Navigating Structural Change: Evidence from Municipal Finances and Bond Market Pricing During the Coal Transition

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Abstract

We study the fiscal consequences of structural change for coal-dependent municipal governments, using the expansion of hydraulic fracturing as a quasi-natural experiment. A one standard deviation decline in coal production causes municipal debt to rise by 14% and bond yields by 8 basis points, reflecting deteriorating fiscal health and heightened credit risk. Investors price coal's decline and the prospect of stranded coal assets as a long-term structural shift. Counties with greater economic diversification are more resilient, experiencing smaller debt and yield increases. Our findings highlight the fiscal and financial costs of economic transformations and the importance of local economic diversification.

Keywords: Structural change, technological innovation, local debt capacity, municipal bonds, coal, hydraulic fracturing, energy transition, transition risks, stranded assets

JEL Classifications: H72, H74, G12, G18, Q41, O33, R58

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1 Introduction

Technological change has long been a driver of structural transformation and economic growth (Kuznets, 1973), often reshaping the industrial base of entire regions in ways that produce uneven outcomes across local economies. Recent studies—ranging from the emergence of pollution abatement technologies in response to environmental regulation (Greenstone, 2002; Walker, 2013), to automation in manufacturing (Acemoglu and Restrepo, 2020a), and the expansion of hydraulic fracturing (Feyrer, Mansur, and Sacerdote, 2017; Bartik, Currie, Greenstone, and Knittel, 2019)—show that while some communities benefit from productivity gains and the emergence of new industries, others face employment polarization and job displacement. However, there is limited empirical evidence on how local adjustments to structural change affect municipal finances, and even less on how financial markets price these fiscal effects. This gap is notable because local governments are directly affected by shifts in industrial composition through changes in their tax bases, infrastructure and service costs, and borrowing capacity.

Our paper addresses this gap by providing new evidence on the effects of structural transformation on municipal finances and, importantly, examining how forward-looking municipal bond market investors price the fiscal risks associated with the demise of coal as the main source of electricity production. By linking changes in local coal production to both government balance sheets and municipal bond offering yields, we offer novel insights into how investors anticipate and respond to long-term structural shocks. We exploit the structural decline in coal-fired electricity generation—driven by the expansion of hydraulic fracturing (fracking)—to examine how the transition away from coal affects municipal finances and borrowing costs in coal-producing municipalities.

Three central questions guide our analysis: First, does the shift away from coal undermine local governments' fiscal sustainability and raise their borrowing costs in the municipal bond market? Second, does coal's decline affect municipal finances uniformly, or are some counties better positioned to adapt through alternative economic pathways? Third, what does investor pricing reveal about the perceived short- versus long-term risks of this structural shift? Understanding these dynamics offers a novel perspective on the fiscal and financial dimensions of structural change and is essential for informing policies that help local governments navigate economic transformation, including the transition away from displaced sources of energy production.

To address these questions, we leverage the structural shift in electricity generation caused by the expansion of fracking since the early 2000s. Over the past two decades, fracking has disrupted the coal industry by supplying abundant natural gas and driving down its price, rendering coal considerably less competitive in electricity production. This technological shift catalyzed a major transformation of the U.S. energy sector, with natural gas surpassing coal as the primary source for electricity generation. Between 2000 and 2020, coal consumption for electricity production fell by 60%, while natural gas demand more than doubled. From the perspective of coal-producing counties, the rise of fracking constitutes an exogenous technological shock, largely independent of local economic conditions.[1]

We employ two complementary empirical strategies to identify the effects of the decline in coal mining over this period. First, we exploit year-to-year variation in coal mining activity within a panel regression framework, isolating the impact of coal's decline from time-invariant county characteristics and regional time-varying factors within the same coal region. This fixed-effects specification leverages exogenous variation in coal mining activity driven by declining demand from electricity producers following the rise of fracking since the mid-2000s. Second, we relax the assumption of exogeneity in coal mining activity by instrumenting coal production with the time series of coal purchases by power plants. These county-level purchases provide a strong instrument: They are highly correlated with coal production yet plausibly exogenous to a county's underlying economic fundamentals, as power plants typically source from multiple counties and are often located outside extraction regions. Moreover, the shift in power plants' demand for natural gas was largely driven by its growing cost competitiveness, further supporting the instrument's validity.[2]

[1]Several studies attribute the shift from coal to natural gas in electricity generation to the expansion of fracking. See, for example, Hausman and Kellog (2015), Cullen and Mansur (2017), Houser, Bordoff, and Marsters (2017), Linn and Muehlenbachs (2018), and Brehm (2019).

[2]A similar instrument is used by Blonz, Roth Tran, and Troland (2023) to study the financial health of consumers in coal-producing counties. Likewise, Kraynak (2022) uses data on coal purchases by large coal-fired power plants to construct a demand instrument for analyzing local employment effects.

Our analysis yields four key findings: First, we provide causal evidence that a decline in coal mining activity significantly strains the fiscal health of municipal governments in coal-producing counties. We estimate that an annual one standard deviation decline in coal employment—roughly equivalent to a reduction of 300 coal workers—corresponds to a 14% annual increase in local government debt, a 15% increase in the debt-to-revenue ratio, and nearly a one percentage point increase in interest payments as a share of revenue. This deterioration in fiscal health is amplified in counties with greater exposure to U.S. natural gas production, with nonlinear effects extending even to counties with moderate exposure.

Second, we show that the decline in coal mining activity raises borrowing costs in the primary municipal bond market, offering the first direct evidence that bond investors price the fiscal risks of structural economic change at the local level. We estimate that a one standard deviation decline in coal mining employment increases municipal bond offering yields by 8 basis points, implying a 20% increase in borrowing costs relative to the average sample offering spread. This effect persists even after controlling for direct fiscal channels of coal's decline, such as coal prices and severance taxes, indicating that investors account for broader economic spillovers beyond the decline in coal-related tax revenues.

Third, to interpret these results, we leverage the fact that bond yields reflect forward-looking expectations of debt capacity and distinguish between two perspectives investors might hold about coal's decline: A temporary setback from which coal-dependent economies may recover, or a long-term structural shift that renders previously valuable coal reserves stranded assets. By analyzing bonds of varying maturities as well as forecast errors from projections of coal production, we show that investors view the decline as structural rather than transitory. Specifically, effects on offering yields are three times larger for long-term bonds, and only long-term forecast errors are significantly priced. Together, this suggests that investors view coal's decline and the associated shift in coal demand driven by the expansion of fracking as a protracted, systemic shock. This is reflected in higher borrowing costs to compensate for elevated long-term credit risks in coal-dependent communities.

Finally, we show that coal-reliant municipalities with greater economic diversification and alternative employment opportunities are more resilient to long-term structural decline. Specifically, counties with high fracking or renewable energy potential experience smaller increases in debt and borrowing costs. More importantly, investors perceive municipal governments with broader or expanding employment bases as more resilient. Using county-level employment data, we find that counties with limited employment diversification face disproportionately larger increases in debt and bond yields, while more diversified ones are largely insulated from such financing pressures. This highlights the importance of local adaptation strategies in mitigating the fiscal risks of structural change.

We contribute to the literature by providing causal empirical evidence linking structural economic transformation to both municipal fiscal health and bond market pricing. In doing so, we expand the broad empirical literature on how local economies adjust to external drivers of structural change—whether from technological disruption, regulatory change, or trade. The literature on the local consequences of the fracking boom has primarily focused on labor market outcomes, public health, crime, housing prices (Feyrer et al., 2017; Allcott and Keniston, 2018; Bartik et al., 2019; Fraenkel, Zivin, and Krumholz, 2024), and changes in local credit supply (Gilje, 2019). A related body of research examines the effects of the coal transition on employment, housing markets, and household finances in coal-dependent regions (Du and Karolyi, 2023; Blonz et al., 2023; Kraynak, 2022; Betz, Partridge, Farren, and Lobao, 2015).[3] Related work on structural change has also explored the impacts of rising import competition from China and occupational automation on plant closures on manufacturing employment, and earnings for low-wage workers (Autor, Dorn, and Hanson, 2013, 2021; Acemoglu and Restrepo, 2020a,b) as well as effects on local public finances (Feler and Senses, 2017) and health outcomes (Pierce and Schott, 2020).

Most closely related to our work is Morris, Kaufman, and Doshi (2021), who examine revenue risks in coal-dependent local governments. Based on a subsample of 27 coal counties, they show that many derive a substantial share of their revenue from coal-related activities, with some relying on coal for over one-third of their budgets—making them particularly vulnerable to a potential phase-out. Although the coal decline and the fracking boom are closely linked, evidence on the local fiscal effects of increased fracking activity

[3]Studies examining earlier historical periods, such as Black, McKinnish, and Sanders (2005) and Matheis (2016), document the profound economic consequences of coal booms and busts on local employment and income. For example, Matheis (2016) finds that the expansion of coal mining between 1870 and 1970 did not benefit manufacturing and instead led to long-term declines in per capita employment.

in fracking-rich counties remains mixed. For example, Newell and Raimi (2018), based on interviews, report that two-thirds of local governments perceived fiscal benefits from natural gas development. However, Bartik et al. (2019) find no statistically significant causal effect of fracking on overall fiscal health. We contribute to this literature by analyzing the fiscal consequences of coal's decline. Specifically, we focus on its impact on municipal debt levels and borrowing costs in the municipal bond market. By extending the analysis beyond revenue impacts, we provide a broader picture of the overall fiscal effects of coal's decline. Moreover, the forward-looking nature of municipal bond yields allows us to move beyond the short-term impact of coal production fluctuations and to estimate the effects of the long-run structural transition away from coal on local debt capacity and perceived credit risk.[4]

Our paper also provides new insight to the literature assessing how municipal bond markets price local fiscal risk by highlighting the role of default risk amid fiscal imbalances.[5] The works of Schwert (2017) and Adelino, Cunha, and Ferreira (2017) emphasize the importance of default risk in the pricing of municipal bonds. We build on prior research that has largely focused on the effects of fluctuations in political uncertainty at the state level (Gao, Murphy, and Qi, 2019), fiscal imbalances related to state pension fund losses (Novy-Marx and Rauh, 2012), the rise of the opioid epidemic (Cornaggia, Hund, Nguyen, and Ye, 2022), physical climate risks (Painter, 2020; Goldsmith-Pinkham, Gustafson, Lewis, and Schwert, 2023; Auh, Choi, Deryugina, and Park, 2022; Acharya, Johnson, Sundaresan, and Tomunen, 2022), and local renewable energy potential (Cornaggia and Iliev, 2023) on municipal borrowing costs. Our findings extends this literature by showing that municipal credit risk is highly responsive to local fiscal health and perceived debt capacity, with investors demanding higher premiums for long-term debt as they internalize stranded asset risks and the broader economic disruptions introduced by the structural transformation in coal regions. Moreover, we document that the municipal bond market prices stranded asset credit risks even after controlling for municipal bond ratings.

[4]Using variation in China's import exposure, Feler and Senses (2017) find that areas most affected by import competition experienced declining tax revenues and reduced public services, but do not investigate effects on debt or borrowing costs.

[5]See Cestau, Hollifield, Li, and Schürhoff (2019) for a survey of recent empirical work assessing the factors driving municipal bond yields and spreads.

Our paper adds to the literature examining how the transition away from fossil fuels is priced in financial markets. Prior work shows that the shift toward lower carbon emissions influences high-emitting firms' valuations and equity returns (Matsumura, Prakash, and Vera-Muñoz, 2014; Bolton and Kacperczyk, 2021; Sautner, Van Lent, Vilkov, and Zhang, 2023; Bolton and Kacperczyk, 2023) as well as their cost of capital (Chava, 2014), cost of hedging against downside risks (Ilhan, Sautner, and Vilkov, 2021), and sensitivity of equity prices to climate policy news (Barnett, 2019; Sen and Von Schickfus, 2020; Ramelli, Wagner, Zeckhauser, and Ziegler, 2021; Ochoa, Paustian, and Wilcox, 2022). While most of this literature centers on corporate equity markets, we examine the primary municipal bond market, which is closely linked to local economic conditions and offers a natural setting to assess whether investors price the risks of stranded assets and industrial transformation affecting local economies. Our findings reveal broad, yet heterogeneous, economic spillovers from the coal transition on local communities—an important dimension difficult to assess in firm-level studies.

Lastly, our findings are particularly relevant for communities reliant on carbon-intensive energy production. Many local economies hold substantial fossil fuel reserves, but as renewable technologies continue to advance alongside improvements in energy storage, more local governments may face the growing risk of these reserves becoming stranded assets due to cleaner, cheaper energy alternatives. In related work on corporations, Delis, Greiff, Iosifidi, and Ongena (2024) and Beyene, Delis, and Ongena (2024) find that banks and bond investors charge higher rates to firms with larger fossil fuel reserves, while Atanasova and Schwartz (2019) show that oil producers lose market value as their reserves increase. We show how fossil-fuel-dependent municipal governments can mitigate these risks. Our analysis provides a clearer picture of how stranded assets affect public finances and offers practical insights into managing the fiscal consequences of structural change in the energy sector. These findings also underscore the potential need for state or federal support to promote employment diversification and strengthen fiscal resilience, thereby contributing to ongoing debates on the relationship between climate change and public finances (Klusak, Agarwala, Burke, Kraemer, and Mohaddes, 2023) and the design of climate policy (Barrage, 2020, 2023; Seghini and Dees, 2024).

The remainder of the paper is organized as follows. Section 2 provides background on the U.S. energy transition and the decline of coal in the context of advancements in natural gas extraction technologies. Section 3 describes the datasets and variable construction. Sections 4 and 5 present the empirical results on how coal's decline affects municipal finances and bond offering yields, respectively. Finally, Section 6 discusses the broader implications of our findings and concludes.

2 Structural Transformation in the U.S. Energy Sector and the Decline in Coal Mining

For decades, coal-fired power generation was the predominant source of electricity in the United States, accounting for around 50% of total electricity generation, according to the U.S. Energy Information Administration (EIA). However, since the early 2000s, U.S. electricity generation has undergone significant changes. As shown in Figure 1, the demand for coal from electricity producers—the largest consumers of U.S. coal production—has fallen by roughly 60% between 2000 and 2020. Figure 2 further illustrates that this decline in demand has sharply reduced the share of electricity generated by coal-fired generators to just under 20% by 2020.[6]

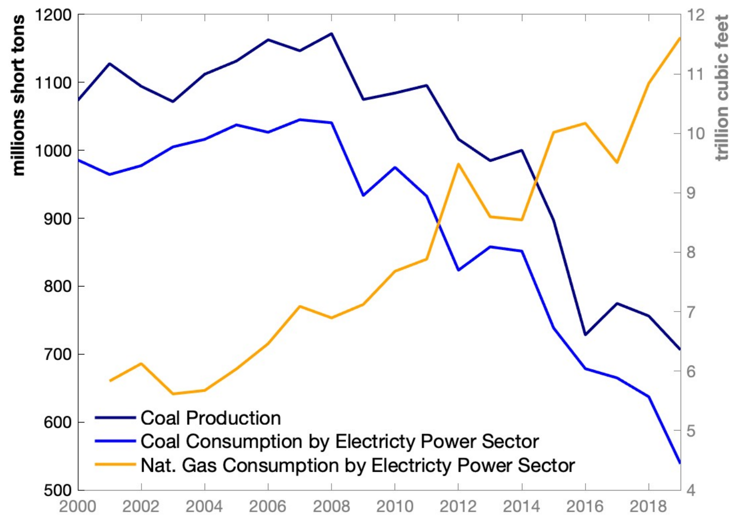
The decline in coal production is directly linked to a shift in electricity generation from coal to natural gas and, to a lesser extent, renewable energy sources—as documented by a growing body of literature.[7] A significant drop in natural gas prices, primarily attributed to advancements in extraction technologies such as fracking, markedly increased the share of natural gas in electricity generation from 16% in 2000 to 41% by 2020 (see Figure 2).[8] As a result, natural gas has become the primary source of electricity generation. In recent years, the growth of renewable energy—driven by state renewable portfolio standards, fed-

[6]The decline in coal demand from electricity producers is not due to a reduction in overall electricity generation. In fact, U.S. electricity production grew 5.5% between 2000 and 2020.

[7]See, for example, Hausman and Kellog (2015), Houser et al. (2017), Cullen and Mansur (2017), Linn and Muehlenbachs (2018), and (Brehm, 2019).

[8]Several factors contributed to the rapid expansion of fracking in the United States, including high global energy prices, domestic investment in shale gas production aimed at enhancing energy independence, and exemptions from certain U.S. Environmental Protection Agency (EPA) regulations—notably the so-called "Halliburton Loophole" in the Energy Policy Act of 2005.

