Navigating the Low-Carbon Shift: Balancing Municipal Finances with Climate Goals

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Abstract

This paper examines the consequences of transitioning away from carbon-intensive energy sources on the sustainability of municipal finances, using the rise of hydraulic fracturing as a quasi-natural experiment. Analyzing data from coal-producing U.S. counties, we present three key findings. First, declining coal mining activity worsens municipal debt sustainability. Second, investors demand higher bond yields in counties experiencing reduced coal mining. Third, investors view the decline in coal as a long-term structural shift, effectively transforming once-valuable coal reserves into stranded assets. These results inform debates on the transition from fossil fuels and its fiscal implications for local governments dependent on them.

Keywords: Municipal bonds, debt sustainability, coal, hydraulic fracturing, energy transition, climate finance, transition risks, stranded assets

JEL Classifications: G12, G18, G38, Q31, Q41, Q51, Q58

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1 Introduction

A decline in coal production is critical to addressing the perils of climate change. Transitioning away from coal—particularly as a source for electricity generation—is essential for meeting internationally agreed-upon climate targets and mitigating the severe impacts of climate change (Jakob, Steckel, Jotzo, Sovacool, Cornelsen, Chandra, Edenhofer, Holden, Löschel, Nace et al., 2020; International Energy Agency, 2022). While policymakers in the United States and abroad often tout the benefits of transitioning from fossil fuels to low-carbon energy sources, there is limited discussion about the potential costs of this structural shift on local communities and the fiscal health of their governments (Morris, Kaufman, and Doshi, 2021). Quantifying these costs is thus essential for justifying and designing policies that mitigate the burden on municipalities reliant on carbon-intensive industries.

In this paper, we use the economic shock caused by the rise of hydraulic fracturing (fracking) in coal-producing municipalities as a lens to examine the financial repercussions of a transition away from a carbon-intensive energy source. Over the past two decades, fracking has significantly disrupted the coal industry by supplying abundant natural gas and driving down gas prices, making coal considerably less competitive in electricity production. The sharp decline in natural gas prices facilitated, if not ensured, a major transformation of the U.S. energy sector, with natural gas overtaking coal as the primary source for electricity generation. According to the U.S. Energy Information Administration, coal consumption in the electricity sector fell by 60% between 2000 and 2020, while demand for natural gas more than doubled over the same period. Indeed, several studies link this decline in coal demand directly to the rise of fracking.[1]

We exploit this structural shift from coal toward natural gas in electricity generation—driven by an exogenous technological shock and unlikely to be explained solely by shifts in local economic conditions of coal-producing counties—to quantify the effects of transitioning away from carbon-intensive energy production on the fiscal health of coal-producing

[1]See, for example, Brehm (2019); Linn, Muehlenbachs, and Wang (2014); Houser, Bordoff, and Marsters (2017); Cullen and Mansur (2017); Hausman and Kellog (2015).

local governments.[2] To conduct this analysis, we compile a unique and comprehensive dataset detailing counties' coal mining activities and local government finances. Specifically, we construct three measures of coal mining activity—the number of employees in the coal industry, total hours worked in coal mining, and coal production—for each coal-producing county in the U.S. from 2002 to 2019 and combine this data with detailed information on county government finances and offering yields in the municipal bond market. We then leverage the fracking-induced shock in coal-producing communities to identify the effect of declining coal mining activity on municipal debt sustainability and borrowing costs in the primary municipal bond market.

We propose two complementary empirical strategies to identify the effects of coal mining over this period. Our first identification strategy uses year-to-year shifts in coal mining activity. This panel regression approach allows us to isolate the impact of the decline in coal from time-invariant county characteristics and absorb regional time-varying characteristics, whether observed or unobserved, within the same coal-supplying region. The fixed effect regression exploits the exogenous variation in coal mining activity in response to the rise of fracking since the mid-2000s, which can be attributed to changes in demand from electricity producers.

Our second identification strategy relaxes the assumption of exogeneity of coal mining activity by using the time series of coal purchases by power plants at the county level as an instrument for coal production. County-level purchases by power plants are a good instrument because they are not only highly correlated with county-level coal production but are also likely exogenous to a county's economic fundamentals. This is because power plants are often located outside the county, and coal is purchased from more than one county. Moreover, power plants' shift toward natural gas was largely driven by the rise in fracking and the increased competitiveness of natural gas.[3]

Our analysis uncovers three novel findings with significant economic implications. First,

[2] Several papers also leverage the unprecedented decline in coal-fired electricity production to examine its effects on mortality, employment, wages, migration, home ownership, and property values, including Feyrer, Mansur, and Sacerdote (2017); Du and Karolyi (2023); Acemoglu, Aghion, Barrage, and Hemous (2023); Fraenkel, Zivin, and Krumholz (2024); and Blonz, Roth Tran, and Troland (2023).

[3] A similar instrument is proposed and used as a regressor in Blonz et al. (2023) to study the financial health of consumers in coal-producing counties. Similarly, Kraynak (2022) uses data on large coal-fired power plants' coal purchases to construct a demand instrument to study the effects on local employment.

a decline in coal mining activity significantly strains municipal debt sustainability in coal-producing counties. We estimate that an annual decline of 200 coal workers—roughly equivalent to moving from the median to the 25th percentile of the distribution—is, on average, associated with a nearly 10% annual increase in local government debt, a 7% increase in the debt-to-revenue ratio, and a 1 percentage point increase in interest payments as a share of revenue. These effects persist across other measures of coal mining activity, such as total worker hours and coal production, reinforcing the robustness of our results. In addition, we show that coal counties' exposure to U.S. natural gas production intensifies this negative relationship, with the adverse impact appearing nonlinear and extending even to counties moderately exposed to natural gas production.

Second, we find that a decline in coal mining activity raises borrowing costs in the primary municipal bond market, consistent with heightened repayment risks for local governments facing eroding coal-related tax revenues. We estimate that a 200-worker annual decline increases municipal bond offering yields by 3 basis points, while a one standard deviation decrease in coal mining activity raises yields by as much as 6 basis points. Given the distribution of municipal offering yields relative to the risk-free rate in our sample, these estimates imply an economically meaningful increase in borrowing costs of 13% to 19%. Moreover, while this increased repayment risk partly stems from the loss of coal-related revenues and obsolete infrastructure, investors likely anticipate a broader economic downturn that could affect multiple sectors beyond coal in impacted communities. For example, our effects cannot be fully explained by regional coal prices or time-varying state trends such as severance taxes that capture direct effects on revenues from the coal mining industry. Our findings that municipal bond investors demand a premium in counties experiencing a significant decline in coal mining also remain robust across a wide range of variables that control for bond characteristics, coal quality differences, and sample periods.

Third, to interpret the documented effects, we try to distinguish between two perspectives investors in municipal bond markets might hold regarding the decline in coal mining: a temporary setback from which coal-dependent economies will eventually recover, or a long-term structural shift that renders once-valuable coal reserves into stranded assets. By examining bonds of varying maturities, we assess whether the decline is seen as a short-term disruption or a lasting shift. Our results strongly suggest that investors view it as a long-term structural shift: the effects on long-term bond yields are three times larger and more significant than those on short-term yields. Additionally, using forward-looking projections of coal production, we find that municipal bond yields are sensitive to long-term forecast errors, while short-term errors have little impact. Overall, our evidence suggests that investors price the decline in coal and associated transition risks as a protracted and broad shock, reflected in higher borrowing costs to compensate for the increased long-term repayment risks facing coal communities.

This paper makes several contributions. Our work relates to the emerging literature on climate-related risks in the U.S. municipal bond market. Thus far, much of this literature has focused on physical climate risks. For instance, Painter (2020) and Goldsmith-Pinkham, Gustafson, Lewis, and Schwert (2023) show that municipal bond borrowing costs rise with increased exposure to sea level rise. Auh, Choi, Deryugina, and Park (2022) show that municipal bond yields increase around extreme weather events. And in a recent paper on renewable energy, Cornaggia and Iliev (2024) show that communities with higher wind potential experience lower bond yields and higher credit ratings. We contribute to this literature by focusing on transition risks. By examining the sharp decline in coal demand and its impact on municipal debt sustainability and offering yields, we demonstrate that coal-related tax revenues can become stranded, thereby clarifying the economic mechanism linking the fiscal health and borrowing costs of coal-producing municipalities. This provides valuable insights into the financial challenges local governments may face as they transition away from carbon-intensive energy sources, a process that mirrors the broader global commitment to reducing reliance on fossil fuels.[4] Furthermore, our findings highlight that uncertainties around coal's decline and the valuation of coal reserves significantly influence the value of municipal debt in coal-reliant counties, offering a fresh perspective on the pricing of transition risks in municipal bonds.

We also contribute to the literature exploring how climate transition risks affect financial markets more broadly. The risks associated with transitioning to a low-carbon econ-

[4]See, for example, "*In a First, Nations at Climate Summit Agree to Move Away From Fossil Fuels*," by B. Plumer and M. Bearak in *The New York Times*, December 13, 2023.

omy have been shown to impact high-emitting firms' market value (Matsumura, Prakash, and Vera-Muñoz, 2014; Bolton and Kacperczyk, 2021; Sautner, Van Lent, Vilkov, and Zhang, 2023). For example, Bolton and Kacperczyk (2023) show that firms with higher emissions offer higher stock returns, resulting in a carbon risk premium, particularly in energy-dependent countries. Ilhan, Sautner, and Vilkov (2021) find that investors pay to hedge against downside risks in carbon-intensive firms. Additionally, studies like Barnett (2019), Sen and Von Schickfus (2020), Ramelli, Wagner, Zeckhauser, and Ziegler (2021), and Ochoa, Paustian, and Wilcox (2022) show that equity returns react to climate policy news, with the largest impact on firms most exposed to climate policy risks.[5] While much of this literature focuses on corporations and their equity prices, we provide evidence that coal-reliant municipalities in the primary municipal bond market are also affected by transition risks. Moreover, our analysis of municipal finances reveals broader spillovers on local economies, which firm-level studies of transition risks often fail to capture.

Moreover, our findings are especially relevant for communities currently reliant on fossil fuels that face the risk of risk having these resources become stranded assets. Numerous local economies possess vast fossil fuel reserves. As climate policies are implemented and green technologies become more affordable, more local governments will face the repercussions of having stranded fossil fuel reserves. Our evidence suggests that this transition may lead to deteriorating debt sustainability and higher borrowing costs for fossil-fuel-rich municipalities, deepening our understanding of the link between stranded assets and public finances. In related research on corporations, Delis, Greiff, Iosifidi, and Ongena (2024) find that banks charge higher loan rates to firms with larger fossil fuel reserves, while Atanasova and Schwartz (2019) show that oil producers lose market value as their oil reserves grow.

