td>277.9</td>
</tr>
<tr>
<td><strong>DI Beneficiaries</strong></td>
<td>261.1</td>
<td>146.8</td>
<td>286.7</td>
</tr>
<tr>
<td><strong>Earnings (Thousands of 2009$)</strong></td>
<td>191,553.2</td>
<td>98,829.5</td>
<td>212,302.6</td>
</tr>
<tr>
<td>Logarithmic Difference in DI Payments</td>
<td>0.044</td>
<td>0.032</td>
<td>0.047</td>
</tr>
<tr>
<td>Logarithmic Difference in DI Beneficiaries</td>
<td>0.035</td>
<td>0.026</td>
<td>0.037</td>
</tr>
<tr>
<td>Logarithmic Difference in Earnings</td>
<td>0.015</td>
<td>0.029</td>
<td>0.012</td>
</tr>
<tr>
<td><strong>Oil Reserves (Thousands of Barrels)</strong></td>
<td></td>
<td>43,993.67</td>
<td></td>
</tr>
<tr>
<td><strong>West Texas Intermediate Crude Oil Price per Barrel (2009$)</strong></td>
<td></td>
<td>56.18</td>
<td></td>
</tr>
<tr>
<td>Logarithmic Difference in the Value of Oil Reserves</td>
<td></td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td>13,501.7</td>
<td>7,740.9</td>
<td>14,790.8</td>
</tr>
<tr>
<td>Logarithmic Difference in Population</td>
<td>-0.003</td>
<td>-0.005</td>
<td>-0.003</td>
</tr>
<tr>
<td><strong>Fraction of Workers in Manufacturing (1999)</strong></td>
<td>0.075</td>
<td>0.023</td>
<td>0.087</td>
</tr>
<tr>
<td><strong>Fraction of Counties with an MSA (1999)</strong></td>
<td>0.057</td>
<td>0</td>
<td>0.070</td>
</tr>
<tr>
<td><strong>Number of Counties</strong></td>
<td>175</td>
<td>32</td>
<td>143</td>
</tr>
</tbody>
</table>
Table 2 - OLS Estimates of the Impact of Earnings Growth on the Change in Disability Insurance Payments and Participation: Montana, North Dakota, and South Dakota, 2000-2009

<table>
<thead>
<tr>
<th></th>
<th>DI Payments</th>
<th></th>
<th>DI Participation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Earnings Growth</td>
<td>-0.152</td>
<td>-0.156</td>
<td>-0.164</td>
<td>-0.169</td>
</tr>
<tr>
<td></td>
<td>(0.102)</td>
<td>(0.103)</td>
<td>(0.063)</td>
<td>(0.062)</td>
</tr>
<tr>
<td>Controls:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>County Contains MSA</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>County Population</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Change in County Population</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fraction of Workers in Manufacturing (1999)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>1575</td>
<td>1575</td>
<td>1575</td>
<td>1575</td>
</tr>
</tbody>
</table>

Notes: DI payments are log differences in real values (not including spousal or child benefits). DI participation is the log difference in the number of beneficiaries (not including spouses or children). Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.
Table 3 - Summary Statistics of Sample by Period:

<table>
<thead>
<tr>
<th></th>
<th>All Counties (1)</th>
<th>Oil Counties (2)</th>
<th>No Oil Counties (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A: Pre-Boom (2000-2004)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DI Payments (Thousands of 2009$)</td>
<td>220.1</td>
<td>127.3</td>
<td>240.9</td>
</tr>
<tr>
<td>DI Beneficiaries</td>
<td>233.4</td>
<td>136.1</td>
<td>255.2</td>
</tr>
<tr>
<td>Earnings (Thousands of 2009$)</td>
<td>180,821.4</td>
<td>90,738.2</td>
<td>200,979.9</td>
</tr>
<tr>
<td>Logarithmic Difference in DI Payments</td>
<td>0.045</td>
<td>0.040</td>
<td>0.046</td>
</tr>
<tr>
<td>Logarithmic Difference in DI Beneficiaries</td>
<td>0.037</td>
<td>0.032</td>
<td>0.038</td>
</tr>
<tr>
<td>Logarithmic Difference in Earnings</td>
<td>0.012</td>
<td>0.020</td>
<td>0.010</td>
</tr>
<tr>
<td>Oil Reserves (Thousands of Barrels)</td>
<td></td>
<td>43,993.67</td>
<td></td>
</tr>
<tr>
<td>West Texas Intermediate Crude Oil Price per Barrel (2009$)</td>
<td>37.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logarithmic Difference in the Value of Oil Reserves</td>
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<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>13,237.5</td>
<td>7,750.0</td>
<td>14,465.4</td>
</tr>
<tr>
<td>Logarithmic Difference in Population</td>
<td>-0.006</td>
<td>-0.010</td>
<td>-0.005</td>
</tr>
<tr>
<td><strong>Panel B: Oil Boom (2005-2009)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DI Payments (Thousands of 2009$)</td>
<td>284.9</td>
<td>151.03</td>
<td>314.9</td>
</tr>
<tr>
<td>DI Beneficiaries</td>
<td>288.8</td>
<td>157.5</td>
<td>318.2</td>
</tr>
<tr>
<td>Earnings (Thousands of 2009$)</td>
<td>202,285.1</td>
<td>106,920.8</td>
<td>223,625.3</td>
</tr>
<tr>
<td>Logarithmic Difference in DI Payments</td>
<td>0.044</td>
<td>0.025</td>
<td>0.048</td>
</tr>
<tr>
<td>Logarithmic Difference in DI Beneficiaries</td>
<td>0.033</td>
<td>0.020</td>
<td>0.036</td>
</tr>
<tr>
<td>Logarithmic Difference in Earnings</td>
<td>0.018</td>
<td>0.037</td>
<td>0.013</td>
</tr>
<tr>
<td>Oil Reserves (Thousands of Barrels)</td>
<td></td>
<td>43,993.7</td>
<td></td>
</tr>
<tr>
<td>West Texas Intermediate Crude Oil Price per Barrel (2009$)</td>
<td>74.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logarithmic Difference in the Value of Oil Reserves</td>
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<td>0.054</td>
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<tr>
<td>Population</td>
<td>13,765.8</td>
<td>7,731.9</td>
<td>15,116.1</td>
</tr>
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<td>Logarithmic Difference in Population</td>
<td>-0.002</td>
<td>-0.0004</td>
<td>-0.002</td>
</tr>
<tr>
<td>Number of Counties</td>
<td>175</td>
<td>32</td>
<td>143</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Change in the Value of Oil Reserves</td>
<td>0.045</td>
<td>0.048</td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td>(0.015)</td>
<td>(0.015)</td>
<td>(0.015)</td>
</tr>
<tr>
<td>Change in the Value of Oil Reserves: One Lag</td>
<td></td>
<td></td>
<td>0.064</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.023)</td>
</tr>
<tr>
<td>Change in the Value of Oil Reserves: Two Lags</td>
<td></td>
<td></td>
<td>0.023</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.027)</td>
</tr>
<tr>
<td>Vector of Control Variables</td>
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<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>F-Statistic</td>
<td>9.03</td>
<td>9.8</td>
<td>10.4</td>
</tr>
<tr>
<td>Observations</td>
<td>1225</td>
<td>1225</td>
<td>1225</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.

