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# The Role of Incumbent Firms and Regulation in America's Natural Gas Energy Transition


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**Abstract**

This paper examines how incumbent firms' adoption of new energy technologies is shaped by the regulatory environment, focusing on the transition from manufactured to natural gas in the United States during the first half of the twentieth century. Using detailed, newly-digitized panel data on municipality-level gas utility services, I exploit variation in pipeline proximity for municipalities along its path and regulatory changes introduced by the 1938 Natural Gas Act to investigate incumbent utility firms' decision to switch from manufactured to natural gas. I find that incumbent firms delayed adopting natural gas during the initial unregulated period but accelerated adoption after the implementation of federal regulation. When considering the factors that predict early adoption by incumbents, ownership by a holding company is associated with switching before federal regulation, while higher switching costs are associated with switching after regulation. These results are consistent with federal regulation creating price consistency that eased transitions by narrowing the gap between regulated retail prices and previously unregulated pipeline wholesale prices, illustrating that coordination through regulation or holding company ownership can reduce uncertainty and expedite technological transitions.

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# 1 Introduction

When technological innovations make cleaner and more efficient energy sources available, the economic gains from their adoption can be significant. Rapid adoption is desirable because it promotes economic growth and reduces the negative externalities associated with older technologies (Hall, 2004; Jovanovic & MacDonald, 1994). However, the market structure and regulatory system can create settings where incumbents are incentivized to delay the adoption of new technologies (Gowrisankaran, Langer, & Reguant, 2024; Holmes, Levine, & Schmitz Jr, 2012). These concerns are salient today when considering the protracted transition to renewable energy sources and the role of fossil fuel incumbents in obstructing their adoption (Hausman, 2025; Gowrisankaran et al., 2024). Because energy transitions are relatively rare and often stretch over decades, historical evidence provides valuable insight into the regulatory environments that shape whether incumbents delay or facilitate adoption.

In this paper, I study America's transition from manufactured gas to natural gas during the first half of the twentieth century. Manufactured gas, produced from coal, was the dominant utility fuel until technological advances in the 1920s enabled the construction of long-distance pipelines connecting large southwestern gas fields to urban markets across the United States. Incumbent manufactured gas utility firms along the path of these pipelines gained the opportunity to switch to providing natural gas. While natural gas offered higher heating quality and greater cleanliness, adoption required large switching costs, capital obsolescence, and organizational change. The initial expansion of gas pipelines occurred without federal oversight. Incumbent utilities faced retail price regulation, while pipeline distributors could exercise monopoly power at municipal gates, limiting utilities' ability to recover switching costs. To address these concerns, Congress passed the Natural Gas Act in 1938, placing interstate pipelines and wholesale natural gas sales under Federal Power Commission regulation.

I examine how incumbency and federal regulation shaped the timing of the adoption of natural gas between 1920 and 1960. My analysis distinguishes between two phases of this transition. The first (1920–1938) was characterized by rapid, unregulated expansion of pipelines and natural gas distribution, driven by investments from holding companies. The second (1938–1960) followed the passage of the Natural Gas Act, which placed interstate pipelines and wholesale natural gas sales under regulation by the Federal Power Commission. These two periods provide a natural setting to examine how incumbents' adoption decisions responded to changing regulatory regimes and market structures. I first analyze whether municipalities with incumbent manufactured gas utilities adopted earlier or later than similar municipalities without prior service in both the unregulated and regulated periods. In order to explore which elements of federal regulation were most effective, I then test which firm and market characteristics associated with switching costs, local demand, and ownership inform why some firms were earlier adopters.

To identify the effect of incumbency, I compare municipalities with existing manufactured gas service to similar municipalities without prior service, testing which received natural gas earlier when equally exposed to pipeline access. I focus on municipalities located along pipeline routes but outside the destination cities that financed pipeline construction. To address concerns about potential endogeneity in pipeline routing, I use a municipality's proximity to the direct path between the southwestern gas fields and the destination city, isolating variation from whether a municipality happened to lie along that path.

I perform my analysis separately over the two periods to analyze how regulation influenced incumbents' decisions to adopt natural gas. Federal regulation marked a turning point. Before its implementation, firms faced monopolistic distribution prices at the city gate, creating long-run uncertainty about recovering switching costs. After regulation, firms were protected from excessive distribution prices, making the transition more feasible. Because incumbents faced fundamentally different conditions before and after the Natural Gas Act, I consider these periods separately to identify how regulation shaped adoption decisions.

To explore which factors informed why some firms were earlier adopters and which elements of federal regulation were most effective, I estimate a multinomial logit model of the timing of adoption. I classify firms into adoption groups by the year they switched to providing natural gas and test across three sets of factors associated with earlier adoption: switching costs (pipeline proximity and miles of local mains), local demand (population and annual gas production), and ownership (public ownership and affiliation with a holding company). To address endogeneity concerns, I use firm characteristics measured before the pipelines were constructed. This approach isolates the factors that informed which incumbents were adopters in the unregulated period and identify the regulatory elements that reduced monopoly power by the pipeline companies and access uncertainty, moving beyond a binary model of adoption to characterize the dynamics of incumbents' switching decisions.

To conduct my analysis, I scanned 21 editions of *Brown's Directory of American Gas Companies*, an annual survey of all United States gas utilities, digitized them with OCR, and used Python to extract data to construct a municipality-level panel dataset. Using the even-year editions from 1920 to 1960, I observe when a municipality first received gas utility service, what type of gas was provided, and if the type of gas changed as well as many firm-level characteristics.[1] I supplement this with data from two additional sources. The first is data from the 1920 to 1960 census population counts for minor civil divisions. The second is historical gas pipeline maps from the Federal Trade Commission and Federal Power Commission.

To preview my results, I find that incumbents initially delayed the adoption of natural gas. Municipalities with incumbent manufactured gas service were 8.9 percentage points less likely to adopt natural gas than comparable municipalities without prior service. After the Natural Gas Act, however, incumbency increased the likelihood of adoption by 33.2 percentage points. These results are robust to alternative specifications, definitions of treatment, and measures of pipeline proximity. I find that proximity to a pipeline increased adoption probability during the unregulated period, but not enough to offset incumbent resistance. The contrasting results between the two periods suggest that the introduction of federal regulation helped mitigate switching delays from incumbents and facilitated a faster energy transition. Before the Natural Gas Act, monopolistic pricing at the city gate created uncertainty that discouraged incumbents from adopting. After the Act, regulation limited distributors' monopoly power and allowed incumbents to recover switching costs more reliably.

When considering the factors that inform earlier adoption, ownership and switching costs were important determinants for which incumbents adopted earliest. Firms owned by holding companies were more likely to adopt before the implementation of federal regulation than independent or publicly owned firms. Firms with larger preexisting infrastructure, proxied by miles of local mains, were more likely to adopt after the implementation of federal regulation, which is consistent with the Natural Gas Act reducing switching uncertainty by regulating wholesale prices and allowing

[1] The transition from manufactured gas to natural gas typically took around a year, so two-year intervals are sufficiently granular to identify adoption timing. Longer gaps would obscure differences in the timing of adoption.

incumbents to recoup switching costs. Local demand, measured by population and annual gas production, do not meaningfully predict adoption, which suggests that demand conditions did little to accelerate conversion. Taken together, these results suggest that consolidation within a larger corporation mitigated problems associated with pipeline monopolies, and that federal regulation later improved cost recovery and enabled incumbents to convert.

This paper contributes to three areas. The first focuses on the role of incumbents in technological transitions. I provide insight by contrasting incumbent behavior during an initial unregulated era with a subsequent regulated period, documenting how regulatory environments shape firm responses to technological transitions. I contribute to earlier works studying why incumbents may be slow to adopt new technologies (Hall, 2004; Henderson, 1995; Parente, 1994; Jovanovic & MacDonald, 1994; Chari & Hopenhayn, 1991). In particular, my setting contributes an empirical analysis illustrating earlier theoretical results on why monopolistic firms may be less likely to innovate (Holmes et al., 2012) and the role of the regulatory environment in generating conditions which make incumbents more likely to adopt to new technologies (Gowrisankaran et al., 2024). My particular historical setting is advantageous since I observe both a period without and with federal regulation allowing me to analyze directly the role that regulation played in shaping incumbents' decisions.