Our analysis also contributes to the literature examining the effects of transitioning away from fossil-intensive energy sources on local economies, whether driven by climate

[5]Similarly, Pankratz, Bauer, and Derwall (2023) and Addoum, Ng, and Ortiz-Bobea (2023) find that extreme temperatures negatively affect firm performance. Acharya, Johnson, Sundaresan, and Tomunen (2022) shows that exposure to heat stress is associated with higher yield spreads for corporate bonds and Bansal, Kiku, and Ochoa (2019) demonstrate that rising temperatures reduce firm valuations. Natural disaster effects on asset prices are explored, for example, in Kruttli, Roth Tran, and Watugala (2023), Correa, He, Herpfer, and Lel (2022), and Bernstein, Gustafson, and Lewis (2019). For a comprehensive review of the effects of climate events and rising temperatures on asset prices, see Giglio, Kelly, and Stroebel (2021).

policies or technological advances. Prior research has primarily focused on estimating the coal transition's impact on labor markets, household finances, and housing markets (see, for example, Du and Karolyi, 2023; Blonz et al., 2023; Fraenkel et al., 2024; Kraynak, 2022; Betz, Partridge, Farren, and Lobao, 2015a). Our study provides novel empirical evidence of the decline in coal on local governments' debt sustainability. More importantly, we demonstrate that municipal bond investors view the transition away from coal over the past two decades as a protracted structural shock, a perspective that previous studies of short-term coal production fluctuations have not fully captured (see, for example, Black, McKinnish, and Sanders, 2005; Betz, Partridge, Farren, and Lobao, 2015b).

More broadly, our paper also contributes to the empirical literature quantifying the local effects of large, persistent economic shocks. Several studies have examined the impact of increased imports from China to the United States, commonly referred to as the "China trade shock." For example, these studies have explored its impact on wages and employment (Autor, Dorn, and Hanson, 2013, 2021), local public finances and the provision of public goods (Feler and Senses, 2017), as well as health outcomes (Pierce and Schott, 2020). Similarly, a growing body of research investigates the effects of fracking on local labor markets (Feyrer et al., 2017; Bartik, Currie, Greenstone, and Knittel, 2019), local credit supply (Gilje, 2019), as well as firm values (Gilje and Taillard, 2017; Gilje, Ready, and Roussanov, 2016). We contribute to this work by documenting the realized and anticipated effects of a large shock to the U.S. energy landscape on public finances and municipal borrowing costs in coal-dependent communities. Our insights are particularly timely, as the experiences of these local coal communities offer valuable lessons for the potential fiscal repercussions of transitioning to renewable energy sources.

Finally, our findings contribute to debates on the link between climate change and government finances. While much of the literature has focused on rising temperatures (Klusak, Agarwala, Burke, Kraemer, and Mohaddes, 2023) or climate policies (Barrage, 2020, 2024; Seghini and Dees, 2024) within theoretical models, our study offers new empirical insights into the fiscal costs of transition risks. Specifically, we show that the shift to low-carbon energy sources weakens the fiscal health of local governments reliant on fossil fuel resources. This deterioration may prompt state or federal interventions to support local economies, highlighting how our results inform the broader discussion on government finances.

The remaining sections of the paper are organized as follows. Section 2 provides a brief background on the U.S. energy transition and the decline of coal in the context of advancements in gas extraction technologies. Section 3 outlines our datasets and variable construction. Sections 4 and 5 present our empirical results on the effects of the coal decline on municipal finances and bond offering yields, respectively. Finally, Section 6 discusses the broader implications of our findings and concludes the paper.

2 Background on the U.S. Energy Transition 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, as reported by the U.S. Energy Information Administration (EIA). However, electricity generation in the United States has undergone significant changes since the early 2000s. As depicted 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. This decline has drastically reduced the share of electricity generated by coal-fired generators to just under 20% by 2020 (see Figure 2).[6]

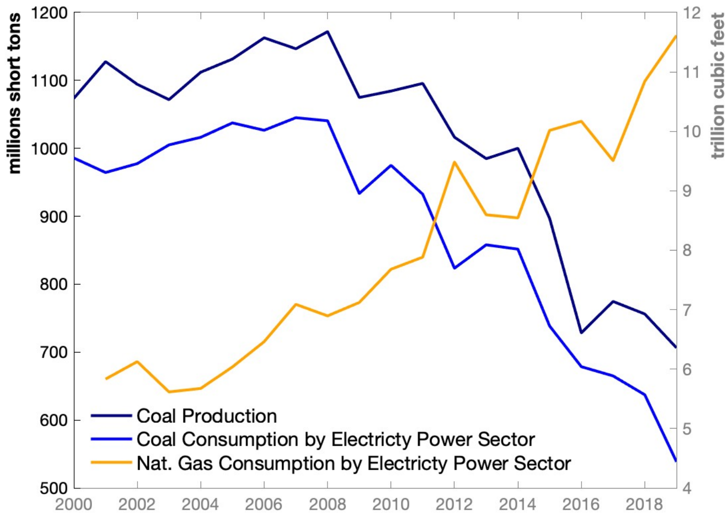
The decline in coal production is directly linked to a shift in electricity generation from coal to natural gas and, to a lesser extent, renewable energy sources—as persuasively documented by a growing body of literature.[7] A significant drop in natural gas prices, primarily attributed to advancements in extraction technologies like hydraulic fracking, increased the share of natural gas as an energy source for electricity generation, climbing from 16% in 2000 to 41% by 2020 (see Figure 2).[8] Consequently, natural gas has emerged as the primary

[6] This reduction in coal demand from electricity producers is not driven by a decline in electricity production. In fact, U.S. electricity production grew 5.5% between 2000 and 2020.

[7] See, for example, Brehm (2019); Linn et al. (2014); Houser et al. (2017); Cullen and Mansur (2017); Hausman and Kellog (2015).

[8] Several factors contributed to the rapid expansion of hydraulic fracking in the United States including: High global energy prices; domestic investment in shale gas production to achieve energy independence; and

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.

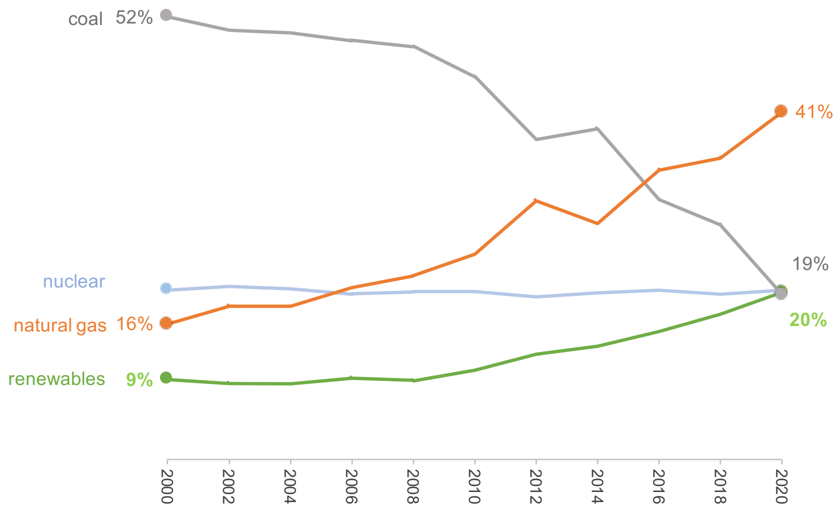
energy source for electricity generation. In recent years, the rise in renewable energy—propelled by state-level renewable portfolio standards, federal production, investment tax credits, and technological advancements—has further contributed to the decline in coal production. Houser et al. (2017), for example, estimate that about two-thirds of the decline in coal production over this period can be attributed to inexpensive natural gas and the expansion of renewable energy, with environmental regulations playing only a minor role.[9]

Still, amid the rapid growth in fracking, the decline of the U.S. coal industry appears to have been unexpectedly swift. Figure 3 illustrates actual coal production alongside the EIA's projections for coal production over the next five years, data we compile from selected issues of the EIA's Annual Energy Outlook. These forecasts are generated using the National Energy Modeling System, a sophisticated model of the economy and energy markets that

exemptions from specific U.S. Environmental Protection Agency (EPA) regulations (that is, the "Halliburton Loophole" in the Energy Policy Act of 2005).

[9]See also, Brehm (2019), Fell and Kaffine (2018), Knittel, Metaxoglou, and Trindade (2015), and Linn and McCormack (2019) for the significance of lower natural 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 on the transition to renewable energy.

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



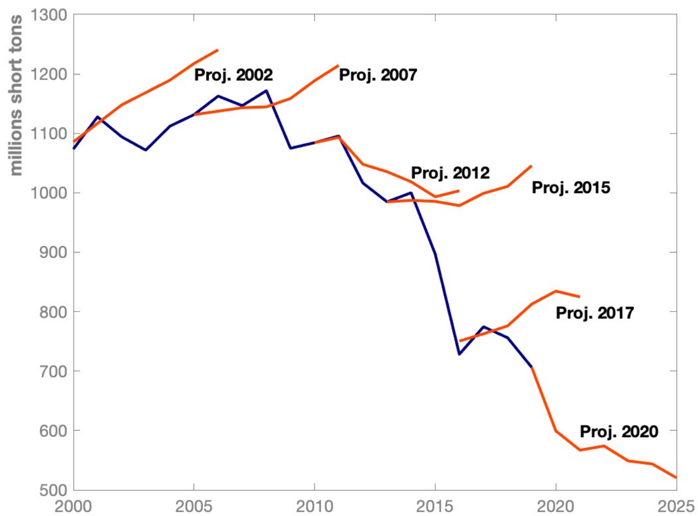
This figure plots the share of coal, natural gas, nuclear power, and renewable energy used to produce electricity since 2000. This annual data comes from the U.S. EIA 2023b.

considers the interplay between various energy sectors like coal, electricity, natural gas, and renewables. Before 2020, as depicted in Figure 3, the EIA's coal forecasts were consistently optimistic, indicating a slight increase in coal production and thus failing to anticipate the swift transition from coal to natural gas. Recent projections, however, suggest an irreversible decline in coal production as natural gas and renewable energy sources are likely to displace coal in the United States. In the most recent Annual Energy Outlook 2023a, U.S. coal-fired power generation capacity is projected to decline to less than half of its 2022 levels by 2050, resulting in coal's share of U.S. electricity generation plummeting to 5%.