Table 4 - First-Stage Relationship between Oil Reserve Instruments and Earnings Growth: North Dakota, South Dakota, and Montana, 2000-2009
Table 5 - IV Estimates of the Impact of Earnings Growth on the Change in Disability Insurance Payments and Participation: Montana, North Dakota, and South Dakota, 2000-2009

<table>
<thead>
<tr>
<th></th>
<th>DI Payments</th>
<th></th>
<th>DI Participation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Earnings Growth</td>
<td>-1.206</td>
<td>-1.039</td>
<td>-0.827</td>
<td>-0.670</td>
</tr>
<tr>
<td></td>
<td>(0.470)</td>
<td>(0.434)</td>
<td>(0.356)</td>
<td>(0.323)</td>
</tr>
<tr>
<td>Controls:</td>
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<td></td>
</tr>
<tr>
<td>County Contains MSA</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>County Population</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Change in County Population</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fraction of Workers in Manufacturing (1999)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>1225</td>
<td>1225</td>
<td>1225</td>
<td>1225</td>
</tr>
</tbody>
</table>

Notes: DI payments are log differences in real values (not including spousal or child benefits). DI participation is the log difference in the number of beneficiaries (not including spouses or children). Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.
Table 6 - Spatial IV Estimates of the Impact of Earnings Growth on the Change in Disability Insurance Payments and Participation: Montana, North Dakota, and South Dakota, 2000-2009

<table>
<thead>
<tr>
<th></th>
<th>DI Payments (1)</th>
<th>DI Participation (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earnings Growth</td>
<td>-1.290</td>
<td>-1.179</td>
</tr>
<tr>
<td></td>
<td>(0.665)</td>
<td>(0.634)</td>
</tr>
<tr>
<td>Observations</td>
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<td>1,575</td>
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Notes: Standard errors are in parentheses.
Table 7 - IV Estimates of the Impact of Earnings Growth on the Change in Social Security Retirement and Supplemental Security Income Program Payments and Participation:
Montana, North Dakota, and South Dakota, 2000-2009

<table>
<thead>
<tr>
<th>Earnings Growth</th>
<th>OAS Payments and Participation</th>
<th>SSI Payments and Participation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Payments</td>
<td>Participation</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Earnings Growth</td>
<td>-0.282</td>
<td>-0.195</td>
</tr>
<tr>
<td></td>
<td>(0.126)</td>
<td>(0.124)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,225</td>
<td>1,225</td>
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</table>

Notes: The specifications in this table use the full det of control variables and instruments. Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.

<table>
<thead>
<tr>
<th>Joint Eligibility</th>
<th>SSI and DI</th>
<th>SSI and OASDI</th>
<th>SSI Participation by Age</th>
<th>18-64</th>
<th>65 plus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td></td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Earnings Growth</td>
<td>0.112</td>
<td>-0.794</td>
<td>-0.672</td>
<td>-1.180</td>
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</tr>
<tr>
<td></td>
<td>(1.120)</td>
<td>(0.431)</td>
<td>(0.460)</td>
<td>(0.668)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>758</td>
<td>1,055</td>
<td>947</td>
<td>900</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The specifications in this table use the full det of control variables and instruments. Robust standard errors in parentheses are clustered at the county level. All models include state-by-year fixed effects.
Chapter 3

Oil Production and the Elasticity of the State Tax Base:
Evidence from North Dakota

I. Introduction

Since the year 2000, increases in oil and natural gas production in the United States represented a positive shock to local labor market conditions that increased earnings and employment in impacted areas (Allcott and Keniston, 2014; Vachon, 2015a and 2015b). This boom in production was made possible due to a combination of rising prices and advancements in extraction technologies – the joint use of horizontal drilling and hydraulic fracturing, colloquially known as “fracking”. Of any state or region, the boom had an outsized impact on North Dakota. During this period, the state surpassed California and Alaska to become the nation’s second-largest producer of oil, behind only Texas, and its share of national oil production increased from nearly 1 percent in 2000 to over 12 percent in 2013.

A central theme of this boom has been a debate over the impact of fracking on local economic conditions in impacted areas. While many studies find that the boom had a positive impact on local labor market conditions, we know little about the impact of increased oil production on tax revenues. An important question in local public finance has been the impact of local economic conditions on the tax base and revenues. This topic is of particular interest given that sales and income tax bases as well as revenues are sensitive to business cycle fluctuations and changes in personal income.

The goal of this analysis is to estimate the impact of this plausibly exogenous increase in oil production on the tax base in North Dakota. I estimate the elasticity of the tax base with respect to the value of oil produced using an instrumental variable (IV) estimation strategy. I
implement this strategy using a county-level panel dataset of administrative income and tax base data as well as oil production data for 2000 through 2010. To estimate the causal relationship between local economic conditions and the tax base, I use the value of county oil reserves as an instrument for the value of oil produced. I construct the instrument using oil reserves data and West Texas Intermediate (WTI) crude oil prices. This methodology allows me to exploit spatial variation in oil reserves at the county level and time-series variation in oil prices.

Overall, my IV estimates suggest that there is a substantial, statistically significant, positive relationship between local economic conditions and the sales and income tax bases. I estimate the short-run elasticities of these tax bases with respect to the value of oil produced for North Dakota. I find an elasticity of the sales tax base with respect to oil production of 0.18 and an elasticity of the income tax base with respect to oil production of 0.16. These estimates suggest that the doubling in the value of oil production during the period of interest led to an 18 percent increase in the sales tax base and a 16 percent increase in the income tax base for oil counties. Beyond providing these new estimates, this paper contributes to a growing body of literature that examines the impact of natural resource booms on various labor market outcomes, such as earnings, employment, migration, and social insurance (Acemoglu et al., 2013; Aldy, 2014; Allcott and Keniston, 2014; Black et al., 2002; Black et al., 2005; Vachon, 2015a; Vachon, 2015b).

The rest of this paper proceeds as follows. Section II provides an overview of the oil boom; the exposition of this section largely draws upon that in Vachon (2015b). Section III describes changes to North Dakota’s state taxes as well as important sources of state tax revenue. Section IV outlines the econometric specification. Section V describes the identification strategy. Section VI presents the estimation and results, and Section VII concludes.
II. Oil Boom Background

The source of oil is organic matter that is preserved and buried in some sedimentary rocks. For an oil deposit to be considered for commercial production, three important geological criteria must be met (Hyne, 2012). First, there must be a subsurface source rock that generated the oil (see Figure 1). The most common source rock is black shale. Shale originated as organic matter-rich mud on ancient seafloors. As it was covered with more and more sediments and buried further below the Earth’s surface, the heat from geological pressure turned the organic matter into oil. Second, there must be a separate subsurface reservoir rock that holds the oil. Reservoir rocks are sedimentary rock layers that contain billions of tiny spaces, or pores. Sandstone (composed of compressed grains of sand) and limestone (composed of broken down seashells and corals) are common reservoir rocks. Oil is able to flow through sandstone, limestone, and other reservoir rocks through the pore spaces between the sediments. Third, there must be a geological trap and cap rock to concentrate the oil into commercially extractable quantities. The trap is a geological high point in the formation that prevents the oil from flowing upward; the cap rock is a seal that prevents oil from flowing through it, concentrating the oil in the reservoir rock.

In “conventional” oil extraction, a well is drilled into the reservoir rock. Such methods characterized oil production in the United States, including North Dakota, for much of the previous century. In contrast, the recent oil boom uses “unconventional” oil extraction because it involves drilling into and extracting resources from the shale source rock, which is less porous.

