Drill Here, Drill Now, Pay Less: Economic and Air Quality Trade-offs of Oil and Gas Extraction*

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Abstract

The advent of hydraulic fracturing and horizontal drilling has transformed the oil and gas industry. While the fracking boom generates economic gains, the distribution of these benefits and the associated environmental harms remains underexplored. This work uses spatial econometric modeling to investigate the local and regional economic and air quality trade-offs of oil and gas extraction in Pennsylvania, Ohio, and West Virginia. First, it tracks the flow of economic benefits, capturing both inter- and intra-regional movements of economic value. Next, using high-resolution satellite-derived pollution concentration data, it examines how extraction activities contribute to local air pollution and its regional dispersion.

The results reveal a disparity: while the economic benefits of oil and gas largely accrue to non-local workers, locals living near production bear the majority of the environmental health costs. Specifically, although extraction activity generates job and earnings gains, these benefits are disproportionately captured by non-local workers, with local economic effects both limited and selective. I find that oil and gas production does not create jobs for local residents who work in their home county. Only a subset of locals—those who commute to jobs outside their home county—experience measurable gains, averaging eight additional jobs and $525,000 in earnings per 100,000 barrels of oil equivalent (BOE) produced. In comparison, the same level of production generates about 12 jobs and $1.19 million in earnings for non-local workers, amounting to about 40% more jobs and more than double the earnings compared to commuting locals.

In contrast, air quality impacts are most severe near the site of production. An additional 100,000 BOE within 1 km of a gridded cell increases its $PM_{2.5}$ concentration by 0.24 $\mu g/m^3$, with the effects diminishing to 0.005 $\mu g/m^3$ for production within 5 to 10 km. Using age-disaggregated population data at the cell level and applying a standard concentration-response function, I estimate oil and gas production $16 billion in health damages in the tri-state region over the 2001–2020 period. Approximately 70% of these premature deaths occurred during the last five years of the study period, between 2015 and 2020.

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1 Introduction

Technological advancements in hydraulic fracturing, coupled with horizontal drilling, have fundamentally shifted the energy landscape by unlocking vast quantities of oil and gas (OG) from shale formations that were previously uneconomical to exploit. After extended periods of declining domestic production, the shale revolution propelled the United States (U.S.) to become the world's largest OG producer. In December 2023, U.S. crude oil production averaged 13.3 thousand barrels per day, while natural gas gross withdrawals reached 128.9 billion cubic feet per day, both reaching record levels [21, 22].

The impact of the shale boom on the economy and the environment has been profound. The surge in shale OG production alleviated geopolitics concerns over the U.S. dependence on foreign oil imports. U.S. became a net exporter of natural gas in 2017 and a net exporter of petroleum three years later, in 2020 [13, 15]. The resulting domestic natural gas supply glut fast-tracked the transition away from coal combustion for electricity, contributing to a substantial decline in greenhouse gas emissions and air pollution in the U.S. At the household level, inexpensive gas has lowered electricity and heating bills.

The proliferation of shale OG has also sparked intense policy debate. Proponents argue that shale development creates jobs and income for the local economy. Critics, on the other hand, emphasize the long-term costs of depleting non-renewable resources and the negative environmental externalities associated with fracking, advocating for restrictions or outright bans. To the extent that policymakers try to balance these competing objectives, a complete understanding of the economic and environmental consequences of hydrocarbon extraction is critical to the development of sound OG policies.

A primary challenge in assessing the consequences of OG extraction is accounting for spatial spillover. Drilling often takes place in remote areas, with long-distance commuters making up a large portion of the workforce. As a result, non-local workers may capture a significant portion of the value generated, leaving less for the producing region. On the other hand, remote producing regions may also lack the infrastructure to support all aspects of resource extraction. As a result, OG activity may generate job opportunities for local residents in other counties where upstream or support industries, such as equipment suppliers, contractors, and drilling services, are based. In these cases, their earnings may flow to their home communities in the producing counties. What further distinguishes OG extraction from many other industrial processes is that it releases air pollution from numerous small, dispersed sources spread over a broad area, including drilling rigs, transport vehicles, and extraction infrastructure. These emissions can accumulate to significant levels, but isolating their impact and propagation remains challenging due to the diffuse nature of the emissions, their complex interaction with broader atmospheric processes, and the limited availability of granular data.

This paper has two primary objectives. The first objective is to examine the distribution of economic benefits from OG production. To do so, I begin by tracing the geographical flow of economic value, weighing local economic gains against the value extracted by non-local workers. I examine these value creation along both the extensive margin (i.e., job creation) and the intensive margin (i.e., hours worked and wage gains). I then investigates whether the local stimuli come from job and earnings growth within extraction counties or whether residents must commute outside their home counties to access these opportunities. I further disaggregates the various job flows by industry segment and age brackets to identify potential sectoral spillover effects and characterize the composition of employment gains. To capture the full scope of the local economic impact, I incorporate income from non-labor sources, particularly royalty payments to local mineral rights holders, and evaluates whether the total benefits accruing to local residents are commensurate with the total economic value generated by OG production. Together, the first part of this study provides a comprehensive examination of the economic consequences of OG extraction.

The second objective is to evaluate the environmental health costs of OG production. The intensive use of diesel engines, trucks, and heavy machinery during drilling and production emits fine particulate matter with diameters of less than 2.5 micrometers. Exposure to elevated $PM_{2.5}$ levels has been linked to increased mortality and a wide range of morbidity, including respiratory and cardiovascular diseases [17]. Therefore, this paper seeks to document the air quality impacts of OG activity, trace their spatial diffusion, and quantify the resulting public health damages over time and space.

This paper makes several contributions. First, it is among the few studies that study the economic and environmental trade-offs of OG under a unified framework. Second, it offers a detailed and nuanced decomposition of the economic impacts across multiple dimensions: (1) distinguishing local workers employed within their home county, those working outside it, and non-local workers; (2) separating intensive and extensive margin effects; (3) disaggregating the impacts by labor market segments and age brackets; (4) incorporating non-labor income; and (5) assessing the leakages of economic value from producing areas. Third, it contributes a spatially exhaustive, grid-based method to estimate pollution changes from emission-intensive activity. Leveraging age-specific, cell-level population data, I provide a granular economic valuation of the resulting health damages that accounts for variation in baseline mortality rates and population vulnerability across space and time.

Drilling and extraction decisions are not exogenous; firms may strategically target counties with lower wages or leasing costs. This potentially introduces bias due to reverse causality where increased drilling is a response to more favorable local economic conditions. In addition, time-varying omitted variables such as local policy changes, could further bias the observed estimates if they are correlated with OG activity and economic outcomes of interest. For causal estimates, I follow on the seminal work of Feyrer et al. (2017) by using exogenous geological variation in shale resource distribution as an instrument for OG production [6].

Specifically, I model the intensity of OG activity by capturing the rollout of new OG production across shale plays while accounting for systematic production differences across counties.

This paper focuses on OG extraction in Pennsylvania, Ohio, and West Virginia over the period from 2001 to 2020. Prior to the shale boom, extraction activity in these states was relatively limited. However, these Appalachian Basin states have since experienced tremendous expansion of shale OG, making it an ideal setting to study the economic and environmental effects of this resource boom. The study period spans both the pre-shale baseline and the subsequent growth and maturation of shale development.

The remainder of the paper proceeds as follows. Section 2 provides background on the shale revolution and the study region. Section 3 describes the data sources and presents summary statistics. Section 4 outlines the empirical strategy, including the identification framework and approach to monetizing economic and environmental impacts. Section 5 presents the main results. Section 6 concludes.

2 Background

2.1 The Shale Revolution

The development of shale resources transformed OG production by replacing traditional, conventional extraction methods with advanced drilling and fracturing techniques that made it possible to extract large volumes of hydrocarbons from geological formations[1] once thought unreachable. Prior to the Shale Revolution, extraction targeted conventional reservoirs, surface-accessible formations where hydrocarbons had naturally migrated from deeper source rocks.[2] These reservoirs, characterized by high permeability and porosity, allowed fluid to flow (thus avoiding the need for well stimulation, i.e., techniques to improve OG flow rate). These early conventional drilling methods required relatively simple technology but often produced wells that depleted quickly and delivered unpredictable production volumes. Exploration at the time evoked the image of a "big game trophy hunt," with operators drilling many dry holes in the hope of finding occasional high-yield ones [14]. Consequently, exploration efforts were geographically scattered, and production remained relatively modest.

The emergence of horizontal drilling and hydraulic fracturing revolutionized the industry by unlocking hydrocarbons trapped in low-permeability, low-porosity shale formations, source rocks once considered uneconomical to develop. Hydraulic fracturing (or fracking) pumps a high-pressure mix of water, sand, and chemicals into the rock to create tiny fractures. The sand keeps these cracks open, making it easier for OG

[1] A formation is a distinct rock layer with consistent composition, texture, and other physical properties that set it apart from adjacent layers.