We exploit this nearly two-decade-long structural shift from coal toward natural gas in electricity generation as a lens to examine the impact of transitioning away from carbon-intensive energy production on the fiscal sustainability of coal-producing local governments.[10] This shift, driven by an exogenous technological shock and unlikely to be explained solely by changes in local economic conditions of coal-producing counties, is ideally

[10]Coal's decline differs from the U.S. manufacturing downturn. The latter was driven by globalization, the NAFTA trade agreement, and China's WTO entry, which shifted production overseas. In contrast, the decline of coal was spurred by advancements in natural gas extraction in the United States, favoring fracking over coal mining. While manufacturing saw job losses from offshoring and automation, coal's decline resulted from cheaper, cleaner natural gas replacing it. Moreover, manufacturing's shift was gradual, whereas coal's transition was unexpectedly swift, driven by the rise of natural gas and renewables.

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.

suited to parse out the effects of the decline in coal on coal-producing municipal finances.

3 Data Sources and Descriptive Statistics

We assemble a unique and comprehensive dataset that combines information on production and employment in coal mining, coal demand from U.S. coal-fired power plants, and municipal finances and financing in bond markets of all coal-producing counties in the United States 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 were made available in 2008, determining the start date of our sample for coal demand.

Data on projections of U.S. coal production are sourced from different 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. Each coal-supplying region shares similar coal quality and mining methods, so the coal supply within each region is likely to react similarly to economic shocks. This dataset allows us to augment the realized coal production data with forward-looking projections, providing novel insights into how changes in expectations for coal production may have affected coal regions.

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, and revenues from taxes from 2002 to 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-producing local government fi-

[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.

nances over time, especially concerning shifts in revenue streams and debt burdens.

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.

3.3 Municipal Bond Data

We retrieve data on municipal bond offerings from 2004 through the end of 2019 from the Mergent Municipal Bond Securities Database (MBSD). The MBSD data provide comprehensive bond-level characteristics, encompassing 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 (where AAA=1, AA+=2, ...). 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 our sample to uninsured bonds,[12] tax-exempt revenue or general obligations (GO) bonds with fixed or zero coupons, and an active investment-grade bond rating at the time of issuance.[13] We further restrict our sample to only bonds (or serial bonds) with total offering amounts exceeding one million U.S. dollars, semi-annual coupon payments, and 30/360 day-count conventions. Finally, we exclude bonds with less than a year until maturity or with a maturity above 30 years because yields tend to be especially noisy for bonds with very short or long maturities.[14] After applying these filters, our sample consists of 17,990 individual municipal bonds that are part of 1,943 serial bonds issued by 797 municipal entities, indicating that each issuer, on average, 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]Bonds with insurances do not adequately reflect the issuer-specific credit risk we want to study in our analysis of yields.

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

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

(Goldsmith-Pinkham et al., 2023). We also use the daily term structure municipal yield curve to construct the level, slope, and curvature 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 the county location information, we link bond offerings data to coal mining activity data of 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 the high complexity of state governments and the difficulty in appropriately linking them with the coal mining activity of local governments.

3.4 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 around 450 coal miners, with considerable variation between counties as the standard deviation equals around 600 workers. The typical county reports close to 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 75$^{\text{th}}$ percentile and 25$^{\text{th}}$ percentile of the distribution is 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 lower 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

[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 (2×2Y - 10Y - 0.5Y) produces qualitatively and quantitatively similar results.

shade of blue. Figure 5 shows a similar map for coal production. As shown in these maps, the distribution of coal employment and coal production has shifted toward lower values, and coal mining has even ceased to exist in many counties, as is evident by the switch of many counties to a "no data" tile. 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 log of the debt-to-revenue ratio is slightly smaller than that of the level of debt, with the spread between the 75th percentile and the 25th 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%—almost 0.4% 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. First, we outline two empirical approaches to gauge the effect: a two-way fixed-effects regression and an IV method. Then, we present and discuss the resulting estimates.

4.1 Empirical Strategy

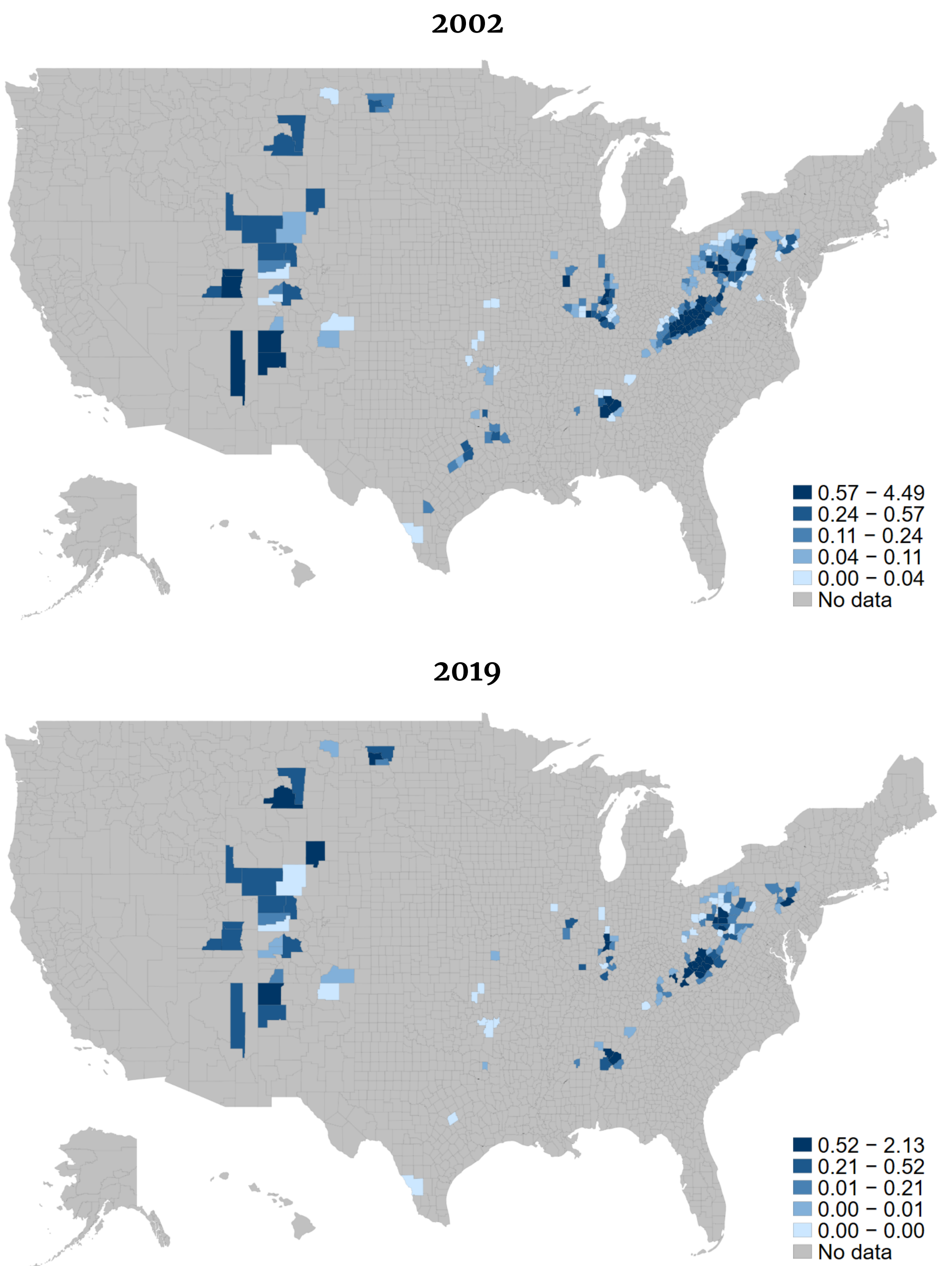
One important empirical challenge in identifying the consequences of the decline in coal mining for local municipal governments is the potential for omitted variable bias. This bias arises from the correlation between coal mining and other local economic factors that also influence municipal finances. For example, communities with higher land values or

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

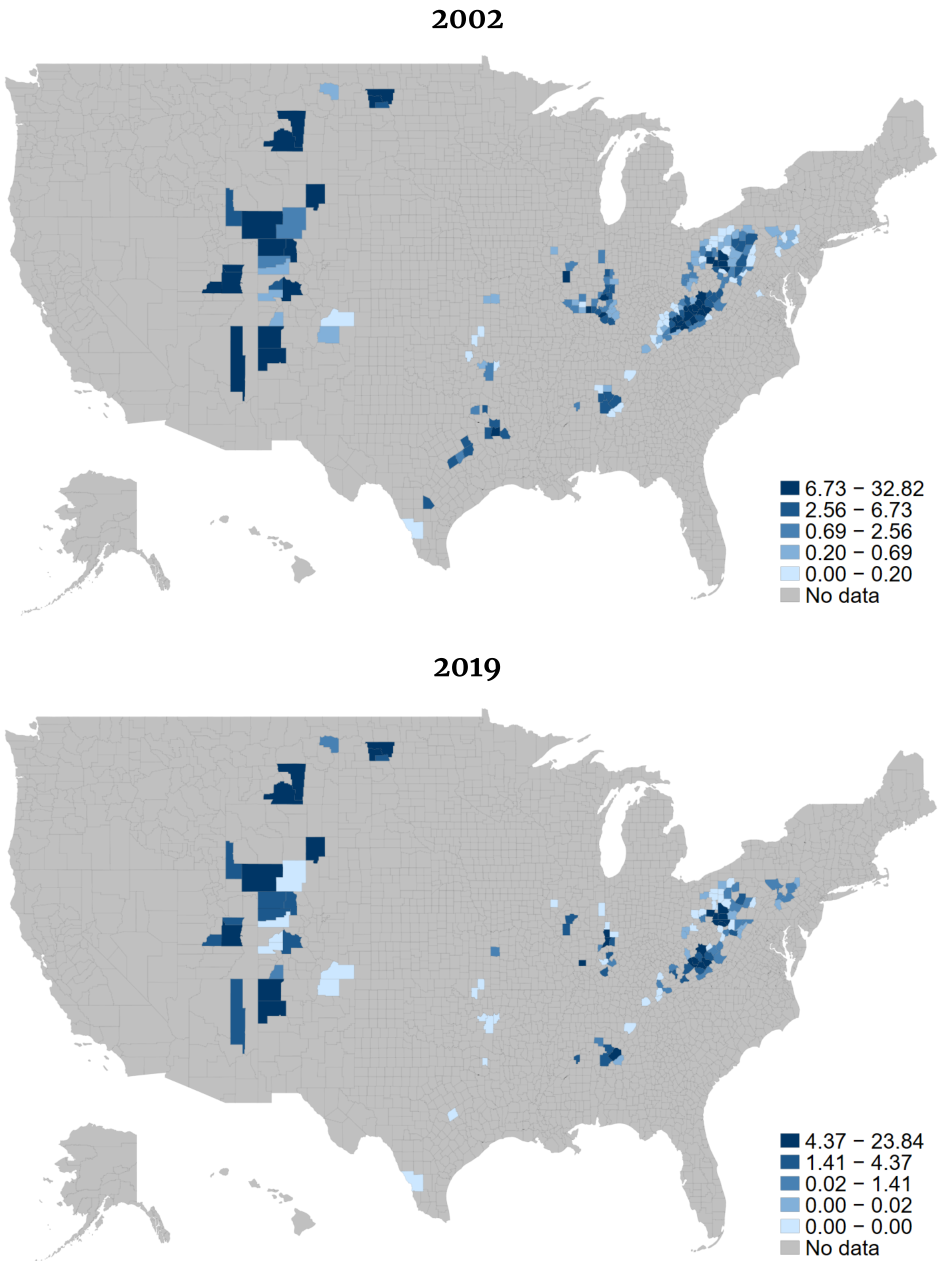
Panel A reports summary statistics of county-level coal mining activity measured by three proxy variables: *CoalLabor*, the number of employees in the coal industry; *CoalLaborHours*, representing total hours worked in coal mining; and *CoalProduction*, the total coal production. Panel A also presents 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