30 The shale oil extracted from the Bakken was formed approximately 350 million years ago during the late Devonian and early Mississippian geologic periods (Hyne, 2012).
31 While the focus of this paper is on the Bakken formation, the explanations of the geology of fossil fuels and extraction technologies can generally be applied to other regions with shale oil and gas reserves and extraction (i.e. Marcellus and Utica in the Appalachian region, Eagle Ford and Barnett in Texas, and Woodford in Oklahoma, among others).
and permeable than typical reservoir rocks (i.e. sandstone and limestone, among others) (Maugeri, 2012). In particular, shale oil is extracted using the combined application of horizontal drilling and fracking techniques. Horizontal drilling is particularly effective in these formations because more well surface area is exposed to the oil-rich rock as compared to traditional vertical drilling. Hydraulic fracturing is the process of injecting large volumes of fluids into a well to fracture the rock. The fluid used is generally combined with sand before it is injected. The sand particles, known as propping agents, hold open the fractures, allowing oil to flow into the well (Hyne, 2012).

Figure 2 presents the time-series price and production data for North Dakota. Geologists and petroleum experts have been aware of North Dakota’s reserves since the middle of the previous century when Amerada Petroleum Corporation drilled the area’s first commercial oil well at the Clarence Iversen farm in Tioga, North Dakota in 1951. However, later that year Amerada made another important discovery at the Henry O. Bakken farm, also in Tioga. The Bakken well is important because it was the first in the area drilled into the older (deeper) geologic formation that became known as the Bakken formation. From 1951 through the 1970s, oil production averaged a modest 20 million to 25 million barrels per year. Beginning in 1973 with the OPEC embargo and continuing through the oil crisis of 1979, rising oil prices led to a boom in production in North Dakota in the 1980s. Even with record-high oil prices, annual production peaked at approximately 50 million barrels in 1984, compared to nearly 900 million barrels produced in Texas that year (U.S. Energy Information Administration, 2014).

While oil companies have had access to horizontal drilling and fracking technologies for some time, their combined application was not successful until 2000, when Mitchell Energy extracted natural gas from the Barnett shale in Texas (Maugeri, 2012). In North Dakota’s
Bakken, Continental Resources is credited with the first commercially successful combined horizontal drilling and fracking oil well in 2004 (Continental Resources, 2014). North Dakota oil production hit nearly 250 million barrels in 2012 and continues to increase. Production resulting from this most recent boom dwarfs that of the 1980s.

III. North Dakota State Tax Background

There are four main sources of state tax revenues in North Dakota. Table 1 presents the share of state tax revenues by source. From Panel A, these major sources of tax revenues are severance taxes, sales taxes, individual income taxes, and corporate income taxes. Severance and sales taxes each make up approximately 27 percent of revenues, and individual income taxes make up 16 percent of revenues. Corporate income taxes represent a much smaller share of total revenues, at less than 6 percent. Panels B and C show the sources of total revenues for the pre-boom (2000-2004) and boom (2005-2012) periods, respectively. Revenues from sales and income taxes declined as a share of total revenues from the pre-boom period to the boom period.

Figures 3a and 3b present the time-series of total tax revenues and oil production and prices, respectively. These data come from the United States Bureau of the Census’ Annual Survey of State Government Finances and the North Dakota Department of Mineral Resources, Oil and Gas Division. From the 1950s through the late 1990s, tax revenues increased from less than $500 million in 1952 to approximately $1.5 billion in 2000. Tax revenues and oil production both increase from the 1950s through the late 1960s. However, revenues and production diverge from the 1960s through the 1980s. From 2000 through 2012, there appears to be a generally positive relationship between tax revenues and prices and production. In 2004, coinciding with the introduction of new extraction technologies, tax revenues and oil production
increase more rapidly; tax revenues increased from $1.5 billion in 2004 to nearly $4 billion in 2012.

A. Severance Taxes

The most important state tax related to oil production is the severance tax. It has two main components: the oil production tax and the oil extraction tax. First, the oil production tax rate is 5 percent on the gross value of all oil produced, except for oil produced on government or Native American lands.\textsuperscript{32} Second, the oil extraction tax rate is 6.5 percent on the gross value of all oil produced.\textsuperscript{33} There are two significant differences between these two taxes. First, revenue allocations differ. Revenues from the production tax are allocated between the state’s general fund and the state’s oil impact fund, while revenues from the extraction tax are allocated between the state’s general fund, the state’s water resources fund, and education (ND OSTC, 2013). Second, various changes to tax law allow for reductions to the extraction tax rate.

Under special circumstances, oil produced is subject to a reduced extraction tax rate or exempt from taxation. Several changes to the extraction tax allow for reduced rates. The extraction tax is lowered to 4 percent for oil produced from wells meeting the following criteria: the well is a “new well” that started producing oil after April 27, 1987, or secondary and tertiary recovery methods are used in extraction. Secondary and tertiary recovery methods are typically used to stimulate production when the subsurface pressure becomes insufficient to force oil to the surface. In these cases, the tax rate is 6.5 percent when the price per barrel of oil exceeds a “trigger” price for each month in any consecutive five-month period, and the tax rate is 4 percent when the price of oil is below the trigger price for each month in any consecutive five-month period.

\textsuperscript{32} The production tax was introduced in 1953 and imposed a 4.25 percent tax on the value of oil produced; the rate increased to 5 percent in 1957.

\textsuperscript{33} The extraction tax was introduced in 1980 at a rate of 6.5 percent.
period. Figure 4a presents a stylized depiction of this mechanism for a trigger price of $45 per barrel. The rates in this figure would apply to wells completed in January 2004, and the figure assumes the trigger is in effect when the well was completed. As such, extraction tax rate remains at 4 percent through June 2014. Because oil prices are above the trigger price of $45 for five consecutive months from February 2004 through June 2004, the extraction tax rate increases to 6.5 percent in July 2004. Prices below $45 from July 2004 to November 2004 put the trigger into effect, and the extraction tax rate is 4 percent through March 2004.

The North Dakota government sets the trigger price each year. From 1991 through 2000, the trigger price was $33 per barrel and not adjusted for inflation. Beginning in 2001, the trigger price was set to $35.50 per barrel and adjusted for inflation using the producer price index for industrial commodities. Table 2 presents nominal and real trigger prices for 2000 through 2010.34

In addition to this basic scenario, there are a number of special cases that reduce extraction tax rates. Some oil produced is subject to a 2 percent extraction tax rate. For oil produced from horizontal wells, the lower amount of the first 75 thousand barrels or 4.5 million dollars of gross revenue is taxed at a 2 percent extraction rate during the first eighteen months oil is produced.35 This rate for horizontal wells takes effect “the first day of the month following a month for which the average price of a barrel of crude oil is less than fifty-five dollars” and is effective until “the first day of the month following a month in which the average price of a barrel of crude oil exceeds seventy dollars” (ND Legislative Branch, 2014). Figure 4b presents a stylized depiction of extraction taxes for horizontal wells in this case. The rates in this figure would apply to wells completed in April 2009, and the figure assumes the 2 percent rate is in

34 For simplicity, real trigger prices presented in Table 2 are adjusted using the consumer price index.
35 The first 75 thousand barrels produced from a well near the Bakken are taxed at a 2 percent extraction rate.
effect upon completion of the well. Extraction tax rates remain at 2 percent until April 2010, after a five-month period of prices above $70 at which point extraction tax rates rise to 6.5 percent.

Furthermore, some oil produced is exempt from extraction tax entirely; initial production is exempt from the extraction tax for fifteen months for vertical wells and twenty-four months for horizontal wells. This tax exemption is in effect when the price of oil is below the trigger price for each month in any consecutive five-month period and becomes ineffective when the price per barrel exceeds the trigger price for each month in any consecutive five-month period (ND OSTC, 2013). Overall, the implementation of the extraction tax is quite complex.