Figure 1: U.S. Coal Production and Coal Demand by Electricity Producers



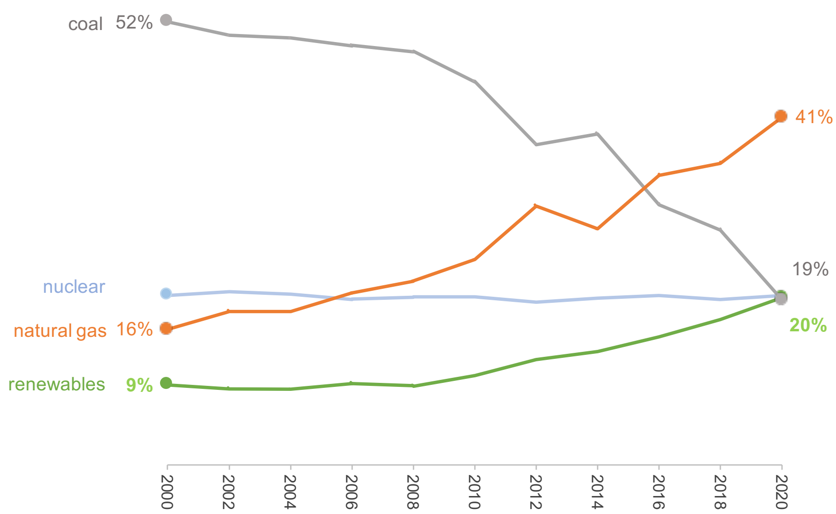
This figure plots U.S. coal production as well as the demand for coal and natural gas by U.S. electricity producers from 2000 through 2019. This annual data comes from the U.S. EIA 2023b.

eral production and investment tax credits, and technological advancements—has further contributed to the decline in coal production. Houser et al. (2017), for example, estimate that roughly two-thirds of the decline in coal production over this period can be attributed to inexpensive natural gas and the expansion of renewables, with environmental regulations playing only a minor role.[9]

Still, amid the rapid expansion of fracking, the decline of the U.S. coal industry has been unexpectedly swift. Figure 3 plots actual coal production alongside the EIA's five-year projections, data we compile from selected issues of the EIA's Annual Energy Outlook. These forecasts are generated using the National Energy Modeling System, a comprehensive model of the economy and energy markets that captures interactions across energy sectors like coal, nuclear, natural gas, and renewables. Before 2020, as shown in Figure 3, the EIA's coal forecasts were consistently optimistic, indicating modest growth in coal production and thus failing to anticipate the swift transition from coal to natural gas. More

[9] See also Brehm (2019), Fell and Kaffine (2018), Knittel, Metaxoglou, and Trindade (2015), and Linn and McCormack (2019) on the role of falling gas prices in explaining the decline in domestic U.S. coal consumption. See Bergquist and Warshaw (2023) for the role of local renewable portfolio standards.

Figure 2: U.S. Electricity Generation by Energy Source



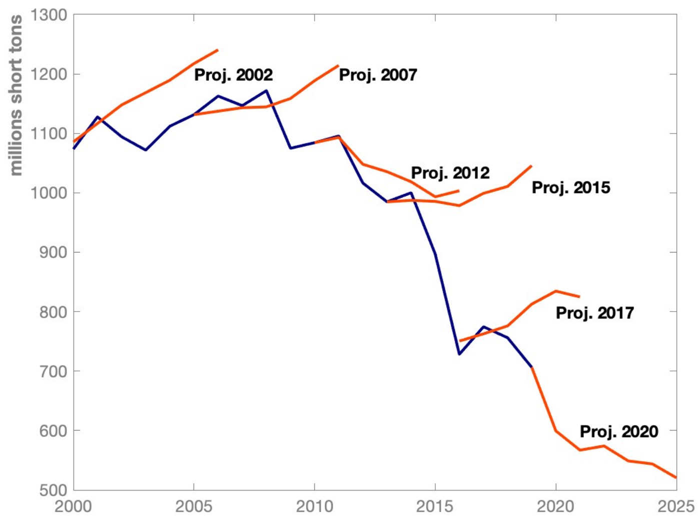
This figure plots the share of coal, natural gas, nuclear power, and renewable energy used to produce electricity since 2000. This annual data comes from the U.S. EIA 2023b.

recent forecasts, however, point to an irreversible decline in coal production as natural gas and renewable energy sources increasingly displace it in the U.S. energy mix. In its most recent Annual Energy Outlook 2023a, the EIA projects that coal-fired power generation capacity will fall to less than half of 2022 levels by 2050, with coal's share of electricity generation dropping to just 5%.

We exploit this nearly two-decade-long transformation in the U.S. energy sector, which was driven by the rapid expansion of hydraulic fracturing, to examine the fiscal health and borrowing costs of coal-producing local governments.[10] Crucially for our identification strategy, the rise of fracking represents an exogenous technological shock that is largely independent of local economic conditions in coal-producing counties. We leverage this quasi-natural experiment to provide causal evidence on how the decline of coal—triggered by external market forces rather than local economic conditions—affects municipal fiscal

[10]While unfolding over a similar time period, the decline of coal differs significantly from the downturn in U.S. manufacturing. The latter was largely driven by globalization, the NAFTA trade agreement, and China's entry into the WTO, which shifted production overseas. In contrast, coal's decline was spurred by advancements in domestic natural gas extraction, which favored fracking over coal mining. Whereas manufacturing experienced job losses due to offshoring and automation, coal was displaced by cheaper, cleaner natural gas extracted from U.S. fracking regions. Moreover, manufacturing's decline was gradual, while coal's transition was unexpectedly swift, accelerated by the rise of natural gas and renewable energy.

Figure 3: Projections of U.S. Coal Production



This figure plots actual and projected U.S. coal production from 2000 through 2019, taken from several issues of the U.S. EIA Annual Energy Outlook.

health and bond market pricing. This approach distinguishes our analysis from prior work by allowing for a cleaner attribution of fiscal and financial outcomes to structural economic change.

3 Data Sources and Descriptive Statistics

We assemble a unique and comprehensive dataset combining information on coal mining production and employment, coal demand from U.S. coal-fired power plants, municipal finances, borrowing costs in municipal bond markets, and various measures of local economic activity across all coal-producing counties in the U.S. from 2000 to 2019.

3.1 Coal Mining Activity and Coal Projections

For all coal-producing mines in the United States, we collect information from the Mine Safety and Health Administration (MSHA) on their precise geo-location, coal production, the average number of employees, and hours worked between 2000 and 2019. Next, we aggregate the number of employees, total hours worked, and coal production at the county level. Our sample excludes information from coal mines in Alaska and the state of Washington, which represent less than 1% of total U.S. coal production.[11]

We also collect information on coal purchases at the power plant level from the EIA-923 survey. The survey reports data on all coal purchases, including the quantity purchased, as well as the state and county of origin. Annual data on coal purchases for utility and non-utility coal-fired power plants became available in 2008, which determines the start date of our sample for coal demand.

We obtains data on projections of U.S. coal production from various issues of the EIA's Annual Energy Outlook. For each issue from 2000 to 2019, we collect the projections of coal production for each major U.S. coal basin over the following 5 years. The projections are generated using the National Energy Modeling System and are available for 14 coal-supplying regions. The coal-supplying regions reported are the following: Northern Appalachian, Central Appalachia, Southern Appalachia, Eastern and Western Interior, Gulf, Dakota, Western Dakota, Western Montana, Wyoming, Western Wyoming, Rocky Mountain, Arizona&New Mexico, and Washington&Alaska. Since each coal-supplying region shares similar coal quality and mining methods, it is reasonable to assume that the coal supply within each region is likely to react similarly to economic shocks. This novel dataset augments realized coal production data with forward-looking projections, allowing us to empirically examine how shifts in expectations for coal production may have affected municipal borrowing costs.

3.2 Municipal Government Debt and Economic Outcomes

We collect information on local government finances from the Census of Governments, conducted every five years (in years ending in 2 and 7), and from the Annual Survey of Governments collected by the U.S. Census Bureau during intercensal years. Specifically, we obtain data on total outstanding debt, long-term debt outstanding, interest payments on debt, total revenues, total expenditures, and revenues from property taxes from 2002 to

[11] We also exclude Campbell County, Wyoming, due to its outsized contribution to U.S. coal production. However, our results remain robust even when this county is included.

2019. We focus on county governments because they are more likely to be surveyed in non-census years than small towns or cities, which allows us to construct a reasonably balanced county-year panel dataset. This dataset enables us to paint a detailed picture of coal counties' local government finances over time, especially concerning shifts in revenue streams and debt burdens.

3.3 Municipal Bond Data

We retrieve data on municipal bond offerings from 2004 through the end of 2019 using the Mergent Municipal Bond Securities Database (MBSD). The MBSD provides comprehensive bond-level characteristics, including the offering amount and yield, issue and maturity dates, credit ratings from Standard & Poor's, Moody's, or Fitch, bond type, taxation status, and various other issuance characteristics. We assign a numeric value to each rating notch (for example, AAA = 1, AA+ = 2, etc.). If two rating agencies rate a bond, we use the lower rating as the bond's composite rating. For bonds rated by all three agencies, the composite rating is determined by the median of the three ratings.

For our analysis, we restrict the sample to uninsured bonds,[12] tax-exempt revenue or general obligation (GO) bonds with fixed or zero coupons, and active investment-grade ratings at the time of issuance.[13] We further limit the sample to bonds (or serial bonds) with total offering amounts exceeding one million U.S. dollars, semi-annual coupon payments, and a 30/360 day-count convention. Bonds with less than one year until maturity or maturities exceeding 30 years are excluded because yields tend to be especially noisy for such bonds.[14] After applying these filters, our sample consists of 17,990 individual municipal bonds issued as part of 1,943 serial bonds by 797 municipal entities. On average, each issuer placed 22.6 individual bonds as part of 2.4 serial issues.

We use the ICE AAA-rated municipal bond yield curve to obtain the maturity-matched benchmark par yield (that is, a maturity-matched risk-free rate) for each bond at issuance.

[12] Insured bonds do not adequately reflect issuer-specific credit risk, which is central to our analysis of municipal bond yields.

[13] Less than 1% of municipal bonds in coal-producing counties are rated as high-yield bonds.

[14] The upper end of the maturity range is also determined by the ICE municipal bond yield curve data, which spans maturities from 1 to 30 years and is used to control for the maturity-matched risk-free rate.

Additionally, we construct measures of the level, slope, and curvature of the daily term structure of municipal bond yields using a principal component analysis and then match each of the three factors to each bond at the day of issuance.[15]

To geographically map a bond to a specific coal county, we collect information on the county of issuance for a given bond from Refinitiv. Using this location information, we link bond offerings to coal mining activity data for coal-producing local governments using Federal Information Processing Standard (FIPS) codes.

Lastly, following Ivanov and Zimmermann (2024), we classify municipal issuers into five types of municipal entities: states, counties, cities, townships, and school districts, as well as special districts and authorities. We then exclude states from our analysis due to their institutional complexity and the challenge of linking them to local coal mining activity.

3.4 Local Economic Characteristics

To assess the role of actual and potential employment opportunities in shaping local government finances and borrowing costs, we collect county-level data on the following characteristics: First, we use the Rystad Energy fracking prospectivity index from Bartik et al. (2019), which captures the potential productivity of a shale formation for fracking techniques. Following their methodology, we aggregate the Rystad prospectivity measure at the county level by computing the maximum Rystad score within each county. Second, we collect the National Renewable Energy Laboratory's (NREL) renewable energy potential, which provides county-level estimates of the maximum energy that utility-scale wind turbines (wind potential) and utility-scale photovoltaics (solar potential) could generate.[16] These estimates account for resource availability, system performance, topographic limitations, and environmental and land-use constraints (Maclaurin, Grue, Lopez, Heimiller,

[15]Litterman and Scheinkman (1991), for example, shows that most of the movements in the term structure of risk-free rates can be explained by these three factors. Using empirical measures of the level (10Y), slope (10Y - 2Y), and curvature ($2\times$2Y - 10Y - 0.5Y) produces qualitatively and quantitatively similar results.

[16]County-level data can be obtained from the National Renewable Energy Laboratory (2020) for 2020. Although the data falls outside our sample period, we use it because 2020 is the earliest year that is available at the county level. We validate this choice by aggregating the 2020 data to the state level and comparing it to the 2015 estimates—the first year for which the data was available, though only at the state level—finding that the relative rankings have remained largely unchanged.

Rossol, Buster, and Williams, 2019). Third, we collect county-level employment data across NAICS industries from the U.S. Census Bureau's County Business Patterns (CBP) for 2001, 2008, and 2011. These years capture employment conditions just before our sample period begins and at two later points, chosen to allow for meaningful variation and balanced sample splits across government finances and municipal bond data. To evaluate the composition of a county's employment opportunities, we use a Shannon Index (1948), defined as:

$$\text{Shannon Index}_{i,t} = -\sum_{n \in \text{NAICS}_{i,t}} \text{ES}_{i,n,t} \ln(\text{ES}_{i,n,t}) \tag{1}$$

where $\text{ES}_{i,n,t}$ represents the employment share of 4-digit NAICS industry n in county i at year $t \in \{2001, 2008, 2011\}$, and $\text{NAIC}_{i,t}$ denotes the set of all 4-digit NAICS industries present in county i at time t. The Shannon Index captures both employment breadth (the number of industries in a county) and balance (the evenness of the employment distribution across industries), with higher values indicating more diversified employment opportunities.[17]

Lastly, we collect information on population at the county level from the Census Bureau, county-level unemployment rates from the Bureau of Labor Statistics, and retrieve the national unemployment rate from the FRED database of the Federal Reserve Bank of St. Louis.

3.5 Summary Statistics

Table 1 reports the county-level summary statistics of key variables used in our empirical analysis. Panel A of Table 1 reports the county-level means of three proxy variables for coal mining activity between 2000 and 2019. Over the full sample period, the average county employed approximately 450 coal miners, with considerable variation between counties as the standard deviation equals around 600 workers. The typical county reports nearly 1 million coal miners' hours, which results in a production of about 4 million short tons of coal. As with the number of workers, there is substantial variation in coal production across counties, as the spread between the 25$^{\text{th}}$ percentile and 75$^{\text{th}}$ percentile of the distribution is

[17] We use the Shannon Index over the Herfindahl–Hirschman Index (HHI), as it better captures the number and balance of industries in a county rather than emphasizing dominance. That said, our results remain qualitatively unchanged and are even slightly more pronounced when using the HHI.

equal to about 6 million short tons.

The time variation of coal mining activity at the county level is summarized in Figures 4 and 5. The top and bottom panels of Figure 4 map coal employment at the county level, divided into quantiles from 2002 to 2019, respectively. The counties in the top quantile of the distribution appear in dark blue, and counties in the bottom quantile are colored the lightest shade of blue. Figure 5 shows a similar map for coal production. These maps show that the distribution of coal employment and coal production has shifted toward lower values, and coal mining even ceased to exist in a few counties, as is evident by the switch to a "no data" tile.[18] More precisely, the average county-level coal production declined by around 2 million tons between 2002 and 2019, a nearly 40% decline in coal production.

Panel B of Table 1 summarizes various metrics of municipal debt sustainability in our sample. The average county has a debt level of $90 million. An increase in debt of 2 log points moves a county from the 25th percentile to the 75th percentile of the distribution. The dispersion of the natural logarithm of the debt-to-revenue ratio is slightly smaller than that of the level of debt, with the spread between the 25th percentile and the 75th percentile standing at around 1.5 log points. The next row shows that a typical coal county pays around 5% of its revenue in interest, with an interquartile range of around 4%.

Panel C of Table 1 shows that the average municipal bond in our sample has a yield of 2.3%, which is almost 0.4 percentage points higher than the average AAA-rated municipal bond yield, and a maturity of around 8 years. The average size of issuance is $25 million, and the credit ratings at issuance are mainly concentrated between AA and AA-.

4 The Effect of the Decline in Coal on Municipal Finances

In this section, we examine the impact of declining coal mining activity on municipal finances. We begin by outlining two empirical strategies: A two-way fixed effects regression framework and an instrumental variable (IV) approach. We then present and discuss the estimated effects of coal mining activity on fiscal outcomes.

[18] Although coal production declines substantially across counties, many continue at low but nonzero levels, limiting the feasibility of a regression discontinuity design around a clear, zero threshold.