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



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.

tighter labor markets may be more likely to experience mine closures. To mitigate this concern, we exploit the shock induced by the rise of hydraulic fracking in coal-producing communities. Our identification strategy relies on the premise that a considerable portion of the variation in coal mining activity amid the rise 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 hydraulic 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):

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

The key covariate of interest is $C_{i,t-1}$, 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 (1) 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. The vector $\mathbf{Z}_{i,t}$ includes the natural logarithm of the population to control for differences in size across counties.[16] 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 pur-

[16]Adding variables that are an outcome of coal mining activity, $C_{i,t-1}$, will not produce an estimate that is close to the true β, as may well be the case for local economic fundamentals such as GDP or employment, which are likely affected by coal mining. To avoid over-controlling, we rely on variables that are more likely to be exogenously determined, such as population.

chased 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 (1) may not fully capture local economic fundamentals that correlate with both declining coal mining and municipal financing. 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 county that provides the coal and purchase coal from mines located in various counties. Moreover, power plants often serve more than one county. Second, the decline in natural gas prices likely influenced electricity producers' coal purchases, thereby reducing the demand for coal.[17] 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 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:

$$\ln C_{i,t} = \alpha_i + \gamma_i \ln C^d_{i,t} + \varepsilon_{i,t} \tag{2}$$

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:

$$\widehat{C}_{i,t} = \exp\left(\hat{\alpha}_i + \hat{\gamma}_i \ln C^d_{i,t}\right) \tag{3}$$

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. Next, we use these predicted values to instrument for coal production when estimating equation (1). For this exercise, we use data from 2008 to 2019 and only keep counties with at least five years of

[17] Coal-fired power plants can be fitted (as in co-fired power plants) or retrofitted for fuel-switching, 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)).

continuous data on coal demand.[18]

4.2 Empirical Results

4.2.1 Baseline Results

Using Equation (1) 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 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 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 suggest a negative and statistically significant relationship between coal mining activity and municipal debt levels. Column 1, for example, shows that an annual decline in 200 coal miners in a county—roughly equivalent to moving from the median to the 25$^{\text{th}}$ percentile of the distribution—leads to an annual increase in debt levels of around 10%. Similarly, a one-time decline in coal mining hours (Column 2) or coal production (Column 3) that moves a county's coal mining activity from the median to the 25$^{\text{th}}$ percentile of the distribution increases debt levels by 7 to 9%.[19]

While rising debt alone may not signal financial stress, an increase in debt and a deterioration in sustainability indicators point 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 indicators of debt sustainability of municipal governments, with the ratio of debt-to-revenue and the interest payments as a share of revenue increasing with the decline in coal mining

[18] In a regression of coal production on predicted coal production from (3), 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.

[19] The magnitude of the range between the median and the 25$^{\text{th}}$ percentile of the distribution of the coal mining proxy variables is very close to a one standard deviation move after removing county and year fixed effects.

activity. An annual decline in 200 coal miners in a county—equivalent to moving from the median to the 25th percentile of the distribution—is associated with a statistically significant 12% increase in the debt-to-revenue ratio and about 1 percentage point higher interest payments as a share to revenue. The estimates of the other coal mining proxies are very similar: An annual decline of coal production of 1.2 million short tons leads to an increase in the debt-to-revenue ratio of 7% and an increase in interest payments as a share of revenues of 50 basis points.

Our findings highlight a broader narrative: the nearly two-decade-long shift away from coal has left coal-dependent communities grappling with stranded coal reserves, leading to substantial financial losses. This has resulted in rising debt burdens and deteriorating debt sustainability indicators in affected local governments. Our estimates provide empirical support for recent studies documenting a risk premium tied to stranded assets (Atanasova and Schwartz, 2019). More importantly, the challenges these coal-reliant regions face may foreshadow the future for municipal governments dependent on other fossil fuels. As the global energy landscape continues to evolve, the experience of coal communities may serve as a cautionary tale for regions reliant on oil and natural gas reserves.

4.2.2 Heterogeneity Analysis: Exposure to Natural Gas Production

Our underlying identifying assumption is that the rapid growth in fracking since the mid-2000s is a crucial source of variation in U.S. coal mining activity. Next, we examine whether heterogeneity in the exposure of local coal production to increased natural gas production in the United States affects the negative relationship between coal mining activity and municipal debt indicators. For this purpose, we first compute a measure of coal mining exposure to fracking by running a regression of the natural log of county-level coal production on the aggregate demand for natural gas of U.S. electricity producers,

$$\ln C_{i,t} = \alpha_i + \phi_i \, \ln NG_t + \varepsilon_{i,t}, \tag{4}$$

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

Table 2: Municipal Debt and Coal Mining Activity

	Dependent Variable		
	ln Debt		
	(1)	(2)	(3)
CoalLabor	-0.571***		
	(0.13)		
CoalLaborHours		-0.231***	
		(0.06)	
CoalProduction			-0.055***
			(0.02)
County FE	Yes	Yes	Yes
Region $\times$ Year FE	Yes	Yes	Yes
Observations	1884	1884	1884
Municipalities	130	130	130
R^2	0.849	0.849	0.848

This table reports coefficients from regressions of the natural log of municipal debt on measures of coal mining activity using the model in Equation (1). All regressions include coal region-by-year and county fixed effects as well as the natural log 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. 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: Municipal Debt Sustainability and Coal Mining Activity

	Dependent Variable					
	Panel A: $\ln$ Debt/Revenue			Panel B: Interest/Revenue		
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-0.616***			-4.314**		
	(0.14)			(2.07)		
CoalLaborHours		-0.250***			-1.711**	
		(0.06)			(0.86)	
CoalProduction			-0.056***			-0.429
			(0.02)			(0.26)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1884	1884	1884	1767	1767	1767
Municipalities	130	130	130	125	125	125
R^2	0.800	0.799	0.798	0.816	0.815	0.815

This table reports coefficients from regressions of debt sustainability metrics on coal mining activity using the model in Equation (1). The dependent variable in Panel A (Columns 1-3) is the natural log 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 log 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.

county using annual data from 2008 to 2019 and restrict our sample to counties with at least 5 years of post-2008 data. We then divide the counties into quartiles based on their estimates of ϕ_i, which stretch 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—and re-estimate Equation (1) 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 log of debt outstanding, and the panels in Figure 7 plot the same coefficients when the dependent variable is the natural log of the debt-to-revenue ratio.

As shown in Figure 6, the pattern that emerges is clear and consistent across our three coal mining activity metrics. Counties with higher exposure to natural gas production experience a more pronounced increase in municipal debt in response to declining coal mining activity than counties with lower natural gas exposure. Panel A illustrates, for example, that counties with the lowest exposure to natural gas production exhibit a slightly negative relationship, albeit statistically and economically insignificant, between coal mining employment and debt levels. In contrast, counties with the highest exposure to natural gas production exhibit a highly significant negative relationship, with the estimated coefficient increasing nearly threefold from approximately -0.2 to -0.6.

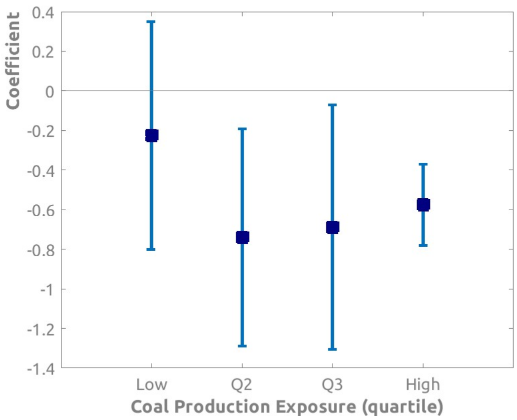
The spread in the estimated coefficients between counties with high and low exposures to natural gas production is also substantial when we use county-level total hours worked in coal mining or coal production as proxy variables for coal mining activity (see Panels B and C of Figure 6). Moreover, our estimates suggest that the adverse effects of declining coal activity extend beyond counties with the highest exposures to natural gas production, as coefficients are also negative and statistically significant for counties in the two middle quartiles.

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. Again, the adverse effects of declining coal activity on local governments are not purely concentrated in counties with the highest exposure to natural gas production but are similarly pronounced in the two middle quartiles. Consistent with our identification assumption, a county's exposure to natural gas production notably determines the effects of coal mining decline on the fiscal sustainability of local governments.