Figure 5a illustrates the time-series relationship between severance tax revenues and oil production. This figure shows a positive relationship between oil production and severance tax revenues. There is an increase in severance tax revenues with the boom in production in the 1970s and early 1980s; as production decreases then levels off in the 1980s, severance tax revenues do the same. Then, with the introduction of new extraction technologies and the Bakken oil boom, there is another increase in both severance tax revenues and oil production. During the most recent boom in oil production, severance tax revenues increased from $200 million in 2000 to over $1.6 billion in 2012; oil production increased from 32 million barrels in 2000 to approximately 250 million barrels in 2012.

Figure 5b presents the time-series relationship between severance tax revenues and oil prices. While there is a positive relationship between oil prices and severance tax revenues, revenues appear to be less sensitive to increases in price from the 1950s through the late 1990s as compared to the period between 2000 and 2012. Despite large price fluctuations and the introduction of the 6.5 percent extraction tax, the increase in severance tax revenues in the 1970s
and 1980s is relatively modest. Oil prices increase from $19 in 1973 to nearly $100 in 1980, whereas severance tax revenues increase from $76 million to $400 million over the same period. From 2000 through 2012, severance tax revenues are more sensitive to large increases in price. During this period, prices increase from approximately $38 in 2000 to almost $90 in 2012; severance tax revenues increase from $200 million to $1.6 billion. Figure 5c illustrates revenues for the production and extraction taxes separately from 1989 through 2012. This data come from ND OSTC. As the figure shows, there is a highly positive correlation between production and extraction tax revenues. There is some divergence between 1994 and 2010, with production tax revenues slightly larger than extraction tax revenues during this period.

Figures 5d and 5e show the time-series relationships between the share of severance tax revenues and oil production and prices, respectively. From Figure 5c, the increase in production in the 1970s and 1980s, in combination with the introduction of the extraction tax in 1980 and the slight decline in total revenues, led to a large increase in the share of total revenues from severance taxes. The share of revenues from severance taxes increased from 1.7 percent in 1973 to 35 percent in 1982. Following the decrease in production during the 1980s, the share of revenue from severance taxes remained between 10 and 15 percent until after 2004. Between 2004 and 2012, the share of revenues from severance taxes increased from 14 percent to over 40 percent. Figure 5d presents the relationship between the share of revenues from severance taxes and the price of oil. The share of revenues is sensitive to changes in price over the entire series.

B. Sales Taxes

From Table 1, sales taxes make up more than one quarter of all tax revenues in North Dakota. North Dakota defines the sales tax base as the sum of taxable sales and taxable
purchases, where taxable sales represent retail sales and taxable purchases represent the purchase of intermediate goods by businesses. The North Dakota state sales tax rate is currently 5 percent. In addition, cities and counties within the state have the choice of whether to implement a local option sales tax.

North Dakota first implemented a state sales tax in 1935. This initial legislation called for a 2 percent tax on “sales to consumers of personal property; sales or service of gas, steam, electricity, water and communication; sales of tickets to places of amusement; and subscription sales of magazines” (ND OSTC, 2013). In the time since the sales tax was enacted, the base has been increased to include hotel accommodations, tobacco products, and alcoholic beverages, among other things. Alcohol is taxed at a higher rate of 7 percent, while farm machinery and equipment are taxed at a lower rate of 3 percent. At the same time, the state legislature exempted certain goods and services from the sales tax. Groceries, with the exception of candy and soda, are exempt from sales taxes. In addition, various exemptions apply to the purchase of medical equipment, farm equipment and chemicals, and computing equipment for new and growing businesses, among others. The sales tax rate has remained at 5 percent since it was lowered from a high of 5.5 percent in 1989. Table 3 outlines the legislative changes to the sales tax base from 2000 to 2010, the primary period of interest for this study. These changes include additional exemptions for farm machinery, computer equipment for businesses, certain medical sales and purchases, and the sales of natural gas, among others.

Figures 6a and 6b present the time-series of sales tax revenues and oil production and prices, respectively. Sales tax revenues increase from less than $100 million in 1952 to approximately $420 million in 1976 and remain between $330 million and $430 million until the late 1990s. The decrease in revenues between 1976 and 1983 coincides with an increase in the
sales tax rate from 3 to 4 percent that was in effect from 1977 through 1983. There is no clear relationship between sales tax revenues and increases in oil production or prices in the 1970s and 1980s despite large fluctuations in both production and prices during this period. From 2000 through 2012, there appears to be a positive relationship between tax revenues and production and prices, although sales tax revenues do not appear responsive to the large, temporary reduction in prices from 2008 to 2009. In 2004, coinciding with the introduction of new extraction technologies, sales tax revenues and oil production increase more rapidly; tax revenues increased from $424 million in 2004 to nearly $1.1 billion in 2012.

Figures 6c and 6d present the time-series of the share of revenues from sales taxes and oil production and prices, respectively. The figures show no clear relationship between sales tax revenue shares and oil production and prices. However, the overall downward trend in sales taxes as a share of total revenues since the 1970s may be explained by the general increase in the share of severance taxes over this time period. Sales taxes as a share of revenue decreased from 39 percent in 1973 to 27 percent in 2012.

C. Income Taxes

Income taxes represent the third largest source of tax revenue in North Dakota. The state requires that individuals with a federal income tax filing requirement file a North Dakota state income tax return. North Dakota uses federal taxable income, minus various deductions, as its income tax base. Federal taxable income is equal to AGI minus personal exemptions and (either standard or itemized) deductions. North Dakota taxable income is equal to federal taxable income minus deductions; the major deductions include certain lump-sum pension distributions and up to 30 percent of capital gains and dividends.
Three major changes to the North Dakota income tax rate schedule between 2000 and 2010 are outlined in Table 4. Until tax year 2000, income tax payments in North Dakota were equal to federal income tax liability times a flat tax rate of 14 percent.\textsuperscript{36} As shown in Table 4, the flat tax was replaced with a new rate schedule for the 2001 tax year. For single filers, the new schedule imposed a 2.1 percent tax on the first $27,050 dollars earned, and the top marginal tax rate of 5.55 percent applied to earnings over $297,350. For the 2009 tax year, this was replaced with a new rate schedule that reduced marginal tax rates overall. The 2009 schedule imposed a 1.84 percent on the first $33,950 dollars earned, and the top marginal tax rate of 4.86 percent applied to earnings over $372,950.\textsuperscript{37}

Figures 7a and 7b present the time-series of income tax revenues and oil production and prices, respectively. There does not appear to be a clear relationship between income tax revenues and oil production or prices. During the initial increase in production and prices in the 1970s and 1980s, income tax revenues fell from $260 million in 1975 to $77 million in 1983 as oil production and prices are rising then increased to $210 million in 1988 as prices and production fell. In contrast, income tax revenues have increased since 1990 as oil production and prices have increased as well.

Figures 7c and 7d show the time-series of the share of revenues from income taxes and oil production and prices, respectively. The figures generally illustrate a negative relationship between the share of revenues from income taxes and oil production and prices. During the initial increase in production and prices in the 1970s and 1980s, the share of revenues from

\textsuperscript{36} The flat tax was initially introduced in 1981 with a rate of 7.5 percent; the rate increased to 10.5 percent in 1983 and 14 percent in 1987 (ND OSTC, 2010 and 2014).