[2] A source rock is an organic-rich sedimentary layer where OG form.

to flow into the well. Horizontal drilling turns the well sideways after reaching the target depth, allowing it to pass through OG-rich rock for thousands of feet, which boosts extraction from a single site. Beyond dramatically increasing output, these techniques also changed the nature of OG exploration itself. Modern unconventional development in shale now more closely resembles a systematic "manufacturing process" rather than high-risk prospecting [14]. Today, operators have much clearer knowledge of where these resources are and how extensive they are. Initial production rates are high, making revenues more predictable and reducing price volatility [8, 10, 14]. Economically speaking, fracking has both shifted the U.S. OG supply curve outward and flattened it [8, 14].

2.2 Appalachian Basin

The tri-state region of Pennsylvania (PA), Ohio (OH), and West Virginia (WV) lies within the Appalachian Basin, one of the leading OG producing regions in the contiguous U.S. Abundant in natural gas resources, the region sits atop the highly productive Marcellus and Utica shales and also intersects with older Devonian formations. Figure A1 in the Appendix maps out the major shale plays across the three states.

Although the Appalachian Basin was home to the nation's first natural gas well in 1821 and first commercial oil discovery in 1859, hydrocarbon production across PA, OH, and WV remained relatively modest for decades. The shale revolution changed this significantly, transforming the region from a marginal producer to a major contributor to the U.S. natural gas supply. In 2023, the tri-state region accounted for about one-third of U.S. dry natural gas production [12].

The fracking boom advanced at varying rates across the tri-state region, with considerable differences in its onset and adoption. Figure 1 displays annual OG production for each state. PA saw a sharp increase in OG output beginning around 2009, followed shortly thereafter by WV. It was not until 2013 that OH began experiencing a similar surge in its OG output. Among the three states, PA, situated directly over the most productive portion of the Marcellus Shale, is by far the largest contributor, accounting for more than 60% of total OG output in the region. Over the full sample period, total OG output in the three states increased 25-fold. Between 2010 and 2020 alone, production grew by a factor of 11.

3 Data Description

To examine the economic and air quality impacts of OG extraction, I compiled data on OG activity, detailed economic indicators, and air pollution to build comprehensive panel datasets at the county and grid cell levels from 2001 to 2020.

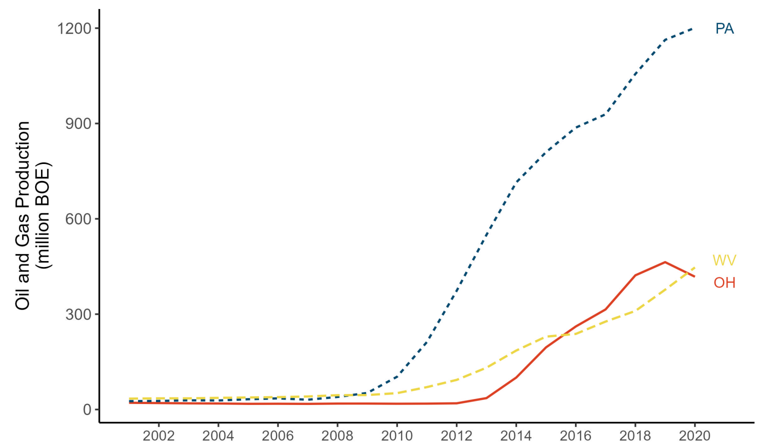

Figure 1: Oil and Gas Production in Pennsylvania, Ohio, and West Virginia (2001 - 2020)
Note: This figure plots the annual oil and gas production measured in million barrels of oil equivalent (BOE) for PA, OH, and WV. The data come from Enverus [5].

Economic data. Most existing studies comparing local and non-local economic outcomes report economic impacts based on either place of work[3] or place of residence[4] [25]. However, these measures overlap and thus, imperfectly capture the flows of economic value generated by OG activity to different groups of workers. To better disentangle labor market forces, I combine county-level annual data on jobs and earnings from the U.S. Census Bureau's Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) [4] and the U.S. Bureau of Economic Analysis's Local Area Personal Income (LAPI)[19]. By analyzing earnings and employment together, I can differentiate the labor market impacts at both the intensive margin (hours worked) and the extensive margin (new jobs). A key advantage of these data sources is their ability to capture both inter- and intra-county distributions of jobs and earnings. LODES tabulates job counts based on both where people live and where they work, whereas BEA aggregates earnings separately by place of residence and place of work, including a net residence adjustment for inter-county commuting. Combining these publicly available data, I construct a set of job and earnings measures that enable me to decompose the flows of economic value into the following measures:

1. **Home-county jobs/earnings**: Jobs/earnings held by locals who live and work in their home county.

2. **Job/earnings inflows**: Jobs/earnings of locals who work outside of their home county.

3. **Job/earnings outflows**: Jobs/earnings of non-locals.

Note that these measures are defined to reflect the movement of economic values, not the physical movement of labor.[5] For example, job outflows in my framework represent jobs filled by non-local workers,

[3] I.e., where extraction occurs.
[4] I.e., where extraction workers reside.
[5] LODES define inflows and outflows according to the commuting patterns of workers.

that is, economic value that "flow out" of the local economy, even if the job itself is performed within the producing county. In addition, I use "job" and "employment" interchangeably throughout this work; however, it is important to clarify that LEHD data count jobs, not persons, meaning a single worker can contribute multiple jobs to the total.[6]

These disaggregated measures reveals important labor market patterns that help explain who gains from OG activity, patterns that may be masked in more aggregated views. For example, if OG creates new local jobs in rural areas where employment opportunities are scarce, I might observe an increase in local employment alongside a decline in job inflows. This would occur if previously out-commuting residents now find work locally. In such a case, the use of a place-of-residence employment measure (which sums home-county jobs and job inflows) could lead to a muted or even null employment effect,[7] despite the real welfare gains from reduced commute.

Employment and income effects may also diverge. As Weber (2012) suggested, a booming sector may attract local workers back home without necessarily offering them higher wages than they previously earned elsewhere [24]. In such cases, the primary benefit comes from shorter commutes rather than increased earnings. Thus, the deconstructed job and earnings measures provide a more complete picture of the effects of the labor market.

Air pollution data. To examine variation in local air quality, I use $PM_{2.5}$ estimates from the recently released Gridded Environmental Impacts Frame (EIF) from the U.S. Census Bureau, which integrates several high-resolution geospatial datasets on air pollution and population by several demographic groups [2]. The data are provided on a fixed $0.01° \times 0.01°$ grid, corresponding to approximately 1.2 km^2 resolution in North America. In particular, I leverage the annual mean $PM_{2.5}$ concentrations originally provided by the Atmospheric Composition Analysis Group. They use the GEOS-Chem chemical transport model to simulate the geophysical relationship between aerosol optical depth (AOD) and $PM_{2.5}$ and relate satellite-based AOD retrieval to surface $PM_{2.5}$ concentrations [3].

In addition, I use the granular age-specific population counts both as a control in my empirical model and to value health damages resulting from OG extraction. The Gridded EIF provides age-specific population counts in three broad groups: under 18, 19–64, and 65 and older. Epidemiological evidence suggests that exposure to particulate matter disproportionately affects infants and adults aged 30 and above. To estimate the 30–64 population at the grid-cell level, I calculate the share of individuals aged 30–64 within the 19–64 group at the county level and apply this proportion to each cell's 19–64 population.

Oil and gas data. I obtained monthly well-level OG production data from Enverus (formerly DrillingInfo)

[6]While it is possible to restrict the analysis to primary jobs, this study focuses on total job counts to reflect the full employment impact of OG activity.

[7]An extreme case would be if all new local jobs were filled by former out-commuters, offsetting job inflows entirely.

[5]. I convert natural gas volumes from cubic feet to barrels of oil equivalent (BOE) and construct a unified production measure by summing oil and gas output. I aggregate this production measure to the annual level. For the economic analysis, I aggregate production to the county-year level. To assess air quality impacts, I construct a spatial measure of OG production by aggregating output within incremental concentric distance bands (0–1 km, 1–2 km, 2–3 km, 3–5 km, and 5–10 km) from the centroid of each pollution grid cell. This allows me to examine how OG activity at varying proximities affects local ambient pollution. This approach helps me identify how pollution exposure varies with proximity to extraction activity.

3.1 Summary statistics

After merging, the final dataset comprises 4,200 county-year and 4 million cell-year observations, covering 210 counties and approximately 237K wells in Pennsylvania, Ohio, and West Virginia between 2001 and 2020. Table 1 presents average characteristics at the county and grid-cell levels over the sample period. All reported values are annual averages, either at the county or cell level.