The second is the literature characterizing the factors that drove historical technological transitions. This paper is the first to document the effect of incumbents on adopting new technologies in the historical context of the natural gas transition complementing research from other contexts such as steam power (Hornbeck, Hsu, Humlum, & Rotemberg, 2024), light bulbs (Armitage, 2022), telephone switchboards (Feigenbaum & Gross, 2024), railroad gauges (Veblen & Mayer, 2022), and cotton ring-frame spinning (Saxonhouse & Wright, 1984). Specifically, I speak to the literature looking at the role of fixed costs which includes works on the mechanical reaper (Olmstead, 1975; David, 2013) and those concerned with industries where firms faced a change in task allocation as seen in the implementation of electric motor (David, 1990). Furthermore, I also add another context where regulation improves the prospect of adopting new technologies complementing earlier work on airline regulation and innovation (Mowery, Rosenberg, & Rosenberg, 1982).

The third is the development of the gas industry and its regulation. My primary contribution is to characterize the transition from manufactured gas and natural gas focusing on the transition period of 1920 to 1960. Previously, Troesken (1997) and Troesken (1995) analyzed the role of ownership and regulation in the development of the manufactured gas industry before the construction of the interstate pipelines. Greenspon and Hanson (2025) analyzes the long-run impact of the exogenous changes in natural gas access on industrial development and composition focusing on pipelines built during World War II. Previously, the literature has focused on the impact of federal regulation on the gas utility industry after 1960 including Wellisz (1963) and Pierce Jr (1982). My work bridges the gaps of the existing literature analyzing the role of federal regulation during its initial implementation.

The remainder of this paper is organized as follows. Section 2 provides historical background of the gas utility industry, its regulation, and the transition from manufactured gas to natural gas. Section 3 describes the data used for analysis. Section 4 outlines the empirical approach. Section 5 discusses the results. Section 6 documents which factors informed why some incumbents were earlier adopters than others. Section 7 concludes.

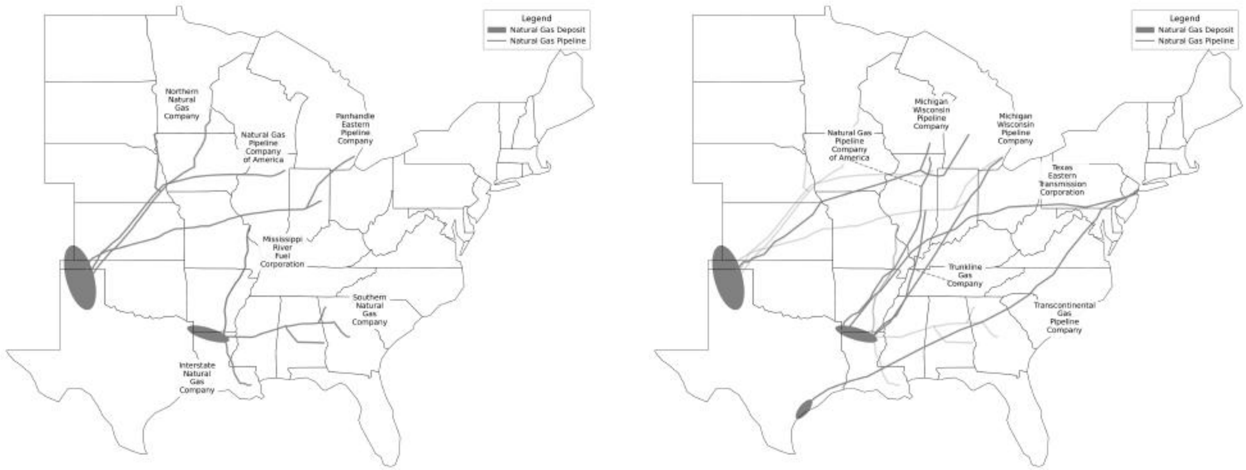
## 2 Historical Background

In the United States, gas was first used as a public utility in the early 19th century as a fuel for streetlamps (Rose, 1995). Burning considerably brighter than oil candles, gas lamps proliferated across the country for public, commercial, and residential lighting. By the late nineteenth century, facing competition from electricity, the gas industry repositioned itself as a fuel for industry, heating, and household appliances. Manufactured gas was the dominant form of gas during this period. Because it was produced from coal, any municipality that could have coal supplied and sufficient demand could sustain manufactured gas service. Natural gas was known but technological limitations in its capture and transport made it available only to municipalities near a natural gas deposit, such as in West Virginia and Pennsylvania.[2] Demand for gas grew steadily through the beginning of the 20th century with the total distribution of manufactured gas increasing from 204 billion cubic feet in 1914 to over 450 billion cubic feet by 1929 (Tarr, 2002).

The industry developed as a regulated natural monopoly due to fixed capital costs and the disruption of laying mains. Monopoly status was first secured through exclusive municipal contracts

[2]Even proximity to a deposit did not ensure long-term access. Many fields were depleted within decades, in part due to leakage or flaring to access underlying oil. An estimated 76 trillion cubic feet of natural gas was lost (Zhao, McDonell, & Samuelsen, 2022).

Figure 1: Natural gas pipelines in the analysis.




(a) Pipelines constructed between 1928 and 1934. (b) Pipelines constructed between 1938 and 1956.

Sources: Federal Trade Commission (1940) and Federal Power Commission (1956).
Notes: Map of natural gas pipelines built over the period 1926–1956. Includes only the primary natural gas pipeline artery; off-shoot pipelines are not mapped.

and later through centralized regulation by state utility commissions. While regulatory methods varied, all systems preserved monopoly rights in exchange for price and quality oversight. Most firms were privately owned; in 1920, only about 3% were public. The 1920s also saw consolidation into large holding companies. Despite this ownership concentration, the industry retained a decentralized structure of local utilities producing and distributing gas only to their immediate markets (Tarr, 2002).

While manufactured gas was the most common gas utility, natural gas was the superior fuel. With an average heating value of 1,000 Btu per cubic foot, natural gas nearly doubled the 600 Btu average of manufactured gas. The higher heating content of natural gas made it a better fuel for use in industry. Manufactured gas could be enriched with oil additives, but doing so was costly. Rising coal and oil prices during the 1920s further increased the cost and reduced the quality of manufactured gas (Stotz & Jamison, 1938). In addition to higher heating content, natural gas was cleaner: manufactured gas production generated local pollution, while natural gas could be transported from distant fields.

In the 1920s, multiple technological advances made it possible to construct long-distance pipelines. Before 1920, the longest gas pipeline was just under 200 miles (Tarr, 2002). What would follow in the late 1920s would be a boom in the building of pipelines that would connect the large gas fields of the Texas Panhandle, Central Oklahoma, and Northern Louisiana to principal urban markets across the United States (Castaneda & Pratt, 1989). These new pipelines would span more than 1,000 miles. Panel (a) of Figure 1 depicts these initial pipelines. The Mississippi River Fuel pipeline, the Interstate pipeline, and the Southern National pipeline connecting to St. Louis, New Orleans, and Atlanta respectively were completed and began service by 1930. The Northern Natural Pipeline, Natural Gas Pipeline Company of America, and Panhandle Eastern Pipeline brought natural gas to Minneapolis, Chicago, Detroit, and Indianapolis by 1932. Natural gas became available to many municipalities previously too far from local deposits. The southwest quickly surpassed the Appalachian states in the production and distribution of natural gas.

This early phase of pipeline expansion was marked by minimal governmental oversight, as states were largely prohibited from regulating interstate pipeline companies (Castaneda & Pratt, 1989). National holding companies based in destination cities financed much of the construction, and by 1935, four companies controlled 60 percent of production and pipeline capacity. While pipelines were primarily built to serve destination cities, municipalities along the route of the pipelines could build their own off-shoot pipelines and gain access to natural gas distribution. Until 1938, both wellhead and municipal-gate sales were unregulated, and pipeline distributors operated as monopolies with unchecked pricing power.

Concerns about the consolidation across the utility industry leading to increased monopoly power and practice of corrupt financial processes, led congress to order a series of investigations of the industry over 1928 to 1935. The findings by the Federal Trade Commission concluded that the utility industry was characterized by excessive pyramiding, stock inflation, financial corruption, and a lack of competition. Congress responded by passing a series of legislative acts which increased the level of oversight over public utilities and their holding companies. The first being the Public Utility Holding Company Act of 1935 which began the process of breaking up the pyramid of holding companies. Between 1935 and 1947, 306 utility companies were divested from their holding companies (Tarr, 2002). The unregulated nature of interstate gas pipelines definitively ended in 1938 with the passage of the Natural Gas Act, marking the start of the regulated period.