\textsuperscript{37} Prior to the 2009 tax year, individuals could choose between two income tax return forms, ND-1 (short form) and ND-2 (long form). Each relied on different deductions, credits, and rates. Long form ND-2 was repealed, and, since 2009, all individuals required to file must use ND-1. Because over 98 percent of filers benefitted from filing ND-1 versus ND-2 during that time, this section focuses on form ND-1.
income taxes fell from 25 percent in 1975 to less than 7 percent in 1983 as oil production and prices are rising then increased to 17 percent million in 1988 as prices and production fell. With the most recent increases in oil production and prices, the share of revenues from income taxes fell from 18 percent in 2007 to just over 10 percent in 2012.

IV. Econometric Specifications

The goal of the current paper is to estimate the impact of local economic conditions, as measured by oil production, on the tax base. This paper is related to a strain of the public finance literature that examines the impact of economic conditions, as measured by changes in income, on tax bases and revenues. Table 5 summarizes some of the major contributions to this literature. For each paper, I show the data sources used in the estimation, the time period studied, the geographic area, the outcomes of interest (tax base or tax revenues), explanatory variables, the tax instrument studied, and the estimates for the income elasticity of the tax base or tax revenues. Beginning with Groves and Kahn’s (1952) seminal paper, the standard model used to estimate the income elasticity of the tax base (revenues) is presented as:

\[ \ln(T_{st}) = \rho + \gamma \ln(Y_{st}) + \delta X_{st} + \epsilon_{st}, \]

where \( \ln(T_{st}) \) is the natural logarithm of the tax base (revenues), \( X_{st} \) is a vector of control variables, and \( \epsilon_{st} \) is the error term for state \( s \) in year \( t \). The explanatory variable, \( \ln(Y_{st}) \), is the natural logarithm of income. Because of the log-log specification of (1), the focal parameter, \( \gamma \), is interpreted as the income elasticity of the tax base.

Groves and Kahn (1952) examined tax revenue data from various states between 1930 and 1950. The authors found estimates of the income elasticity of sales tax revenues ranging from 0.99 in Ohio to 1.11 in California, Illinois, and Oklahoma. Wilford (1965) examined
revenues in Texas between 1947 and 1960. He found that the per capita income elasticity of various tax revenues were larger than the aggregate income elasticity.

As Dye (2004) explains in his review of the literature, “two important criteria used to evaluate state taxes or tax systems are the long-run or trend rate of growth in revenue and the short-run cyclical variability or stability of revenue over the business cycle” (p. 135). The approach by Groves and Kahn (1952) and Wilford (1965), among others, does not consider that short- and long-term elasticity estimates might differ and should be measured separately.

Williams et al. (1973) were the first to point out that long-run and short-run elasticities must be measured separately. Specifically, estimates of $\gamma$ from (1) represent the long-run elasticity. Williams et al. (1973) estimated long-run elasticities using (1). To estimate short-run elasticities, they first-differenced (1), regressing the first-difference in the natural logarithm of the tax base on the first-difference in the natural logarithm of income, where the first-difference of the natural logarithm represents the growth rate. For sales tax revenues, they found a long-run elasticity of 1.4 and a short-run elasticity of 0.8. Following Williams et al. (1973), Fox and Campbell (1984), for example, allowed the income elasticity to vary over the cycle by including a business cycle indicator variable to the standard specification. Using data from Tennessee, they estimated short-run sales tax revenue elasticities for each year from 1975 to 1982. They found elasticity estimates ranging from 0.16 in 1976 to 0.92 in 1979.

Sobel and Holcombe (1996) and Holcombe and Sobel (1997) provided an econometric framework to support Williams et al. (1973). They pointed out that tax revenues and incomes are non-stationary (both taxes and income trend upward over time). They test for non-stationarity using the Augmented Dickey-Fuller test. Non-stationarity poses two econometric challenges in estimating the income elasticity of the tax base. First, non-stationarity in the tax base and income
will bias short-run estimates of \( \gamma \). Following Williams et al. (1973), they used the first-differenced form of the natural logarithm of the tax base and earnings and show that the differenced forms of these variables are stationary. Second, non-stationarity will bias long-run estimates of \( \gamma \) as well as the standard errors in (1). They found that serial correlation in the error term will bias the coefficient and that the direction of that bias will depend on the cyclicality of business cycles (how many peaks v. troughs). Following Stock and Watson (1993), they employed dynamic ordinary least squares (DOLS) to provide long-run estimates of \( \gamma \). DOLS is a procedure that adds leads and lags of the independent variable to correct for coefficient bias. In addition, to consistently estimate the standard errors, they used the Newey-West (1987) correction. DOLS and the error correction produce qualitatively and quantitatively similar estimates of the long-run elasticities as compared to the standard models.

Using a national dataset for 1951-1990, Sobel and Holcombe (1996) found a short-term income elasticity of the tax base of 1.08 and a long-term elasticity of 0.69. Bruce et al. (2006) followed Sobel and Holcombe (1996) using DOLS to estimate long-run elasticities. They build upon short-run models, estimating separate elasticities that depend on location in the business cycle. They estimate separate elasticities for each state. For the sales tax, they find a long-run elasticity of 0.8; they find short-run elasticities that range from -2 to over 3.

To estimate a causal relationship between local economic conditions and the sales tax base, I rely on county-level variation in oil production in North Dakota between 2000 and 2010. I present the relationship between the value of oil produced and the sales tax base as:

\[
\Delta \ln(B_{it}) = \phi + \beta \Delta \ln(P_{it}) + u_{it},
\]
where $B_{it}$ represents the tax base for county $i$ in year $t$, and $u_{it}$ is the error term. The main explanatory variable is $P_{it}$, the value of oil produced. The focal parameter, $\beta$, represents the short-run elasticity of the sales tax base with respect to the value of oil produced.38

Following Sobel and Holcombe (1996) and Bruce et al. (2006), I test for non-stationarity in $\Delta \ln(B_{it})$ and $\Delta \ln(P_{it})$. The Augmented Dickey-Fuller test used by the previous authors is not suitable for panel data. As such, I employ the Im-Pesaran-Shin (IPS) (2003) unit root (i.e. non-stationarity) test for panel data and reject the null hypothesis that all panels contain a unit root at the 1 percent level.

I construct a county-level panel dataset of administrative oil production data as well as administrative sales and income tax base data for 2000 through 2010. I calculate the value of oil produced at the county level using oil production data from United States Department of Agriculture’s Economic Research Service (USDA ERS) as well as WTI crude oil prices from the United States Department of Energy’s Energy Information Administration (EIA). Data from the North Dakota Office of the State Tax Commissioner (ND OSTC) contain the value of county-level taxable sales and purchases, which together make up the sales tax base. Taxable sales represent retail sales while taxable purchases represent the purchase of intermediate goods by businesses. Data from the Internal Revenue Service (IRS) Statistics of Income (SOI) contain Adjusted Gross Income (AGI). I use adjusted gross income (AGI) from federal income tax returns aggregated to the county level as a measure of the income tax base. This data come from the Internal Revenue Service (IRS) Statistics of Income (SOI). AGI is commonly used in the

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38 I am not able to estimate long-run elasticities for two reasons. First, I only have eleven years of data from 2000 through 2010. Second, this period does not cover a complete business cycle; oil production is strictly increasing over the timeframe.
literature as a measure of the income tax base.\textsuperscript{39} North Dakota uses federal taxable income, minus various deductions, as its income tax base. Federal taxable income is equal to AGI minus personal exemptions and itemized deductions. The sales and income tax bases as well as the value of oil produced are measured in real 2010 dollars, adjusted for inflation using the Consumer Price Index (CPI).