The average county receives $5.86 billion in personal income and generates $6.92 billion in GDP, with substantial variation across the sample. The decomposed labor market measures reveal pronounced and interesting differences between locally employed workers and those commuting across counties. On average, home-county earnings (i.e., earnings of residents who work in their home county) are about twice as large as earnings inflows (i.e., earnings of residents who work elsewhere). Combined, these two components constitute place-of-residence earnings, which account for about 64% of total personal income.[8] Dividends, interest, and rental income contribute an additional 17% on average, implying that transfer payments[9] account for the remaining 19%.

The scale of cross-county work activity is substantial. The total number of inbound and outbound workers is approximately 1.7 times the number of local workers employed within the county. Despite this, their combined annual earnings are comparable to local earnings, implying that commuters, on average, either work fewer hours or receive lower wages. In addition, job and earnings inflows and outflows are roughly equal, suggesting that commuting workers primarily travel to other counties within the broader tri-state region.

Oil and gas production is highly skewed, with a mean of 3.21 million BOE per county-year and a standard deviation more than five times the mean, indicating significant heterogeneity in extraction intensity. At the

[8] Personal income comprises three main components: place-of-residence earnings, property income (dividends, interest, and rental income), and transfer payments.

[9] Personal current transfer receipts are "receipts of persons from government and business for which no current services are performed. Current transfer receipts from government include Social Security benefits, medical benefits, veterans' benefits, and unemployment insurance benefits. Current transfer receipts from business include liability payments for personal injury and corporate gifts to nonprofit institutions." — U.S. Bureau of Economic Analysis

grid-cell level, Table 1 reports annual average OG production within concentric distance bands from each cell centroid. Production volumes rise steeply with increasing distance. In the closest band (0–1 km), annual average production is approximately 7,000 BOE. In the largest but furthest ring (5-10 km), annual average production is roughly 580K BOE. This spatial gradient in production forms the basis for defining treatment intensity in the air quality analysis. Average annual $PM_{2.5}$ concentrations are 10.24 $\mu g/m^3$. Each cell has an average population of about 8,000.

Table 1: Summary Statistics

Variable	Mean	Std. Dev.
County-level measures		
Outcome variables		
Personal Income ($ billion)	5.86	11.5
Real Gross Domestic Product ($ billion)	6.92	15.5
Local earnings ($ billion)	2.53	5.86
Earnings inflows ($ billion)	1.22	2.22
Earnings outflows ($ billion)	1.18	3.09
Local jobs (thousand)	29.5	65.9
Job inflows (thousand)	24.2	49
Job outflows (thousand)	24.7	34.9
Dividends, interest, and rental income ($ billion)	0.98	2.18
Independent and control variables		
Oil & Gas (million BOE)	3.21	16.5
Population (thousand)	124	214
Cell-level measures		
Outcome variable		
$PM_{2.5}$ (μg/m^3)	10.24	2.7
Independent and control variables		
Oil & Gas by Source Zones (thousand BOE)		
0-1 km	7.54	107.4
1-2 km	23.2	224
2-3 km	39	327
3-5 km	125	844
5-10 km	580	3,274
Population (thousand)	8.06	20.8

Note: The table shows annual averages; dollar values are inflation-adjusted to 2020 dollars.

4 Empirical Model

4.1 Economic Analysis

While the underlying geological formations and hydrocarbon resources are plausibly exogenous to local economic conditions, drilling and extraction decisions may not be. To mitigate endogeneity concerns, I follow Feyrer et al. (2017) in exploiting exogenous geological variation in the distribution of shale resources to instrument for OG production [6]. Specifically, the intensity of OG activity is modeled using county fixed effects to account for persistent differences in production levels across counties, and the interaction between shale plays and year dummies,[10] which capture the timing of the rollout of OG production within a given shale play. I estimate the following equation:

$$\text{arcsinh}(OG_{i,t}) = \lambda_i + \lambda_{st} + \epsilon_{i,t} \tag{1}$$

where $OG_{i,t}$ represents OG production measured in BOE in county i and year t, λ_i is the county fixed effect that controls persistent county-specific characteristics (e.g., altitude.), λ_{st} denotes a vector of shale play-year dummies, and ϵ_{it} is the error term.

Note that I use the inverse hyperbolic sine (IHS) transformation to approximate a log transformation for both OG and outcome variables,[11] allowing for zeros in production and addressing skewness in both production and economic outcomes. This specification weighs the exposure of each county to shale production by the fraction of the county's area that overlaps with the shale formation. The predictions from equation (1) is a valid instrumental variable (IV) because they capture the overall timing of production growth across the entire shale play, rather than relying on OG activity within any individual county, thereby minimizing potential correlation with county-specific unobservables. I do not transform the fitted values back to levels in a second step, as this work aims to estimate elasticities, which are directly interpretable from the coefficients in the arcsinh-arcsinh framework.[12] Standard errors are clustered by county and year to account for serial correlation and contemporaneous shocks within counties over time.

[10] Shale plays enter the model as categorical variables indicating which shale formation(s), if any, are present within the county.

[11] I examine the impacts of OG extraction on the following outcomes: personal income, personal income/OG revenue, personal income/GDP, local jobs, job inflows, job outflows, local earnings, earnings inflows, earnings outflows, annual average own-county and downwind $PM_{2.5}$ concentration.

[12] Bellemare and Wichman (2019) show that for large values of the outcome and explanatory variables, the IHS transformation approximates the natural logarithm, allowing coefficients to be interpreted as elasticities as those in a log–log model. As a rule of thumb, they suggest that this approximation is reasonable when variable values exceed 10.

4.2 Air Quality Analysis

I apply a similar empirical strategy to examine the impact of OG activity on $PM_{2.5}$, adapting for key differences in the structure of the data and the nature of the outcome. Specifically, the analysis uses pollution measurements at the grid-cell level (rather than counties) and accounts for the fact that pollution can disperse spatially beyond the point of emission. In contrast to economic outcomes, which are typically measured and experienced within administrative boundaries, air pollution is governed by atmospheric processes and disperses continuously across space, requiring a design that is not constrained by jurisdictional lines and captures spatial variation in exposure.

To this end, I define production-based exposure as the total volume of production occurring within concentric distance bands, specifically, 0–1 km, 1–2 km, 2–3 km, 3–5 km, and 5–10 km, from the centroid of each pollution grid cell. I will refer to these areas as *source zone*. To estimate how production within different source zones impacts pollution concentrations in the receptor (focal) cell, I estimate the following specification:

$$\text{arcsinh}(OG^{d}_{j,t}) = \gamma_j + \gamma_{s,t} \times S_j + \mu^{d}_{j,t} \tag{2}$$

where γ_j is the cell fixed effect, $\gamma_{s,t}$ denotes a vector of shale play-by-year dummies, defined by all cells within a source zone—not just the focal cell j, S_j denotes the proportion of grid cells within a d-km source zone around the centroid of the receptor cell j that lie on at least one shale play.

The IV specification for the air quality analysis in equation (2) parallels that of equation (1), absorbing baseline differences in production levels within cell's buffer and leveraging exogenous temporal variation in production intensity linked to geological formations, while accounting for spatial heterogeneity in shale play presence across varying buffer sizes. For the 0-1 km source zone, the variable $\gamma_{s,t}$ (shale play-by-year fixed effects) corresponds directly to the shale play and year of the focal cell, and the weighting term S_j becomes binary, indicating whether the cell overlaps a shale formation or not. In this case, the IV specifications in equations (1) and (2) are almost equivalent, differing mainly in the spatial unit of analysis (i.e., county versus cell) and in the construction of OG production measure. Lastly, I cluster standard errors by cell and year.

4.3 Back-of-the-Envelope Calculation of Average Predicted Effects

To interpret the estimated elasticities in a more tangible way, it is useful to convert them into marginal effects at the mean. Elasticity measures the *percentage* change in the outcome variable y resulting from a *one* *percent* change in the explanatory variable x. However, policy relevance often requires understanding how level changes in x affects the level of y. I take the following steps to provide a first-order estimation of the effects in levels

Formally, elasticity is defined as:

$$\varepsilon_{yx} = \frac{\partial y}{\partial x} \cdot \frac{x}{y} \tag{3}$$

Rearranging this expression, we can solve for the marginal effect:

$$\frac{\partial y}{\partial x} = \varepsilon_{yx} \cdot \frac{y}{x} \tag{4}$$

Since the arcsinh–arcsinh transformation approximates a log–log relationship and assumes elasticity is constant or approximately constant locally, I can approximate the marginal effect evaluated at the average values of x and y as:

$$\left.\frac{\partial y}{\partial x}\right|_{\bar{x},\bar{y}} \approx \varepsilon_{yx} \cdot \frac{\bar{y}}{\bar{x}} \tag{5}$$

This expression gives the average predicted effect (APE), the expected change in y associated with a one-unit change in x around the mean levels of both variables. For a finite Δx-unit change in x, the approximate change in y is given by:

$$\Delta y \approx \Delta x \cdot \hat{\varepsilon}_{yx} \cdot \frac{\bar{y}}{\bar{x}} \tag{6}$$

To account for the fact that OG production varies substantially and is often concentrated in rural regions, instead of using the simple mean of y, I use a weighted average of y where the weights correspond to OG production. This weighting ensures that observations with higher OG production exert proportionally greater influence on the average outcome. I recognize that this approximation relies on the assumption that elasticity is constant or approximately constant locally, and as such, it may not capture nonlinearities or changes in elasticity over larger changes in OG. Despite this limitation, the expression can still provide useful and interpretable estimates of the general magnitude and direction of the effect, facilitating comparisons and informing policy implications.