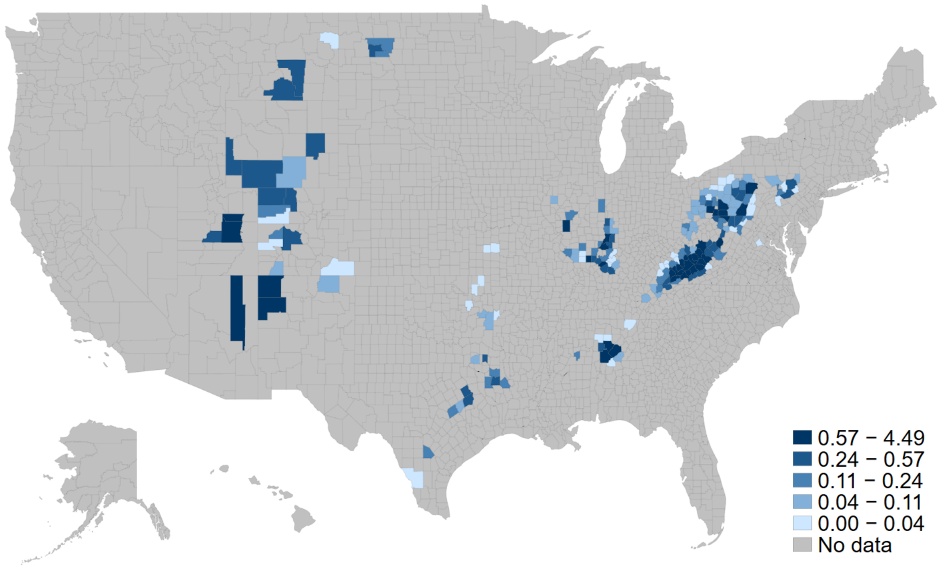
Table 1: County-Level Summary Statistics

	Mean.	Std. Dev.	25^{th}	Median	75^{th}
Panel A: Coal Mining Activity					
CoalLabor (thousands)	0.442	0.600	0.039	0.224	0.601
CoalLaborHours (millions)	0.974	1.362	0.076	0.473	1.258
CoalProduction (million short tons)	4.127	5.882	0.198	1.437	5.880
Number of Mines	10	17	1	4	11
Population	80,321	137,967	21,580	38,142	82,895
Panel B: Municipal Debt Indicators					
$\ln$ Debt	10.044	1.729	9.168	10.192	11.013
$\ln$ Debt-to-Revenue	-0.092	1.510	-0.887	-0.080	0.856
Interest as Share of Revenue (%)	5.665	10.493	0.961	2.000	4.940
Observations per county	16	2	14	17	18
Panel C: Municipal Cost of Financing					
Bond Yield (%)	2.306	1.184	1.300	2.200	3.200
Benchmark Bond Yield (%)	1.919	1.125	0.963	1.806	2.773
Coupon (%)	2.959	1.183	2.000	3.000	4.000
Maturity (years)	8.020	5.661	3.490	6.814	11.288
Amount Issued (millions)	25.884	78.509	4.700	9.000	16.800
Rating	3.850	1.627	3.000	4.000	5.000

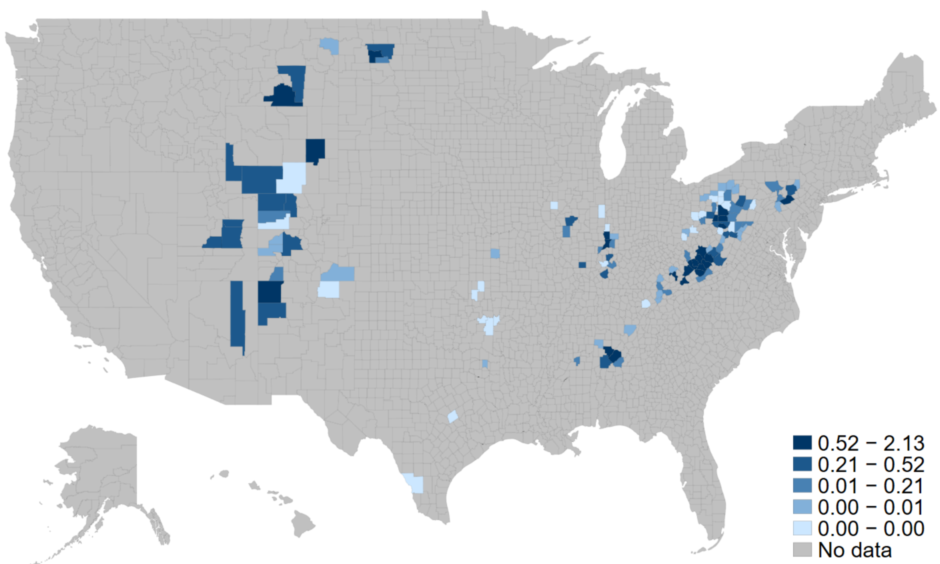
Panel A reports summary statistics of county-level coal mining activity measured by three proxy variables: *CoalLabor*, the number of employees in the coal industry; *CoalLaborHours*, representing total hours worked in coal mining; and *CoalProduction*, the total coal production. Panel A also presents summary statistics of the *Number of Mines* and *Population*. Panel B presents summary statistics of metrics for municipal debt sustainability at the county level: *Debt* is the total debt outstanding, *Debt-to-Revenues* is the ratio of total debt outstanding to revenue, and *Interest as Share of Revenue* is total interest payments on debt relative to total revenues. Panel C reports bond-level statistics on offering yields and municipal bond characteristics. *Bond Yield* is the offering yield of bonds at issuance; *Benchmark Bond Yield* denotes the maturity-matched AAA-rated municipal bond benchmark yield for a given municipal bond on its issuance day; *Coupon* is the bond's coupon rate for coupon-paying bonds; *Maturity* represents a bond's time-to-maturity; *Amount Issued* reflects the issue size of bonds; and *Rating* represents the numerical credit rating of bonds, ranging from AAA=1 to BBB-=10.

Figure 4: U.S. Coal Mining Employment, 2002 vs. 2019

2002



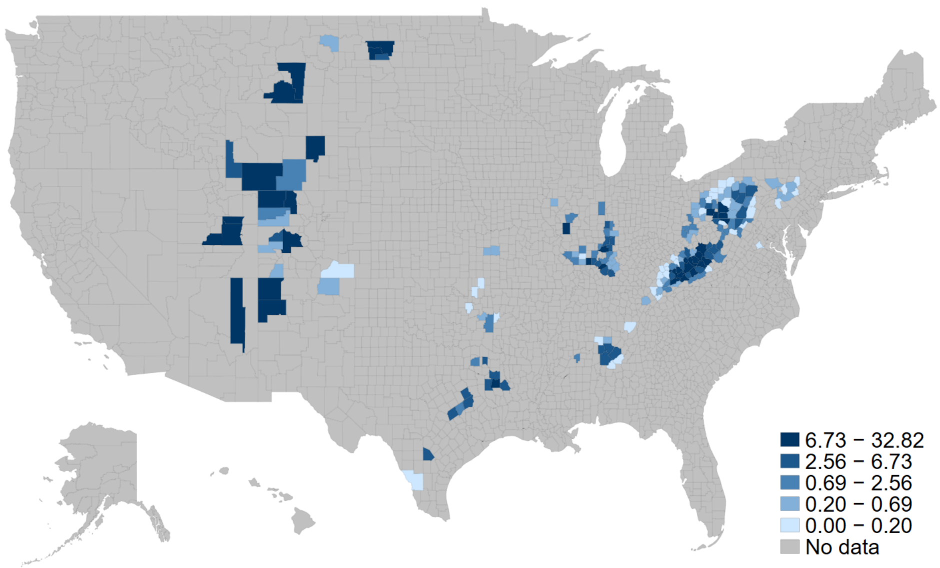
2019



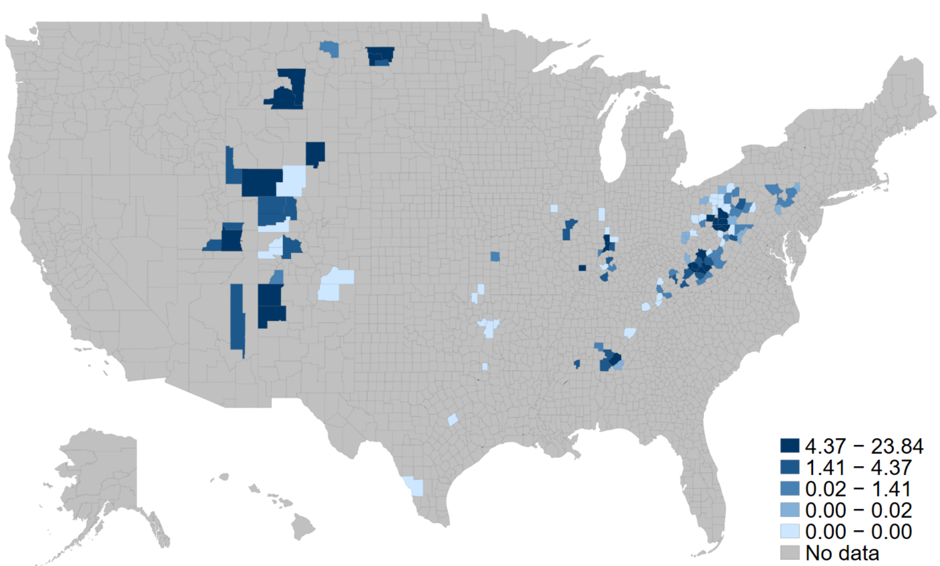
This figure depicts coal mining employment across U.S. counties. Counties shaded in dark blue represent those in the top quantile of the employment distribution, while those in the bottom quantile are shown in the lightest shade of blue. Counties with no coal employment in the respective year are shaded in gray.

Figure 5: U.S. Coal Production, 2002 vs. 2019

2002



2019



This figure depicts coal production across U.S. counties. Counties shaded in dark blue represent those in the top quantile of the coal production distribution, while those in the bottom quantile are shown in the lightest shade of blue. Counties with no coal production in the respective year are shaded in gray.

4.1 Empirical Strategy

A key empirical challenge in identifying the fiscal consequences of coal's decline for local governments is the potential for omitted variable bias. This bias arises from the correlation between coal mining and other local economic factors that also influence municipal finances. For example, communities with higher land values or tighter labor markets may be more likely to experience mine closures. To mitigate this concern, we exploit the shock induced by the rise of fracking in coal-producing communities. Our identification strategy relies on the premise that a considerable portion of the variation in coal mining activity during the expansion of fracking in the mid-2000s can be attributed to changes in demand from electricity producers. These demand shifts are unlikely to be related to local economic conditions. Instead, they are more likely linked to the introduction and success of fracking and the abundance of cheap natural gas, as detailed in Section 2.

Our first empirical approach relies on a two-way fixed-effects model to estimate the effect of the decline in coal mining on municipal finances, and we run the following regression model on the outcome variable $y_{i,t}$ where subscripts refer to county i and year t:

$$y_{i,t} = \beta \, \mathbf{C}_{i,t-1} + \theta' \, \mathbf{Z}_{i,t} + \theta_{r,t} + \mu_i + \varepsilon_{i,t} \tag{2}$$

The key covariate of interest is $C_{i,t-1}$, which represents the level of coal mining activity in county i in the prior year $t-1$. We consider three measures of coal mining as proxy variables for county-level coal mining activity: The number of employees in the coal industry, the total hours worked in coal mining, and total coal production. Equation (2) includes coal region-by-year fixed effects, $\theta_{r,t}$, and county fixed effects, μ_i. These fixed effects absorb any fixed or regional time-varying characteristics, whether observed or unobserved, separating the shocks to coal mining activity from many potential sources of omitted variable bias. Consequently, the parameter β measures the effect of idiosyncratic changes in coal mining activity within a county on the municipal debt sustainability metric of interest. To facilitate interpretation and comparison across our three proxy variables for coal mining activity, we standardize each by dividing it by its cross-sectional standard deviation, calculated over the sample period after removing county fixed effects. As a result, the estimated coefficient β for each measure will represent the effect of a one standard deviation change in the corresponding proxy. This standardization enables more meaningful comparisons across the different measures of coal mining activity.

The vector $\mathbf{Z}_{i,t}$ includes the natural logarithm of the population to control for differences in size across counties.[19] Finally, we report standard errors clustered simultaneously at the county level and region-year to allow for arbitrary serial correlation in the residuals within counties and over time (Cameron, Gelbach, and Miller, 2011).

Our second and complementary empirical approach uses the time series of coal purchases by power plants at the county level as an instrument for local coal production. This IV approach addresses concerns that county-level and time fixed effects in Equation (2) may not fully capture local economic fundamentals that correlate with both declining coal mining and municipal finances. County-level coal purchases are a suitable instrument for two reasons: First, county-level coal purchases are likely exogenous to a specific county's economic conditions. This is because coal-fired power plants are often located outside the counties where coal is extracted and typically source coal from multiple counties. Second, the decline in natural gas prices likely influenced electricity producers' decision for coal purchases, thereby reducing the demand for coal.[20] Overall, electricity producers' coal demand is highly correlated with coal production and unlikely to be driven by local economic conditions, making it a good candidate for an instrument. The disadvantage of this approach relative to the two-way fixed-effects model is limited data availability: Electricity producers only began reporting county-level coal purchases only in 2008, which shortens our sample period.

In particular, we first use the time series variation of coal purchases by domestic electricity producers to predict county-level coal production by estimating the following time-series regression:

$$\ln C_{i,t} = \alpha_i + \gamma_i \ln C^d_{i,t} + \varepsilon_{i,t} \tag{3}$$

[19]Including variables that are outcomes of coal mining activity, $C_{i,t-1}$, will not yield an estimate close to the true β, particularly for local economic fundamentals such as GDP or employment, which are likely influenced by coal mining itself. To avoid over-controlling, we rely on variables that are more plausibly exogenous, such as population.

[20]Coal-fired power plants can be fitted or retrofitted for fuel-switching (as in *co-fired* power plants), which involves replacing coal-burning equipment with gas-fired turbines or boilers, enabling them to burn both coal and natural gas (see, for example, Fell and Kaffine (2018)).

where the dependent variable, $C_{i,t}$, is coal production in county i in year t, and the independent variable is the total coal purchases of power plants from county i, $C^d_{i,t}$. We then predict coal production for each county and year as follows:

$$\widehat{C}_{i,t} = \exp\left(\hat{\alpha}_i + \hat{\gamma}_i \ln C^d_{i,t}\right) \tag{4}$$

The predicted values of coal production capture the portion of variation explained by the demand for coal, which is likely exogenous to local economic conditions.[21] Next, we use these predicted values to instrument for coal production when estimating equation (2). For this exercise, we use data from 2008 to 2019 and only keep counties with at least five years of continuous data on coal demand.

4.2 Empirical Results

4.2.1 Baseline Results

Using the model in Equation (2) for the period 2002 to 2019, Tables 2 and 3 test the null hypothesis that coal mining activity does not affect municipal finances, either through its effect on the level of local government debt or through indicators of debt sustainability. These estimates are based on three county-level proxies for coal mining activity: The number of employees in the coal industry (CoalLabor), the total hours worked in coal mining (CoalLaborHours), and coal production (CoalProduction). The variables are standardized and the coefficients represent the effect of a one standard deviation change in each coal mining proxy variable. The sample includes all counties producing coal in 2002, with at least 10 years of data on municipal finances between 2002 and 2019. The estimates presented in Table 2 document a negative and statistically significant relationship between coal mining activity and municipal debt levels. For example, Column 1 shows that a one standard deviation annual decline in coal mining employment—roughly equivalent to a reduction of 300 coal miners—is associated with a 14% annual increase in debt levels. Similarly, a one-time

[21] In a regression of coal production on predicted coal production from (4), the F-statistic is a little higher than 18, indicating that our coal demand-based instrument is both relevant and highly correlated with coal production.

one standard deviation decline in coal mining hours worked (Column 2) or coal production (Column 3) increases debt levels by 12%.

While rising debt alone may not signal financial stress, an increase in debt combined with a deterioration in sustainability indicators points to financial strain in municipal governments. In Table 3, we explore the effects of coal mining on two metrics of debt sustainability: Debt-to-revenue ratio and interest expenditures as a share of revenue. The point estimates in Table 3 suggest that the decline in coal mining activity also leads to a deterioration in municipal governments' debt sustainability indicators, with the ratio of debt-to-revenue and the interest payments as a share of revenue increasing with the decline in coal mining activity. As shown in Columns 1 and 4, a one standard deviation decline in the number of employees in the coal industry leads to a statistically significant 15% increase in the debt-to-revenue ratio and nearly a 1 percentage point increase in interest payments as a share to revenue. The estimates of the other coal mining proxies reveal a similar trend: A one standard deviation decline in coal mining hours worked (Columns 2 and 5) and coal production (Columns 3 and 6) is associated with an increase in the debt-to-revenue ratio of 14% and an increase in interest payments as a share of revenues of 80 basis points. Taken together, these results provide robust empirical evidence that structural decline in coal mining activity—driven by an exogenous technology shock—substantially weakens the fiscal position of local governments in coal-producing counties.

One key identifying assumption behind these results is that the rapid expansion of fracking since the mid-2000s is a key source of variation in U.S. coal mining activity. To validate this assumption and further explore our findings, we examine whether heterogeneity in the exposure of local coal production to increased natural gas production in the U.S. affects the negative relationship between coal mining activity and municipal debt indicators. For one thing, this exercise allows us to validate our key underlying assumption by testing whether the effect of coal mining on municipal finances differs between counties with lows and high exposure to natural gas production growth. For another, it allow us to quantify the extent to which our results are driven by counties highly exposed to increased natural gas production.