Panel A of Table 6 presents summary statistics for the entire sample period. North Dakota is a relatively small state; according to the 2000 Census, its population was 642,000. From column 1, the average population per county is nearly 11,000, and per capita income is approximately $22,000. Throughout the period of interest, counties in the state experienced average annual increases in sales tax base of 2.6 percent, respectively. The average value of oil produced in each county was nearly $200 million.

V. Identification Strategy

There are two empirical challenges that arise in estimating the relationship between economic conditions, as measured by oil production, and the tax base. First, sales tax policy endogeneity will bias my results if sales tax rates are reduced in response to increases in the value of oil produced. Second, oil production is a function of wage rates (income tax base); this link leads to an endogeneity problem as increases in the price of labor will put downward pressure on oil production.

To overcome these challenges, I estimate the parameters in (2) using an IV strategy following closely the approach of Black et al. (2002) and Vachon (2015a and 2015b). This strategy is based on natural variation in county-level oil reserves. The oil reserve data used in

\textsuperscript{39} “Most states use something close to federal adjusted gross income as the base for state income taxes, so this measure closely approximates the state income tax base” (Sobel and Holcombe. 1996).
this analysis come from the 2004 EIA assessment of the Bakken formation of the Williston Basin. I calculate oil reserves using EIA shape files and MapInfo software. I use midpoint estimates for each oil field, as the reserves are listed in ranges, then aggregate to the county level. Based on this method, in North Dakota, there are 16 counties that have oil reserves, and 37 counties that have no reserves. From column 2 of Table 6, the average oil county has over forty-eight million barrels of oil reserves. I calculate the value of oil reserves by multiplying county-level reserves by the price of West Texas Intermediate (WTI) crude oil. From Panels B and C of Table 6, the average price per barrel of WTI crude oil increased from $37 to $76 between the early and later years of the oil boom. I use the value of oil reserves as an instrument for the value of oil produced to econometrically capture the impact of the oil price increases on the value of oil produced.40

Figures 8 through 11b present a visual depiction of my identification strategy. Estimates are based on data from 2000-2010. Figure 8 shows the level of oil reserves for counties in North Dakota. These reserves depict the portion of the Bakken formation of the Williston Basin that falls within the state’s boundaries. The counties with the darkest shading have the highest levels of oil reserves; those areas that are white have no oil reserves. The darkest shaded counties have between 50 and 217 million barrels of oil. The counties shaded in dark gray have between 5 and 50 million barrels of oil. The counties shaded in the light gray have less than less than 5 million barrels of oil (but more than zero). Figure 9 presents the quartile of average annual oil production. The areas with the darkest shading have the greatest annual production over the timeframe. The first through fourth quartiles represent production below 90 thousand barrels.

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40 During the late part of the oil boom from 2005 through 2010, oil production in the Bakken increased from 1 million to 5 million barrels per month. In 2009, oil production in the Bakken was approximately 3 percent of the US total monthly oil production. From 2009 to 2012, oil production in the Bakken increased from 5 million to 22 million barrels per month. In 2012, oil production in the Bakken represented approximately 10 percent of the US total monthly oil production (Federal Reserve Bank of Minneapolis, 2012).
between 380 thousand and 1 million barrels, between 1 million and 4.6 million barrels, and above 4.6 million barrels of oil per year, respectively. The county with the lowest annual oil production extracted an average of 650 barrels per year; the county with the highest production extracted over 10 million barrels per year.

Figures 10a and 10b depict quartiles of average annual growth in the sales tax base for the pre-boom (2000-2004) and boom (2005-2010) periods, respectively. Areas with the darkest shading have the highest growth. For the pre-boom period in Figure 10a, the first through fourth quartiles represent sales tax base growth below -4.3 percent, between -4.3 percent and -1.8 percent, between -1.8 percent and 0.5 percent, and above 0.5 percent, respectively. The county with the lowest sales tax base growth experienced a 13.5 percent decrease; the county with the highest growth experienced a 5.4 percent increase. For the boom period in Figure 10b, the first through fourth quartiles represent sales tax base growth below 1.9 percent, between 1.9 percent and 3.6 percent, between 3.6 percent and 6.1 percent, and above 6.1 percent, respectively. The county with the lowest sales tax base growth experienced a 2.5 percent decrease; the county with the highest growth experienced a 34.8 percent increase.

Figures 11a and 11b depict quartiles of average annual growth in the income tax base for the pre-boom (2000-2004) and boom (2005-2010) periods, respectively. Areas with the darkest shading have the highest growth. For the pre-boom period in Figure 11a, the first through fourth quartiles represent income tax base growth below -1.9 percent, between -1.9 percent and -0.9 percent, between -0.9 percent and 0.9 percent, and above 0.9 percent, respectively. The county with the lowest income tax base growth experienced a 9.7 percent decrease; the county with the highest growth experienced a 4.6 percent increase. For the boom period in Figure 11b, the first through fourth quartiles represent income tax base growth below 3.5 percent, between 3.5
percent and 4.9 percent, between 4.9 percent and 6.9 percent, and above 6.9 percent, respectively. The county with the lowest income tax base growth experienced a 0.7 percent decrease; the county with the highest growth experienced a 32 percent increase.

Figures 8 and 9 represent the first-stage relationship between oil reserves and growth in the value of oil produced. Those counties with high growth in the value of oil produced have the highest levels of oil reserves, as evidenced by the dark shading on both maps. Figures 8, 10a, and 10b represent the reduced-form relationship between oil reserves and the sales tax base. Figures 8, 11a, and 11b represent the reduced-form relationship between oil reserves and the income tax base. These reduced-form relationships depict a positive relationship between oil reserves and growth in the sales and income tax bases. Those areas with high levels of oil reserves have high growth in the tax bases, especially during the boom period. This is evidenced by the fact that high oil reserve counties are more darkly shaded while low tax base growth counties are lightly shaded.

VI. Estimation and Results

The first-stage of the IV estimation is:

\[ \Delta ln(B_{it}) = \alpha_0 + \alpha_1 \Delta ln(R_{it}) + \theta_{it}, \]

where the instrument, \(\Delta ln(R_{it})\), represents the natural logarithm of the value of county oil reserves for each year in 2010 dollars. Table 7 presents estimates of \(\alpha_1\) from (3). These estimates represent the first stage relationship between growth in the value of oil reserves and growth in the value of oil produced. As illustrated in Table 7, these estimates suggest that a doubling in the value of county-level oil reserves increases the value of oil produced by 139 percent. The associated F-statistic is 15.6, suggesting that the instrument is relatively strong.
Table 8 presents estimates of $\beta$, the elasticity of the tax base with respect to oil production, from (2). The estimate in Column 1 of Table 8 indicates an elasticity of the sales tax base with respect to the value of oil produced is 0.18. This elasticity suggests that a doubling in the value of oil produced increases the county-level sales tax base by 18 percent. Column 2 presents estimates of the elasticity of the retail sales with respect to the value of oil produced. I find an elasticity of 0.13, suggesting a doubling in the value of oil produced will increase retail sales by 13 percent. Column 3 of Table 8 presents the elasticity of the income tax base with respect to the value of oil produced. I find an elasticity of 0.16. The point estimate suggests that a doubling in the value of oil produced increases the county-level income tax base by 16 percent. In reality, average annual increases in the value of oil produced were approximately 23 percent in oil counties from 2005 through 2010. This suggests the oil boom led to a 25 percent increase in the sales tax base and a 22 percent increase in the income tax base for oil counties compared to counties without oil.

Finally, changes in county-level local option sales tax rates could impact my estimates of $\beta$. To account for this, I add the change in county-level sales tax rates as a control variable in Table 9. The inclusion of sales tax rates to results in estimates of $\beta$ that are quantitatively the same as those in Table 8. In addition, the coefficient on the tax rate variable is insignificant.