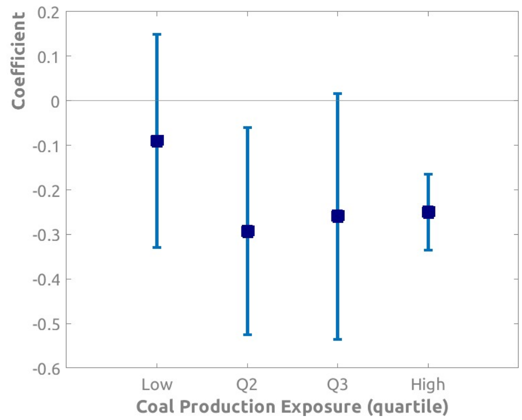
Local economic slack may also amplify the effects of the decline in coal mining on municipal finances. Table 4 reports estimates of Equation (1) in which we interact coal mining employment with an indicator variable that captures the degree of economic slack. Specifically, we construct an indicator variable 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 CoalLabor $\times$ HighSlack and CoalLabor $\times$ LowSlack in our baseline regression. The coefficients on these interaction terms thus capture the effects of coal mining on the municipal finances of counties with high and low economic slack.

Column 1 of Table 4 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. Similarly, Columns 2 and 3 show that deterioration in both indicators of debt sustainability—the debt-to-revenue and interest payments-to-revenue ratios—is equally pronounced in counties with high and low economic slack, as we cannot reject the hypothesis that the coefficients on the interaction terms are different from each other. In the Appendix A, we show that our conclusion about the effects of coal mining being independent of economic slack remains unchanged when we use total hours in coal mining or coal mining production as measures of coal mining activity. Overall, our results suggest that municipal governments with low economic slack have not been immune to the adverse effects of the decline in coal mining.

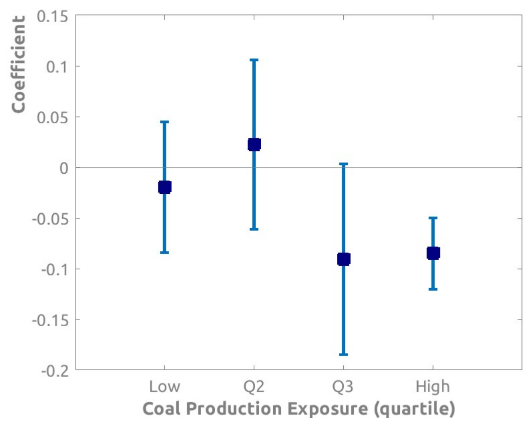
Figure 6: Coal Mining Effects on Debt By Exposure to Natural Gas Production



(A) Response of Municipal Debt to Coal Labor



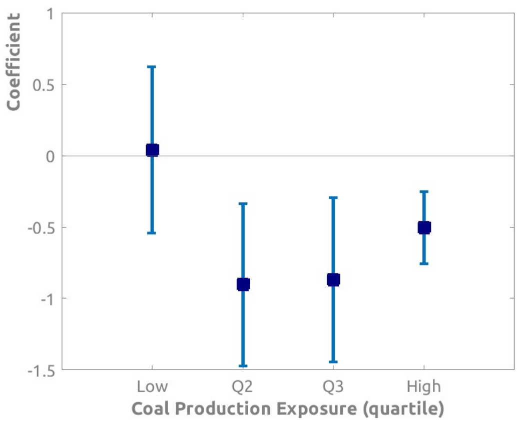
(B) Response of Municipal Debt to Coal Labor Hours



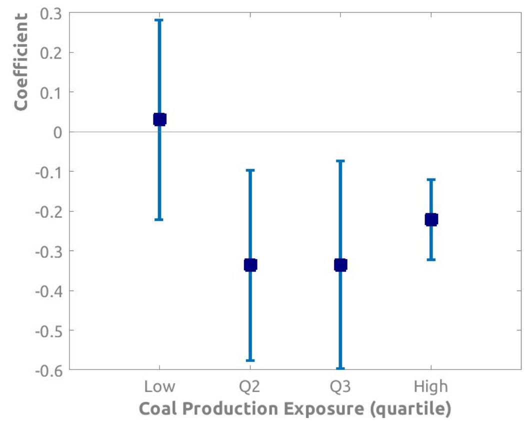
(C) Response of Municipal Debt to Coal Production

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 1 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 4. The dependent variable is the natural log of total debt outstanding. All regressions include coal region-by-year and county fixed effects as well as the natural log of the county-level population. 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.

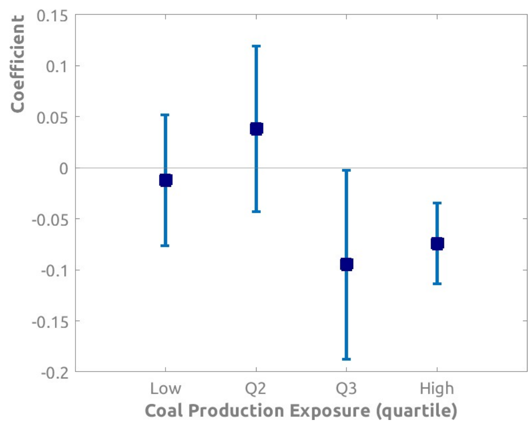
Figure 7: Coal Mining Effects on Debt-to-Revenue By Exposure to Natural Gas Production



(A) Response of Municipal Debt-to-Revenue Ratio to Coal Labor



(B) Response of Municipal Debt-to-Revenue Ratio to Coal Labor Hours



(C) Response of Municipal Debt-to-Revenue 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 1 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 4. The dependent variable is the natural log of the total debt-to-revenue ratio. All regressions include coal region-by-year and county fixed effects as well as the natural log of the county-level population. 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.

Table 4: Effect of Coal Mining on Municipal Finances and The Role of Economic Slack

	Dependent Variable		
	ln Outstanding Debt	ln Debt/Revenue	Interest/Revenue
	(1)	(2)	(3)
CoalLabor $\times$ HighSlack	-0.574***	-0.617***	-4.366**
	(0.13)	(0.14)	(2.10)
CoalLabor $\times$ LowSlack	-0.562***	-0.613***	-4.151**
	(0.14)	(0.14)	(2.05)
County FE	Yes	Yes	Yes
Region $\times$ Year FE	Yes	Yes	Yes
High $-$ Low Slack	-0.012	-0.004	-0.215
	(0.07)	(0.06)	(0.50)
Observations	1884	1884	1767
Municipalities	130	130	125
R^2	0.849	0.800	0.816

This table reports coefficients from regressions of municipal debt indicators on coal mining activity using the model in Equation (1). 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 log 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 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.

4.3 Instrumental Variable Results

Our results present strong empirical evidence indicating 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 unleashed by hydraulic fracking created an exogenous shock to counties' coal mining activity over our sample period. However, declining local economic fundamentals could potentially explain some of the downturn in the coal industry and the deterioration in municipal debt sustainability. If not adequately controlled for by our regional time-varying fixed effects, this could introduce omitted variable bias to our estimates. Since we cannot entirely discount this possibility, as discussed in Section 4.1, we use a second and complementary approach that uses the time-series variation of coal purchases by power plants as an instrument for local coal production.

Table 5 presents the results from estimating Equation (1) with coal production instrumented with coal demand from power plants from 2008 to 2019. All regressions include county fixed effects and year fixed effects, and the error term is assumed to be simultaneously clustered by county and region-year. In Column 1, the dependent variable is the natural log of municipal debt. Columns 2 and 3 present results in which the dependent variable is the natural log of the ratio of debt-to-revenue and the interest payments as a share of revenues, respectively. Table 5 shows that the effect of coal mining remains negative, with statistically significant estimates, even as our sample period is shorter. While the IV estimates are smaller than those from the two-way fixed effects model, they remain economically significant and demonstrate that declining coal production adversely impacts debt levels and sustainability indicators. Overall, we conclude that the decline in coal production resulted in significant increases in municipal debt and a deterioration of municipal debt sustainability indicators, especially in counties experiencing substantial decreases in the demand for coal from electricity producers. Again, these findings are consistent with the notion of stranded assets, where dwindling demand for coal reduces coal-related revenues and heightens financial strain on local governments.

Table 5: Instrumental Variable Estimates of the Effect of Coal Production

	Dependent Variable		
	$\ln$ Outstanding Debt	$\ln$ Debt/Revenue	Interest/Revenue
	(1)	(2)	(3)
CoalProduction	-0.021*	-0.027**	-0.198*
	(0.01)	(0.01)	(0.10)
County FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	1187	1187	1107
Municipalities	128	128	124
R^2	0.868	0.813	0.821

This table reports the effect of coal production on municipal debt indicators from estimating equation (1) 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 (1) as an instrument for coal production. The dependent variable in Column 1 is the natural log of the municipal debt-to-revenues ratio. Columns 2 and 3 present results for the natural log 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 log 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.

4.4 Robustness

This subsection summarizes additional robustness tests of our results on municipal finances, considering alternative measures of municipal debt sustainability, various methods for controlling local economic shocks, and different 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 very 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 remain substantial and statistically significant, with only a slight reduction in magnitude compared to our baseline specification. Finally, we also show that there are no significant differences in the effects of coal mining before and after 2007, the onset of the global financial crisis (GFC). The estimates are similar in magnitude and statistically significant for both sub-periods.

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

Our results thus far demonstrate that a decline in coal mining activity leads to an increase in municipal debt and a deterioration of debt sustainability indicators. While our evidence strongly supports the notion that the transition away from coal has weakened municipal debt sustainability, a key question in the ongoing debate about the effects of a future transition away from fossil fuels is whether investors incorporate the risks of this transition into municipal bond yields—and, if so, how significant these premiums are. This section examines whether municipal bond investors price shifts in coal mining activity into bond offering yields during a period when U.S. electricity generation significantly shifted from coal to natural gas.

5.1 Empirical Strategy

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

$$Y_{b,i,t} = \beta\ \mathbf{C}_{i,t-1} + \theta'\ \mathbf{Z}_{b,i,t} + \delta'\mathbf{X}_t + \theta_{r,t} + \mu_i + \varepsilon_{b,i,t}, \tag{5}$$

where the dependent variable, $Y_{b,i,t}$, is the offering yield on bond b of county i in year-month t. The key independent variable, $C_{i,t-1}$, represents the level of coal mining activity in county i during the previous year, $t-1$. The coefficient of interest, β, reflects the average change in offering yields associated with variations in coal mining activity. As in Section 4.1, we use 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). Equation 5 also includes coal region-by-year fixed effects, $\theta_{r,t}$, and county fixed effects, μ_i, to absorb any fixed or regional time-varying observed and unobserved characteristics.

The vector $\mathbf{Z}_{b,i,t}$ includes common bond characteristics 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 log 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, the vector $\mathbf{X}_t$ 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.[20] 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.