For this purpose, we first compute a measure of coal mining exposure to fracking by

Table 2: Coal Mining Activity and Municipal Debt

	Dependent Variable		
	ln Debt		
	(1)	(2)	(3)
CoalLabor	-0.135***		
	(0.03)		
CoalLaborHours		-0.126***	
		(0.03)	
CoalProduction			-0.116***
			(0.04)
Observations	1,884	1,884	1,884
Municipalities	130	130	130
R^2	0.849	0.849	0.848

This table reports coefficients from regressions of the natural logarithm of municipal debt on measures of coal mining activity using the model in Equation (2). All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of the county-level population. The sample includes all counties producing coal in 2002, with at least 10 years of data on municipal finances between 2002 and 2019. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table 3: Coal Mining Activity and Municipal Debt Sustainability

	Dependent Variable					
	Panel A: ln Debt/Revenue			Panel B: Interest/Revenue		
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-0.146***			-0.483**		
	(0.03)			(0.20)		
CoalLaborHours		-0.137***			-0.398**	
		(0.03)			(0.19)	
CoalProduction			-0.119***			-0.230
			(0.04)			(0.24)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,884	1,884	1,884	1,730	1,730	1,730
Municipalities	130	130	130	125	125	125
R^2	0.800	0.799	0.798	0.801	0.800	0.799

This table reports coefficients from regressions of debt sustainability metrics on coal mining activity using the model in Equation (2). The dependent variable in Panel A (Columns 1-3) is the natural logarithm of the municipal debt-to-revenue ratio. Panel B (Columns 4-6) presents results for interest expenditures as a share of revenue multiplied by 100. All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of county-level population. The sample includes all counties producing coal in 2002, with at least 10 years of observations on municipal finances between 2002 and 2019. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

running a regression of the natural logarithm of county-level coal production on the aggregate demand for natural gas of U.S. electricity producers,

$$\ln \mathbf{C}_{i,t} = \alpha_i + \phi_i \ln \mathbf{NG}_t + \varepsilon_{i,t}, \tag{5}$$

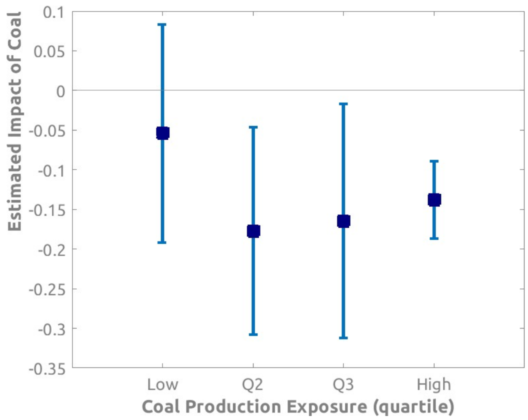
where $C_{i,t}$ is coal production of county i in year t, and NG_t is the amount of natural gas used for electricity generation as shown by the orange line in Figure 1. We estimate ϕ_i for each county using annual data from 2008 to 2019 and restrict our sample to counties with at least 7 years of post-2008 data. We then divide the counties into quartiles based on their estimates of ϕ_i, which range from those with the lowest exposure to natural gas production (a median ϕ of 0.68) to those with the highest exposure (a median ϕ of -6.56). We re-estimate Equation (2) by interacting $\mathbf{C}_{i,t-1}$ with an indicator variable for each of these four groups. Panels A to C of Figure 6 plot the estimated coefficients on the interaction terms when the dependent variable is the natural logarithm of debt outstanding, and the panels in Figure 7 plot the same coefficients when the dependent variable is the natural logarithm of the debt-to-revenue ratio. As shown in Figure 6, a clear and consistent pattern emerges across all three coal mining activity measures. Counties with higher exposure to natural gas production experience a more pronounced increase in municipal debt in response to declining coal mining activity compared to counties with lower exposure to natural gas production. Panel A illustrates, for example, that counties with the lowest exposure to natural gas production exhibit a slightly negative relationship between coal mining employment and debt levels, albeit statistically and economically insignificant. In contrast, counties with the highest exposure to natural gas production exhibit a highly significant negative relationship, with the estimated effect of a one standard deviation decline in coal mining employment on municipal dent increasing nearly threefold from approximately 5% to 15%. The spread in the estimated coefficients between counties with high and low exposures to natural gas production is also substantial when we use county-level total hours worked in coal mining or coal production as proxy variables for coal mining activity (see Panels B and C of Figure 6). Moreover, our estimates suggest that the adverse effects of declining coal activity extend beyond counties with the highest exposure to natural gas production: Coefficients are also negative and statistically significant for counties in the two middle quartiles. While coal's decline and the fracking boom are closely linked, the nonlinear pattern suggests that coal's decline is not simply the inverse of fracking's rise, but a broader structural shock that played out unevenly across regions.

Figure 7 shows the same relationship for the debt-to-revenue ratio. The estimated coefficients on coal mining activity for counties with low exposure to natural gas production are statistically and economically insignificant, while those with high exposure to natural gas production experience a large and statistically significant increase in the debt-to-revenue ratio in response to a decline in coal mining activity. Consistent with our identification assumption, a county's exposure to natural gas production significantly determines the effects of coal mining decline on the fiscal sustainability of local governments. However, the adverse effects of declining coal activity on local governments are, once again, not purely concentrated in counties with the highest exposure to natural gas production but are similarly pronounced in the two middle quartiles.

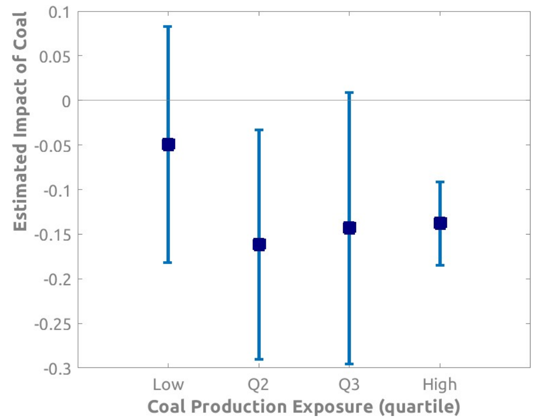
In this subsection, we document several key empirical findings. First, we show that the nearly two-decade-long shift away from coal has increased debt burdens and worsened debt sustainability indicators for coal-dependent local governments. Table A.1 in Appendix A further demonstrates that the decline in coal led to a reduction in revenues available to local governments after interest payments, while expenditures remained largely unchanged. This stands in contrast to the experience of fracking-rich counties, as documented by Bartik et al. (2019), who find that fracking is largely budget neutral, with local government revenues and expenditures rising in tandem. Second, the expansion of natural gas, alongside the decline of coal, has left coal-dependent communities with stranded coal reserves, particularly in areas more exposed to natural gas production. Taken together, our findings suggest that cash flow declines are a key mechanism linking the shift to low-carbon energy sources with increased financial risk and borrowing costs for local governments.[22]

[22]Our evidence highlights the role of cash flow declines and increased debt burdens in response to coal's shock, providing valuable new input for the calibration of structural credit risk models, such as the one proposed by Goldsmith-Pinkham et al. (2023).

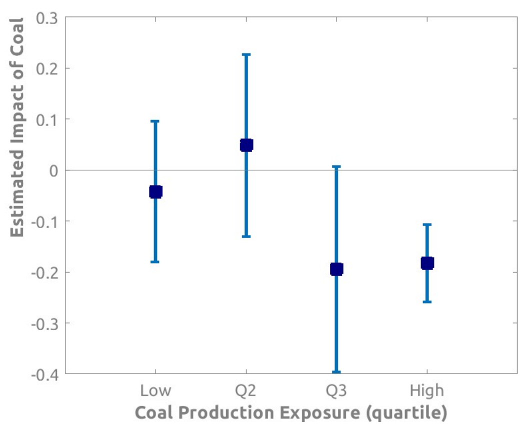
Figure 6: Response of Municipal Debt to Coal Mining By Natural Gas Exposure



(A) Response to Coal Labor



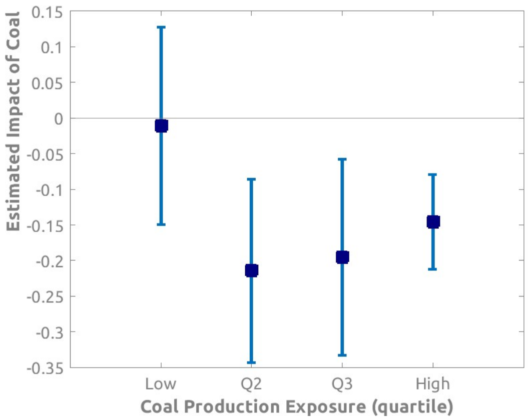
(B) Response to Coal Labor Hours



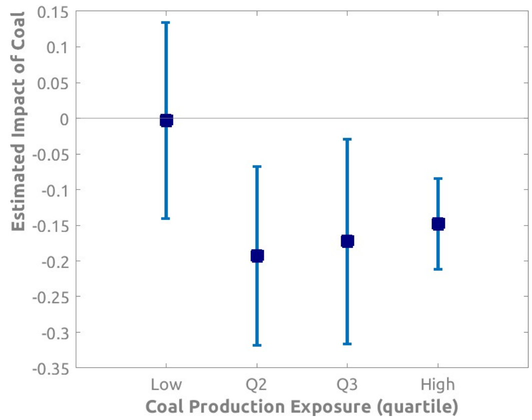
(C) Response to Coal Production

This figure plots the estimated coefficients on the interaction between coal mining activity and the level of exposure to natural gas production. Each point represents the estimated coefficient from Equation (2) on a measure of coal mining activity interacted with an indicator of a county's level of exposure to natural gas—from the lowest to the highest quartile—as estimated by the sensitivity coefficient in Equation (5). The dependent variable is the natural logarithm of total debt outstanding. All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of the county-level population. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. The vertical bars denote the 95% confidence intervals based on standard errors adjusted for two-way clustering at county and coal region-year levels. The sample covers 2008 to 2019.

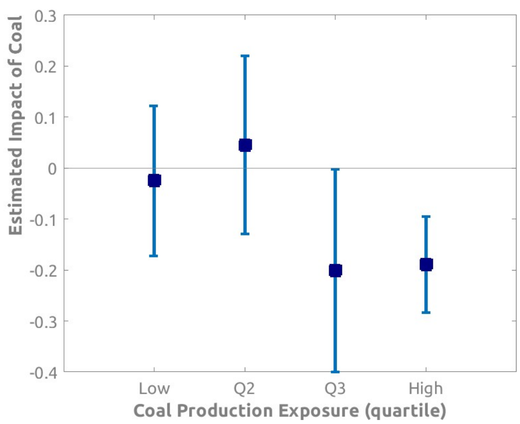
Figure 7: Response of Municipal Debt-to-Revenue to Coal Mining By Natural Gas Exposure



(A) Response to Coal Labor



(B) Response to Coal Labor Hours



(C) Response to Coal Production

This figure plots the estimated coefficients on the interaction between coal mining activity and the level of exposure to natural gas production. Each point represents the estimated coefficient from Equation (2) on a measure of coal mining activity interacted with an indicator of a county's level of exposure to natural gas—from the lowest to the highest quartile—as estimated by the sensitivity coefficient in Equation (5). The dependent variable is the natural logarithm of the total debt-to-revenue ratio. All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of the county-level population. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. The vertical bars denote the 95% confidence intervals based on standard errors adjusted for two-way clustering at county and coal region-year levels. The sample covers 2008 to 2019.

4.2.2 Heterogeneity Analysis: Economic Diversification Beyond Coal

Building on our causal evidence that coal's decline strains municipal finances, we next investigate whether the fiscal impact of this structural shock varies systematically with counties' capacity for economic diversification. Our central hypothesis is that counties with broader or alternative employment bases are more resilient, as they can offset economic losses from coal by leveraging new opportunities. To test this, we examine three county-specific characteristics that reflect both realized and potential employment diversification: fracking potential, renewable energy potential (wind and solar), and overall employment diversification.

Table 4 presents estimates from our baseline specification, Equation (2), where we interact coal mining employment with an indicator for counties' fracking potential. Following Bartik et al. (2019), we classify counties as having high fracking potential (HighFracking) if their Rystad prospectivity index is above the sample median; the remainder are classified as low fracking potential (LowFracking). The interaction terms allow us to causally assess whether access to shale gas development systematically mitigates the fiscal repercussions of coal's decline. This approach leverages the exogenous variation in fracking opportunities to identify a key mechanism of local adaptation.[23]

Columns 1 and 2 show that counties with low fracking potential experience a substantial and statistically significant increase in indebtedness—both in levels and as a share of revenues—in response to a decline in coal mining employment. In contrast, counties with high fracking potential exhibit a much smaller and statistically insignificant effect. For example, a one standard deviation decline in coal employment is associated with a roughly 16% increase in debt for low-fracking counties, while the effect for high-fracking counties is about half as large and not statistically significant. Similarly, interest payments as a share of revenues rise significantly in low-fracking counties, but the effect remains insignificant in high-fracking areas. These results provide new evidence that access to alternative energy industries can buffer local governments against the fiscal risks of structural economic change.

[23]For brevity, we report results using coal employment only, though our other coal activity measures (production and hours worked) yield qualitatively similar results.

Next, we turn to the renewable energy sector to examine whether counties with high wind and solar potential—much like those with fracking opportunities—are better positioned to absorb the economic impact of coal's decline. We classify counties as having high solar energy potential (HighSolar) if their utility-scale photovoltaic capacity exceeds the sample median, while the remaining counties are classified as having low solar potential (LowSolar). Similarly, we use counties' potential to produce electricity using wind turbines to classify counties as having either above-median wind energy potential (HighWind) or below-median wind energy potential (LowWind).

The estimates in Columns 1 and 3 in Table 5 show that a one standard deviation decline in coal mining employment increases debt and debt-to-revenue by about 15% in counties with low solar potential, while the corresponding effect in high solar potential counties is lower than 10% and not statistically significant by conventional criteria. Similarly, the interest-to-revenue ratio in Column 5 shows a strong negative and statistically significant effect for counties with low solar potential, but an economically and statistically insignificant effect for those with high solar potential. Likewise, as shown in Columns 2, 4, and 6, coal's decline significantly raises municipal debt indicators in counties with low wind energy potential, while the estimated effects for counties with high wind energy potential are smaller and statistically insignificant. These results suggest that, although renewable energy industries are not direct substitutes to coal mining, their presence can nonetheless provide governments with a buffer against the fiscal challenges associated with the structural economic transition away from coal.

Beyond energy-related sectors, we examine whether broader employment diversification enhances fiscal resilience to the shift away from coal. Table 6 investigates whether counties with a more diversified employment base are better able to manage the fiscal impacts of coal's decline. Using CBP employment data across NAICS industries, we compute the change in each county's employment diversification between 2001 and 2008, as measured by the Shannon Index, which captures both the breadth and evenness of employment across sectors. Counties with above-median increases are classified as HighDiversification, and those below median as LowDiversification. The results show that the effects on debt and debt-to-revenues of coal mining decline are negative and statistically significant

Table 4: Fracking Potential, Coal Mining, and Municipal Finances

	Dependent Variable		
	ln Debt	ln Debt/Revenue	Interest/Revenue
	(1)	(2)	(3)
CoalLabor × LowFracking	-0.157***	-0.146***	-0.775*
	(0.03)	(0.03)	(0.45)
CoalLabor × HighFracking	-0.076	-0.069	-0.240
	(0.13)	(0.12)	(0.40)
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	911	911	845
Municipalities	61	61	59
R^2	0.875	0.816	0.773

This table presents coefficients from regressions of municipal debt indicators on coal mining activity, using the model specified in Equation (2). The number of employees in the coal industry (CoalLabor) is interacted with indicator variables that are equal to one when fracking potential is low (LowFracking) or high (HighFracking). Fracking potential is determined by whether a county's Rystad prospectivity score is above the median among counties with available prospectivity data. All regressions include coal region-by-year and county fixed effects, as well as the natural logarithm of county-level population. The sample comprises all counties producing coal in 2002, with at least 10 years of municipal finance data between 2002 and 2019. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation, calculated over the sample period after removing county fixed effects. Robust standard errors, adjusted for two-way clustering at the county and coal region-year levels, are reported in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 5: Renewable Energy Potential, Coal Mining, and Municipal Finances

	Dependent Variable					
	ln Debt		ln Debt/Revenue		ln Interest/Revenue	
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor × LowSolar	-0.145***		-0.152***		-0.628**	
	(0.03)		(0.04)		(0.27)	
CoalLabor × HighSolar	-0.058		-0.096		0.081	
	(0.11)		(0.12)		(0.47)	
CoalLabor × LowWind		-0.138***		-0.150***		-0.481***
		(0.03)		(0.03)		(0.18)
CoalLabor × HighWind		-0.121		-0.122		-0.896
		(0.08)		(0.09)		(0.68)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,884	1,884	1884	1,884	1,730	1,730
Municipalities	130	130	130	130	125	125
R^2	0.849	0.849	0.800	0.799	0.802	0.802

This table presents coefficients from regressions of municipal debt indicators on coal mining activity, using the model specified in Equation (2). The number of employees in the coal industry (CoalLabor) is interacted with indicator variables that equal one when a county's potential for solar energy production is low (LowSolar) or high (HighSolar). Solar energy potential is determined by whether a county's potential to generate electricity using utility-scale photovoltaics, as estimated by NREL, is above the sample median. Similarly, the NREL's estimates of wind energy potential are used to classify counties as having high wind energy potential (HighWind) and low wind energy potential (LowWind). All regressions include coal region-by-year and county fixed effects, as well as the natural logarithm of county-level population. The sample comprises all counties producing coal in 2002, with at least 10 years of municipal finance observations between 2002 and 2019. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation, calculated over the sample period after removing county fixed effects. Robust standard errors, adjusted for two-way clustering at the county and coal region-year levels, are reported in parentheses. Significance levels: *** p<0.01; ** p<0.05; * p<0.1.

only for counties with low diversification, while effects are economically and statistically insignificant for highly diversified counties. Additional analysis (not shown) reveal that coal's decline increases debt and worsens debt sustainability in counties with low *initial* employment diversification, suggesting that both pre-existing diversification levels and subsequent growth shape the fiscal impact of coal's decline.

Taken together, these results provide causal evidence that local economic diversification—whether through fracking, renewables, or broader employment opportunities—significantly reduces the fiscal risks associated with the structural decline of coal. Municipal governments in areas with high pre-existing or expanding employment diversification are better able to withstand the fiscal pressures of the energy transition, while those lacking such opportunities face heightened debt burdens and fiscal stress. These findings underscore the critical role of local adaptation strategies in enhancing fiscal resilience to long-term structural shocks and point to the need for targeted policies that support fossil-fuel-dependent communities as they navigate the transition away from coal.