VII. Summary, Caveats, and Implications

In this paper, I exploit exogenous variation in local economic conditions due to a boom in oil production to estimate the relationship between economic growth and the tax base for counties in North Dakota. The boom in oil production in the Bakken formation impacting western North Dakota created an unexpected, positive shock for local economies, particularly for
oil-rich counties. Overall, my estimates suggest a statistically significant and positive relationship between the value of oil produced and the tax base. I find elasticities of the tax base with respect to the value of oil produced of 0.18 and 0.16 for the sales and income tax bases, respectively. From 2000 through 2010, the value of oil produced in North Dakota nearly doubled, suggesting oil counties experienced increases in sales and income tax bases of 18 percent and 16 percent, respectively.

The current paper builds upon the previous literature in three important ways. First, I rely on an IV strategy to overcome the identification challenges. Second, the use of a natural experiment is a novel approach that provides new causal evidence of the impact of economic booms on the tax base in North Dakota. I use this approach because the national boom in oil and natural gas production was an exogenous shock that differentially impacted resource-abundant counties. Despite a long history of research in this area, we have few causal estimates of the relationship between local economic conditions and the tax base. Finally, this paper contributes to the growing literature examining impact of natural resources on local economic conditions (Acemoglu et al., 2013; Aldy, 2014; Allcott and Keniston, 2014; Black et al., 2002; Black et al., 2005; Vachon, 2015a and 2015b). The estimates in this paper may serve to shed light on the impact of booms in natural resource extraction, particularly fracking, on the fiscal position of state and local governments.

In addition, the new estimates of the elasticity of the tax base with respect to changes in local economic conditions that I provide in this paper can provide insight into how changes in the price of oil will impact both production and the tax base. Between June 2014 and February 2015, oil prices fell by just over 50 percent from $106 to $51 per barrel. Based on my first stage estimates, this decrease in prices should reduce the value of oil produced by 70 percent. From my
estimates of $\beta$, a 70 percent reduction in the value of oil produced at the county level will reduce the sales and income tax bases by 13 percent and 11 percent respectively.

While my findings suggest large impacts of oil production on the sales and income tax bases, there is an important limitation to this study. North Dakota is less populous and more rural than the rest of the United States. As such, caution should be taken when attempting to generalize these estimates to other areas impacted by the recent boom in oil and natural gas production. This caveat provides a natural avenue for future research. Expanding this county-level analysis beyond North Dakota to other areas impacted by the national shale boom is important as it may further inform the debate over the impact of fracking on local economic conditions.
Figure 1 – Petroleum Geology and Extraction
Figure 2 – Historical North Dakota Oil Production and Prices
Figure 4a – Depiction of Trigger Prices and Extraction Tax Rates

Figure 4b – Depiction of Extraction Tax Rate Reductions for Horizontal Wells
Figure 5a – Time Series of Severance Tax Revenues and Oil Production

Severance Tax Revenues and Oil Production:
North Dakota, 1952-2012

Figure 5b – Time Series of Severance Tax Revenues and Oil Prices

Severance Tax Revenues and the Price of Oil:
North Dakota, 1952-2012
Figure 5c – Severance Tax Revenues by Source

Severance Tax Revenues by Source:
North Dakota, 1989-2012

- Production Tax Revenues
- Extraction Tax Revenues
Figure 5d – Share of Severance Tax Revenues and Oil Production

Figure 5e – Share of Severance Tax Revenues and Oil Prices
Figure 6a – Sales Tax Revenues and Oil Production

Sales Tax Revenues and Oil Production:
North Dakota, 1952-2012

Figure 6b – Sales Tax Revenues and Oil Prices

Sales Tax Revenues and the Price of Oil:
North Dakota, 1952-2012
Figure 6c – Share of Sales Tax Revenues and Oil Production

Figure 6d – Share of Sales Tax Revenues and Oil Prices
Figure 7a – Income Tax Revenues and Oil Production

Figure 7b – Income Tax Revenues and Oil Prices
Figure 7c – Share of Income Tax Revenues and Oil Production

Figure 7d – Share of Income Tax Revenues and Oil Prices
Figure 8 - Oil Reserves in North Dakota

- No oil reserves
- Less than 5 million barrels
- Between 5-50 million barrels
- Greater than 50 million barrels
Figure 9 – Quartile of the Average Value of Oil Produced: 
North Dakota, 2000-2010
Figure 10a – Quartile of Average Annual Growth in the Sales Tax Base: North Dakota, 2000-2004

Figure 10b – Quartile of Average Annual Growth in the Sales Tax Base: North Dakota, 2005-2010
Figure 11a – Quartile of Average Annual Growth in the Income Tax Base: North Dakota, 2000-2004

Figure 11b – Quartile of Average Annual Growth in the Income Tax Base: North Dakota, 2005-2010
Table 1 - State Sales and Income Tax Revenues as a Percent of Total Revenues by Period: North Dakota, 2000-2004 and 2005-2012

<table>
<thead>
<tr>
<th>Total Tax Revenues (Billions of 2010$)</th>
<th>Sales Tax Revenues (2)</th>
<th>Individual Income Tax Revenues (3)</th>
<th>Severance Tax Revenues (4)</th>
<th>Corporate Income Tax Revenues (5)</th>
<th>Other Tax Revenues (6)</th>
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<tr>
<td><strong>Panel A: 2000-2012</strong></td>
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<td><strong>Panel B: Pre-Boom (2000-2004)</strong></td>
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<tr>
<td>1.5</td>
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<td>13.4</td>
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<td><strong>Panel C: Oil Boom (2005-2012)</strong></td>
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<tr>
<td>2.7</td>
<td>25.9</td>
<td>14.7</td>
<td>31.2</td>
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<td>22.4</td>
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Table 2 - Nominal and Real Trigger Price:
North Dakota, 2000-2012

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<tr>
<th>Year</th>
<th>Nominal Trigger Price</th>
<th>Real Trigger Price (CPI-Adjusted)</th>
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<tr>
<td>2000</td>
<td>33</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>35.50</td>
<td>35.50</td>
</tr>
<tr>
<td>2002</td>
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<td>36.07</td>
</tr>
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<td>2003</td>
<td>35.50</td>
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<td>2004</td>
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<td>37.88</td>
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<td>2005</td>
<td>35.50</td>
<td>39.15</td>
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<td>2006</td>
<td>35.50</td>
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<td>2007</td>
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<td>2008</td>
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<tr>
<td>2009</td>
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<td>33.86</td>
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<td>2010</td>
<td>35.50</td>
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<td>2012</td>
<td>35.50</td>
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<table>
<thead>
<tr>
<th>Year</th>
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<th>Law Change</th>
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<tbody>
<tr>
<td>2001</td>
<td>0.05</td>
<td>“The 1.5% tax rate on used farm machinery and repair parts was extended through June 30, 2002 and thereafter exempt from sales tax. Car rentals became subject to the state’s 5% sales tax and to a special 3% sales tax surcharge. Sales of computers and telecommunications equipment to a new primary sector business, or as a result of an economic expansion of an existing primary sector business, became exempt from sales tax” (NDOSTC, 2013 p. 6).</td>
</tr>
<tr>
<td>2005</td>
<td>0.05</td>
<td>“Legislation was enacted that adopted the national Streamlined Sales Tax Project definitions and policies. The 2005 Assembly granted sales tax exemptions for purchases made by emergency medical service providers and sales to licensed assisted living facilities. It also authorized the sale of alcoholic beverages on Thanksgiving Day” (NDOSTC, 2013 p. 6).</td>
</tr>
<tr>
<td>2007</td>
<td>0.05</td>
<td>“Legislation was enacted that reduced the sales tax rate on natural gas to 1% effective July 1, 2007, and repealed the sales tax on natural gas entirely effective July 1, 2009. The 2007 Assembly also removed the sales tax on Bingo cards and certain materials used to construct power plants that utilize 'waste' heat” (NDOSTC, 2013 p. 6).</td>
</tr>
<tr>
<td>2009</td>
<td>0.05</td>
<td>“Legislation was enacted that created an exemption for repair parts used in irrigation systems. The 2009 assembly also created an exemption for purchases of tangible personal property used to construct or expand telecommunication infrastructure in the state” (NDOSTC, 2013 p. 6).</td>
</tr>
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</table>
Table 4 - Changes to the Income Tax Rate Schedule: North Dakota, 2000-2010