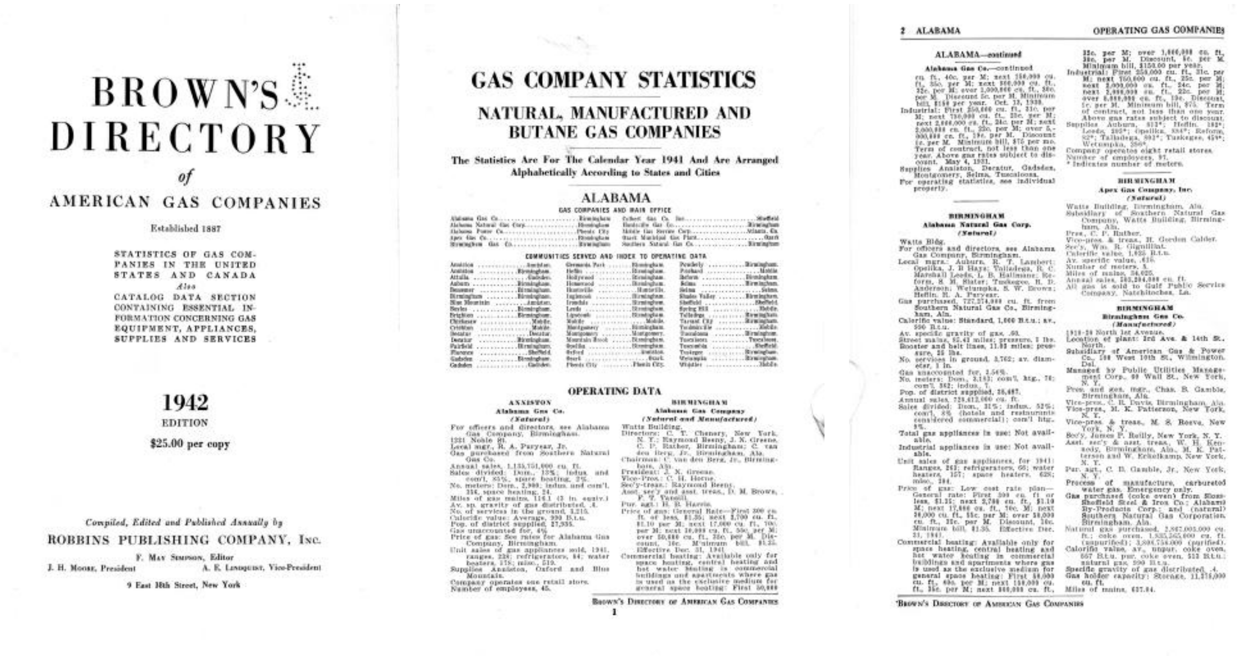
The Act restructured the industry by empowering the Federal Power Commission (FPC) to regulate pipeline companies. The Act gave the FPC power the power to regulate the rates pipeline companies charged at municipal gates through cost plus reasonable return rates (Tussing & Barlow, 1983).[3] The Act also gave the FPC the authority to approve the construction of new pipelines and the power to compel service to municipalities along the pipeline's path. The passing of the Act came with promises protecting pipeline company's monopoly status in exchange for rate regulation (Sanders, 1981).

Pipeline construction slowed during the Great Depression and World War II. Two emergency pipelines were built during WWII to carry oil and refined products from the southwest to the northeast which would be later converted to natural gas distribution (Blanchard, 2021). Following the conclusion of WWII was a second boom in the construction of natural gas pipelines (Tussing & Barlow, 1983). Panel (b) of Figure 1 depicts the pipelines included in this second wave. The Texas Eastern Transmission Corporation is one of the emergency pipelines converted to natural gas distribution in 1945. The Michigan-Wisconsin Pipeline Company completed a line reaching Minneapolis and Grand Rapids in 1949 and complete a another line to Detroit in 1956. The Transcontinental Gas Pipeline Company also completed a pipeline in 1949 connecting Southern Texas to New York. The Natural Gas Pipeline Company of America and the Trunkline Gas Company, owned by Panhandle Eastern, completed lines in 1951.

Switching from manufactured to natural gas service was not inconsequential. While there were benefits to switching to natural gas service, manufactured gas firms faced concerns about making the transition. Switching would mean retiring and abandoning existing capital used for the production of manufactured gas. This was problematic for incumbent firms who spent the previous decade taking on additional debt to finance expansion in production capabilities (Blanchard, 2021). Existing manufactured gas infrastructure, both the local gas mains and gas appliances, was not directly compatible with natural gas due to its higher heating quality (Tarr, 2002). As a result, all gas infrastructure would need to be converted to handle natural gas. This presented a large complicated organizational task for firms in order to convert their existing infrastructure. Some firms tried to ease into the transition by providing a mixed gas product that was a combination of manufactured gas and natural gas, but this was relatively uncommon. Furthermore, there were concerns that the new natural gas supplies would not be sufficient to provide long-term supplies.

[3]The first sale of natural gas from the producer to the the pipeline distributor remained unregulated until in 1954 when the Supreme Court's ruling on the *Philips Petroleum Company vs. Attorney General of Wisconsin* gave the FPC's power was extended to regulate wellhead prices.

Figure 2: Brown's Directory of American Gas Companies Example



BROWN'S DIRECTORY of AMERICAN GAS COMPANIES

Established 1887

STATISTICS OF GAS COMPANIES IN THE UNITED STATES AND CANADA *Also* CATALOG DATA SECTION CONTAINING ESSENTIAL INFORMATION CONCERNING GAS EQUIPMENT, APPLIANCES, SUPPLIES AND SERVICES

1942 EDITION

$25.00 per copy

*Compiled, Edited and Published Annually by*
ROBBINS PUBLISHING COMPANY, INC.

GAS COMPANY STATISTICS

NATURAL, MANUFACTURED AND BUTANE GAS COMPANIES

The Statistics Are For The Calendar Year 1941 And Are Arranged Alphabetically According to States and Cities

ALABAMA

OPERATING DATA

2 ALABAMA — OPERATING GAS COMPANIES

This increased the uncertainty for incumbent firms making the transition. A final barrier incumbent firms faced was that while all their sales were subject to price regulation by state or local utility commissions, the gas they purchased from the pipelines was unregulated. This disconnect may have increased the uncertainty for incumbent firms in being able to reliably pay off the switching costs in the future. Given these challenges, it was not obvious that incumbent firms would adopt natural gas faster than municipalities without prior service.

## 3 Data

For the analysis, I compiled and digitized a novel panel dataset identifying all minor civil divisions, referred to here as municipalities, that received gas utility service by 1960.[4] The data are drawn from the 1920 to 1960 even-year editions of *Brown's Directory of American Gas Statistics*, an annual industry catalog and survey documenting all gas utility firms in the United States. Figure 2 provides examples of the 1942 edition. I digitized 21 editions by scanning, preprocessing with Python, applying Amazon Textract OCR, and extracting data with Python (appendix section A.3 describes the digitization process). Each directory records detailed firm-level information, including

[4]While most municipalities in my analysis are incorpoated there are a few unincorporated places.

municipalities served, type of gas provided, ownership, holding company affiliation, annual sales, customers, and miles of gas mains. From these editions, I construct a panel dataset where I observe yearly whether a municipality had gas utility service, the firm providing it, and the type of gas supplied. During this period, gas utility services included manufactured, natural, mixed, coke oven, butane, propane, gasoline, propane, and acetylene gases. Manufactured, natural, and mixed gases constitute more than 92 percent of services observed in the sample. I categorize butane, gasoline, acetylene, and propane gas separately from natural gas due to their distinct distribution methods. For my main analysis they are grouped with manufactured gas and I exclude them completely in a robustness check. Mixed gas is categorized with natural gas in the main analysis, as mixed gas required connection to the natural gas distribution system. Coke oven gas, a by-product of manufactured gas production, is typically classified with manufactured gas in utility records. I exclude firms that only produce coke oven gas since it was not used as a residential fuel. Since my data are at the minor civil division level, I linked each municipality to its population counts from the 1920, 1930, 1940, 1950, and 1960 U.S. censuses, interpolating linearly for years between censuses.

I supplement the municipality-level data with information about natural gas source proximity from historical pipeline maps. I use the digitized 1940 Federal Trade Commission map of the Northern Natural, Natural Gas Pipeline Company of America, Panhandle Eastern, Mississippi River Fuel, and Southern Natural pipelines, as shown in Panel (a) of Figure 1 and the 1956 Federal Power Commission map of the Texas Eastern Transmission Corporation, Transcontinental Natural Gas Pipeline Company, Michigan-Wisconsin Pipeline Company, Natural Gas Pipeline Company of America, and Trunkline Gas Company as shown in Panel (b) of Figure 1. Figure A.1 depicts the progressive roll out of these pipelines. Since *Brown's Directory* surveys firms based on the prior year's data, the 1928 edition reflects information collected in 1927, the 1930 edition reflects 1929 data, and so forth. As a result, 1930 is the first year observed after completion of the initial pipelines, and 1932 after completion of the second set of pipelines. Using the digitized pipeline map, I calculate the distance to the the nearest natural gas source, either a pipeline or southwestern gas field, for each municipality in each year.