4.3 Instrumental Variable Results

Our results so far provide strong empirical evidence that declining coal mining worsens the fiscal sustainability of coal-dependent municipal governments. This conclusion rests on the assumption that the rise in natural gas production, spurred by fracking, created an exogenous shock to coal mining activity in coal-dependent counties during our sample period. However, declining local economic fundamentals could potentially explain both the downturn in the coal industry and the deterioration in municipal debt sustainability. If such unobserved factors are not fully captured by our regional time-varying fixed effects, our estimates could be subject to omitted variable bias. To address this concern and strengthen our causal interpretation, we employ a complementary IV approach. Specifically, we instrument local coal production using time-series variation in coal purchases by power plants, capturing demand-driven shocks that are plausibly exogenous to local economic conditions.

Table 7 presents the results from estimating Equation (2) with coal production instru-

Table 6: Employment Diversification, Coal Mining, and Municipal Finances

	Dependent Variable		
	ln Debt	ln Debt/Revenue	Interest/Revenue
	(1)	(2)	(3)
CoalLabor × LowDiversification	-0.081**	-0.094**	-0.103
	(0.04)	(0.04)	(0.19)
CoalLabor × HighDiversification	-0.000	-0.028	-0.090
	(0.05)	(0.06)	(0.18)
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	1,190	1,190	1,152
Municipalities	125	125	122
R^2	0.877	0.833	0.872

This table presents coefficients from regressions of municipal debt indicators on coal mining activity, using the model specified in Equation (2). The number of employees in the coal industry (CoalLabor) is interacted with indicator variables that equal one when the change in employment diversification between 2001 and 2008 is low (LowDiversification) or high (HighDiversification). The change in employment diversification is measured using the Shannon Index, which captures changes in employment breadth and evenness across industries. Counties with employment diversification growth above the sample median are classified as HighDiversification, and those below are classified as LowDiversification. All regressions include coal region-by-year and county fixed effects, as well as the natural logarithm of county-level population. The sample includes all counties producing coal in 2008, with at least 7 years of municipal finance data between 2008 and 2019. The coal mining explanatory variables are standardized by dividing each variable by their cross-sectional standard deviation, calculated over the sample period after removing county fixed effects. Robust standard errors, adjusted for two-way clustering at the county and coal region-year levels, are reported in parentheses. Significance levels: *** p<0.01; ** p<0.05; * p<0.1."

mented by power plants' coal demand between 2008 and 2019. All regressions include county and year fixed effects, with error terms clustered by county and region-year. In Column 1, the dependent variable is the natural logarithm of municipal debt. Columns 2 and 3 present results where the dependent variables are the natural logarithm of the debt-to-revenue ratio and interest payments as a share of revenue, respectively. Table 7 shows that the effect of coal mining remains negative and statistically significant, even with the shorter sample period. While the IV estimates are smaller than those from the two-way fixed effects model, they remain economically significant, confirming that declining coal production adversely impacts debt levels and sustainability indicators. Taken together, these findings provide robust causal evidence that the decline in coal production—driven by exogenous demand shocks—has led to increases in municipal debt and a deterioration of fiscal sustainability, especially in counties experiencing substantial reductions in coal demand from electricity producers. This pattern is consistent with the concept of stranded assets: As demand for coal dwindles, coal-dependent local governments face eroding revenues and heightened fiscal strain, underscoring the long-term risks posed by structural economic change.

4.4 Robustness

This subsection presents additional results and robustness checks, including alternative measures of municipal debt sustainability, different strategies for controlling for local economic shocks, and various panel specifications and samples. Full details are presented in Appendix A. First, we show that the impact of declining coal demand on municipal debt remains broadly consistent when we exclude debt with less than 1-year of maturity. Interestingly, when we focus solely on debt with a maturity greater than 1-year by excluding ultra-short-term obligations, the impact of coal mining on municipal debt is approximately 20% more pronounced compared to our estimates that include debt of all maturities. Second, we conducted robustness tests by including year-by-state fixed effects and additional county-level economic variables, namely GDP growth and changes in local employment. Even with these additional controls, the adverse effects of declining coal mining on municipal debt

Table 7: Instrumental Variable Estimates of Coal Production and Municipal Finances

	Dependent Variable		
	$\ln$ Debt	$\ln$ Debt/Revenue	Interest/Revenue
	(1)	(2)	(3)
CoalProduction	-0.052**	-0.066**	-0.245*
	(0.02)	(0.03)	(0.13)
County FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	1,187	1,187	1,139
Municipalities	128	128	125
R^2	0.881	0.829	0.876

This table reports the effect of coal production on municipal debt indicators from estimating equation (2) with coal production instrumented with coal demand from power plants. In the first stage, we use the time series of coal purchased by power plants to predict county-level coal production. We then use the predicted values of coal production in Equation (2) as an instrument for coal production. The dependent variable in Column 1 is the natural logarithm of the municipal debt-to-revenues ratio. Columns 2 and 3 present results for the natural logarithm of municipal debt-to-revenues and debt-to-tax revenues, respectively. All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of county-level population. The sample includes all counties producing coal in 2008, with at least 7 years of municipal finances observations between 2008 and 2019. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** $p<0.01$; ** $p<0.05$; * $p<0.1$.

remain substantial and statistically significant, with only a slight reduction in magnitude compared to our baseline specification. Third, we also show that there are no significant differences in the effects of coal mining before and after 2008, the onset of the global financial crisis (GFC). The estimates are similar in magnitude and statistically significant for both sub-periods. Finally, we also show that the impact of declining coal mining on municipal finances is not significantly influenced by local economic slack, as counties with both high and low unemployment rates experience similar negative fiscal consequences. These results suggest that even municipal governments in relatively healthy economies are not immune to the adverse effects of coal industry decline.

5 The Effect of the Decline in Coal on Municipal Offering Yields

Our results thus far show that declining coal mining activity increases municipal debt burdens and weakens debt sustainability indicators. This section investigates whether, and to what extent, investors incorporate the risks associated with coal's decline into bond yields. If investors perceive these fiscal pressures as indicative of heightened credit risk, we should expect to see rising risk premiums in offering yields. Moreover, because municipal bond yields incorporate forward-looking expectations of debt capacity, they offer a useful lens for assessing whether financial markets view the coal transition as a temporary shock or a long-term, structural decline.

5.1 Empirical Strategy

To estimate the effect of the decline in coal mining on municipal bond yields, we rely on the exogenous decline in coal production following the expansion of fracking in the mid-2000s, as detailed in Section 2, and use issuance data from 2004 to 2019. Specifically, we estimate the following model for municipal bond yields:

$$Y_{b,i,d,t} = \beta\ \mathbf{C}_{i,t-1} + \theta'\ \mathbf{Z}_{b,i,d} + \delta'\mathbf{X}_d + \theta_{r,t} + \mu_i + \varepsilon_{b,i,d,t}, \tag{6}$$

where $Y_{b,i,d,t}$ represents the offering yield on bond b issued by county i on issuance day d in year t. The key independent variable, $C_{i,t-1}$, is the level of coal mining activity in county i during the prior year, $t-1$. The parameter of interest, β, captures the average change in offering yields associated with changes in coal mining activity. As in Section 4, we employ three alternative measures of coal mining activity: The number of employees in the coal industry (CoalLabor), the total hours worked in coal mining (CoalLaborHours), and coal production (CoalProduction). To facilitate comparison across these coal mining activity measures, each is standardized so that estimated coefficients represent the average effect of a one standard deviation change. Equation (6) also incorporates coal region-by-year fixed effects, $\theta_{r,t}$, and county fixed effects, μ_i, to account for any fixed or regional time-varying observed and unobserved factors.

The vector $\mathbf{Z}_{b,i,d}$ includes common bond characteristics on issuance day known to be predictors of municipal offering yields: The maturity-matched AAA-rated municipal bond par yield to proxy for the risk-free rate, coupon rate, time-to-maturity, natural logarithm of the issue size, indicator variables for the bond's credit rating, indicator variables for the use of proceeds (for example, general purpose, education, utilities), and an indicator variable for callable bonds. Lastly, to control for time-varying interest rate conditions in the municipal bond market at issuance, the vector $\mathbf{X}_d$ includes controls for the term structure of interest rates on a given issuance day, namely, the level, slope, and curvature derived from the ICE AAA-rated municipal bond yield curve. Finally, we report standard errors clustered at the county and region-year levels to allow for arbitrary serial correlation in the residuals within counties and over time.

5.2 Empirical Results

5.2.1 Baseline Results on Offering Yields

Table 8 presents the estimated effects of shifts in county-level coal mining activity using our three coal activity measures.[24] The results indicate that a decline in coal mining activ-

[24]For brevity, we do not report estimates for the control variables. Table A.6 in Appendix B shows that the coefficients on the controls exhibit the expected empirical relationships with offering yields. Moreover, the coefficient estimates for coal activity remain stable as we systematically add control variables.

ity is associated with a statistically significant increase in municipal bond offering yields. In Column 1, we find that a one standard deviation decline in coal employment increases municipal bond yields by approximately 8 basis points. Columns 2 and 3 report slightly smaller effects for declines in coal mining hours and coal production, respectively. Given the distribution of offering yields relative to the risk-free rate in our sample (that is, the offering spread), these estimates imply an economically meaningful increase in borrowing costs of nearly 20% relative to the average offering spread.[25]

Next, we apply the empirical specification in Equation (6) to estimate the borrowing cost implications of projected coal production declines, allowing us to assess the economic magnitude of our baseline estimates in the context of planned phase-out targets. Specifically, we estimate the annual increase in counties' bond financing costs under three coal production trajectories: First, an immediate phase-out (from 2019 levels to zero). Second, a gradual phase-out by 2035 (consistent with the proposed G7 target for eliminating unabated coal power generation).[26] Third, a dynamic path capturing the incremental increase in yields as 2035 approaches.

Column 1 of Table 9 presents estimates from Equation (6), using coal production scaled by the average production level in 2019. The results show that an immediate phase-out of coal production from 2019 levels would raise municipal offering yields by 4 basis points, increasing financing costs by approximately 15% relative to the average offering spread in our sample. Under a gradual phase-out scenario (Column 2), the effect is 0.3 basis points per year, corresponding to a 1.3% annual increase in borrowing costs through 2035. Over the full phase-out period, the cumulative effect matches the 4 basis-point increase observed in the immediate phase-out scenario.[27] Column 3 presents estimates from interacting coal production with a time trend measuring the years remaining until 2035 based

[25]Additional analysis (not shown) reveals that declining coal activity is associated with lower bond ratings at issuance, even when accounting for county and region-by-year fixed effects. This finding is consistent with the deteriorating fiscal health discussed in Subsection 4.2. To demonstrate that coal activity provides information beyond what is captured by credit ratings, we include rating fixed effects in Equation (6) and still find a significant negative relationship between coal mining activity and bond yields. This underscores the broader economic impact of declining coal activity on municipal financial health and credit risk.

[26]Phasing out coal, especially in electricity generation, has been embedded in some international policy initiatives such as the "*Powering Past Coal Alliance*" and the G7 pledge to eliminate unabated coal plants by 2035.

[27]For any linear phase-out scenario, the effect for alternative target dates from 2019 levels can be approximated by dividing the full phase-out effect by the number of years remaining until the target date.

Table 8: Coal Mining Activity and Municipal Offering Yields

	Dependent Variable		
	Offering Yield (1)	Offering Yield (2)	Offering Yield (3)
CoalLabor	-7.645***		
	(1.85)		
CoalLaborHours		-6.987***	
		(1.56)	
CoalProduction			-6.647***
			(2.00)
Bond controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region $\times$ Year FE	Yes	Yes	Yes
Observations	17,990	17,990	17,990
Municipalities	181	181	181
R^2	.9622	.9622	.9622

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

on a bond's offering year (CoalProduction $\times$ YearsTo2035), thereby capturing the required offering yield for continued coal production as the 2035 deadline approaches. The results show that the required yield for continued coal production rises over time: from 1.4 basis points at the start of the sample, to 2.6 basis points by 2019, and reaching 3.9 basis points by 2035.[28] These findings suggest that investors are increasingly pricing in coal's long-term decline, driving up offering yields as the projected phase-out deadline approaches. While the estimated increase in borrowing costs is significant for coal-reliant municipalities, the annual burden under a gradual phase-out appears moderate, indicating that—with sufficient planning—these communities may be able to manage the structural economic transition effectively.

Taken together, the decline in debt sustainability indicators (Subsection 4.2) and the increase in bond offering yields (this subsection) suggest that the transition away from coal has heightened financial risks for coal-dependent municipalities. A plausible mechanism for these findings is that investors perceive municipal coal resources as stranded assets due to the rapid expansion of fracking, which undermines both current and future coal-linked tax revenues. Investors may also anticipate broader economic spillovers—such as declining property values, reduced consumer spending, or lower income taxes—stemming from weakened local economic activity. These concerns likely compound municipal credit risk, driving borrowing costs higher. Next, we test whether direct fiscal channels (for example, reduced severance tax revenues) fully explain our findings.

Severance taxes, levied on coal extraction and redistributed to support local communities, represent an important direct fiscal channel. To account for changes in these revenue streams, we use two proxies: First, state-by-year fixed effects to control for state-level variation in severance tax rates, which governments adjust periodically based on fiscal needs, economic conditions, and political dynamics. Second, we control for regional coal prices, which are closely linked to severance tax revenues (higher prices increase revenue, and vice versa). Columns 1 through 3 present results with state-by-year fixed effects. While the coefficients on coal mining variables are moderately smaller than in our baseline specification (Table 8), they remain statistically significant and economically meaningful.

[28] That is, $-3.864 + 31 \times 0.0782$ in 2004, $-3.864 + 16 \times 0.0782$ in 2019, and -3.864 by 2035.

Table 9: Coal Phase-Out and its Impact on Municipal Offering Yields

	Dependent Variable		
	Offering Yield (1)	Offering Yield (2)	Offering Yield (3)
CoalProduction(2019Level)	-4.161***		
	(1.25)		
CoalProduction(2019RequiredDecline)		-0.277***	
		(0.08)	
CoalProduction			-3.864***
			(0.86)
CoalProduction × YearsTo2035			0.078***
			(0.03)
Bond Controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	17,990	17,990	17,990
Municipalities	181	181	181
R^2	.9622	.9622	.9622

This table reports coefficients from regressions of municipal bond offering yields on alternative standardizations of coal production measures using the model in Equation (6) between 2004 and 2019. For CoalProduction(2019Level), we scale coal production by dividing with the sample average coal production in 2019, the final year of our sample. For CoalProduction(2019RequiredDecline), we divide coal production by the annual reduction required to bring average 2019 coal production to zero by 2035, assuming a linear phase-out. Lastly, we interact standardized coal production with YearsTo2035, a time trend measuring the number of years remaining until 2035 based on the bond's offering year. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Columns 4 through 6 use regional coal prices as an alternative proxy, yielding similar results: the coefficient on coal mining activity remains negative and statistically significant. Notably, the coefficient on regional coal prices is also negative and significant, suggesting that lower prices reduce severance tax revenue, weakening debt repayment capacity and increasing yields.

These results underscore that stranded asset risks extend beyond direct fiscal channels like severance taxes. The negative effect of coal's decline across different specifications—even after accounting for direct fiscal channels—points to broader systemic risks for local economies, including limited economic diversification, labor market dislocations, and diminished long-term growth prospects. In the following subsections, we explore these systemic risks and their implications for municipal borrowing costs, providing insights into how investors assess coal-dependent communities facing fiscal challenges

5.2.2 Coal's Decline as a Long-Term Risk

Our findings so far confirm that declining coal mining activity increases municipal bond offering yields, reflecting heightened fiscal risks for coal-dependent communities. However, an important question remains: Do investors perceive the downturn in coal mining as a temporary disruption or a lasting structural shift? If investors believe fluctuations in coal mining activity are temporary, we would expect its impact to be more pronounced on the offering yields of short-term bonds compared to long-term bonds. Conversely, if investors view the decline in coal as a persistent transformation, we anticipate a stronger effect on the yields of long-term bonds relative to short-term bonds. To test this hypothesis, we divide the sample into two groups: Bonds with maturities of 5 years or less and bonds with maturities exceeding 5 years.

Panel A of Table 11 presents coefficient estimates for short-term bonds, while Panel B reports estimates for long-term bonds. The results indicate that declining coal mining activity has a significantly larger impact on the yields of long-term bonds than on short-term bonds. Specifically, while the effect of declining coal mining activity on short-term bond yields is statistically insignificant, long-term bond yields exhibit an economically mean-

Table 10: Coal Severance Taxes, Coal Prices, and Municipal Offering Yields

	Dependent Variable					
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-4.236**			-5.947***		
	(1.83)			(1.61)		
CoalLaborHours		-3.356**			-5.300***	
		(1.44)			(1.59)	
CoalProduction			-5.243***			-5.233***
			(1.90)			(1.90)
CoalPrice				-0.790***	-0.792**	-0.823***
				(0.29)	(0.31)	(0.30)
Bond controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State × Year FE	Yes	Yes	Yes	No	No	No
Observations	17,989	17,989	17,989	17,990	17,990	17,990
Municipalities	181	181	181	181	181	181
R^2	.9669	.9669	.9669	.9624	.9624	.9624

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. In Columns 1 through 3, we add state-by-year fixed effects to Equation (6), while Columns 4 through 6 incorporate regional coal prices as an additional control variable. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

ingful and statistically significant increase. For instance, as shown in Column 1 of Panels A and B, a one standard deviation annual decline in coal production leads to an increase in offering yields of approximately 10 basis points for long-term bonds, compared to less than 3 basis points for short-term bonds. These findings suggest that investors perceive the decline in coal mining during our sample period as a long-term negative shock to coal-dependent communities.