<table>
<thead>
<tr>
<th>Tax Year</th>
<th>Rate</th>
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<tr>
<td></td>
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<td>Flat Tax on Federal Income Tax Liability</td>
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<tr>
<td>2000</td>
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<tr>
<td></td>
<td></td>
<td>2.1 0 27,050 0 45,200</td>
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<tr>
<td>2001</td>
<td></td>
<td>3.92 27,050 65,550 45,200 109,250</td>
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<tr>
<td></td>
<td></td>
<td>4.34 65,550 136,750 109,250 166,500</td>
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<td>5.04 136,750 297,350 166,500 297,350</td>
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<td></td>
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<td>5.55 297,350 297,350</td>
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<tr>
<td>2009</td>
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<td>1.84 0 33,950 0 56,750</td>
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<td>3.44 33,950 82,250 56,750 137,050</td>
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<td>3.81 82,250 171,550 137,050 208,850</td>
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<td>4.86 372,950 372,950</td>
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Source: ND OSTC (2010)
<table>
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<th>Study</th>
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<th>Explanatory Variable(s)</th>
<th>Tax Instrument</th>
<th>Elasticity Estimates</th>
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Table 5 (continued) - Tax Base Elasticities from the Previous Literature

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<th>Study</th>
<th>Data Source</th>
<th>Time Period</th>
<th>Geographic Area</th>
<th>Outcome(s) of Interest</th>
<th>Explanatory Variable(s)</th>
<th>Tax Instrument</th>
<th>Elasticity Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sobel and Holcombe (1996)</td>
<td>Internal Revenue Service (IRS) Statistics of Income (SOI)</td>
<td>1951-1990</td>
<td>United States</td>
<td>Tax Base</td>
<td>Aggregate Income</td>
<td>Sales</td>
<td>Short-Run 1.08</td>
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<td></td>
<td>Statistical Abstract of the United States</td>
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<td>Individual Income</td>
<td>0.74</td>
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<td>Corporate Income</td>
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<td>Alcohol</td>
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<td>Motor Fuel</td>
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<td>Individual Income</td>
<td>Estimates range from -1.69 (NY) to 8.37 (NM).</td>
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<tr>
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<td>All Counties</td>
<td>Oil Counties</td>
<td>No Oil Counties</td>
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<td>(2)</td>
<td>(3)</td>
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<tr>
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<td>8,612.6</td>
<td>11,758.3</td>
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<tr>
<td>Income per Capita (Thousands of 2010$)</td>
<td>21.8</td>
<td>23.4</td>
<td>21.2</td>
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<tr>
<td>Logarithmic Difference in the Sales Tax Base</td>
<td>0.026</td>
<td>0.067</td>
<td>0.008</td>
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<tr>
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<td>0.069</td>
<td>0.018</td>
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<tr>
<td>West Texas Intermediate Crude Oil Price per Barrel (2010$)</td>
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<tr>
<td>Oil Reserves (Thousands of Barrels)</td>
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<td>Value of Oil Produced (Billions of 2010$)</td>
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<td>197</td>
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<td>Logarithmic Difference in the Value of Oil Reserves</td>
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<td>Logarithmic Difference in the Value of Oil Produced</td>
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Panel B: Pre-Boom (2000-2004)

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<th>Oil Counties</th>
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<td>Population</td>
<td>10,561.6</td>
<td>8,415.4</td>
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<td>Income per Capita (Thousands of 2010$)</td>
<td>19.3</td>
<td>18.8</td>
<td>19.5</td>
</tr>
<tr>
<td>Logarithmic Difference in the Sales Tax Base</td>
<td>-0.021</td>
<td>-0.009</td>
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<tr>
<td>Logarithmic Difference in the Income Tax Base</td>
<td>-0.007</td>
<td>0.010</td>
<td>-0.014</td>
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<tr>
<td>West Texas Intermediate Crude Oil Price per Barrel (2010$)</td>
<td>37.4</td>
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<tr>
<td>Oil Reserves (Thousands of Barrels)</td>
<td></td>
<td>48,237.4</td>
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<tr>
<td>Value of Oil Produced (Billions of 2010$)</td>
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<td>Logarithmic Difference in the Value of Oil Reserves</td>
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<td>Logarithmic Difference in the Value of Oil Produced</td>
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Panel C: Oil Boom (2005-2010)

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<th>Oil Counties</th>
<th>No Oil Counties</th>
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<tr>
<td>Population</td>
<td>11,014.6</td>
<td>8,776.9</td>
<td>11,982.3</td>
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<tr>
<td>Income per Capita (Thousands of 2010$)</td>
<td>23.95</td>
<td>27.28</td>
<td>22.51</td>
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<tr>
<td>Logarithmic Difference in the Sales Tax Base</td>
<td>0.057</td>
<td>0.118</td>
<td>0.031</td>
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<td>Logarithmic Difference in the Income Tax Base</td>
<td>0.061</td>
<td>0.109</td>
<td>0.040</td>
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<td>West Texas Intermediate Crude Oil Price per Barrel (2010$)</td>
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<td>Oil Reserves (Thousands of Barrels)</td>
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<td>Value of Oil Produced (Billions of 2010$)</td>
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<tr>
<td>Logarithmic Difference in the Value of Oil Reserves</td>
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<tr>
<td>Logarithmic Difference in the Value of Oil Produced</td>
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Number of Counties

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Table 7 - First-Stage Relationship between the Value of Oil Reserves and Production: North Dakota, 2000-2010

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<td>Observations</td>
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Table 8 - IV Estimates of the Relationship between Oil Production Value and the Tax Base: North Dakota, 2000-2010

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<th>Taxable Sales (2)</th>
<th>Adjusted Gross Income (1)</th>
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<td>Change in the Value of Oil Produced</td>
<td>0.182 (0.075)</td>
<td>0.131 (0.057)</td>
<td>0.155 (0.049)</td>
</tr>
<tr>
<td>Observations</td>
<td>530</td>
<td>530</td>
<td>530</td>
</tr>
</tbody>
</table>
Table 9 - IV Estimates of the Relationship between Oil Production Value and the Sales Tax Base: North Dakota, 2000-2010

<table>
<thead>
<tr>
<th></th>
<th>Taxable Sales and Purchases (1)</th>
<th>Taxable Sales (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in the Value of Oil Produced</td>
<td>0.182 (0.075)</td>
<td>0.131 (0.056)</td>
</tr>
<tr>
<td>Change in the County-level Sales Tax Rate</td>
<td>0.441 (1.132)</td>
<td>0.693 (1.342)</td>
</tr>
<tr>
<td>Observations</td>
<td>530</td>
<td>530</td>
</tr>
</tbody>
</table>
Bibliography


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