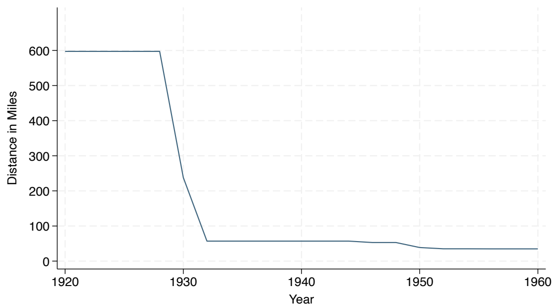
My analysis focuses on the municipalities that received any type of gas utility service by 1960 in the states crossed by the interstate pipelines shown in Figure 1. These states include Alabama, Georgia, Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin. I exclude Arkansas, Kansas, Louisiana, Mississippi, and Nebraska because they lie near a natural gas source and experienced different exposure to natural gas prior to pipeline construction. Since the analysis focuses on municipalities along the pipelines' path, I exclude municipalities located within 30 miles of the principal destination cities of Atlanta, Birmingham, Chicago, Columbus, Detroit, Des Moines, Indianapolis, Kansas City, Macon, Milwaukee, Minneapolis, Sioux City, and St. Louis. As a robustness check, I also exclude municipalities within 60 miles of these cities. Additionally, I exclude the 57 municipalities that already had natural gas service prior to pipeline completion. These municipalities were primarily located in southwestern Missouri and far eastern Indiana, areas with existing exposure to natural gas before the interstate pipelines. As another robustness check, I exclude Indiana and Missouri entirely. The final data is a balanced panel of 1,123 municipalities.

## 3.1 Summary Statistics

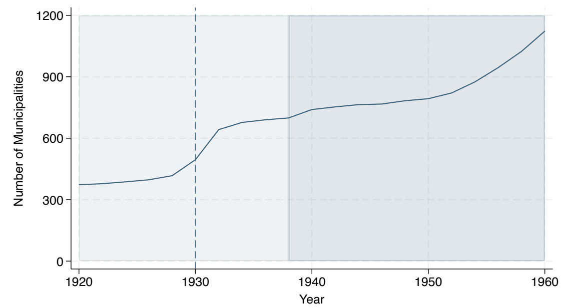
The completion of interstate pipelines substantially reduced the distance to the nearest natural gas source. Panel (a) of Figure 3 shows that the average distance for the 1,123 municipalities fell from 597 to 34 miles. The completion of the initial interstate pipelines coincided with a notable increase in the number of municipalities receiving gas utility service. Panel (b) shows that the number of municipalities with gas service rose from 417 in 1928 to 699 in 1938, and to 945 by 1956. Service expanded even during the 1930s and 1940s as incumbents transitioned from manufactured to natural gas. Panel (c) shows that while natural gas expanded, manufactured gas service did not decline proportionally, indicating that many incumbents delayed switching. By 1956, the number of manufactured gas municipalities fell from 417 to 93. However, overall the transition proceeded relatively quickly. By 1956, the number of municipalities with manufactured gas service had fallen from 417 in 1928 to 93 in 1956. Panel (d) shows that the population served by natural gas grew from just over 3 million in 1938 to almost 9.5 million by 1960.

Figure 4 further depicts the progression of the natural gas transition. Panel (a) maps the distribution of manufactured gas firms in 1928, prior to the completion of the first interstate pipelines. Panel (b) depicts the transition in the 1938 right before the passage of the Natural Gas Act highlighting that several distant municipalities constructed extended off-shoot lines to to gain natural gas distribution. Panel (c) depicts the transition in 1956, by which time the majority

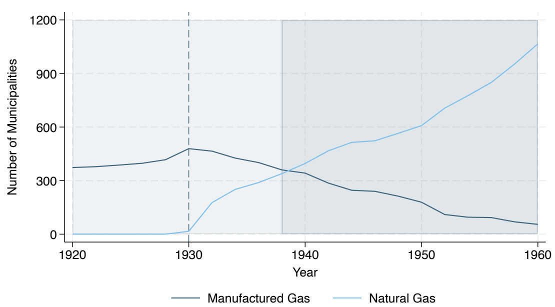
Figure 3: Natural Gas Transition from 1920 to 1960 in the states in the analysis.



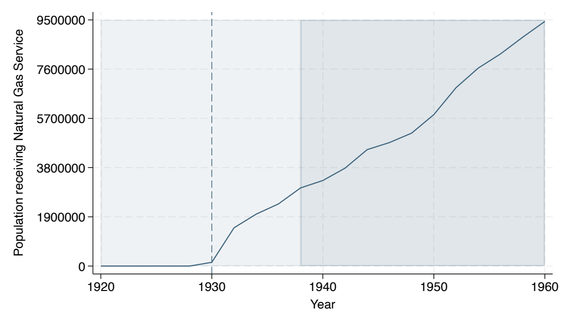

(a) Average distance to a natural gas pipeline.




(b) Number of municipalities with gas utility service.




(c) Number of municipalities by gas service type.



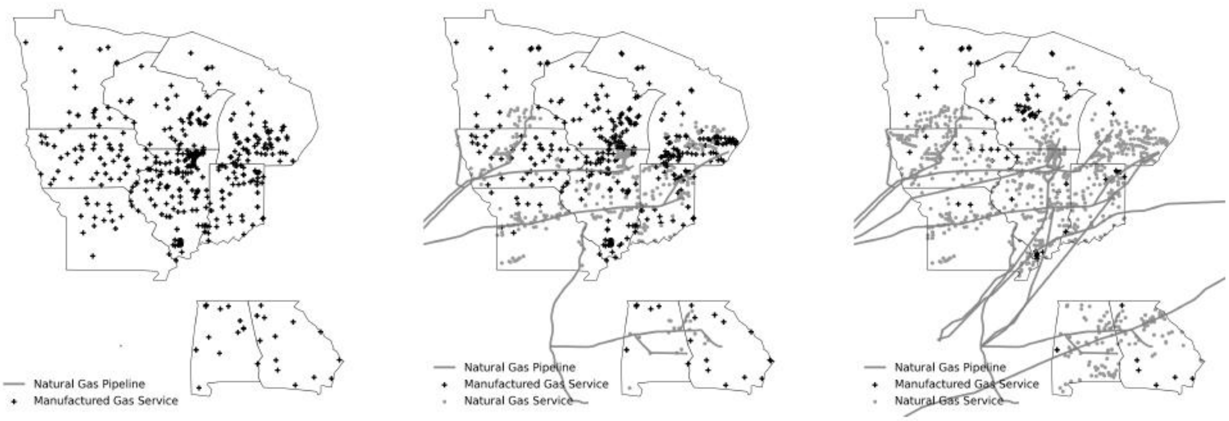

(d) Total population with natural gas utility service.

Notes: Panel (a): Average distance by year in miles to the nearest natural gas source. The nearest natural gas source is defined as the closest of distance to a natural gas pipeline or distance to southwestern natural gas field. Panel (b): Total count of municipalities with any type of gas utility service for the even years of 1920 to 1960. The light shaded region indicates the unregulated period from 1920 to 1938. The dark shaded region indicates the regulated period from 1938 to 1960. The dashed line marks the first year of completed interstate pipelines in 1930. The dashed line marks the first year of completed interstate pipelines in 1930. Panel (c): Count of municipalities by gas service type for the even years of 1920 to 1960. Mixed gas is combined with natural gas. The light shaded region indicates the unregulated period from 1920 to 1938. The dark shaded region indicates the regulated period from 1938 to 1960. The dashed line marks the first year of completed interstate pipelines in 1930. Panel (d): Total population in municipalities receiving natural gas service. The light shaded region indicates the unregulated period from 1920 to 1938. The dark shaded region indicates the regulated period from 1938 to 1960. The dashed line marks the first year of completed interstate pipelines in 1930.

of municipalities had completed the conversion from manufactured to natural gas.

Table 1 presents summary statistics for the full sample and for three specific years: 1928, immediately before completion of the first interstate pipelines; 1938, the final year without regulation; and 1956, by which time most incumbent firms had transitioned to natural gas. The share of municipalities with natural gas rose from 30 percent in 1928 to 76 percent by 1956. However, the share of municipalities receiving manufactured gas remained stable during the early part of this

Figure 4: Location of Gas Services and Pipelines.