4.4 Premature Mortality Attributable to Oil & Gas Production

Extensive epidemiological research have demonstrated that exposure to $PM_{2.5}$ elevates the risk of premature mortality. Indeed, increased mortality risk accounts for the majority of health damages linked to air pollution (EPA 2011). However, pollution levels alone do not fully encapsulate the public health burden, as the true impact also jointly depends on exposure levels, the size of the exposed population, and the baseline vulnerability of different demographic groups.

To estimate the mortality consequences of changes in $PM_{2.5}$ concentrations due to OG, I apply a concentration–response function (CRF), which relates fine particulate exposure to all-cause mortality risk among adults. Then, by combining estimated pollution changes with high-resolution population counts and group-specific mortality rates, I account for the fact that identical pollution increments can result in very different health burdens depending on who and how many are exposed.[13] For each grid cell c, age group d, and year t, the change in the mortality rate is calculated as:

$$\Delta m_{c,d,t} = m_{0,c,d,t}\left(1 - \frac{1}{\exp\left(\beta \cdot \Delta \text{PM}_{2.5,c,t}\right)}\right) \tag{7}$$

where: $m_{0,c,d,t}$ is the baseline annual mortality rate for age group d in state s in year t. β is the natural log of the relative risk corresponding to a 10 $\mu g/m^3$ increase in ambient $PM_{2.5}$ pollution. $\Delta PM_{2.5,c,t}$ is the estimated average change in $PM_{2.5}$ attributable to total OG production in cell c and year t.

The baseline mortality rate information $m_{0,c,d,t}$ come from the Centers for Disease Control and Prevention's (CDC)'s WONDER database [11]. Although county-level mortality rates are available, many are suppressed or unreliable due to small counts and data quality issues, especially in less-populated areas. To ensure more stable and reliable estimates, I use state-level annual mortality rates disaggregated by two age groups: 30 to 64 and above 65. The β coefficient comes from Turner et al. (2016), which reports a mortality hazard ratio of 1.06 (95% CI: 1.04–1.08) per 10 $\mu g/m^3$.[14]

To estimate exposed population counts, I use cell-level demographic-specific population data from the Gridded EIF. The expected change in the number of deaths in each cell, age group, and year is the product of the change in mortality rate and the corresponding population:

$$\Delta \text{Mortality}_{c,d,t} = \Delta m_{c,d,t} \times \text{Population}_{c,d,t} \tag{8}$$

[13] This functional form assumes the CRF is log-linear in relative risk (RR). Specifically, RR $= \exp(\beta \cdot \Delta \text{PM}_{2.5})$. The attributable fraction is therefore $1 - \frac{1}{\text{RR}}$, reflecting the proportion of baseline mortality attributable to the pollutant increment.

[14] Turner et al. (2016) is used as the default hazard risk estimate because it provides one of the most comprehensive and methodologically rigorous estimates of long-term $PM_{2.5}$ mortality risk based on EPA's assessment [20].

I aggregate these estimates across all grid cells, age groups, and years to obtain the total mortality burden:

$$\Delta\text{Mortality}_{\text{Total}} = \sum_{c}\sum_{d}\sum_{t} \Delta\text{Mortality}_{c,d,t} \tag{9}$$

To translate the health impacts into monetary social damages, I use the Value of a Statistical Life (VSL), which quantifies the monetary value associated with small changes in mortality risk across a population.[15] This valuation applies a VSL of $7.4 million ($2006), consistent with EPA guidelines cite. The monetized damages from elevated premature mortality due to OG are given by:

$$\text{Total Damages} = \Delta\text{Mortality}_{\text{Total}} \times \text{VSL} \tag{10}$$

5 Results

5.1 Economic Impacts

5.1.1 Place-of-work versus Place-of residence

The first set of results reported in Table 2 compares the impact of OG extraction on economic measures based on place of residence with those based on place of work. The first two columns of Table 2 focus on the job effects, while the last two present the earnings effects. The exercise aims to replicate what has commonly been done in the literature, which often relies on one type of measure or, in some cases, compares the two. The coefficients approximate elasticities, representing the percentage change in an outcome given a percentage increase in OG production, holding other things constant. To provide a more intuitive understanding of the results, I also report the average predicted effects per 100K BOE alongside the marginal estimates.

Consistent with the literature, I find larger effects on work-based measures than residence-based measures, indicating leakages of economic value out of producing counties [7, 25]. I find that the employment measured by place of work increases by 0.0099%, which corresponds to an average of about 10 additional jobs for every 100K BOE. In contrast, the effect on resident employment is two-thirds as large and is not statistically significant. Although resident employment did not increase, their earnings grow by 0.0243%, which translates to roughly 1M for the average county for each 100K BOE increase in OG production. However, work-based earnings effects are about twice as large. Specifically, earnings by place of work increase by 0.0243%, or about 2M for an additional 100K BOE.

[15] Rather than assigning a value to any individual life, the VSL reflects the aggregate willingness to pay for marginal reductions in the probability of death. For example, if 100,000 people each pay a small amount to reduce their individual risk by 1 in 100,000, the total willingness to pay equals the VSL [23].

Table 2: Work versus Residence

	Job by place of		Earnings by place of	
	Residence (1)	Work (2)	Residence (3)	Work (4)
Oil & Gas Production	0.0066	0.0099**	0.0133**	0.0243***
	(0.0048)	(0.0046)	(0.0048)	(0.0063)
Avg Pred. Effect (100K BOE)	-	10.2	1.03M	2.03M
Observations	3,990	3,990	4,200	4,200
R^2	0.99523	0.99749	0.99747	0.99615
Within R^2	0.06450	0.20468	0.21023	0.14638

Robust standard errors clustered at the county and year level in parentheses.
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

The exercise is informative but comes with caveats. First, place-of-work and place-of-residence measures overlap since both of them include home-county workers. The overlap clouds the interpretation of how OG production affects the local labor market, as it combines the effects on different and potentially heterogeneous groups of workers. Furthermore, while the results suggest that non-local workers capture a significant share of the economic benefits of OG extraction, Table 2 does not allow for a direct estimation of the outflows of economic value from the producing area. Additionally, the place-of-residence measure, which combines labor market outcomes for home-county and inflow workers, may obscure important within-county variations in the distribution of economic benefits.

5.1.2 Decomposing Flows of Job and Earnings

To address the limitations, I decompose the place-of-work and place-of-residence measures to study the labor market patterns at a more granular level in Table 3. Table 3 examines both job and earnings outcomes across three worker groups, with the first three columns focusing on jobs and the latter three on earnings. Home-county jobs and earnings reflect the job and earnings of residents who both live and work within the producing county. Inflow variables capture the jobs and earnings of residents who commute outside their home county for work, while outflow variables represent the economic outcomes of out-of-county workers coming into the producing area. This framework offers a thorough understanding of how OG production affects both inter-county (comparing local and non-local workers) and intra-county (comparing home-county and inflow workers) economic flows.

Columns 1-3 estimate the effect of OG production on employment. I find a null effect of OG production on home-county jobs (column 1), suggesting that OG production does not create jobs for locals within the producing county. This suggests that OG production generates little to no induced labor demand within the local area. In contrast, there is modest evidence that OG increases employment for inflow workers—those

Table 3: Labor Market Outcomes

	Job outcomes			Earnings outcomes		
	Home-county (1)	Inflows (2)	Outflows (3)	Home-county (4)	Inflows (5)	Outflows (6)
Oil & Gas Production	-0.0026	0.0153*	0.0253***	0.0109	0.0220**	0.0568***
	(0.0045)	(0.0077)	(0.0084)	(0.0067)	(0.0079)	(0.0146)
Avg Pred. Effect (100K BOE)	-	8.4	11.7	-	525K	1.19M
Observations	3,990	3,990	3,990	4,200	4,200	4,200
R^2	0.99678	0.98791	0.99274	0.99523	0.99468	0.98620
Within R^2	0.10687	-0.02103	0.03708	0.18571	-0.04772	-0.10928

Robust standard errors clustered at the county and year level in parentheses.
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

who leave their home counties to work—experience some job gains. Specifically, a 1% increase in OG extraction leads to a 0.0153% increase in job outflows or about eight job for each 100K BOE (column 2). However, the employment elasticity for non-local outflow workers is over 1.65 times larger, with a 1% increase in OG production raising outflow jobs by 0.0253% (column 3). For the average county, this increase represents about 12 additional jobs going to non-locals. Overall, the results indicate that OG production exclusively creates job for mobile commuting workers, with the majority of employment gains accruing to non-local workers.