[20] More precisely, we extract these measures from a principal component analysis and construct them for a given issuance day. Using empirical measures of the level (10Y), slope (10Y - 2Y), and curvature (2×2Y - 10Y - 0.5Y) produces qualitatively and quantitatively similar results.

5.2 Empirical Results

5.2.1 Baseline Results on Offering Yields

Table 6 presents the estimated coefficients on our three proxy variables for county-level coal mining activity: the number of employees in the coal industry (CoalLabor), the total hours worked in coal mining (CoalLaborHours), and coal production (CoalProduction).[21] The estimated coefficients suggest that declining coal mining activity leads to a statistically significant increase in municipal bond offering yields. In Column 1, we find that an annual decline of 200 coal miners in a county—roughly equivalent to moving from the median to the 25$^{\text{th}}$ percentile of the distribution—increases municipal bond yields by around 3 basis points on average. Despite varying magnitudes, the estimated coefficients in Columns 2 and 3 imply that municipal bond yields experience a similar increase in response to decreases in both coal mining hours (Column 2) and coal production (Column 3). The similarity in effect sizes becomes clearer in Columns 4 through 6, where we run the same regressions using standardized coal activity measures. Importantly, based on 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 the cost of financing of 13% relative to the average offering spread. Shifting from the median to the 25$^{\text{th}}$ percentile of coal mining activity provides conservative economic magnitudes. Considering a one standard deviation decrease in coal mining activity, our estimates indicate a more pronounced effect: municipal bond offering yields increase by an average of 7 basis points, accounting for approximately 19% of the average offering spread. Arguably, 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 coal activity measures capture their full association with offering yields.[22] In Column 4 of Table 16 in Appendix B, where rating controls

[21]For brevity, we do not report estimates for the control variables. Table 16 in Appendix B shows that the coefficients on the control variables display the expected theoretical and typical empirical relationships with offering yields. In addition, the coefficient estimates for the measures of coal activity remain fairly stable as we systematically introduce the control variables.

[22]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 5 and still find a significant negative relationship between coal mining activity and bond yields. This underscores the broader

are excluded, the coefficient estimates increase slightly, indicating 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.

What's more, the increase in the cost of municipal bond issuance is not limited to offering yields. As shown in Table 17 in Appendix B, underwriter discount costs (that is, gross spreads) also rise significantly, with estimates indicating an economically meaningful cost increase of approximately 6% relative to the average discount for a one standard deviation reduction in coal activity. This further underscores the financial strain on coal-dependent municipal issuers.

Taken together, the deterioration of municipal debt sustainability indicators and the increase in municipal bond financing costs suggest that the shift away from coal has increased the financial risk for coal-dependent municipal governments. A plausible economic mechanism for these findings is that investors perceived municipal coal resources as being at risk of becoming stranded assets due to the rapid rise of fracking, anticipating declines in current and future tax revenues from the coal industry. Additionally, investors may have anticipated broader adverse effects on economic activity in affected communities, expecting lower tax revenues from sources beyond coal. These concerns likely exacerbated the financial strain on municipalities, increasing their perceived credit risk and borrowing costs. Next, we examine whether the direct fiscal effects of the decline in coal mining fully account for our findings.

One direct channel through which financial strains might manifest in coal-dependent communities is a reduction in severance taxes. These taxes are imposed on the extraction or production of coal and are typically collected at the state level, with the revenue often allocated to support local communities. To account for changes in severance tax revenue streams, we use two proxies: First, we include state-by-year fixed effects, as severance tax rates can vary significantly from state to state, with state governments periodically adjusting rates based on fiscal needs, economic conditions, and political considerations. Second, we consider regional coal prices, which are closely tied to the amount of severance tax revenue. When commodity prices rise, severance tax revenues generally increase, and vice

economic impact of declining coal activity on municipal financial health.

Table 6: Municipal Offering Yields and Coal Mining Activity

	Dependent Variable					
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-13.255***					
	(3.21)					
CoalLaborHours		-5.348***				
		(1.20)				
CoalProduction			-1.742***			
			(0.53)			
CoalLabor(Std.)				-6.423***		
				(1.36)		
CoalLaborHours(Std.)					-5.673***	
					(1.14)	
CoalProduction(Std.)						-6.580***
						(1.76)
Bond controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region $\times$ 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	.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 (5) between 2004 and 2019. In Columns 1 through 3, coal mining activity measures are in native units, while in Columns 4 through 6 the 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 log 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.

versa.

Columns 1 through 3 present the results for the specification that includes state-by-year fixed effects as a proxy for severance taxes. While the estimated coefficients on the three coal mining variables are somewhat smaller than those in our baseline specification in Table 6, they remain highly statistically and economically significant. Similarly, the estimates using coal prices as an alternative proxy for severance taxes, shown in Columns 4 through 6, tell the same story—coal mining activity variables remain negative and statistically significant, though slightly smaller in magnitude. Notably, the coefficient on regional coal prices is negative and statistically significant, suggesting that lower coal prices are linked to reduced severance tax revenues and, consequently, to a deterioration in a county's ability to repay debt, thus raising offering yields. Overall, our evidence suggests that the negative effect of coal mining cannot be fully explained by severance taxes, indicating that the risks from stranded assets likely extend to the broader local economy.

5.2.2 Coal as a Long-Term Risk

Our findings confirm that declining coal mining activity increases municipal offering yields, reflecting the heightened financial risks stemming from economic downturns in coal-dependent communities. However, a key question remains: Do investors view this decline as a temporary setback or a lasting trend? This section examines whether investors perceive the decline in coal as a short-term disruption or a long-term structural shift. If investors perceive the fluctuations in coal mining as temporary, one would expect that coal mining activity affects short-term bonds' offering yields more than long-term bonds. On the other hand, if investors perceive the decline in coal as persistent, we anticipate a more pronounced impact on yields of long-term bonds compared to short-term bonds. To test this hypothesis, we divide our sample into two sub-groups: one containing bonds with maturities equal to or below 5 years and another containing bonds with maturities exceeding 5 years.

Panel A of Table 8 reports the coefficient estimates of coal mining activity on short-term bonds, while Panel B presents the corresponding estimates for long-term bonds. The results suggest that the decline in coal mining has a more substantial impact on the yields

Table 7: Effects of Coal Mining Activity and the Role of Coal Severance Taxes

	Dependent Variable					
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-7.345**			-10.312***		
	(3.15)			(2.81)		
CoalLaborHours		-2.569**			-4.057***	
		(1.09)			(1.22)	
CoalProduction			-1.374***			-1.372***
			(0.50)			(0.50)
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 $\times$ Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State $\times$ 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 (5) between 2004 and 2019. In Columns 1 through 3, we add state-by-year fixed effects to Equation (5), 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 log 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.

of long-term bonds compared to short-term bonds. While a decline in coal mining activity has a statistically insignificant effect on municipal bond yields of short-term bonds, long-term bonds experience an economically larger and statistically significant effect from a decline in coal mining. For example, as shown in Column 1 of Panels A and B, a one standard deviation annual decline in coal production (after removing fixed effects) leads to an increase in the offering yield of approximately 4 basis points for long-term bonds. In contrast, the coefficient estimate for short-term bonds suggests a mere 1 basis point increase. The significantly larger effects on long-term bonds suggest that investors perceive the decline in coal during our sample period as a persistent negative shock to coal-dependent communities.

To gain further insight into whether investors price short-term or long-term risks, we examine whether the information in forward-looking forecasts at short or long horizons can explain the relationship between coal mining and municipal bond yields. Short-term forecasts provide information more closely tied to immediate market fluctuations. In contrast, long-term forecasts capture the potential risks associated with a sustained decline in the coal industry.

To obtain forward-looking forecasts of coal production at the county level, we gather coal production projections for various time horizons from the EIA at the coal supply region level. These projections are publicly available and published annually in the EIA's Annual Energy Outlook. It is 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 market analyses and investment strategies. They may also use this information to assess the potential impact of energy policies, market developments, and technological advancements on their business models and investment portfolios.

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

$$C_{i,t+\tau} = \alpha_i + \rho_i \, C^e_{t|r,t+\tau} + \varepsilon_{i,t+\tau} \tag{6}$$

Table 8: Effects of Coal Mining on Offering Yields of Short-Term and 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	-5.124			-17.810***		
	(3.18)			(3.70)		
CoalLaborHours		-2.198			-7.018***	
		(1.60)			(1.22)	
CoalProduction			-0.816			-2.373***
			(0.63)			(0.57)
Bond Controls	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Region $\times$ 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 (5) between 2004 and 2019. 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 log 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.

where $C_{i,t+\tau}$ is coal production of county i in year $t+\tau$, and $C^{e}_{t|i,t+\tau}$ is the projection of coal production in region r from the EIA for year $t+\tau$ in year t. We estimate this model from 2004 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 short-term (1-year ahead) and long-term (5-years ahead) forecasts and short-term and long-term forecast errors ($\varepsilon^{ST}_{i,t}$ and $\varepsilon^{LT}_{i,t}$).

Table 9 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). Specifically, we augment Equation (5) by including an interaction term between coal production and the average forecast error over the past three years. For comparison, we report the baseline estimates in Column 1. Column 2 shows that the adverse effect of 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 the overly optimistic regional production forecasts. The findings in Table 9 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 decline of coal.

Our findings in Tables 8 and 9 present a compelling picture: The decline in coal mining represents a long-term structural shift, not just a temporary setback. This carries significant implications for coal-producing communities. Our evidence from the primary municipal bond market indicates that once-valuable coal reserves have effectively become stranded assets. Notably, major coal industry players have already acknowledged 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.[23]

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

Table 9: Effects of Coal Mining and Coal Production Forecast Errors

	Dependent Variable		
	Offering Yield (1)	Offering Yield (2)	Offering Yield (3)
CoalProduction	-1.742***	-1.735***	-1.868***
	(0.53)	(0.46)	(0.47)
CoalProduction × Short-Term Forecast Errors		0.136	
		(0.12)	
CoalProduction × Long-Term Forecast Errors			0.138**
			(0.07)
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 (5) between 2004 and 2019. Column 1 reproduces results from Table 6. 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 log 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.

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 realized production levels and forecast errors but also to broader regional changes in forward-looking projections. To test this hypothesis, we re-estimate Equation (5) using regional coal production forecasts for both 1-year and 5-years ahead. The results are presented in Table 10. The coefficient estimates for 1-year (Column 1) and 5-year (Column 2) coal production forecasts are 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. Notably, this further confirms our empirical evidence that bond investors factor in the risks tied to decreasing expectations of coal production in coal-dependent communities.