(a) 1928 (b) 1938 (c) 1956

Sources: Federal Trade Commission (1940) and Federal Power Commission (1956).
Notes: Map covers 1926–1956; only the primary pipeline artery is shown.

Table 1: Summary Statistics by Year

| | Full Sample | 1928 | 1938 | 1956 |
|---|---|---|---|---|
| Proportion of Municipalities with Manu Gas Service | 0.25 | 0.37 | 0.32 | 0.08 |
| Proportion of Municipalities with Natural Gas Service | 0.36 | 0.00 | 0.30 | 0.76 |
| Proportion of Municipalities without Gas Service | 0.39 | 0.63 | 0.38 | 0.16 |
| Distance to Pipeline | 187.7 | 597.3 | 56.9 | 34.8 |
| | (251.6) | (167.5) | (49.8) | (39.3) |
| Population | 6,842 | 5,958 | 6,477 | 8,353 |
| | (14,945) | (13,180) | (13,986) | (17,885) |
| Observations | 23,583 | 1,123 | 1,123 | 1,123 |

Standard deviations are in parentheses. *Proportion of Municipalities with Manu Gas Service* is the proportion of municipalities that received manufactured gas service. *Proportion of Municipalities with Natural Gas Service* is the proportion of municipalities that received natural gas service. *Distance to Pipeline* is the distance in miles to the nearest natural gas source whether natural gas pipeline or southwestern natural gas field. *Population* is the population of each municipality taken from the 1920, 1930, 1940 1950, and 1960 censuses. Population for the years between census years are linearly interpolated.

period, decreasing from 37 percent in 1928 only to 32 percent by 1938. This is partially attributed to establishment of new manufactured gas services in the early 1930s, despite the availability of natural gas pipelines.

Table 2 reports the summary statistics of the years 1928, 1938, and 1956 by type of gas service. In 1928, as shown in Panel A, manufactured gas municipalities had an average population of 13,291, compared to 1,773 for municipalities with any gas service. Pipelines enabled smaller municipalities,

Table 2: Summary Statistics by Gas Service Type

| | Manu Gas Serviced Municipalities | Natural Gas Serviced Municipalities | Municipalities without Gas Service |
|---|---|---|---|
| *Panel A: 1928* | | | |
| Distance to Pipeline | 642.0 | - | 570.7 |
| | (151.5) | | (170.8) |
| Population | 13,023 | - | 1,785 |
| | (19,571) | | (1,868) |
| Observations | 417 | - | 706 |
| *Panel B: 1938* | | | |
| Distance to Pipeline | 79.1 | 36.5 | 54.4 |
| | (61.0) | (33.8) | (41.8) |
| Population | 9,758 | 8,898 | 1,756 |
| | (15,854) | (18,220) | (2,010) |
| Observations | 360 | 339 | 424 |
| *Panel C: 1956* | | | |
| Distance to Pipeline | 95.9 | 28.6 | 33.0 |
| | (69.1) | (29.5) | (30.7) |
| Population | 9,074 | 9,629 | 1,953 |
| | (13,369) | (19,804) | (1,943) |
| Observations | 93 | 850 | 180 |

Standard deviations are in parentheses. *Distance to Pipeline* is the distance in miles to the nearest natural gas source whether natural gas pipeline or southwestern natural gas field. *Population* is the population of each municipality taken from the 1920, 1930, 1940 1950, and 1960 censuses. Population for the years between census years are linearly interpolated.

previously unable to support capital-intensive manufactured gas systems, to adopt less capital-intensive natural gas. Panel B highlights this difference. By 1938, municipalities without gas remained significantly smaller on average than both manufactured and natural gas municipalities. These population differences emphasize the importance of selecting an appropriate comparison group for municipalities with incumbent service. Moreover, because municipalities located closer to pipelines were also more likely to adopt natural gas earlier, it is essential to control for distance when estimating incumbents' effect on adoption.

## 4 Empirical Approach

For the main empirical analysis, I use the variation in the geographic location of interstate natural gas pipelines and incumbent manufactured gas service. The initial interstate natural gas pipelines were constructed to serve major destination cities. Municipalities located along pipeline routes experienced exogenous changes in access to natural gas. By comparing municipalities that had existing manufactured gas service with municipalities that had none, I measure the role of incumbent manufactured gas firms in the adoption of natural gas. I use a difference-in-difference framework where the first difference is the timing of the exposure to the natural gas pipeline and the second difference is whether a municipality had incumbent manufactured gas service. Formally, I estimate the following equation:

$$\begin{aligned} natural\_gas_{mt} = &\beta_1\, manufactured\_gas_m \cdot \mathbb{1}\{distance_{mt} \leq 60\ miles\} \\ &+ \beta_2 \cdot \mathbb{1}\{distance_{mt} \leq 60\ miles\} + \gamma X_{mt} + \lambda_t + \alpha_m + \varepsilon_{mt} \end{aligned} \tag{1}$$

In equation (1), the dependent variable $natural\_gas_{mt}$ is an indicator equal to one if a municipality receives natural gas service and is equal to zero otherwise. $manufactured\_gas_m$ is an indicator that is equal to one if a municipality received manufactured gas service before 1930, the first year of treatment, and is equal to zero otherwise. $distance_{mt}$ is the distance in miles to straight-line path from the southwestern natural gas fields to the principal destination cities. $X_{mt}$ is a matrix of controls that includes municipality population. $\lambda_t$ and $\alpha_m$ are year and municipality fixed effects, respectively. The error term $\varepsilon_{mt}$ captures the unobservable municipality characteristics not accounted for by the set of controls and fixed effects and is clustered at the county level.

My primary coefficient of interest is $\beta_1$ which captures the differential effect of having incumbent manufactured gas service on the likelihood of adopting natural gas service for municipalities equally close to a pipeline. Conditional on the control variables, fixed effects, and the assumption that municipalities without gas service serve as a valid counterfactual, this coefficient indicates the causal effect of incumbent manufactured gas service on the probability of of earlier adoption of natural gas service compared to municipalities without prior gas service.

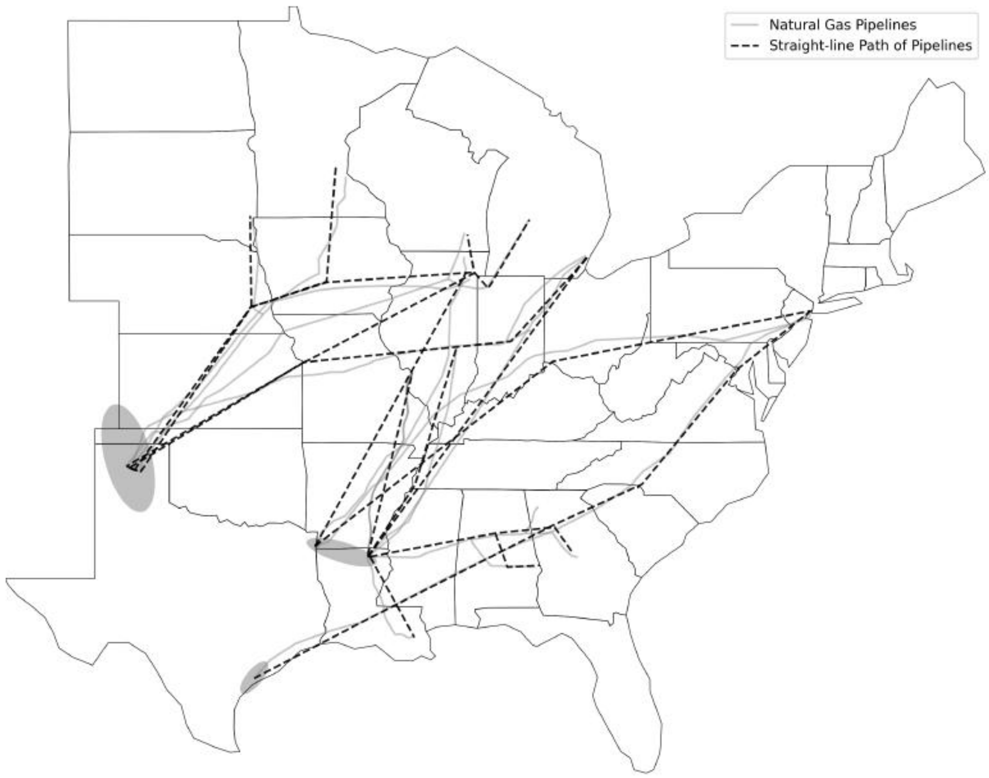
I employ a linear model because it allows for the implementation of fixed effects to control for unobserved municipality characteristics. I also estimate my equation as a probit with municipality random effects. Table A.1 in the appendix reports the results which are qualitatively similar to the linear probability model estimates. I treat the adoption of natural gas service as an absorbing state since municipalities do not revert to alternative gas services once natural gas is adopted. Once $natural\_gas_{mt}$ is equal to one after the completion of the first pipelines in 1930, the municipality is removed from my panel. The distance threshold of 60 miles is used to define being close to a pipeline as it is the average distance to the natural gas pipelines observed among municipalities in the sample following the initial completion of pipelines in 1932. I also implement other distance thresholds as robustness checks.