Next, I turn to earnings to examine whether OG activity primarily drives job creation or also leads to gains in earnings through higher wages or increased hours. Columns 4 through 6 report the estimated effects on total earnings. Consistent with employment results, home-county earnings are not significant, but earnings inflows are. A 1% increase in OG raises earnings inflows by 0.022%, which is about $525K in aggregate, or about $22 per worker, on average. However, earning outflows are more than twice as large. Specifically, a 1% increase in OG raises earning outflows by 0.0567%. On average, this translates to about $1.2M, or $48 per worker, for every 100K BOE.

Aggregate earnings are the sum product of job count, hours worked, and the prevailing wage rates that correspond to those jobs. By comparing growth in employment with growth in total earnings, I can assess whether earnings gains arise from the extensive margin (i.e., job creation) and/or the intensive margin (i.e., increased hours or higher pay). For inflow workers, the elasticities of employment and earnings are roughly equal and statistically indistinguishable.[16] This implies that earnings gains for inflow workers are driven almost entirely by job creation, rather than by increases in wages or hours worked. In contrast, for outflow workers, the elasticity of earnings (column 6) is more than twice as large as the elasticity of employment

[16] A two-sided Z-test fails to reject the null hypothesis that the two elasticities are equal (p-value = 0.6).

(column 3).[17] This result suggests that outflow workers benefit along both the extensive and intensive margins. That is, they gain more jobs and also earn more per job, due to longer hours and/or higher wages.

To provide additional perspective on the scale of these intensive margin gains and as a robustness check on the earlier margin analysis, Table 4 reports the estimated changes in earnings per job across the three worker groups. While this measure does not distinguish between wages and hours worked, it offers a straightforward summary of how much earnings per job increase alongside employment. Column (2) shows no statistically significant change in per-job earnings for inflow workers, consistent with the interpretation that their gains are driven primarily by job creation. In contrast, column (3) indicates that non-local workers experience significant growth in per-job earnings of 0.0310%, which corresponds to about $3.20 more per job for each 100K BOE produced.

Table 4: Intensive Margin: Effects on Per-job Earnings

	Per-job Earnings		
	Home-county (1)	Job inflows (2)	Job outflows (3)
Oil & Gas Production	0.0137*	0.0059	0.0310**
	(0.0077)	(0.0101)	(0.0130)
Avg Pred. Effect (100K BOE)	36.5	-	40.5
Observations	3,990	3,990	3,990
R^2	0.71835	0.85134	0.78032
Within R^2	0.00788	0.00615	-0.06727

Robust standard errors clustered at the county and year level in parentheses.
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

Interestingly, Table 4 shows a weakly positive effect on per-job earnings for home-county workers, despite the null results in Table 3. This suggests that OG activity may have modestly increased local labor demand, enough to raise wages or hours worked among existing workers, but insufficient to generate net job creation. Such effects likely arise from local economic multiplier effects from OG production, where increased spending boosts demand for housing, services, and other sectors. At the same time, given the null but negative employment effect (column 1 of Table 3), there might have also been a compositional shift in the home-county workforce, wherein lower-wage workers exit the labor force or relinquish lower-paying jobs while retaining higher-paying ones. Such a shift would mechanically increase average earnings per job without genuine labor market gains.[18] However, because total earnings did not decline, it is unlikely that the increase in per-job earnings is solely due to compositional changes; modest growth in local labor demand is

[17] A Z-test of the difference yields a p-value of 0.06.

[18] This could occur if: (1) low-wage jobs within the producing county are displaced, (2) such employment becomes unnecessary due to alternative income sources such as royalty payments, or (3) home-county workers find jobs outside of their home county. In the third case, the positive employment effects reported in column 2 of Table 3 would partially capture a spatial reallocation of labor rather than net job creation.

a more consistent explanation for the observed per-job earnings increase.

The detailed decomposition reveals several insights. First, only workers who are both willing and able to commute outside their home county benefit from OG production. This signals labor mobility as a central factor in shaping the distribution of labor market gains in resource-rich regions, as workers must overcome commute-relate constraints (e.g., transportation costs, travel time, and availability of transit options) to access these employment opportunities. Second, the benefits manifest differently in magnitude and margin for local versus non-local commuters. Non-local commuters experience gains in both employment and earnings (extensive and intensive margins), while local workers employed outside their home county see smaller economic stimulus, primarily along the extensive margin with job increases but little change in earnings.

5.1.3 Labor Market Segmentation

To better understand the mechanisms through which OG influences the labor market, this section further disaggregates employment by three broad labor market segments and three age groups. The sectoral breakdown provides some insight into which parts of the local economy expand in response to OG activity, and whether benefits accrue primarily through direct industry linkages or broader general equilibrium effects. Meanwhile, age-based breakdown examines whether younger or older workers disproportionately benefit, potentially capturing differences in mobility, skills, or opportunity costs. Together, these breakdowns clarify how resource-driven demand shocks translate into labor market outcomes across sectors and age groups.

The analysis relies on the industry and age groupings available in the LODES origin-destination data, which classifies employment into three broad labor market segments: Goods Producing,[19] Trade, Transportation, and Utilities,[20] and All Other Services.[21] These segments differ in their exposure to OG-driven demand shocks and their capacity to absorb mobile labor. While the classification is relatively coarse and does not allow for precise isolation of OG employment, it still provides useful insights and captures indirect effects on related industries and the broader economy. The age bins include three cohorts: young adults ($\leq$29), middle-aged (30–54), and older workers (55+).

The Goods Producing category, which includes Mining, Quarrying, and Oil and Gas Extraction (NAICS 21), is the closest to capturing direct effects of OG. However, because it also includes Construction, Manufacturing, and Agriculture, the estimated effect may misrepresent the true direct job impact of OG extraction.

[19] The Goods Producing category includes the following NAICS sectors: 11 (Agriculture, Forestry, Fishing, and Hunting); 21 (Mining, Quarrying, and Oil and Gas Extraction); 23 (Construction); and 31–33 (Manufacturing).

[20] The Trade, Transportation, and Utilities category includes the following NAICS sectors: 22 (Utilities); 42 (Wholesale Trade); 44–45 (Retail Trade); and 48–49 (Transportation and Warehousing).

[21] The All Other Services category includes the following NAICS sectors: 51 (Information); 52 (Finance and Insurance); 53 (Real Estate and Rental and Leasing); 54 (Professional, Scientific, and Technical Services); 55 (Management of Companies and Enterprises); 56 (Administrative and Support and Waste Management and Remediation Services); 61 (Educational Services); 62 (Health Care and Social Assistance); 71 (Arts, Entertainment, and Recreation); 72 (Accommodation and Food Services); 81 (Other Services, except Public Administration); and 92 (Public Administration).

OG operations also depend heavily on the Trade, Transportation, and Utilities segment for trucking, pipeline transport, and power supply at wellsites. Finally, the All Other Services segment has little direct involvement in OG extraction and therefore likely captures indirect spillovers.

Figure 2 displays the annual average number of jobs for the three worker groups in the tri-state region, segmented by labor market type in Panel A and age group in Panel B. The employment and age profiles for inflow and outflow workers are essentially the identical. The majority of jobs fall within the All Other Services segment, comprising 66% of home-county workers' jobs compared to 58% for commuting workers. This difference reflects the higher share of commuters employed in Trade, Transportation, and Utilities, 24% versus 17% for home-county workers. The share of workers in Goods Producing industries is roughly similar across all groups, at about 17-18%. Panel B shows that the age distribution is comparable across the three worker groups, with home-county workers having a slightly smaller share of workers aged 29 or younger and larger share of workers aged 55 or older. This is consistent with the notion that older workers may be less willing or able to commute. Workers aged 30 to 54 make up over half of the labor force.