5.2.3 Heterogeneity Analysis: Differences Across Bond and Coal Types

While the previous analysis demonstrates that declining coal mining activity is reflected in municipal offering yields, it is important to understand whether these effects might differ depending on the types of bonds municipalities issue and the specific types of coal they produce. To this end, we first explore whether revenue bonds react differently from GO bonds to shifts in coal mining activity. These two bond types have distinct characteristics: Revenue bonds are repaid from income generated by a specific project's cash flows (for example, water treatment facilities, toll roads, or bridges), 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.

Table 11 differentiates effects across bond types by adding to our main specification an interaction between the coal mining activity measures and an indicator variable (RevenueBond_b). This variable equals one if bond b is a revenue bond and zero if it is a GO bond. The estimates for the coal mining activity variables—CoalLabor, CoalHours, and CoalProduction—are all negative and statistically significant, suggesting that the risks associated with the decline in coal extend beyond pledgeable revenues, thereby increasing the overall repayment risk

5, 2020.

Table 10: Municipal Offering Yields and Regional Coal Mining Projections

	Dependent Variable	
	Offering Yield	Offering Yield
	(1)	(2)
CoalProduction (1Y-ahead)	-1.424***	
	(0.36)	
CoalProduction (5Y-ahead)		-1.245**
		(0.55)
Bond Controls	Yes	Yes
County FE	Yes	Yes
Region $\times$ 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 (5) between 2004 and 2019. (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 log 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.

of the issuing municipality. Notably, the interaction terms between the revenue bond indicator and the coal mining activity measures are significantly negative and economically meaningful for two of the three measures, indicating that revenue bonds, which rely on pledged revenues from specific projects tied to local economic activities, are more sensitive to the decline in coal mining. Overall, these results indicate that the negative relationship between coal mining activity and municipal bond yields is significant across revenue and GO bonds, further underscoring the broad influence of changes to coal mining activity in these communities.

Next, we assess whether the decline in coal production affects municipal bonds differently based on coal quality by examining potential heterogeneity related to the coal's heat content. Specifically, coal quality is typically measured by its carbon content and thus heat energy, with higher-quality coal burning longer and producing more heat. U.S. coal can be broadly categorized into thermal coal and metallurgical coal. Thermal coal is primarily used domestically for electricity generation, while metallurgical coal is often exported for use in steelmaking abroad due to its superior quality. We use data on coal heat content reported by power plants to account for differences in coal quality. Figure 8 illustrates the distribution of coal heat content across counties. The graph includes a line indicating the average heat content of U.S. coal used for exports during our sample period. As shown in Figure 8, there is considerable variation in coal quality across counties, with approximately 10% of counties producing coal with a heat content above the average heat content of U.S. coal exports. 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.

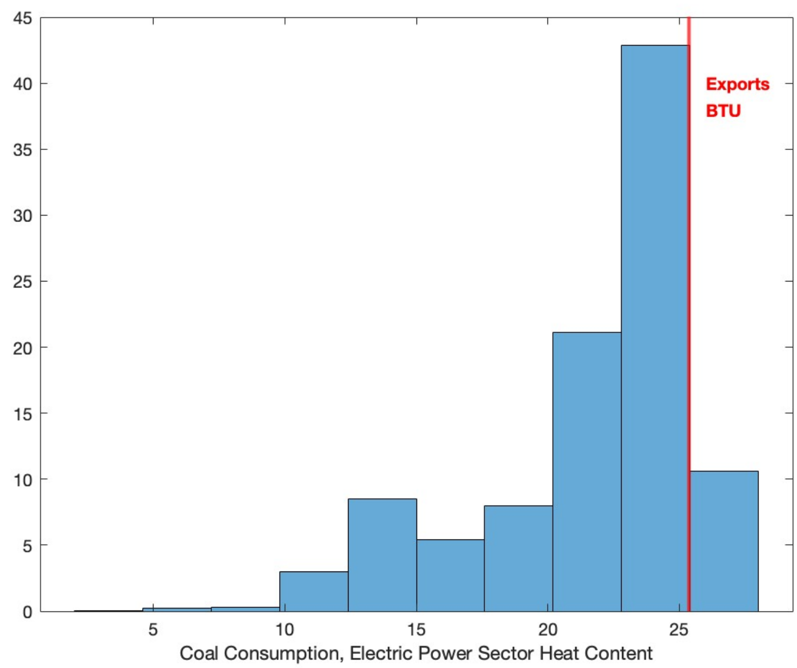
In Columns 1 through 3 of Table 12, we present estimates that include an interaction term between the coal mining activity measures and the indicator variable (HighQuality-Coal). We hypothesize that counties producing high-quality coal might be perceived by investors as more resilient to the decline in local coal demand, given their potential to access alternative markets, either domestically or internationally. However, our analysis finds no evidence to support this hypothesis. The interaction between high-quality coal indicators and all three coal mining activity measures is statistically insignificant. More importantly,

Table 11: Effects of Coal Mining on Offering Yields of Revenue and GO Bonds

	Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)
CoalLabor	-8.487**		
	(3.65)		
CoalLabor×RevenueBond	-6.664**		
	(2.60)		
CoalLaborHours		-3.217**	
		(1.39)	
CoalLaborHours×RevenueBond		-3.055**	
		(1.18)	
CoalProduction			-1.267**
			(0.62)
CoalProduction×RevenueBond			-0.684
			(0.47)
RevenueBond	18.292***	18.401***	17.394***
	(3.47)	(3.46)	(3.30)
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 (5) between 2004 and 2019. 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 log 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.

the baseline effect of coal mining remains largely unchanged, suggesting that the observed effects on municipal bond yields broadly impact all coal-producing counties, regardless of coal quality.

One possible explanation for the lack of heterogeneity in Columns 1 through 3 of Table 12 could be that our first definition of high-quality coal is based on data from power plants, which primarily receive thermal coal used for power and heat generation. Counties producing metallurgical coal might primarily export it, thus avoiding any records of their coal's heat content at power plants. If this is the case, our estimates based on the first definition of (HighQualityCoal) may underestimate the actual impact. To address this, we redefine the indicator of high-quality coal to better focus on counties likely to produce metallurgical coal. Specifically, we identify counties as metallurgical coal producers if they are located in traditional metallurgical coal regions (Alabama, Arkansas, Pennsylvania, Virginia, or West Virginia) and are not reported selling any of their coal to U.S. power plants, indicating a likely focus on metallurgical coal production.

Columns 4 through 6 of Table 12 present the results using the redefined indicator of high-quality coal production (HighQualityCoal). We find that the baseline coefficients for all three measures of coal mining activity remain negative and highly statistically significant. While the coefficients on the interaction terms are statistically insignificant at conventional levels, they suggest that counties producing metallurgical coal may experience a somewhat smaller effect from the decline in coal mining across all three measures of coal activity.[24]

5.3 Robustness

Appendix B provides additional robustness tests to validate our results on municipal offering yields. First, Table 16 presents the impact of our regression control variables. Second, we also examine gross spreads at issuance by using them as the dependent variable in place of offering yields.[25] Table 17 shows that the increased cost of issuance due to declin-

[24]The statistical insignificance is not surprising, given that less than 10% of U.S. coal production is metallurgical.

[25]Following Painter (2020), we obtain issuance discount spread data from Bloomberg and substitute it, where available, for offering yields in Equation 5.

Table 12: Effects of Coal Mining and Coal Quality

	Dependent Variable					
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-13.207***			-13.003***		
	(3.04)			(3.21)		
CoalLabor×HighQualityCoal	-0.409			4.933		
	(3.33)			(5.27)		
CoalLaborHours		-5.301***			-5.211***	
		(1.11)			(1.23)	
CoalLaborHours×HighQualityCoal		0.370			1.645	
		(1.57)			(2.15)	
CoalProduction			-1.721***			-1.830***
			(0.52)			(0.49)
CoalProduction×HighQualityCoal			0.102			0.978
			(0.82)			(0.71)
HighQualityCoal	0.782	-0.167	0.548	-0.613	-0.087	0.066
	(7.21)	(7.08)	(7.13)	(3.79)	(3.62)	(3.36)
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 (5) between 2004 and 2019. 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 log 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.

ing coal activity largely extends beyond offering yields, as it also materializes in higher fees charged by bond underwriters to coal-dependent municipal issuers. Third, in Table 18, we demonstrate that the baseline results are qualitatively similar when we differentiate municipal bond issuers or restrict our analysis to county issuers only. In fact, the effect does not significantly differ across issuer types and remains negative and significant, with little change, in the subset of county-issued municipal bonds. Lastly, in Table 19, we confirm that our effects are consistent over time and not merely artifacts of dislocations such as the GFC.

6 Conclusion

In this paper, we examine the consequences of transitioning away from carbon-intensive energy sources on the financial health of U.S. municipalities in coal-producing regions. To this end, we use a novel identification strategy that exploits the drastic shift from predominantly coal-fired to now largely natural gas-fired electricity generation in the United States over the past two decades. This energy transition was primarily driven by the introduction of hydraulic fracking, which made natural gas extraction more economically viable, replacing coal with cheaper, cleaner natural gas. Importantly, this shift occurred largely independent of local economic conditions in coal-producing counties, providing an ideal natural experiment to isolate the impact of declining coal mining activity on municipal finances.

We document that the decline in coal production leads to increased municipal debt, higher debt-to-revenue ratios, and a larger share of revenue allocated to interest payments, indicating a deterioration in municipalities' debt sustainability. Additionally, we find that the decline in coal results in higher borrowing costs in the municipal bond market. Taken together, this suggests that investors view coal-reliant communities as higher-risk borrowers and price in the risk of reduced economic activity and thus lower coal-related tax revenues. Accordingly, our findings underscore the need for a more nuanced approach to energy transition policies, as the shift away from coal, while environmentally beneficial, creates significant fiscal challenges for coal-reliant regions.

We also demonstrate that offering yields of long-term municipal bonds experience a larger and more statistically significant adverse effect from declining coal mining activity than short-term bonds. Additionally, investors seem to primarily respond to signals from long-term forecast errors in coal production while overlooking discrepancies in short-term forecast errors. That is, our findings suggests 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 coal reserves into stranded assets. These findings have pertinent implications for the pricing of transition risks in fossil fuel-dependent communities, as the rise of cheaper renewable energy sources or the introduction of carbon taxes could rapidly decrease their tax revenues while increasing their financing costs. This highlights the financial vulnerabilities faced by fossil fuel-reliant local governments amid the evolving energy landscape.