I estimate the regression separately for two distinct periods to account for differences in regulatory regimes: the unregulated period, 1920 to 1938, and the regulated period, 1938 to 1960. The first period was characterized by the unregulated building of natural gas pipelines and pipeline companies charged unregulated prices at municipal gates. By 1935, four utility holding companies controlled approximately 60 percent of natural gas production and pipeline networks. Incumbent manufactured gas firms and prospective new gas firms entering municipalities without previous gas utility service would have faced unregulated prices from natural gas pipelines companies that exercised monopolistic power as the sole natural gas supplier. The second period began with the passage of the Natural Gas Act in 1938, granting the Federal Power Commission authority to regulate gas distribution prices. This period shifted the market structure because pipeline companies transitioned from unregulated monopolies to regulated monopolies under the authority of the Federal Power Commission, which enforced rate regulation. Gas utility firms remained regulated monopolies throughout both periods. I estimate these periods separately as the introduction of pipeline price regulation altered the adoption decisions of incumbent manufactured gas firms and municipalities without prior gas service by providing price stability.

To interpret the resulting differences in the likelihood of adopting natural gas service as the causal effect of an incumbent manufactured gas firm on the adoption of natural gas requires the random assignment of both the location of existing manufactured gas service and natural gas pipelines. Two primary sources of potential endogeneity indicate that this was not the case.

First, the location of existing manufactured gas service is likely correlated with both the demand characteristics of a municipality and the probability of adopting natural gas service. Municipalities served by manufactured gas firms before the construction of interstate natural gas pipelines likely differ systematically from those that lacked gas utility service but later received natural gas. In order for a municipality to support a manufactured gas firm, demand for gas utility services had

Figure 5: Natural Gas Pipelines in Analysis and Straight-line Path




Sources: Federal Trade Commission (1940).
Notes: Map of natural gas pipelines built over the period 1926 to 1932. Includes only the primary natural gas pipeline artery. Off-shoot natural gas pipelines not mapped. Straight-line path used for empirical analysis depicted with gray dashed lines.

to be sufficient to allow firms to recover the fixed costs of starting service. As illustrated in Table 1, Panel B, in 1928 the average population of municipalities served by a manufactured gas firm was 13,651, compared to 1,773 in municipalities without prior gas utility service. This difference could introduce a positive bias as municipalities with higher demand for manufactured gas service might also have higher demand for natural gas service. I address this concern in three ways. First, I restrict my sample to only those municipalities which received any type of gas service by the end of each studied period, 1938 for the unregulated period and 1960 for the regulated period. I limit my sample in this way to ensure that comparisons are made between municipalities with similar demand for gas utility services. Second, I control for municipality population to condition my analysis on municipalities of similar size. Finally, I include a municipality fixed effect to control for demand differences across municipalities that do not vary by time. For example, municipalities in colder climates may have greater demand for gas utility service as a fuel for residential heating than municipalities in warmer climates.

The second endogeneity concern is that the location of the natural gas pipeline was not determined independently of a municipality's demand for natural gas service. If pipeline placement decisions considered the likelihood of adoption by nearby municipalities, the estimated effect of reduced distance would be positively biased. To mitigate this concern, I exclude the principal destination cities and all municipalities within a 30-mile radius from these cities. I argue that pipeline locations were effectively exogenous for municipalities situated along the pipeline routes between the natural gas fields and the principal destination cities, as these pipelines were constructed and funded in part by large holding companies to serve their principal urban markets. As a robustness check, I also exclude all municipalities within a 60 mile radius of the principal destination cities. However, there still may be concerns regarding the exact location of the pipelines' path. To alleviate these concerns, I estimate the regressions using distance to the straight-line path connecting the natural gas fields and principal destination cities, as illustrated in Figure 5, isolating exogenous variation due to incidental municipality locations along the pipeline routes. I chose to this reduced form approach since the the distance to the pipeline and the distance to the pipeline's path is highly correlated as depicted in Figure A.3 in the appendix. In the appendix I also report estimates using distance to the straight-line path as an instrument for distance to the pipeline's path. Table A.2 reports these estimates. The results are similar to the reduced form estimates.

# 5 Main Results

Table 3 reports the results of estimating equation (1), analyzing how having incumbent manufactured gas service affected a municipality's likelihood of adopting natural gas earlier. I perform the analysis over two distinct time periods to account for the different regulatory environments: the initial unregulated period (1920-1938) and the subsequent period of federal regulation (1938-1960), which began after the passage of the Natural Gas Act in 1938.

I first examine how the presence of an incumbent manufactured gas firm influenced the probability of adopting natural gas during the initial, unregulated period. Columns (1) and (2) report these estimates. Column (1), which estimates equation (1) as it is written, is my preferred specification. In column (1), the second row indicates that that for a municipalities without previous gas utility

Table 3: The Effect of Having Incumbent Gas Service on the Adoption of Natural Gas

| | Municipality Receives Natural Gas Service | | | |
|---|---|---|---|---|
| | **Unregulated Period 1920 − 1938** | | **Regulated Period 1938 − 1960** | |
| | (1) | (2) | (3) | (4) |
| Incumbent Firm × Within 60 Miles of Path | -0.089* | -0.098*** | 0.332*** | 0.271*** |
| | (0.045) | (0.037) | (0.066) | (0.067) |
| Within 60 Miles of Straight-line Path | 0.223*** | 0.134*** | 0.032 | 0.046 |
| | (0.037) | (0.035) | (0.037) | (0.034) |
| Municipality FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | No | Yes | No |
| State × Year FE | No | Yes | No | Yes |
| Observations | 6,257 | 6,257 | 6,440 | 6,440 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are in parentheses, robust to heteroskedasticity, and clustered at the county level. The dependent variable for all regressions is an indicator equal to 1 if a municipality receives natural gas in that year and 0 otherwise. *Incumbent Manufactured Gas Firm* is an indicator variable equal to 1 if a municipality ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. *Within 60 Miles of Straight-line Path* is an indicator variable equal to 1 if a municipality lies within 60 miles of the straight-line path of the natural gas pipeline. All regressions include the log of population as a control variable.

service, being within 60 miles of the pipeline's path increased the likelihood of receiving natural gas service by 22.3 percentage points. This result is statistically significant at the 99 percent confidence level. However, as shown in the first row of column (1), among municipalities within 60 miles of a pipeline, those with an incumbent manufactured gas firm were 8.9 percentage points less likely to switch to natural gas compared to similar municipalities without incumbent firms. This result is also statistically significant at the 99 percent confidence level. Column (2) introduces state-by-year fixed effects, restricting comparisons to municipalities within the same state. Although these fixed effects absorb more variation, the results remain qualitatively and quantitatively similar.

These results suggest that despite being as well-suited geographically and having existing gas utility infrastructure, incumbents were less likely to switch to natural gas than firms entering markets previously not served by a gas utility service during this initial period. Incumbent manufactured gas firms faced switching costs related both to upgrading existing infrastructure and appliances for compatibility with natural gas and retiring sunk capital invested in manufactured gas production. Incumbents also faced logistical challenges in coordinating the conversion process, as updating gas mains and consumer appliances required significant organizational resources. Some utility firms even hired specialized contractors to coordinate this transition (Tarr, 2002). Finally, incumbent firms faced price uncertainty. State utility commissions regulated the prices charged by the gas utility firms to consumers, yet pipeline companies operated as monopolies, charging unregulated prices to gas utility firms at municipal gates. The monopoly pricing practices of the pipelines may have made it difficult for existing firms to recover the costs of transition through regulated consumer rates. Because public utility commissions regulated their rates, incumbent gas utility firms may have found it difficult to increase prices to recoup the costs of switching to natural gas.