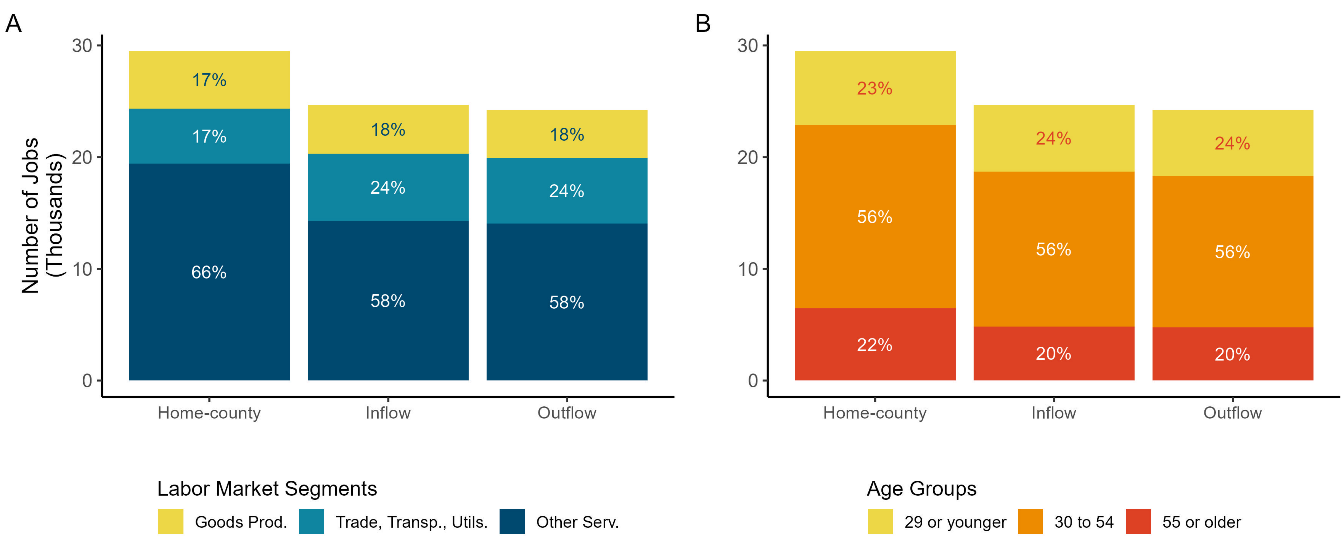

Figure 2: Workforce Composition by Age and Labor Market Segment

Table 5 presents the employment impacts across labor market segments for commuting workers, both inflow and outflow. The Goods Producing segment sees the largest effects, followed by Trade, Transportation, and Utilities. This holds true for both non-local workers and locals working outside their home county. The job growth among these out-commuting local workers may result from producing counties lacking the industrial base needed to support OG activity locally. Increased OG output raises demand for critical inputs to the extraction process, such as steel, cement, and specialized equipment. In the absence of local inputs, OG operators must source them elsewhere.[22] This demand may prompt input producers to expand operations and scale up production, thereby creating additional employment opportunities in areas better equipped with industrial infrastructure, such as machine shops, fabrication yards, or equipment suppliers. Similarly, OG production increases the need for transportation and logistics services, including trucking and freight. These activities may be based in commercial or logistical hubs with better highway access and warehouse capacity, rather than in the producing counties themselves. As a result, even local residents may find jobs tied to OG activity outside their home county, contributing to the observed pattern of larger job outflows than inflows in these segments.

Interestingly, in the All Other Services segment, job gains are statistically significant, albeit weak, only for non-local workers. One possible explanation is that in addition to extraction workers and truckers, OG firms may also bring in non-local specialists, such as engineers, environmental consultants, geologists, regulatory experts, and royalty managers, to provide technical and administrative support essential to OG operations.

Moreover, job outflows consistently exceed inflows across all labor market segments. In Goods Producing, outflows are nearly double inflows in both elasticity and predicted effect; in Trade, Transportation, and Utilities, outflow elasticity is about 60% larger. Table 9 in the Appendix presents segment-specific job effects for home-county workers, showing null effects across all segments. This further reinforces the findings in Table 3 suggesting that OG does not generate employment for locals in the producing county. Taken together, these results confirm that OG mostly benefits non-local workers and generates limited induced jobs from increased local spending. Spillover effects mainly occur through increased job opportunities outside of the producing county for mobile local workers in sectors closely linked to OG.

Table 5: Job Flows by Labor Market Segments

	Job Inflows			Job Outflows		
	Goods Prod. (1)	Trade, Transp., Utils. (2)	Other Serv. (3)	Goods Prod. (4)	Trade, Transp., Utils. (5)	Other Serv. (6)
Oil & Gas Production	0.0262**	0.0173**	0.0112	0.0488**	0.0271**	0.0133*
	(0.0094)	(0.0072)	(0.0089)	(0.0184)	(0.0103)	(0.0072)
Avg Pred. Effect (100K BOE)	2.6	2.3	-	5.1	2.9	3.3
Observations	3,990	3,990	3,990	3,990	3,990	3,990
R^2	0.97881	0.98751	0.98727	0.96430	0.99146	0.99307
Within R^2	-0.06429	-0.01745	-0.01484	-0.04352	0.02155	0.07501

Robust standard errors clustered at the county and year in parentheses
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

Table 6 presents the job inflow and outflow effects across three age brackets. For inflow workers, job gains largely go to workers under 30, with smaller but detectable effects for those 55 and older. In contrast, job gains for non-local workers span all three age bins, suggesting that OG demands a mix of mobile young labor

[22] For example, Minnesota and Wisconsin supply much of the sand used in fracking despite not sitting on top of shale formations [16].

for physically demanding fieldwork as well as older, more experienced workers for technical, supervisory, or regulatory roles that support OG extraction and operations. Among non-local workers, the youngest group shows the most elastic employment response, while individuals aged 30 to 54 see largest average predicted effect, reflecting their larger share of the workforce, In both inflow and outflow groups, young adults respond most strongly to OG-driven job growth. Since young adults are more likely to be single, rent rather than own their homes, and have fewer family obligations, they may be more willing to commute or relocate for work and better able to respond to the spatially dispersed and transient labor demands of the resource sector. Table 9 in the Appendix also presents age-specific job effects for home-county workers and, consistent with the segment-level results, shows null employment effects across all age cohorts.

Table 6: Job Flows by Age Cohorts

	Job Inflows			Job Outflows		
	29 or younger (1)	30 to 54 (2)	55 or older (3)	29 or younger (4)	30 to 54 (5)	55 or older (6)
Oil & Gas Production	0.0185**	0.0107	0.0174*	0.0316***	0.0223**	0.0246**
	(0.0079)	(0.0074)	(0.0090)	(0.0093)	(0.0086)	(0.0089)
Avg Pred. Effect (100K BOE)	2.2	3.2	2.3	3.4	5.5	2.6
Observations	3,990	3,990	3,990	3,990	3,990	3,990
R^2	0.98762	0.98770	0.98609	0.99167	0.99202	0.99126
Within R^2	-0.03316	-0.00019	-0.03640	0.04262	0.06356	-0.00240

Robust standard errors clustered at the county and year in parentheses
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

5.1.4 Total Economic Benefits

Until now, my analysis has focused on labor market outcomes, without considering other sources of income such as royalty payments. To gauge the extent to which total economic benefits remain in extraction counties versus flowing outward—accounting for both labor and non-labor income— I compare personal income growth[23] to three broader measures of economic value: OG revenue, mining sector GDP (NAICS 21), and total county GDP. OG revenue captures the direct market value of extracted resources, while GDP represents the total value of goods and services produced within the county. These measures encapsulate not only local gains but also leakages of economic value to nonlocal firms, workers, or landowners. In contrast, personal income is strictly residence-based and serves as a comprehensive measure of local economic stimulus, capturing labor earnings, dividends, and royalty payments received by county residents.

[23] According to BEA, personal income as measured by BEA includes rental income, which includes royalty payments, along with earnings from wages, self-employment, and other sources. Rental income “consists of the net income from the rental of tenant-occupied housing by persons, the imputed net income from the housing services of owner-occupied housing, and the royalty income of persons from patents, copyrights, and rights to natural resources” [18].

Table 7 first presents the effects on dividends, interest, rental income in column 1 and personal income in column 2. The results confirm that royalty income represents an key income source for the extraction counties. A 1% increase in OG raises dividends, interest, and rental income by 0.016%, or roughly $316K for the average county. The comprehensive personal income measure increases by 0.0088% or $1.05M on average.

Table 7: Effects of Oil and Gas Production on Personal Income

	Dividends, Interest, & Rent (1)	Personal Income (2)
Oil & Gas Production	0.0160***	0.0088***
	(0.0047)	(0.0028)
Avg Pred. Effect (100K BOE)	316K	1.05M
Observations	4,200	4,200
R^2	0.99744	0.99885
Within R^2	0.22562	0.33198

Robust standard errors clustered at the county and year in parentheses.
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

Table 8 presents the effects of OG production on the ratios of personal income to OG revenue, mining GDP, and total GDP. A negative coefficient on the personal income-to-GDP (or OG revenue) ratio indicates that the local income stimulus is weaker relative to the the economic value generated by extraction. Indeed, the results show clear evidence of economic leakage associated with OG production in extraction counties. Column 3 shows that as OG production increases, the share of revenue that translates into personal income for local residents declines sharply, indicating that much of the direct resource wealth flows to nonlocal firms, workers, or landowners. Even when moving to broader GDP measures, which incorporate a wider range of economic activities including sectors less prone to economic leakage such as healthcare, the negative relationship persists, although with diminished magnitude (columns 4 and 5). This persistence across increasingly comprehensive economic indicators suggest that resource extraction reduces the share of economic benefits accruing to local residents. In other words, these findings demonstrate that resource booms do not proportionally translate into local economic gains.