To gain further insight into how investors price short- versus long-term risks, we examine whether coal production forecasts at different horizons help differentiate the relationship between coal's decline and municipal bond yields. Short-term forecasts capture risks closely tied to immediate market fluctuations. In contrast, long-term forecasts reflect risks associated with structural shifts, such as permanent declines in coal demand due to structural change or an anticipated phase-out. If short-term forecasts dominate, this would align with investors viewing coal's decline as transient. Conversely, if long-term forecasts drive the relationship, it would corroborate our maturity-split results, reinforcing the interpretation that the rise in municipal bond yields reflect investors' perception of coal's decline as a persistent, structural risk.

We obtain forecasts of coal production from EIA projections at the coal region level, available for various time horizons. These projections are publicly available and published annually in the EIA's Annual Energy Outlook. It appears plausible that these projections influence the private sector's understanding of long-term energy trends and may indirectly inform investment decisions. For example, energy companies, investors, and analysts might use the data and trends highlighted in the EIA's reports to guide their business decisions, market analyses, and investment strategies.

First, we construct county-level coal production forecasts using the regional projections in the following regression model:

$$C_{i,t+\tau} = \alpha_i + \rho_i \, C^e_{t|r,t+\tau} + \varepsilon_{i,t+\tau} \tag{7}$$

where $C_{i,t+\tau}$ is coal production of county i in year $t+\tau$, and $C^e_{t|i,t+\tau}$ is the EIA's projection of coal production in region r for year $t+\tau$ in year t. We estimate this model from 2004

Table 11: Coal Mining and Municipal Offering Yields: Short- vs. Long-Term Bonds

	Panel A: Short-Term Bonds			Panel B: Long-Term Bonds		
	Dependent Variable			Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-2.956			-10.272***		
	(1.84)			(2.13)		
CoalLaborHours		-2.872			-9.169***	
		(2.09)			(1.60)	
CoalProduction			-3.112			-9.052***
			(2.40)			(2.16)
Bond Controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,668	6,668	6,668	11,315	11,315	11,315
Municipalities	177	177	177	174	174	174
R^2	.9287	.9287	.9288	.9426	.9426	.9426

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Panel A (Columns 1-3) reports estimates for short-term bonds with maturities equal to or below 5 years, while Panel B (Columns 4-6) reports estimates for long-term bonds with maturities above 5 years. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

to 2019 for two forecast horizons: 1-year ahead ($\tau = 1$) and 5-years ahead ($\tau = 5$). Using this model, we compute county-level coal production forecasts for the short and long term (1-year ahead versus 5-year ahead), as well as the corresponding short- and long-term forecast errors ($\varepsilon_{i,t}^{ST}$ versus $\varepsilon_{i,t}^{LT}$). Then, we augment Equation (6) by including an interaction term between coal production and the average forecast error over the past three years.

Table 12 tests the hypothesis that the relationship between coal production and municipal bond yields depends on short-term forecast errors (Column 2) or long-term forecast errors (Column 3). For comparison, we report the baseline estimates in Column 1. Column 2 shows that the adverse effect of declining coal production on yields is not significantly associated with short-term forecast errors in coal production. In contrast, Column 3 indicates that the coefficient on the interaction term with the long-term forecast errors is positive and statistically significant, suggesting an increase in offering yields for counties with negative long-term forecasting errors—that is, in counties where actual coal production fell short of an overly optimistic regional production forecasts. The findings in Table 12 indicate that investors in municipal bond markets may overlook discrepancies in short-term forecasts. However, they appear particularly attentive to persistent long-term forecast errors in coal production. This emphasis on long-term projections is consistent with compensation for the long-term risks associated with the structural decline of coal.

Our findings in Tables 11 and 12 present a compelling picture: Forward-looking bond market investors view the decline in coal mining as a long-term structural risk, not just a temporary setback. This carries important implications for coal-producing communities, as once-valuable coal reserves have effectively become stranded. Notably, major coal industry players acknowledge these long-term challenges. For example, in 2020, Peabody Energy Corporation wrote down the value of its largest Wyoming coal mine by $1.42 billion due to expectations of lower long-term natural gas prices and increasing competition from cheaper renewable energy sources.[29]

Thus, if investors are indeed forward-looking and perceive shifts in coal production as persistent, municipal bond yields are likely to respond not only to county-specific real-

[29] See "*Peabody Writes Down Value of Sprawling Coal Mine*," by M. Maidenberg in *Wall Street Journal*, August 5, 2020.

Table 12: Coal Production Forecast Errors and Municipal Offering Yields

	Dependent Variable		
	Offering Yield (1)	Offering Yield (2)	Offering Yield (3)
CoalProduction	-6.647***	-6.369***	-6.887***
	(2.00)	(1.74)	(1.77)
CoalProduction × Short-Term Forecast Errors		0.593	
		(0.52)	
CoalProduction × Long-Term Forecast Errors			0.559*
			(0.29)
Bond Controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	17,990	17,510	17,251
Municipalities	181	167	166
R^2	.9622	.9617	.9614

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity interacted with coal forecast errors using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Column 1 reproduces results from Table 8. Columns 2 and 3 include the interactions of coal mining production with the average forecast error over the past three years. (Short-Term Forecast Errors) represents 1-year-ahead forecast errors, while (Long-Term Forecast Errors) are 5-year-ahead forecast errors. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

ized production levels and forecast errors but also to broader regional changes in forward-looking projections. To test this hypothesis, we re-estimate Equation (6) using the EIA's regional coal production forecasts for both 1-year and 5-year horizons. The results are presented in Table 13. The coefficient estimates for 1-year (Column 1) and 5-year (Column 2) coal production forecasts are also negative and statistically significant, suggesting that projections of declining coal production lead to significantly higher offering yields and increased bond financing costs for affected local governments. This further confirms our empirical evidence that bond investors factor in the risks tied to declining expectations of coal production in coal-dependent communities.

5.2.3 Heterogeneity Analysis: Employment Diversification Beyond Coal

Subsection 4.2.2 documents that municipal governments with broader employment opportunities can mitigate the adverse effects of coal's decline on indebtedness. While a broad and growing employment base appears to help local governments avoid deterioration in debt sustainability indicators, it is less clear whether investors view these factors as sufficient to offset the long-term structural decline in coal-reliant communities. This subsection examines whether investors perceive the energy transition as a uniformly disruptive shock to coal-reliant counties or whether some counties are viewed as better equipped to manage the fiscal challenges and associated credit risks. As in Subsection 4.2.2, we analyze three county-specific characteristics that capture actual and potential employment diversification: Fracking potential, renewable energy potential (wind and solar), and overall employment diversification.

Table 14 reports estimates from Equation (6), examining whether the relationship between coal mining activity and offering yields differs by fracking potential. To measure fracking potential, we use county-level Rystad prospectivity scores to construct indicator variables for counties with above-median (HighFracking) and below-median (LowFracking) fracking potential. These indicators are interacted with our standardized coal activity measures to assess differential effects. Columns 1 through 3 of Table 14 reveal that declining coal mining activity significantly increases offering yields in counties with low frack-

Table 13: Regional Coal Mining Projections and Municipal Offering Yields

	Dependent Variable	
	Offering Yield	Offering Yield
	(1)	(2)
CoalProduction (1Y-ahead)	-5.258***	
	(1.32)	
CoalProduction (5Y-ahead)		-4.064**
		(1.80)
Bond Controls	Yes	Yes
County FE	Yes	Yes
Region × Year FE	Yes	Yes
Observations	17,665	15,559
Municipalities	169	159
R^2	.9615	.9629

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining projections from the EIA using the model in Equation (6) between 2004 and 2019. Coal projection measures are standardized to have a mean of 0 and standard deviation of 1. CoalProduction (1Y-ahead) represents 1-year-ahead regional coal production projections, while CoalProduction (5Y-ahead) are 5-year-ahead regional coal production projections. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

ing potential, while counties with high fracking potential show no statistically significant increase. These results suggest that counties with greater fracking potential are largely insulated from rising borrowing costs, supporting the notion that investors view alternative employment opportunities in fracking as a buffer to the fiscal strain associated with the long-term decline in coal production.

In Table 15 we explore how investors perceive counties' wind and solar potential in mitigating the impact of coal's decline on municipal borrowing costs. Similar to fracking, high renewable energy potential could create new employment opportunities and generate alternative tax revenues, helping stabilize municipal finances and lower borrowing costs (Cornaggia and Iliev, 2023). To test this hypothesis, we introduce wind and solar potential indicator variables and assess whether counties with greater renewable capacity experience smaller increases in offering yields. We interact coal mining activity measures with indicator variables for high (HighPotential) and low (LowPotential) renewables potential, using county-level data from NREL. Panel A reports results for wind energy potential, while Panel B focuses on solar energy potential. The estimates show that declining coal mining activity significantly raises offering yields in counties with low renewable energy potential, with effects of similar magnitude for both wind and solar energy. In contrast, counties with high renewable energy potential exhibit no statistically significant increase in borrowing costs. These results reinforce the notion that investors view counties with alternative employment pathways—such as renewable energy development—as better equipped to absorb the fiscal strain associated with coal's structural decline.

While energy-related employment opportunities, such as fracking and renewables, can serve as localized buffers for coal-dependent communities, a county's broader employment base—extending beyond reliance on any single energy sector—may play an even more critical role in determining fiscal resilience. We hypothesize that counties with a broader set of employment opportunities—or those that expanded their employment base over time—are better equipped to manage the fiscal challenges of the coal transition. To test this hypothesis, we conduct a twofold analysis of how employment diversification affects offering yields. Using CBP employment data across 4-digit NAICS industries, we compute the diversification of a county's employment base, as measured by a Shannon Index, both in

Table 14: Fracking Potential, Coal Mining, and Municipal Offering Yields

	Dependent Variable		
	Offering Yield (1)	Offering Yield (2)	Offering Yield (3)
CoalLabor × LowFracking	-6.875***		
	(1.03)		
CoalLabor × HighFracking	6.787		
	(7.44)		
CoalLaborHours × LowFracking		-6.929***	
		(1.09)	
CoalLaborHours × HighFracking		4.997	
		(7.62)	
CoalProduction × LowFracking			-8.091***
			(1.52)
CoalProduction × HighFracking			4.351
			(3.96)
Bond controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	5,983	5,983	5,983
Municipalities	69	69	69
R^2	.9685	.9685	.9686

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Coal mining activity measures are interacted with an indicator variable for counties with high (HighFracking) or low (LowFracking) fracking potential using Rystad prospectivity scores. Counties with non-missing prospectivity Rystad scores are classified as (HighFracking) if their fracking potential is above the median and (LowFracking) if it is below. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table 15: Renewable Energy Potential, Coal Mining, and Municipal Offering Yields

	Panel A: Wind Potential			Panel B: Solar Potential		
	Dependent Variable			Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor × LowPotential	-8.622***			-8.873***		
	(2.34)			(2.57)		
CoalLabor × HighPotential	0.789			0.056		
	(5.43)			(4.81)		
CoalLaborHours × LowPotential		-8.032***			-8.405***	
		(1.83)			(2.03)	
CoalLaborHours × HighPotential		0.120			0.171	
		(5.35)			(4.63)	
CoalProduction × LowPotential			-6.812***			-7.318***
			(2.19)			(2.33)
CoalProduction × HighPotential			-5.953			-5.045
			(4.41)			(3.34)
Bond Controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,990	17,990	17,990	17,990	17,990	17,990
Municipalities	181	181	181	181	181	181
R^2	.9623	.9622	.9622	.9623	.9623	.9622

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Panel A (Columns 1-3) presents estimates based on county rankings using wind potential, while Panel B (Columns 4-6) reports estimates based on solar potential. Coal mining activity measures are interacted with indicator variables for counties with high (HighPotential) or low (LowPotential) renewables potential using NREL data. In Panel A, counties are classified as (HighPotential) if their wind potential is above the median and (LowPotential) if it is below. In Panel B, the same classification into (HighPotential) and (LowPotential) applies but is based on counties' solar potential. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

2001—before our sample starts—and a decade later in 2011. The Shannon Index captures both the breadth (number of industries in a county) and balance (evenness of employment distribution across industries), with higher values indicating greater economic diversification and more alternative employment opportunities for displaced coal workers.

Columns 1 through 3 of Table 16 show the results of interacting coal mining activity with indicator variables for counties with above-median (HighDiversification) or below-median (LowDiversification) Shannon Index scores in 2001. We find that a decline in coal mining activity is only associated with an increase in offering yields in counties with low pre-existing employment diversification. Instead, counties with broader employment opportunities exhibit no significant impact from declining coal activity on borrowing costs, suggesting that a more diversified employment base helps offset the financial strain and associated increase in credit risk from the structural economic transition.

In Columns 4 through 6 of Table 16, we interact coal mining activity with indicator variables that classify counties into above-median (HighDiversification) and below-median (LowDiversification) groups based on changes in their Shannon Index scores between 2001 and 2011. Using data from 2012 to 2019, these estimates show that counties that experienced above-median changes in employment diversification during the first half of the sample period were better positioned to buffer the adverse effects of coal's decline in the second half, as suggested by the negative, albeit statistically insignificant, interaction terms. In contrast, counties with below-median changes in employment diversification face higher offering yields. Similar to fracking and renewable energy potential, these results reveal nonlinear patterns: Counties with limited employment diversification experienced disproportionately large increases in borrowing costs, whereas those with greater employment diversification were largely shielded from such financial pressures.

Taken together, our findings highlight the central role of employment diversification in mitigating stranded asset risks and lowering perceived credit risks in coal communities. Investors view coal counties with broader employment opportunities as better positioned to manage the fiscal challenges of coal's structural decline, suggesting that technological change resulting in industrial displacement need not be uniformly disruptive. This distinction has key policy implications: Policymakers may need to tailor transition assistance to prioritize support for coal counties with limited employment opportunities. More broadly, fostering a broad and even employment base should remain central to policies aimed at strengthening the resilience of local communities impacted by industrial decline.

5.3 Robustness

Appendix B provides additional robustness tests to validate our results on municipal offering yields. First, Table A.6 presents the impact of our control variables as we systematically introduce them to the baseline specification. Second, in Table A.7, we confirm that our baseline effects are consistent over time and not merely artifacts of dislocations such as the GFC. Third, we also analyze gross spreads as the dependent variable, replacing offering yields, and confirm qualitatively similar results.[30] That is, Table A.8 shows that the increased cost of issuance due to declining coal activity largely extends beyond offering yields, with estimates indicating an economically meaningful increase in issuance discounts of approximately 5% relative to the average discount for a one standard deviation reduction in coal activity. This underscores the financial strain on coal-dependent municipal issuers, as it also manifests in higher fees charged by bond underwriters. Fourth, in Table A.9, we demonstrate that the baseline results are qualitatively similar when we differentiate municipal bond issuers or restrict our analysis to county issuers only. On balance, the effect does not significantly differ across issuer types and remains negative and significant, with a slight increase in magnitude, in the subset of county-issued municipal bonds. Fifth, in Table A.10 we examine whether revenue bonds and GO bonds respond differently to declines in coal mining activity, given their distinct repayment structures. Our results show that both bond types experience higher yields as coal mining declines, indicating broader fiscal risks beyond pledgeable revenues. However, revenue bonds, which depend on project revenues, are particularly sensitive, with significantly stronger effects for two of the three coal mining measures, highlighting their greater exposure to local economic downturns. Sixth, in Figure 8 and Table A.11, we examine whether coal quality influences the effect of declining coal activity on municipal offering yields by distinguishing between thermal

[30]Following Painter (2020), we obtain issuance discount spread data from Bloomberg and substitute it, where available, for offering yields in Equation (6).

Table 16: Employment Diversification, Coal Mining, and Municipal Offering Yields

	Panel A: Pre-Existing Employment Diversification			Panel B: Acquired Employment Diversification		
	Dependent Variable			Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor × LowDiversification	-9.151***			-7.470***		
	(2.55)			(2.57)		
CoalLabor × HighDiversification	1.887			-4.230		
	(6.20)			(12.60)		
CoalLaborHours × LowDiversification		-8.812***			-6.563***	
		(2.03)			(2.20)	
CoalLaborHours × HighDiversification		2.567			-2.745	
		(5.56)			(11.25)	
CoalProduction × LowDiversification			-9.120***			-7.058*
			(2.00)			(3.50)
CoalProduction × HighDiversification			1.124			-1.132
			(5.36)			(5.82)
Bond Controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,990	17,990	17,990	11,486	11,486	11,486
Municipalities	181	181	181	159	159	159
R^2	.9623	.9623	.9623	.9592	.9591	.9591

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Panel A (Columns 1-3) presents estimates based on county rankings using 2001 Shannon Index scores and captures pre-existing employment diversification, while Panel B (Columns 4-6) reports estimates based on changes in Shannon Index scores from 2001 to 2011 and captures acquired employment diversification. Coal mining activity measures are interacted with indicator variables for counties with high (HighDiversification) or low (LowDiversification) employment diversification using CBP data. In Panel A, counties are classified as (HighDiversification) if their 2001 Shannon Index score is above the median and (LowDiversification) if it is below. In Panel B, the same classification into (HighDiversification) and (LowDiversification) applies but is based on changes in Shannon Index scores between 2001 and 2011, with the sample restricted to the years 2012 through 2019. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

and metallurgical coal. We find little evidence to support the claim that investors perceive counties producing higher-quality coal as more resilient. Lastly, in Tables A.12 and A.13, we confirm that the effects of renewables potential and employment diversification on bond offering yields remain largely unchanged when counties with high fracking potential are excluded from the analysis. This suggests that the mitigating effects hold up as buffers against the financial strain of coal's decline, independent of counties' fracking potential.