Next, I consider the later period from 1938 to 1960, following the passage of the Natural Gas Act. This period is characterized by the federal regulation of natural gas prices of the pipeline companies at the municipal gates and oversight of the expansion of interstate natural gas pipelines and services. Columns (3) and (4) report these estimates. In contrast to the earlier period, proximity to the natural gas pipeline was no longer a significant factor in the likelihood of adopting natural gas service for municipalities that previously were without gas utility service. However, having an incumbent manufactured gas firm has a positive effect on the likelihood of adopting natural gas service. As indicated in the first row of column (3), municipalities with an incumbent manufactured gas firm were 33.2 percentage points more likely to receive natural gas service compared to municipalities who had yet to receive gas utility service by 1938. This estimate is statistically significant at the 99 percent confidence level. The increase in magnitude of the coefficient in the third row is likely indicative of the importance of controlling for unobserved time indifferent municipality characteristics correlated with the demand for natural gas service which bias downward the estimates.

The role of incumbent manufactured gas firms reversed between the initial unregulated and subsequent regulated period. Initially, incumbents were slower to adopt natural gas than similar municipalities with the same geographic proximity. Later, under federal regulation, geographic proximity became less important and having an gas incumbent increased the likelihood of transitioning earlier compared to similar municipalities without prior gas service. One possible explanation is that incumbents, given additional time, overcame the initial barriers of raising sufficient capital and coordinating the transition. Federal price regulation also likely reduced price uncertainty at municipal gates compared to the unregulated period. This oversight may have reduced the risks

Table 4: Robustness – Different Distance Thresholds

| | Municipality Receives Natural Gas Service | | | | | |
|---|---|---|---|---|---|---|
| | **Unregulated Period 1920 – 1938** | | | **Regulated Period 1938 – 1960** | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Incumbent Firm × Within 40 Miles of Path | -0.088 | | | 0.329*** | | |
| | (0.056) | | | (0.078) | | |
| Within 40 Miles of Straight-line Path | 0.272*** | | | 0.046* | | |
| | (0.041) | | | (0.027) | | |
| Incumbent Firm × Within 80 Miles of Path | | -0.104*** | | | 0.331*** | |
| | | (0.039) | | | (0.081) | |
| Within 80 Miles of Straight-line Path | | 0.198*** | | | 0.033 | |
| | | (0.034) | | | (0.052) | |
| Incumbent Firm × Within 100 Miles of Path | | | -0.085** | | | 0.474*** |
| | | | (0.035) | | | (0.069) |
| Within 100 Miles of Straight-line Path | | | 0.162*** | | | -0.045 |
| | | | (0.031) | | | (0.046) |
| Observations | 6,257 | 6,257 | 6,257 | 6,440 | 6,440 | 6,440 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are in parentheses, robust to heteroskedasticity, and clustered at the county level. The dependent variable for all regressions is an indicator equal to 1 if a municipality receives natural gas in that year and 0 otherwise. *Within X Miles of Straight-line Path* is an indicator variable equal to 1 if a municipality lies within X miles of the straight-line path of the natural gas pipeline. *Incumbent Firm* is an indicator variable equal to 1 if a municipality ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. All regressions include municipality and year fixed effects. Control variables include the log of population.

associated with switching to natural gas and retiring manufactured gas infrastructure, enabling incumbents to confidently transition relying on pipeline companies to supply their gas product.

## 5.1 Robustness Checks

To ensure that my results are not driven by the specific sample of municipalities or by the discrete nature of the variables, I conduct a series of robustness checks. These include alternative thresholds for key variables and variations in the sample composition. Table 4 presents estimates using different distance thresholds to define whether a municipality is considered near the pipeline. Table 5 shows results based on changes to the definition of the municipalities in the sample. All specifications include the full set of controls, as well as state and municipality fixed effects.

I first test whether the main results are driven by using within 60 miles as the definition of whether a municipality is near the pipeline. I estimate three alternative specifications using thresholds of 40, 80, and 100 miles. These estimates appear in columns (1), (2), and (3) of Table 4 for the unregulated period and columns (4), (5), and (6) for the regulated period, respectively. For

Table 5: Robustness – Different Sample Definitions

| **Panel A: Unregulated Period 1920 - 1938** | | | | | |
|---|---|---|---|---|---|
| | Municipality Receives Natural Gas Service | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| Incumbent Firm × Within 60 Miles of Path | -0.210*** | -0.085* | -0.088* | -0.084 | -0.039 |
| | (0.050) | (0.043) | (0.046) | (0.052) | (0.047) |
| Within 60 Miles of Straight-line Path | 0.298*** | 0.200*** | 0.222*** | 0.247*** | 0.170*** |
| | (0.049) | (0.035) | (0.037) | (0.041) | (0.038) |
| Observations | 4,319 | 6,349 | 6,256 | 5,459 | 5,740 |
| **Panel B: Regulated Period 1938 - 1960** | | | | | |
| | Municipality Receives Natural Gas Service | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| Incumbent Firm × Within 60 Miles of Path | 0.304*** | 0.300*** | 0.458*** | 0.342*** | 0.333*** |
| | (0.071) | (0.059) | (0.084) | (0.071) | (0.067) |
| Within 60 Miles of Straight-line Path | 0.026 | 0.037 | -0.025 | 0.038 | 0.032 |
| | (0.030) | (0.036) | (0.039) | (0.039) | (0.040) |
| Observations | 4,509 | 6,670 | 5,891 | 6,177 | 5,988 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are in parentheses, robust to heteroskedasticity, and clustered at the county level. The dependent variable for all regressions is an indicator equal to 1 if a municipality receives natural gas in that year and 0 otherwise. *Within 60 Miles of Straight-line Path* is an indicator variable equal to 1 if a municipality lies within 60 miles of the straight-line path of the natural gas pipeline. *Incumbent Firm* is an indicator variable equal to 1 if a municipality ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. All regressions include municipality and year fixed effects. Control variables include the log of population. Column (1) excludes all municipalities within a 60-mile radius of the principal destination cities. Column (2) does not group mixed gas and natural gas service. Column (3) groups propane utility service with natural gas service. Column (4) excludes the municipalities in Indiana from the analysis. Column (5) excludes the municipalities in Missouri from the analysis.

the unregulated period, the effect on the distance from the pipeline is decreasing as the threshold increases. Municipalities without previous gas service that are within 40 miles of the pipeline's path have an increased the likelihood of receiving natural gas service by 27.2 percentage points. This effect decreases to 19.8 percentage points when the distance threshold is increased to 80 miles and decreases further to 16.2 percentage points when its increased to 100 miles. These comparisons suggest the likelihood of adoption increases as a municipality is closer to the pipeline path. The estimates on the role of the incumbent remain relatively consistent across the different distance thresholds suggesting the chosen distance threshold is not driving the results on the effect of having incumbent service in the unregulated period.

In the regulated the period, the estimates for the 40 mile threshold remains consistent with those from the main results. However for the the larger distance thresholds of 80 miles and 100 miles the estimate on the interaction term is larger and statistically significant. This suggests that in the regulated period, for municipalities beyond the 60 miles yet not further than 100 miles from the natural gas pipeline, having an incumbent manufactured gas firm increased the likelihood of adopting natural gas service relative to municipalities that were within the same distance threshold but did not previously receive gas utility service. These results support the earlier conclusion from the main results that in the regulated period having an incumbent firm greatly increased the likelihood of receiving natural gas service.

Next, I vary the sample composition to address the possibility that the results are driven by a few specific states or municipalities. Table 5 presents these estimates. Panel A covers the unregulated period and Panel B the regulated period. In column (1), I exclude all municipalities within 60 miles of the principal destination cities to test whether the results depend on municipalities located just outside the metropolitan areas but are still relatively close to destination cities. In the unregulated period the magnitude for estimates for the effect of being within 60 miles of the pipeline path and for the interaction term roughly doubled. This suggests the the benefit of proximity to the pipeline was more important for municipalities located far from population centers, and that incumbent firms in these isolated ares more reluctant to switch to natural gas in this earlier period. In the regulated period, the results remain similar to the main estimates.

In my baseline analysis, I group mixed gas service with natural gas service because supplying mixed gas still required receiving natural gas from the pipelines. Although only a small portion of municipalities in the sample adopt mixed gas, I test the robustness of this grouping. Column (2) reports estimates from a specification where I do not group mixed gas service with natural gas service. The results remain consistent with the main findings for both the unregulated and regulated periods suggesting that the classification mixed gas service with natural gas was not driving the results. In column (3) I group propane service with natural gas service. While receiving propane service did not require direct connection to the natural gas pipeline, it was at times implement as a temporary service preceding later connection to the natural gas pipeline. These estimates also remain consistent with the main findings for both the unregulated and regulated periods.