Table 8: Economic Effects on Personal Income Ratios

	Personal Income / OG Revenue (3)	Personal Income / GDP (NAICS 21) (4)	Personal Income / GDP (5)
Oil & Gas Production	-0.8571***	-0.3998***	-0.0449***
	(0.0281)	(0.0600)	(0.0093)
Observations	2,705	4,036	4,200
R^2	0.99479	0.87592	0.81602
Within R^2	0.96745	0.01915	-0.18851

Robust standard errors clustered at the county and year in parentheses.

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

5.2 Air Quality Impacts

5.2.1 Estimating Spatial Pollution Gradients

Having thoroughly examined the economic consequences of OG extraction, I now shift focus to its impact on local air quality and how pollution disperses across space. To do this, I examine $PM_{2.5}$ concentrations at the grid-cell level and estimate how OG production within each source zone surrounding a given receptor cell affects observed pollution levels. This approach captures both the localized impacts from nearby OG activity and the broader dispersion and accumulation of pollutants as they travel over longer distances.

Figure 3 presents the estimated air quality Panel (A) display the estimated pollution elasticities alongside 95% confidence intervals and Panel (B) present the corresponding average predicted changes in $PM_{2.5}$ concentrations per 100K BOE along with the range of predicted values implied by the results. Note that panel (B) only displays the effects for statistically significant estimates at the 5% level.

The figure reveals a non-monotonic spatial pattern in pollution response. Pollution concentrations respond most strongly to nearby production, but the effects are not statistically significant for production occurring immediately adjacent, within 1km. This pattern reflects atmospheric dispersion and chemical formation processes that govern $PM_{2.5}$ concentrations. At very short distances, pollutant plumes may rise and disperse before settling at ground level, resulting in lower measured concentrations near the emission source [1, 9]. Turbulent air near the source can also lift emissions upward, delaying their accumulation at ground level [1, 9]. Moreover, $PM_{2.5}$ consists not only of directly emitted particles (primary $PM_{2.5}$), but also of secondary particles formed through atmospheric reactions involving precursor gases such as NOx, SO_2, and VOCs. These chemical transformations require both time and distance to occur, which may explain why pollution effects are more detectable at short-to-moderate distances rather than immediately adjacent to

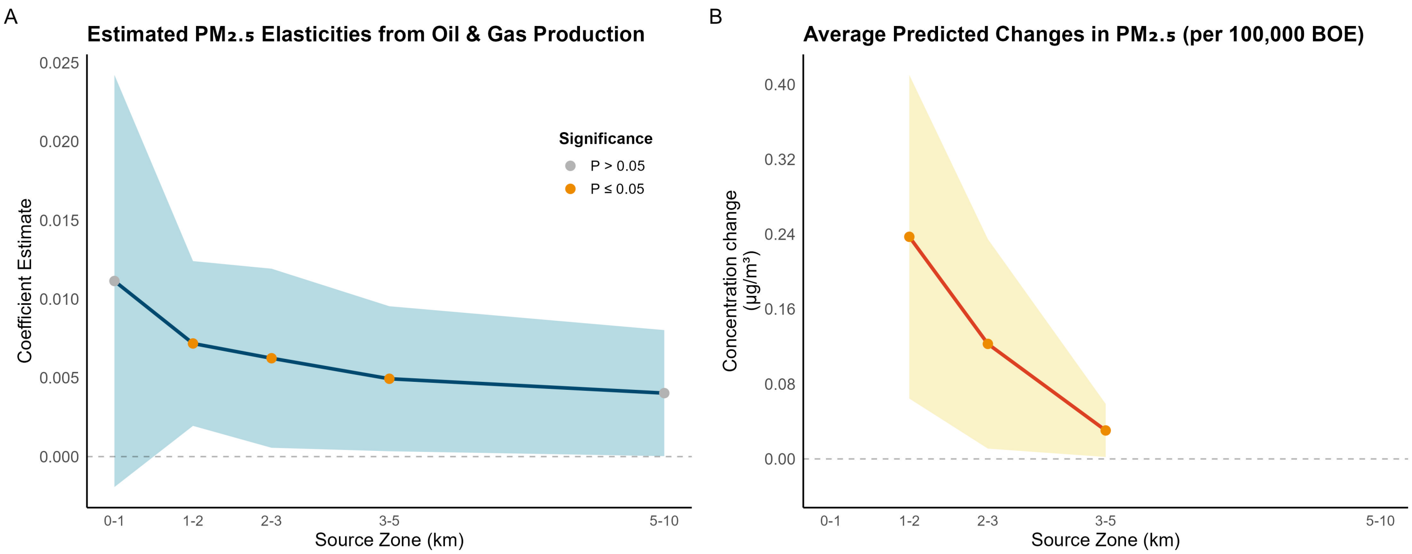

Figure 3: Air Quality Impacts of Oil & Gas Production

production. This spatial lag reflects well-established atmospheric processes and underscores the importance of examining the full dispersion pattern of pollution.

Figure 3 shows a spatial gradient in the estimated effects. Pollution impacts diminish as production originates farther from the receptor cell. The effects of production on $PM_{2.5}$ concentrations are statistically significant at the 5% level for source zones between 1-5 km. A 1% increase in production within 1–2 km raises $PM_{2.5}$ concentrations by 0.007%, equivalent to approximately 0.24 $\mu g/m^3$ per 100K BOE. At distances between 3 and 5 km, the effect declines to 0.0049%, or about 0.03 $\mu g/m^3$ per 100K BOE, roughly one-third of the nearer-zone impact. The magnitude and significance of these effects decrease with distance. For production occurring beyond 5 km, the estimated impact per 100K BOE falls to 0.005 $\mu g/m^3$ and is statistically significant only at the 10% level.

Taken together, my economic and air quality findings point to a clear disparity: employment and earnings gains largely benefit non-local workers, while the health costs are overwhelmingly borne by local residents.

5.2.2 Monetizing Health Impacts of Air Pollution

While changes in pollution concentrations provide a physical measure of local environmental impact, they do not capture broader social costs arise from increased exposure to fine particulates, most notably the elevated risk of premature mortality. In this section, I translate these pollution effects into economic damages using a dose-response function, informed by the epidemiological literature, that links changes in exposure to $PM_{2.5}$ to mortality risk. I then monetize the resulting health impacts using a value of a statistical life (VSL), yielding spatially explicit estimates of the health costs imposed by OG activity.

Figure 4 presents the estimated health damages attributable to OG production in the tri-state region between 2001 and 2020. Panel A reports excess premature mortality (left y-axis) and the corresponding monetized damages (right y-axis), disaggregated by two at-risk age groups: 30–65 and over 65. Panel B plots the total population over time and Panel C shows average baseline mortality rates across counties in the study area.