6 Conclusion

In this paper, we present new causal evidence on the fiscal and financial consequences of structural economic change in coal-dependent U.S. regions. Our identification strategy exploits the substantial shift in the U.S. energy composition over the past two decades—from predominantly coal-fired to largely natural gas-fired electricity generation—to isolate causal effects on municipal finances and borrowing costs. Crucially, this structural shift away from coal occurred largely independently of local economic conditions in coal-producing counties, offering a quasi-natural experiment to assess the fiscal impact of declining coal mining activity. Our findings underscore a salient trend: The decline in coal mining is linked to increasing debt burdens, worsening debt sustainability indicators, and rising borrowing costs—highlighting that investors view coal-reliant communities as higher-risk borrowers.

Our empirical evidence also reveals that investors view the decline in coal mining as a protracted structural shift with profound implications for coal-producing communities: Transitioning away from coal has effectively turned once-valuable reserves into stranded assets. However, we also find that local economic diversification—such as developing renewable energy sectors or fostering resilience through broader employment bases—can mitigate deteriorating fiscal health and reduce long-term credit risks. For example, our results show that broad employment opportunities across alternative industries can partially offset the adverse effects of coal's decline on local public finances. Counties with high fracking and renewable energy potential experience smaller increases in debt and offering yields in response to declining coal activity. More broadly, municipal governments with diversified local economies—or those that managed to expand employment diversification during the structural shift—were better positioned to withstand the fiscal ramifications of coal's decline. This highlights the dual role of economic diversification: Buffering the fiscal impacts of coal's decline while also supporting the implementation of sustainable transition policies during the ongoing shift away from carbon-intensive energy production.

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Appendix

A Robustness of Coal's Effects on Municipal Debt Indicators

This appendix provides a detailed account of several robustness tests examining the impact of declining coal mining activity on municipal debt sustainability.

In Table A.1, we show that the decline in coal reduces net revenues available to local governments while expenditures remained largely unchanged—unlike the budget-neutral effects found for fracking in Bartik et al. (2019). These revenue pressures, combined with evidence of stranded coal reserves in areas more exposed to natural gas, suggest that broad cash-flow constraints are a key mechanism linking the energy transition to rising debt burdens and deteriorating fiscal health.

Our analysis uses outstanding debt of all maturities, though one might expect longer-term debt to be more sensitive to a persistent shock to coal demand. To investigate this possibility, we use outstanding debt with maturity above 1-year (Debt 1Y+) and re-estimate Equation (2). Columns 1 and 2 in Panel A of Table A.2 report the results of this exercise using *CoalLabor* as the key explanatory variable. The estimated coefficient on coal mining is negative and statistically significant. Notably, our findings indicate that the coefficients for debt with a maturity greater than 1-year are at least 20% more negative compared to those for all maturities (shown in Table 2). Table A.2 also presents the estimated effects of our coal mining activity measures when we consider tax revenue to compute the debt-to-income sustainability indicators. In particular, Columns 3 and 4 report estimates for the effects of coal on the natural logarithm of debt-to-tax-revenue ratio for outstanding Debt 1Y+ and all outstanding debt, respectively. Again, our results show that a decline in coal mining activity leads to a deterioration of municipal debt sustainability ratios across all measures of coal activity.

In Table A.3, we also investigate concerns that the year-by-region fixed effects may only partially capture potential confounding variables that could bias our results. First, we repeat our analysis by including year-by-state fixed effects to account for observed and unobserved time-varying factors affecting municipal finances. In contrast to our baseline specification, the state-by-year fixed effects capture a more granular regional variation in dynamic trends. As shown in Columns 1, 3, and 5 of Table A.3, the effect of the decline in coal mining on municipal debt and debt sustainability indicators remains negative and statistically significant. Second, we repeat our analysis by including additional county-level variables that capture local economic conditions, namely, GDP growth and the changes in employment. Columns 2, 4, and 6 of Table A.3 present the estimated coefficients on various measures of coal mining activity while controlling for these economic variables. Even after including these additional controls, we continue to find substantial negative effects of coal mining on municipal debt, with only some decline in the magnitude of the effects compared to the baseline specification.

In Table A.4, we examine whether the estimated effects vary over time. In particular, we add an interaction variable to our baseline regression to capture the effects of coal mining before and after 2008, which marks the onset of the Great Financial Crisis (GFC). One critique of Goldsmith-Pinkham et al. (2023) about Painter (2020)'s findings for the effect of seal level rise on municipal bonds is that the effects are concentrated around the end of the GCF. The results in Appendix Table A.4 reveal that the estimated coefficients on coal are economically and statistically the same before and after 2008 across all three proxy variables for coal mining activity. The key takeaway from these regressions is that our findings are not influenced by the GFC or the years following this tumultuous period.

Finally, we also test wether local economic slack amplifies the effects of the decline in coal mining on municipal finances. Table A.5 reports estimates of Equation (2) in which we interact coal mining employment with an indicator variable that captures the degree of economic slack. Specifically, we construct an indicator variable that equals one for counties where the unemployment rate is above the national unemployment rate (HighSlack) and another indicator variable that equals one for counties with an unemployment rate below the national unemployment rate (LowSlack). We then include the interaction terms of these indicator variables and our coal activity measures in our baseline regression. The coefficients on these interaction terms capture the effects of coal mining on the municipal finances of counties with high and low economic slack. Table A.5 shows that the effects of coal mining are negative and statistically significant for all counties, regardless of the level of economic slack. The estimates suggest that counties with high economic slack experience an increase in debt almost as large as those with low or no economic slack.

Table A.1: Coal Mining Activity and Municipal Cash-Flows

	Dependent Variable		
	ln Revenues−Interest	ln PropertyTax	ln Expenditures
	(1)	(2)	(3)
CoalLabor	0.031**	0.022**	0.013
	(0.01)	(0.01)	(0.01)
Observations	1,960	2,190	1,884
Municipalities	131	136	130
R^2	0.962	0.968	0.848

This table reports coefficients from regressions of the natural logarithm of municipal debt on coal mining employees (CoalLabor) using the model in Equation (2). All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of the county-level population. The sample includes all counties producing coal in 2002, with at least 10 years of data on municipal finances between 2002 and 2019. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.2: Coal Mining Activity and Alternative Indicators of Municipal Debt

	Dependent Variable			
	ln Debt 1Y+	ln Debt 1Y+/Revenue	ln Debt 1Y+/TaxRevenue	ln Debt/TaxRevenue
	(1)	(2)	(3)	(4)
Panel A: CoalLabor				
CoalLabor	-0.163***	-0.176***	-0.167***	-0.143***
	(0.04)	(0.04)	(0.05)	(0.04)
R^2	0.781	0.693	0.733	0.819
Panel B: CoalLaborHours				
CoalLaborHours	-0.152***	-0.165***	-0.154***	-0.132***
	(0.04)	(0.04)	(0.05)	(0.04)
R^2	0.781	0.692	0.732	0.818
Panel C: CoalProduction				
CoalProduction	-0.143**	-0.151***	-0.141**	-0.120***
	(0.06)	(0.05)	(0.06)	(0.04)
R^2	0.780	0.691	0.731	0.818
Observations	1,815	1,815	1,815	1,884
County FE	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes

This table reports coefficients from regressions of municipal debt sustainability metrics on coal mining activity measures using the model in Equation (2). Columns 1 and 2 present results using the natural logarithm of debt with a maturity greater than 1-year (Debt 1y+) and the logarithm of debt with maturity above 1 year as a share of revenue as dependent variables, respectively. Columns 3 and 4 report estimates for the effects of coal on the natural logarithm of debt with maturity above 1 year as share of tax revenue and the natural logarithm of all outstanding debt-to-tax revenue ratio, respectively. The estimated coefficient on *CoalLabor* is reported in Panel A, while Panels B and C report the estimates of Equation (2) using *CoalLaborHours* and *CoalProduction* as the key explanatory variable, respectively. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of county-level population. The sample includes all counties producing coal in 2002, with at least 10 years of observations on municipal finances between 2002 and 2019. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.3: Coal Mining Activity and Alternative Controls for Local Economic Conditions

	Dependent Variable					
	ln Debt		ln Debt/Revenue		Interest/Revenue	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: CoalLabor						
CoalLabor	-0.127***	-0.115***	-0.138***	-0.126***	-0.471**	-0.536**
	(0.03)	(0.03)	(0.04)	(0.03)	(0.18)	(0.24)
R^2	0.871	0.852	0.829	0.802	0.841	0.801
Panel B: CoalLaborHours						
CoalLaborHours	-0.121***	-0.106***	-0.131***	-0.117***	-0.364**	-0.431*
	(0.03)	(0.03)	(0.04)	(0.03)	(0.18)	(0.23)
R^2	0.871	0.873	0.828	0.802	0.842	0.800
Panel C: CoalProduction						
CoalProduction	-0.118***	-0.095**	-0.123***	-0.097***	-0.422*	-0.215
	(0.04)	(0.04)	(0.04)	(0.04)	(0.24)	(0.29)
R^2	0.871	0.851	0.828	0.801	0.844	0.799
County FE	Yes	Yes	Yes	Yes	Yes	Yes
State $\times$ Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Local Controls	No	Yes	No	Yes	No	Yes
Observations	1,787	1,767	1,787	1,767	1,654	1,654

This table reports coefficients from regressions of municipal debt sustainability metrics on coal mining activity measures using the model in Equation (2). Columns 1, 3, and 5 include state-by-year fixed effects, and Columns 2, 4, and 6 add county-level real GDP growth and employment growth to this specification as control variables. All regressions include county fixed effects as well as the natural logarithm of the county-level population. The estimated coefficient on *CoalLabor* is reported in Panel A, while Panels B and C report the estimates of Equation (2) using *CoalLaborHours* and *CoalProduction* as the key explanatory variable, respectively. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. The sample includes all counties producing coal in 2002, with at least 10 years of data on municipal finances between 2002 and 2019. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.4: Coal Mining Activity and Municipal Finances: Time Consistency

	Dependent Variable		
	ln Debt	ln Debt/Revenue	Interest/Revenue
Panel A: CoalLabor			
CoalLabor × Year<2008	-0.147***	-0.154***	-0.516**
	(0.04)	(0.04)	(0.22)
CoalLabor × Year≥2008	-0.125***	-0.139***	-0.586**
	(0.03)	(0.03)	(0.25)
R^2	0.849	0.800	0.801
Panel B: CoalLaborHours			
CoalLaborHours × Year<2008	-0.139***	-0.145***	-0.410*
	(0.04)	(0.04)	(0.23)
CoalLaborHours × Year≥2008	-0.119***	-0.132***	-0.492**
	(0.03)	(0.03)	(0.24)
R^2	0.849	0.799	0.801
Panel C: CoalProduction			
CoalProduction × Year<2008	-0.118***	-0.117***	-0.219
	(0.04)	(0.04)	(0.28)
CoalProduction × Year≥2008	-0.113***	-0.123***	-0.402
	(0.04)	(0.04)	(0.31)
R^2	0.848	0.798	0.800
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Municipalities	130	130	125
Observations	1,884	1,884	1,730

This table reports coefficients from regressions of municipal debt sustainability metrics on coal mining activity measures using the model in Equation (2). The model includes the interaction of an indicator variable indicating whether the sample is before 2008 or the years thereafter. The estimated coefficient on *CoalLabor* is reported in Panel A, while Panels B and C report the estimates of Equation (2) using *CoalLaborHours* and *CoalProduction* as the key explanatory variable, respectively. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of county-level population. The sample includes all counties producing coal in 2002, with at least 10 years of observations on municipal finances between 2002 and 2019. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.5: Coal Mining Activity and Municipal Finances: The Role of Economic Slack

	Dependent Variable		
	ln Debt	ln Debt/Revenue	Interest/Revenue
	(1)	(2)	(3)
CoalLabor × HighSlack	-0.133***	-0.145***	-0.487**
	(0.03)	(0.03)	(0.20)
CoalLabor × LowSlack	-0.136***	-0.146***	-0.524**
	(0.03)	(0.03)	(0.21)
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	1,884	1,884	1,791
Municipalities	130	130	126
R^2	0.849	0.800	0.800

This table reports coefficients from regressions of municipal debt indicators on coal mining activity using the model in Equation (2). The variable capturing the number of employees in the coal industry (CoalLabor) is interacted with indicator variables that equal to one when economic slack is high (HighSlack) or low (LowSlack). To capture economic slack, we construct an indicator variable that takes a value equal to one in counties where the unemployment rate is above the national unemployment rate (HighSlack) and an indicator variable that equals one in counties with an unemployment rate below the national unemployment rate (LowSlack). All regressions include coal region-by-year and county fixed effects as well as the natural logarithm of county-level population. The table also reports the difference in the effect between counties with high and low economic slack (High − Low Slack) along with its standard error. The coal mining explanatory variables are standardized by dividing each variable by its cross-sectional standard deviation calculated over our sample period once county fixed effects are removed. The sample includes all counties producing coal in 2002, with at least 10 years of observations on municipal finances between 2002 and 2019. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

B Robustness of Coal's Effects on Municipal Offering Yields

In this appendix, we present additional robustness tests of our baseline results to validate the findings in Section 5.2.1. These include assessing the role of control variables, testing for time consistency, analyzing gross spreads instead of offering yields, and differentiating results by municipal bond issuer, bond type, and coal quality. We also verify that our findings on renewables and employment diversification remain robust when excluding counties with high-fracking potential.

As shown in Table A.6, the coefficients on the controls align with expected theoretical and empirical relationships with bond yields. For example, consistent with theory and upward-sloping yield-over-maturity curves, a longer time-to-maturity of municipal bonds significantly increases yields. Additionally, an upward sloping municipal yield curve and larger issue sizes are associated with higher bond yields. Moreover, the inclusion of credit rating fixed effects in the regression—where increased credit risk consistently widens municipal bond yields—exhibits the expected signs.

Notably, sequentially introducing control variables allows us to isolate the effect of coal activity measures while accounting for potential correlations between the controls and the dependent variable that might otherwise obscure coal's full impact. For example, due to the strong correlation between offering yields and credit ratings, controlling for credit ratings may limit the extent to which the coefficient estimates for the coal activity measures capture their full association with offering yields.[31] In Column 4 of Table A.6, where rating controls are excluded, the coefficient estimates increase slightly relative to the baseline specification, implying an average increase of just under 9 basis points for a one standard deviation decrease in coal mining activity, representing 22% of the average offering spread.

Table A.7 confirms that our effects are consistent over time, and thus not merely artifacts of events like the GFC—a critique of Goldsmith-Pinkham et al. (2023) about Painter (2020)'s findings. Specifically, we split our 16-year sample period in half by constructing

[31] In unreported results, we find that declining coal activity is linked to lower bond ratings at issuance, even after accounting for county and region-by-year fixed effects. This aligns with the deteriorating economic fundamentals discussed in Subsection 4.2. To demonstrate that coal activity measures provide relevant information beyond what credit ratings capture, we include rating fixed effects as a control in Equation (6) and still find a significant negative relationship between coal mining activity and bond yields. This underscores the broader economic impact of declining coal activity on municipal financial health.

the indicator variable ($\text{Year}\geq 2012_t$), which equals one for years after 2012 and zero for years before 2012, and include this variable and its interaction with the coal activity measures in Equation (6). For a municipal bond to be included in this analysis, the issuer must have issued bonds at least once in both subperiods. The estimated coefficients are stable across subperiods and not statistically different from one another, reinforcing the temporal robustness of our results.

In Table A.8, we follow Painter (2020) and further assess the impact on issuance costs by also examining gross spreads, by substituting them as the dependent variable in place of offering yields. In Columns 1 to 3, we find that underwriter discount costs also significantly increase in response to the decline in coal. Specifically, a one standard deviation reduction in coal activity results in an approximately 5% rise relative to the average underwriter discount, emphasizing the heightened borrowing costs facing coal-dependent municipal issuers.

Table A.9 demonstrates that our baseline results remain consistent across different issuer types and when restricted to county issuers only. Specifically, following Ivanov and Zimmermann (2024), we classify municipal issuers into counties, cities, townships, as well as special districts and authorities. Then, in Columns 1 to 3, we re-estimate Equation (6) with an issuer type category variable interacted with the three coal activity measures. Similarly, in Columns 4 to 6, we re-estimate Equation (6) separately on the subset of municipal bonds issued by counties.

In Table A.10, we analyze whether revenue bonds and GO bonds respond differently to declines in coal mining activity, given their distinct repayment structures. Revenue bonds, which are backed by income from specific projects (for example, water treatment facilities, toll roads, or bridges), are more vulnerable to local economic shifts, while GO bonds are backed by the taxing authority of the issuing municipality, making them less dependent on the economic performance of specific projects or sectors. Our findings show that both bond types experience higher yields as coal mining declines, indicating broader fiscal risks beyond pledgeable revenues. However, revenue bonds exhibit significantly stronger negative effects for two of the three coal mining measures, suggesting they are more exposed to local economic downturns. These results highlight the widespread impact of coal's decline on municipal borrowing costs, affecting both revenue-backed and tax-backed bonds.