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Appendix

A Robustness of the Effects of Coal on Municipal Debt Sustainability

This section provides a more detailed account of several robustness tests on the impact of declining coal mining activity on municipal debt sustainability. In our analysis, we use outstanding debt of all maturity, whereas one might suspect that longer-term debt might be more affected by a persistent shock to coal demand. To investigate this possibility, we use outstanding debt with maturity above 1-year to estimate Equation (1). Columns 1 and 2 of Panel A in Appendix Table 13 report the results of these exercises using *CoalLabor* as the key explanatory variable. The estimated coefficient on coal mining is negative and statistically significant. Even more strikingly, our findings indicate that the coefficients for debt with a maturity greater than 1-year are larger by 20% compared to those for all maturities. The effects of coal mining on debt are also negative and statistically significant when we measure coal mining activity with total hours in coal mining (CoalLaborHours in Panel B) or coal production (CoalProd in Panel C).

Moreover, Table 13 presents the results when we consider tax revenue to compute the debt-to-income debt sustainability indicators. In particular, Columns 3 and 4 report estimates for the effects of coal on the natural log of long-term debt-to-tax revenue ratio and the natural log of all outstanding debt-to-tax revenue ratio, 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.

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 Appendix Table 14, the effect of the decline in coal mining on municipal debt and debt sustainability indicators remains negative and statistically significant, though. Second, we repeat our analysis by including additional county-level variables that capture local economic conditions, namely, GDP growth and the change in employment. Columns 2, 4, and 6 of Appendix Table 14 present the estimated coefficients on various measures of coal mining activity and these economic variables. Even after including these additional controls, we continue to find substantial negative effects of coal mining on municipal debt, with only a slight decline in the magnitude of the effects compared to the baseline specification.

Finally, 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 since 2008, which marks the onset of the GFC. The results in Appendix Table 15 reveal that the estimated coefficients 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.

Table 13: Alternative Indicators of Municipal Debt

	Dependent Variable			
	ln Debt above 1y	ln Debt above 1y/Revenue	ln Debt above 1y/TaxRevenue	ln Debt/TaxRevenue
	(1)	(2)	(3)	(4)
	Panel A			
CoalLabor	-0.690***	-0.744***	-0.706***	-0.606***
	(0.18)	(0.18)	(0.19)	(0.16)
R^2	0.781	0.693	0.733	0.819
	Panel B			
CoalLaborHours	-0.279***	-0.302***	-0.282***	-0.242***
	(0.08)	(0.08)	(0.09)	(0.06)
R^2	0.781	0.692	0.732	0.818
	Panel C			
CoalProd	-0.067**	-0.071***	-0.067**	-0.057***
	(0.03)	(0.03)	(0.03)	(0.02)
R^2	0.780	0.691	0.731	0.818
Observations	1815	1815	1815	1884
County FE	Yes	Yes	Yes	Yes
Region $\times$ 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 (1). Columns 1 and 2 present results using the natural log of long-term debt, defined as debt with a maturity greater than 1-year, and the natural log of the long-term debt-to-revenue ratio as dependent variables, respectively. Columns 3 and 4 report estimates for the effects of coal on the natural log of long-term debt-to-tax revenue ratio and the natural log 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 (1) using *CoalLaborHours* and *CoalProduction* as the key explanatory variable, respectively. All regressions include coal region-by-year and county fixed effects as well as the natural log 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 14: Robustness to Alternative Controls for Local Economic Conditions

	Dependent Variable					
	ln Debt		ln Debt/Revenue		Interest/Revenue	
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A					
CoalLabor	-0.539***	-0.455***	-0.582***	-0.492***	-3.324**	-3.486**
	(0.14)	(0.13)	(0.16)	(0.15)	(1.49)	(1.63)
R^2	0.871	0.874	0.829	0.831	0.842	0.842
	Panel B					
CoalLaborHours	-0.222***	-0.185***	-0.241***	-0.201***	-1.275**	-1.335**
	(0.06)	(0.06)	(0.07)	(0.06)	(0.61)	(0.67)
R^2	0.871	0.873	0.828	0.831	0.842	0.842
	Panel C					
CoalProd	-0.056***	-0.048***	-0.058***	-0.050***	-0.416*	-0.426*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.21)	(0.22)
R^2	0.871	0.874	0.828	0.831	0.844	0.844
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	1787	1767	1787	1767	1835	1815

This table reports coefficients from regressions of municipal debt sustainability metrics on coal mining activity measures using the model in Equation (1). 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 log 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. 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: Effects of Coal Mining Before and After the 2007–2008 GFC

	Dependent Variable		
	ln Debt	ln Debt/Revenue	Interest/Revenue
		Panel A	
CoalLabor $\times$ Year<2008	-0.623***	-0.653***	-3.214**
	(0.15)	(0.17)	(1.51)
CoalLabor $\times$ Year$\geq$2008	-0.531***	-0.588***	-3.959**
	(0.12)	(0.13)	(1.98)
		Panel B	
CoalLabor $\times$ Year<2008	-0.254***	-0.266***	-1.226*
	(0.07)	(0.07)	(0.63)
CoalLabor $\times$ Year$\geq$2008	-0.217***	-0.241***	-1.579*
	(0.05)	(0.06)	(0.82)
		Panel C	
CoalLabor $\times$ Year<2008	-0.055***	-0.055***	-0.258
	(0.02)	(0.02)	(0.18)
CoalLabor $\times$ Year$\geq$2008	-0.053***	-0.058***	-0.431
	(0.02)	(0.02)	(0.27)
County FE	Yes	Yes	Yes
Region $\times$ Year FE	Yes	Yes	Yes
Observations	1884	1884	1960

This table reports coefficients from regressions of municipal debt sustainability metrics on coal mining activity measures using the model in Equation (1). 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 (1) using *CoalLaborHours* and *CoalProduction* as the key explanatory variable, respectively. All regressions include coal region-by-year and county fixed effects as well as the natural log 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.

B Robustness of the Effects of Coal on Municipal Offering Yields

In this section, we present additional robustness tests of our baseline results, validating our findings in Section 5.2.1 by examining the impact of various controls, differentiating results by municipal bond issuers, and testing for time consistency.

As shown in Table 16, 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, higher municipal interest rates and larger issue sizes are associated with elevated bond yields. Lastly, the inclusion of credit rating fixed effects in the regression—where increased credit risk consistently widens municipal bond yields—exhibits the expected signs.

In Table 17, we follow Painter (2020) and further assess the impact on issuance costs by 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 6% rise relative to the average underwriter discount, emphasizing the heightened financial strain on coal-dependent municipal issuers.

Table 18 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 5 with an issuer type category variable interacted with the three coal activity measures. Similarly, in Columns 4 to 6, we re-estimate Equation 5 separately on the subset of municipal bonds issued by counties.

Additionally, Table 19 confirms that our effects are consistent over time, thus not merely artifacts of events like the GFC. Specifically, we split our 16-year sample period in half by constructing the indicator variable (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 5. For a municipal bond to be included in this analysis, the issuer must have issued bonds at least once in both subperiods.

Table 16: Municipal Offering Yields and Coal Mining Activity — Impact of Controls

	Dependent Variable				
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)
	Panel A: CoalLabor				
CoalLabor	-22.850***	-15.700***	-16.551***	-15.476***	-13.255***
	(6.42)	(4.61)	(3.63)	(3.26)	(3.21)
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 × Year FE	Yes	Yes	Yes	Yes	Yes
UoP & Call Option FE	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 16 continued)

	Dependent Variable				
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)
	Panel B: CoalLaborHours				
CoalLaborHours	-8.431***	-6.512***	-6.729***	-6.305***	-5.348***
	(3.17)	(1.89)	(1.36)	(1.18)	(1.20)
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 $\times$ Year FE	Yes	Yes	Yes	Yes	Yes
UoP & Call Option FE	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 16 continued)

	Dependent Variable				
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)
	Panel C: CoalProduction				
CoalProduction	-2.728**	-2.103***	-1.955***	-1.875***	-1.742***
	(1.20)	(0.65)	(0.61)	(0.56)	(0.53)
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 × Year FE	Yes	Yes	Yes	Yes	Yes
UoP & Call Option FE	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 16 continued)

This table reports coefficients from regressions of municipal bond offering yields on measures of coal mining activity using the model in Equation (5) between 2004 and 2019. Across Panels A through C, Columns 1 through 5 systematically introduce the control variables outlined in Subsection 5.1 into Equation (5). Regressions ultimately include the following bond-level controls: coupon rate, bond maturity, the natural log 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 17: Municipal Gross Spreads and Coal Mining Activity

	Dependent Variable		
	Gross Spread	Gross Spread	Gross Spread
	(1)	(2)	(3)
CoalLabor	-0.096***		
	(0.03)		
CoalLaborHours		-0.034**	
		(0.01)	
CoalProduction			-0.007
			(0.01)
Bond controls	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Region $\times$ 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 (5) between 2004 and 2019. All regressions include the following bond-level controls: coupon rate, bond maturity, the natural log 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 18: Municipal Offering Yields and Coal Mining Activity — By Issuer

	Dependent Variable					
	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)	(4)	(5)	(6)
CoalLabor	-14.386***			-19.001***		
	(3.40)			(5.51)		
CoalLaborHours		-5.835***			-7.952***	
		(1.34)			(1.92)	
CoalProduction			-1.976***			-3.005***
			(0.55)			(0.62)
City × Coal...	1.924	0.863	0.471			
	(2.54)	(1.13)	(0.49)			
SchoolDistrict × Coal...	2.679	1.096	0.861			
	(12.09)	(5.34)	(3.19)			
SpecialDistrict/Authority × Coal...	2.056	0.887	0.456			
	(2.78)	(1.19)	(0.42)			
Township × Coal...	1.144	1.208	1.036**			
	(7.00)	(2.67)	(0.45)			
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 (5) between 2004 and 2019. 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 log 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 19: Municipal Bond Yields and Coal Mining Activity — Time Consistency

	Dependent Variable		
	Offering Yield	Offering Yield	Offering Yield
	(1)	(2)	(3)
CoalLabor	-14.030***		
	(3.59)		
Year≥2012 × CoalLabor	-0.754		
	(1.88)		
CoalLaborHours		-5.622***	
		(1.19)	
Year≥2012 × CoalLaborHours		-0.234	
		(0.85)	
CoalProduction			-2.031***
			(0.41)
Year≥2012 × CoalProduction			-0.066
			(0.41)
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 (5) between 2004 and 2019. 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 log 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.