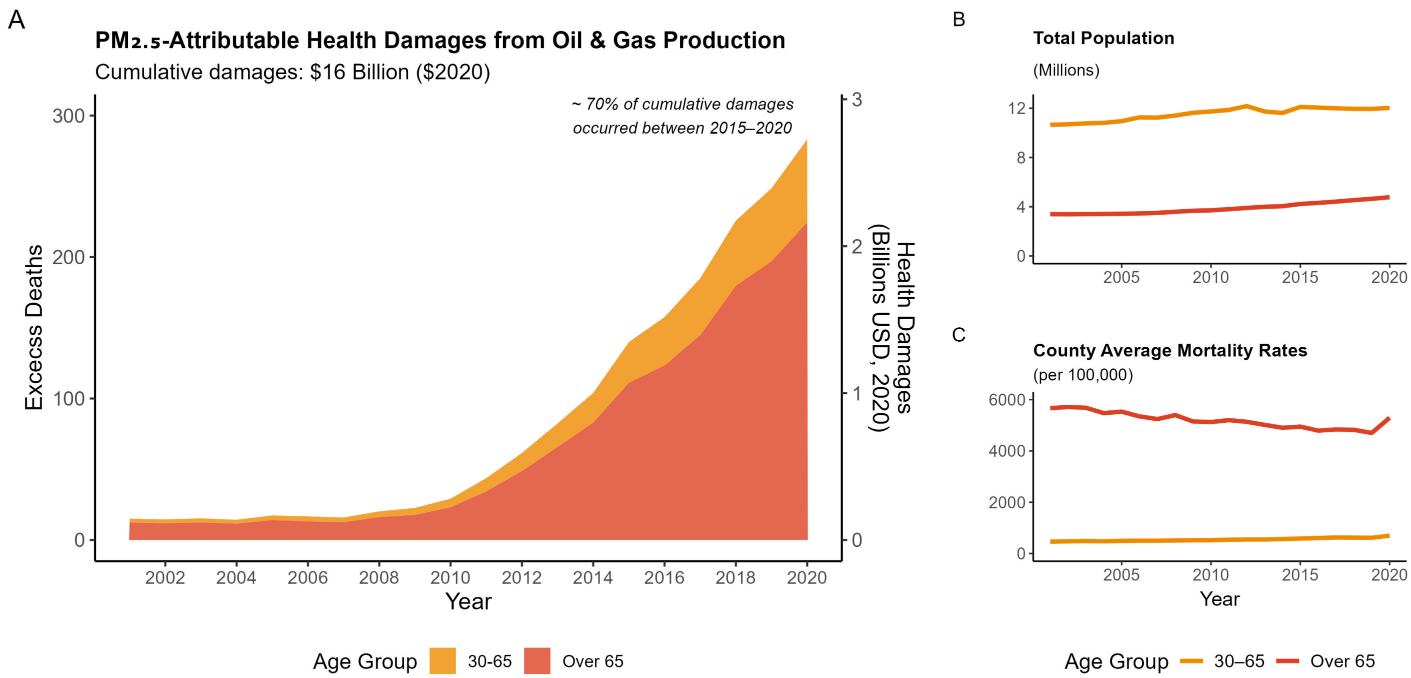

Figure 4: $PM_{2.5}$-Attributable Health Damages from Oil and Gas Production

Cumulative damages over this period amount to approximately $16 billion. Health damages sharply increased beginning around 2010, with an almost exponential rise over the following decade. In contrast, the population size remained relatively stable (Panel B), while baseline mortality rates generally declined (Panel C), aside from a spike in 2020 due to the COVID-19 pandemic. These patterns suggest that most of the increase in health damage is attributable to the surge in production driven by the shale boom. The exception is 2020, when damages continued to rise despite little changes in production, reflecting elevated mortality due to pandemic.

The bulk of health damages, about 70%, occurred between 2015 and 2020, with more than half concentrated in the final three years of the sample. Nearly 80% of these damages fell on individuals over age 65, underscoring the disproportionate burden borne by the most vulnerable residents, who face higher baseline mortality risks. This pattern stands in stark contrast to labor market evidence showing that local workers aged 30 and above experienced little to no employment benefits from OG. Accordingly, the allocation of health costs and economic gains is unequal not only between local and non-local populations but also within local communities themselves. Older residents, in particular, bear a disproportionate share of the health impacts while receiving few, if any, of the economic benefits.

Figure 5 maps health damages in the tri-state region at a granular level for the years 2005, 2010, 2015, and 2020 to document document their progression across time and space. Between 2005 and 2010, there was some expansion into adjacent areas, but activity remained concentrated near established sites, and the impacts in areas newly exposed to production were moderate overall. After 2010, damages spread widely into regions that had previously seen little or no production-related activity, and the scale of impacts in these new areas grew substantially larger.

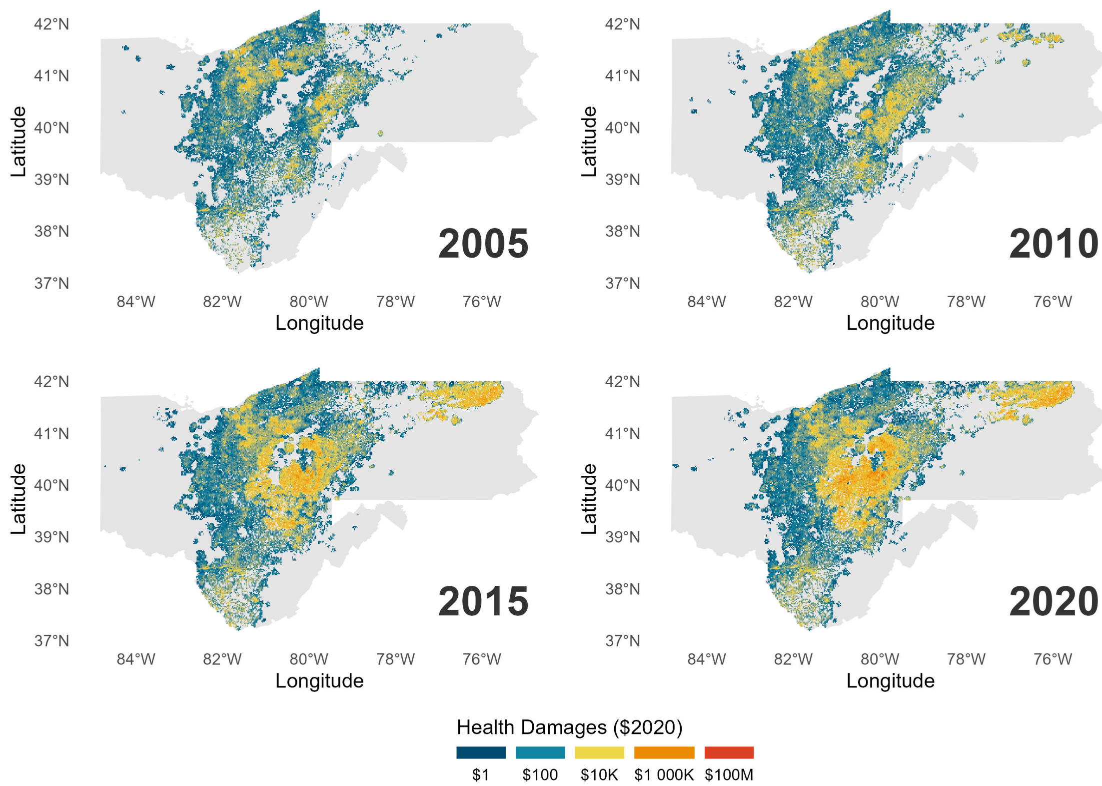

Figure 5: Geographic Distribution of Health Damages from Oil and Gas Production Over Time

Specifically, damages in PA expanded to both ends of the state: toward the Pittsburgh region in the southwest, a historically industrial area, and the predominantly rural Endless Mountains region in the north. In OH, impacts extended into largely rural southeastern counties. In WV, damages concentrated in the Northern Panhandle, a narrow corridor with mixed urban and rural communities, as well as Mountaineer Country in North Central West Virginia, a region characterized by a legacy of coal mining and dispersed small towns. Of the total $16 billion in estimated health damages, PA accounts for over half ($10.7 billion), followed by OH ($3.7 billion) and WV ($2.2 billion). The high damages in PA result from its extensive gas production combined with the encroachment of drilling activity into the densely populated Pittsburgh metropolitan area.

6 Conclusion

This paper provides new evidence on the localized economic and environmental impacts of OG production, revealing stark asymmetries in who gains and who bears the costs. While OG activity significantly increases employment and earnings, these benefits overwhelmingly accrue to non-local, commuting workers rather than to residents of producing counties. Locals working in the producing county see no statistically meaningful gains in employment or earnings, indicating minimal induced labor demand. Instead, the economic gains primarily reflect job creation for mobile workers, especially non-local out-commuters but also, to a lesser extent, residents who commute out of their home counties, whose mobility allows them to meet the geographically dispersed labor demands of the resource sector. Indeed, the strongest job effects are observed among younger and prime-age mobile workers, who are more likely to relocate or commute in response to OG-driven labor demand.

Earnings effects mirror the employment results: inflow and outflow workers experience gains, but outflow workers, those who live outside the producing county, see twice as large earning gains. Yet even as the value of OG production grows, the share of local income relative to extraction revenue and mining GDP declines. This leakage indicates that resource booms do not translate into proportional local economic development; rather, much of the generated wealth flows to external firms, workers, and landowners.

Local air quality degradation further exacerbates the disparity. Although employment benefits bypass local residents, the health damage resulting from elevated $PM_{2.5}$ is geographically concentrated around the extraction sites, disproportionately affecting nearby communities. Cumulative health damages exceed $16 billion over the study period, with impacts intensifying sharply after 2015. The health burden falls disproportionately on older adults, who face higher baseline mortality risks and constitute the majority of those affected.

Together, these findings show that while the OG boom generates significant economic activity, the people who benefit most are often different from those who bear the environmental costs. The limited economic returns to local communities alongside the substantial, localized public health burden, should cause local leaders to hesitate before implementing policies that facilitate OG extraction and shale development.

Appendix

Table 9: Home-county

	Labor Market Segment			Age Groups		
	Goods Prod. (1)	Trade, Transp., Utils. (2)	Other Serv. (3)	29 or younger (4)	30 to 54 (5)	55 or older (6)
Oil & Gas Production	-0.0002	-0.0056	-0.0025	-0.0018	-0.0056	-0.0020
	(0.0063)	(0.0051)	(0.0047)	(0.0103)	(0.0070)	(0.0046)
Observations	3,990	3,990	3,990	3,990	3,990	3,990
R^2	0.98701	0.99410	0.99661	0.99558	0.99632	0.99594
Within R^2	0.00754	0.04673	0.11398	0.09221	0.11753	0.03602

Robust standard errors clustered at the county and year level in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

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