In Table A.11, we examine whether coal quality, measured by heat content, influences the impact of declining coal production on municipal bond yields. Higher-quality coal burns longer and produces more heat, with U.S. coal broadly classified into thermal coal (used for domestic electricity generation) and metallurgical coal (exported for steelmaking). We use power plant-reported heat content data to assess differences in coal quality and illustrate its distribution in Figure 8, which shows substantial variation across counties. About 10% of counties produce coal with heat content above the U.S. export average. We then investigate whether municipal bond yields in counties producing high-quality coal—defined as those producing coal with a heat content above the average U.S. export quality each year—are affected differently by changes in coal mining activity. We hypothesize that investors may view counties with high-quality coal as more resilient due to access to alternative markets. However, in Columns 1 through 3 of Table A.11, interactions between high-quality coal indicators and coal mining activity measures are statistically insignificant, and baseline effects remain unchanged, suggesting that bond yields respond similarly across all coal-producing counties. Our initial classification relied on power plant data, which mainly captures thermal coal, potentially missing metallurgical coal producers that strictly export their output. To address this, we redefine high-quality coal producers as counties in traditional metallurgical coal regions (Alabama, Arkansas, Pennsylvania, Virginia, or West Virginia) that do not sell coal to U.S. power plants, indicating a likely focus on metallurgical coal production. While results using this refined definition remain statistically insignificant, they suggest slightly smaller increases in borrowing costs for metallurgical coal-producing counties, though the effect is limited given that metallurgical coal accounts for less than 10% of U.S. production.

Lastly, in Tables A.12 and A.13, we confirm that the effects of renewables and employment diversification on bond offering yields remain largely unchanged when restricting our analysis to counties without high fracking potential. This robustness check strengthens our findings by demonstrating that the mitigating effects of renewables and employment diversification are not merely driven by the presence of fracking, but instead represent independent economic buffers against the financial strain of coal's decline.

Table A.6: Coal Mining and Municipal Offering Yields: Impact of Controls

	Dependent Variable				
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)
Panel A: CoalLabor					
CoalLabor	-13.179***	-9.055***	-9.546***	-8.926***	-7.645***
	(3.70)	(2.66)	(2.10)	(1.88)	(1.85)
Maturity-matched AAA yield		1.000***	0.891***	0.876***	0.891***
		(0.01)	(0.02)	(0.02)	(0.02)
Time-to-Maturity			2.097***	2.284***	2.080***
			(0.24)	(0.26)	(0.29)
Coupon			2.197	2.080	0.180
			(1.63)	(1.60)	(1.13)
Isse Size			0.746	0.880	2.225***
			(0.67)	(0.68)	(0.66)
Slope				8.498**	6.250*
				(3.60)	(3.52)
Level				-2.197	-1.015
				(1.37)	(1.28)
Curvature				10.193**	6.579
				(4.41)	(4.25)
AA+					0.227
					(10.71)
AA					11.179
					(8.41)
AA-					19.093**
					(9.05)
A+					23.560**
					(9.55)
A					30.899***
					(9.75)
A-					40.628***
					(11.66)
BBB+					110.424***
					(15.07)
BBB					104.314***
					(13.72)
BBB-					124.848***
					(27.72)
County FE	Yes	Yes	Yes	Yes	Yes
Region $\times$ Year FE	Yes	Yes	Yes	Yes	Yes
UoP & Call Option FEs	No	No	Yes	Yes	Yes
Observations	17,990	17,990	17,990	17,990	17,990
Municipalities	181	181	181	181	181
R^2	.323	.9326	.9495	.9504	.9622

(Table A.6 continued)

	Dependent Variable				
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)
Panel B: CoalLaborHours					
CoalLaborHours	-11.015***	-8.508***	-8.792***	-8.237***	-6.987***
	(4.15)	(2.48)	(1.78)	(1.54)	(1.57)
Maturity-matched AAA yield		1.000***	0.891***	0.877***	0.891***
		(0.01)	(0.02)	(0.02)	(0.02)
Time-to-Maturity			2.089***	2.281***	2.077***
			(0.24)	(0.26)	(0.29)
Coupon			2.197	2.080	0.180
			(1.62)	(1.59)	(1.13)
Isse Size			0.751	0.884	2.229***
			(0.68)	(0.69)	(0.67)
Slope				8.480**	6.233*
				(3.57)	(3.49)
Level				-2.175	-0.995
				(1.36)	(1.27)
Curvature				10.205**	6.582
				(4.37)	(4.22)
AA+					0.176
					(10.71)
AA					11.158
					(8.40)
AA-					19.081**
					(9.05)
A+					23.575**
					(9.54)
A					30.829***
					(9.75)
A-					40.494***
					(11.68)
BBB+					110.463***
					(15.05)
BBB					104.230***
					(13.73)
BBB-					124.917***
					(27.73)
County FE	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes
UoP & Call Option FEs	No	No	Yes	Yes	Yes
Observations	17,990	17,990	17,990	17,990	17,990
Municipalities	181	181	181	181	181
R^2	.3228	.9326	.9495	.9504	.9622

(Table A.6 continued)

	Dependent Variable				
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)
Panel C: CoalProduction					
CoalProduction	-10.407**	-8.023***	-7.459***	-7.152***	-6.647***
	(4.58)	(2.46)	(2.35)	(2.15)	(2.00)
Maturity-matched AAA yield		1.000***	0.890***	0.876***	0.890***
		(0.01)	(0.02)	(0.02)	(0.02)
Time-to-Maturity			2.090***	2.285***	2.080***
			(0.24)	(0.26)	(0.29)
Coupon			2.192	2.073	0.173
			(1.63)	(1.60)	(1.14)
Isse Size			0.810	0.940	2.284***
			(0.68)	(0.69)	(0.66)
Slope				8.584**	6.313*
				(3.61)	(3.52)
Level				-2.195	-1.010
				(1.36)	(1.28)
Curvature				10.303**	6.675
				(4.40)	(4.24)
AA+					0.487
					(10.61)
AA					11.540
					(8.29)
AA-					19.555**
					(8.92)
A+					23.727**
					(9.46)
A					31.083***
					(9.64)
A-					40.825***
					(11.57)
BBB+					110.922***
					(14.84)
BBB					104.874***
					(13.55)
BBB-					125.211***
					(27.60)
County FE	Yes	Yes	Yes	Yes	Yes
Region $\times$ Year FE	Yes	Yes	Yes	Yes	Yes
UoP & Call Option FEs	No	No	Yes	Yes	Yes
Observations	17,990	17,990	17,990	17,990	17,990
Municipalities	181	181	181	181	181
R^2	.3228	.9326	.9494	.9503	.9622

(Table A.6 continued)

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Across Panels A through C, Columns 1 through 5 systematically introduce the control variables outlined in Subsection 5.1 into Equation (6). Regressions ultimately include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** $p<0.01$; ** $p<0.05$; * $p<0.1$.

Table A.7: Coal Mining Activity and Municipal Offering Yields: Time Consistency

	Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)
CoalLabor	-8.092***		
	(2.07)		
CoalLabor × Year≥2012	-0.435		
	(1.09)		
CoalLaborHours		-7.345***	
		(1.55)	
CoalLaborHours × Year≥2012		-0.306	
		(1.11)	
CoalProduction			-7.748***
			(1.58)
CoalProduction × Year≥2012			-0.252
			(1.55)
Bond controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	11,055	11,055	11,055
Municipalities	98	98	98
R^2	.967	.967	.967

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. The coal mining activity measures are interacted with an indicator variable (Year≥2012) that equals one for municipal bonds issued in or after 2012—the indicator variable (Year≥2012) split the 16-year sample period in half. For a municipal bond to be included in this regression, the issuer must have issued bonds at least once in both subperiods. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.8: Coal Mining and Municipal Gross Spreads

	Dependent Variable		
	Gross Spread	Gross Spread	Gross Spread
	(1)	(2)	(3)
CoalLabor	-5.521***		
	(1.69)		
CoalLaborHours		-4.454**	
		(1.96)	
CoalProduction			-2.585
			(2.69)
Bond controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	14,444	14,444	14,444
Municipalities	159	159	159
R^2	.5238	.5236	.5233

This table reports coefficients from regressions of municipal bond gross spreads on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.9: Coal Mining and Municipal Offering Yields by Issuer

	Dependent Variable					
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-8.297***			-10.959***		
	(1.96)			(3.18)		
CoalLaborHours		-7.623***			-10.390***	
		(1.74)			(2.51)	
CoalProduction			-7.540***			-11.462***
			(2.08)			(2.36)
City × Coal...	1.109	1.127	1.795			
	(1.46)	(1.47)	(1.92)			
SchoolDistrict × Coal...	1.545	1.432	3.285			
	(7.23)	(7.29)	(12.55)			
SpecialDistrict/Authority × Coal...	1.186	1.158	1.740			
	(1.62)	(1.56)	(1.62)			
Township × Coal...	0.660	1.578	3.952**			
	(4.12)	(3.58)	(1.73)			
Bond controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,990	17,990	17,990	6,207	6,207	6,207
Municipalities	181	181	181	141	141	141
R^2	.9623	.9623	.9623	.9698	.9698	.9698

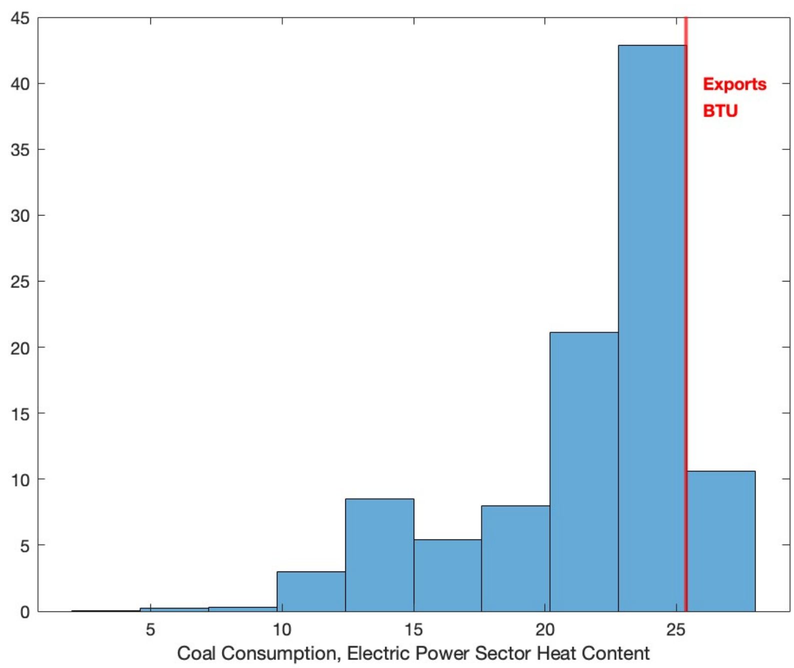
This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. In Columns 1 through 3, the coal mining activity measures are interacted with indicator variables for different types of municipal issuers, with the baseline effect representing county-issued municipal bonds. In addition to counties, we distinguish issuers as (City), (Township), (SchoolDistricts), and (SpecialDistrict/Authority). In Columns 4 through 6, we restrict the sample to county-issued municipal bonds only. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.10: Coal Mining and Municipal Offering Yields: Revenue vs. GO Bonds

	Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)
CoalLabor	-4.895**		
	(2.12)		
CoalLabor×RevenueBond	-3.843**		
	(1.53)		
CoalLaborHours		-4.203**	
		(1.83)	
CoalLaborHours × RevenueBond		-3.992**	
		(1.56)	
CoalProduction			-4.835**
			(2.36)
CoalProduction × RevenueBond			-2.610
			(1.84)
RevenueBond	16.250***	16.312***	15.957***
	(3.13)	(3.12)	(3.14)
Bond controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes
Observations	17,990	17,990	17,990
Municipalities	181	181	181
R^2	.9634	.9634	.9632

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. The coal mining activity measures are interacted with an indicator variable (RevenueBond) that equals one for revenue bonds and zero for GO bonds. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Figure 8: Distribution of U.S. Coal Heat Content Consumed by Electricity Producers



This figure displays the distribution of U.S. coal heat content (measured in million Btu per short ton) consumed by electricity producers from 2008 to 2019. The vertical line indicates the average heat content of U.S. coal exports over the same period. The data is sourced from plant-level coal purchases reported in the EIA-923 survey and the EIA Monthly Energy Review.

Table A.11: Coal Quality and Municipal Offering Yields

	Dependent Variable					
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-7.617***			-7.500***		
	(1.75)			(1.85)		
CoalLabor×HighQualityCoal	-0.236			2.845		
	(2.01)			(3.14)		
CoalLaborHours		-6.925***			-6.808***	
		(1.45)			(1.61)	
CoalLaborHours ×HighQualityCoal		0.484			2.149	
		(2.14)			(2.91)	
CoalProduction			-6.566***			-6.980***
			(1.98)			(1.89)
CoalProduction×HighQualityCoal			0.391			3.731
			(3.37)			(2.73)
HighQualityCoal	0.657	0.086	0.763	0.899	1.038	2.120
	(6.82)	(6.68)	(6.80)	(2.72)	(2.67)	(2.35)
Bond controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,990	17,990	17,990	17,990	17,990	17,990
Municipalities	181	181	181	181	181	181
R^2	.9622	.9622	.9622	.9623	.9622	.9622

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. The coal mining activity measures are interacted with an indicator variable (HighQualityCoal). In Columns 1 through 3, the high-quality coal indicator variable is based on coal heat content data reported by power plants, with (HighQualityCoal) equaling one if a county's coal heat content is above the average heat content of U.S. coal used for exports. In Columns 4 through 6, the high-quality coal indicator variable is based on the county's location in a metallurgical coal region, with (HighQualityCoal) equaling one if the county is in Alabama, Arkansas, Pennsylvania, Virginia, or West Virginia, and has missing heat content data. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature of the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.12: Renewables Potential given Low Fracking Potential and Municipal Offering Yields

	Panel A: Wind Potential			Panel B: Solar Potential		
	Dependent Variable			Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor × LowOpportunities	-9.330***			-8.439***		
	(2.77)			(2.37)		
CoalLabor × HighOpportunities	2.869			-1.936		
	(6.56)			(7.05)		
CoalLaborHours × LowPotential		-8.866***			-8.025***	
		(2.18)			(1.94)	
CoalLaborHours × HighPotential		2.398			1.286	
		(6.79)			(6.32)	
CoalProduction × LowPotential			-10.152***			-8.265***
			(2.13)			(2.34)
CoalProduction × HighPotential			0.137			-5.374
			(6.01)			(4.00)
Bond Controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,096	14,096	14,096	14,096	14,096	14,096
Municipalities	146	146	146	146	146	146
R^2	.9636	.9636	.9636	.9635	.9635	.9635

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019 and excluding coal counties with high fracking potential. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Panel A (Columns 1-3) presents estimates based on county rankings using wind potential, while Panel B (Columns 4-6) reports estimates based on solar potential. Coal mining activity measures are interacted with indicator variables for counties with high (HighPotential) or low (LowPotential) renewables potential. In Panel A, counties are classified as (HighPotential) if their wind potential is above the median and (LowPotential) if it is below. In Panel B, the same classification into (HighPotential) and (LowPotential) applies but is based on counties' solar potential. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.

Table A.13: Employment Diversification given Low Fracking Potential and Municipal Offering Yields

	Panel A: Pre-Existing Employment Opportunities			Panel B: Acquired Employment Opportunities		
	Dependent Variable			Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor × LowOpportunities	-9.240***			-5.885**		
	(2.71)			(2.29)		
CoalLabor × HighOpportunities	1.034			-14.544		
	(7.50)			(17.65)		
CoalLaborHours × LowOpportunities		-8.851***			-4.993**	
		(2.18)			(2.01)	
CoalLaborHours × HighOpportunities		1.520			-11.845	
		(6.85)			(16.75)	
CoalProduction × LowOpportunities			-9.629***			-5.624*
			(2.07)			(2.98)
CoalProduction × HighOpportunities			-0.811			-9.985
			(6.63)			(6.13)
Bond Controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,096	14,096	14,096	9,031	9,031	9,031
Municipalities	146	146	146	127	127	127
R^2	.9636	.9636	.9636	.9592	.9591	.9591

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (6) between 2004 and 2019 and excluding coal counties with high fracking potential. Coal mining activity measures are standardized to have a mean of 0 and standard deviation of 1. Panel A (Columns 1-3) presents estimates based on county rankings using 2001 Shannon Index scores and captures pre-existing employment opportunities, while Panel B (Columns 4-6) reports estimates based on changes in Shannon Index scores from 2001 to 2011 and captures acquired employment opportunities. Coal mining activity measures are interacted with indicator variables for counties with high (HighOpportunities) or low (LowOpportunities) employment diversity. In Panel A, counties are classified as (HighOpportunities) if their 2001 Shannon Index score is above the median and (LowOpportunities) if it is below. In Panel B, the same classification into (HighOpportunities) and (LowOpportunities) applies but is based on changes in Shannon Index scores between 2001 and 2011. All regressions include the following bond-level controls: Coupon rate, bond maturity, the natural logarithm of bond issuance size, the risk-free rate measured as the maturity-matched AAA-rated municipal bond par yield, indicator variables for the numeric credit rating, indicator variables for the use of proceeds, and an indicator variable for callable bonds. The model also includes controls for the level, slope, and curvature from the municipal bond yield curve on a given bond's issuance day derived from a principal component analysis, as well as coal region-by-year and county fixed effects. Robust standard errors are in parentheses, adjusted for two-way clustering at county and coal region-year levels. *** p<0.01; ** p<0.05; * p<0.1.