Finally, in columns (4) and (5), I exclude all municipalities in Indiana and Missouri respectively. These states are geographically closer to natural gas fields than others in the sample, and municipalities there may not have experienced the same distance-related adoption effects. In both restricted samples, for the unregulated period the estimate on the interaction term are smaller and statistically insignificant. This result suggests that incumbent manufactured gas firms in Indiana and Missouri may have been more reluctant to switch than incumbents in other states. This is not surprising since some municipalities in the late 19th in Indiana experienced the depletion of a local natural gas source requiring the reversion to manufactured gas service (Stotz & Jamison, 1938). The results are similar to the main estimates in the regulated period suggesting that this uncertainty was alleviated after the implementation of federal regulation.

## 6 Factors that Led to Earlier Adoption

In this section, I explore the factors that led certain incumbent manufactured gas utility firms to adopt natural gas service earlier than others. Incumbent firms faced several potential constraints that could delay adoption. This analysis identifies the factors most associated with delayed adoption before 1938 and considers which provisions of the Natural Gas Act are consistent with addressing them. Documenting which factors contribute to the firm's switching decision provides insight into how the regulatory environment and market structure shaped the diffusion of natural gas, beyond what can be observed through a binary analysis of whether a firm adopted or not.

To examine these factors, I supplement my data with detailed information for manufactured gas firms from the 1926 edition of *Brown's Directory.* I observe a firm's ownership status in 1926 (public or private), whether the firm was held or controlled by a holding company, miles of local gas distribution mains, annual gas production, distance to the natural gas pipeline, and the population of each served municipality. Consistent with the earlier analysis, the sample is restricted to municipalities located more than 30 miles from the principal destination cities. The resulting sample includes 341 manufactured gas firms; of these, 149 had switched to natural gas by 1938, 105 switched between 1938 and 1950, 66 by 1960, and 21 after 1960. The sample represents about 82 percent of municipalities served by manufactured gas utility firms in 1926. I use characteristics measured in 1926 to mitigate concerns that firms adjusted behavior in anticipation of pipeline access. Because some firms served multiple municipalities and converted them at different dates, each municipality is treated as a separate observational unit. For firms serving multiple municipalities, I allocate firm totals across municipalities in proportion to each municipality's share of the firm's total population served.

I consider three main factors that could have led some incumbent manufactured gas firms to be early adopters. The first are the costs of switching from providing manufactured gas to natural gas. Manufactured gas firms would have encountered two primary switching costs. The first would be the construction of an off-shoot distribution pipeline to connect the local system to the interstate line. I proxy for this with an indicator that is equal to 1 if a municipality is within 60 miles of the straight-line path of the pipeline. The second cost relates to retrofitting existing infrastructure. Natural gas is dryer than manufactured gas so existing gas mains and appliances needed to be treated to handle the new gas. I use the miles of local gas distribution mains as a measure of the cost of retrofitting existing infrastructure. Larger manufactured gas firms would have encountered greater costs to retrofit all their existing gas main infrastructure compared to smaller firms.

The second factor is local demand characteristics which I measure with population and annual gas production. Municipalities with greater demand for gas service may have switched earlier. Annual gas production serves as a proxy for existing demand for gas utility service. Population serves as a proxy for market potential and the gains from expanding service. Switching to natural gas would lower the marginal cost of expansion because firms would no longer need to invest in increasing production capacity. These variables provide insight into the role of local demand on a firm's decision to switch service from manufactured to natural gas.

The final factor is ownership. Firms that were owned by large holding companies may have had greater access to financing to fund the switch from manufactured to natural gas. Also, being part of a holding company may have facilitated knowledge transfer about the logistics of adoption. Publicly owned firms may have faced greater difficulty raising funds.

I classify firms into adoption groups by the year they first provided natural gas service. I consider firms that adopted before and after the implementation of federal regulation. I further divide the period with federal regulation into an initial period, that includes World War II, and a later period, after the conclusion of World War II. The four adoption groups are: (1) adopted by 1938, the last year before the Natural Gas Act; (2) adopted by 1950, in the initial period after the implementation of federal regulation; (3) adopted by 1960, a later period after the introduction of federal regulation; and (4) adopted after 1960.

Table 6 reports the summary statistics of these factors for the full sample and by adoption

Table 6: Factors of Natural Gas Adoption Summary Statistics

| | Full Sample | Switched by 1938 | Switched by 1950 | Switched by 1960 | Switched after 1960 |
|---|---|---|---|---|---|
| Proportion Within 60 Miles of Straight-line Path | 0.57 | 0.79 | 0.49 | 0.39 | 0.10 |
| | (0.50) | (0.41) | (0.50) | (0.49) | (0.30) |
| Population | 14,159 | 15,384 | 13,164 | 13,076 | 13,850 |
| | (20,153) | (22,626) | (18,914) | (15,817) | (20,555) |
| Miles of Gas Mains | 34.77 | 39.40 | 35.14 | 25.98 | 27.73 |
| | (47.16) | (57.81) | (39.44) | (28.21) | (43.95) |
| Annual Gas Production | 78.0 | 81.2 | 85.2 | 60.9 | 72.9 |
| | (165.0) | (176.0) | (175.0) | (91.8) | (213.0) |
| Proportion Owned by a Holding Company | 0.54 | 0.63 | 0.49 | 0.52 | 0.29 |
| | (0.50) | (0.48) | (0.50) | (0.50) | (0.46) |
| Proportion Publicly Owned | 0.02 | 0.01 | 0.01 | 0.06 | 0.10 |
| | (0.15) | (0.08) | (0.10) | (0.24) | (0.30) |
| Observations | 341 | 149 | 105 | 66 | 21 |

Standard deviations are in parentheses. *Within 60 Miles of Straight-line Path* equals 1 if a municipality lies within 60 miles of the straight-line pipeline path after the completion of the first wave of natural gas pipelines in 1932. *Population* is the municipality's population in 1926. *Miles of Gas Mains* is total miles of local gas distribution mains in 1926. *Annual Gas Production* is the total gas produced for sales in 1926 and is in units of millions of cu. ft. *Owned by a Holding Company* equals 1 if the utility was owned or controlled by a holding company in 1926. *Publicly Owned* equals 1 if the utility was owned and operated by the municipality. Values are population-weighted for firms serving multiple municipalities.

group. Earlier adopters were, on average, located closer to the pipeline. Of those that switched by 1938, 79 percent were located within 60 miles of the straight line path of the pipeline compared with 49 percent among those switching by 1950, 39 percent by 1960, and 10 percent after 1960. Earlier adopters also served larger markets. Average market population was over 15,000 for firms switching by 1938 compared to averages of 13,000 for later adopters. Early adopters also had larger local networks on average. Miles of gas mains averaged 39.4 for those switching by 1938 and 35.1 for those switching by 1950, relative to 26.0 and 27.7 for the later groups. Annual gas production is highest among firms that switched by 1938 and 1950 and lower for those switching by or after 1960. Ownership patterns differ across groups. Among early adopters, 63 percent were owned by holding companies, compared with 49 and 52 percent in the middle groups and 29 percent among those switching after 1960. Public ownership is rare but more common among later adopters.

To test these factors, I estimate a multinomial logit model. The dependent variable assigns each municipality to one of four categories: switched by 1938, by 1950, by 1960, or after 1960. The decision of whether to adopt natural gas for an incumbent firm can be described by the relative costs and benefits of providing natural gas as opposed to manufactured gas. A firm will make the switch when the profitability of providing natural gas is greater than continuing to provide manufactured gas. This can be modeled as below:

$$y_{it}^* = \beta' x_{it} + \varepsilon_{it} \tag{2}$$

Where $y_{it}^*$ is an unobservable latent variable and $x_{it}$ are the observed explanatory variables, $\beta$ is a vector of parameters to be estimated, and $\varepsilon_{it}$ is an error term which includes both firm specific and idiosyncratic components. Because only the timing of adoption is observed, not the underlying profit difference, I define the observed indicator:

$$y_{it} = 1 \quad \text{if } y_{it}^* > 0$$
$$y_{it} = 0 \quad \text{if } y_{it}^* \leq 0$$

I describe the probability of adoption as a function of the observed explanatory variables:

$$\Pr(y_{it}^* > 0) = \Pr(y_{it} = 1) = G(\beta' x_{it}) \tag{3}$$

Under the assumption $\varepsilon_{it}$ is i.i.d. type-1 extreme value, $G(\beta' x_{it})$ is the logistic probability formula. I map the different unordered outcomes to $j = 1, 2, 3, 4$ respectively as: (1) adopted by 1938; (2) adopted by 1950 conditional on not adopting before 1938; (3) adopted by 1960 conditional on not adopting before 1950; and (4) adopted after 1960 conditional on not adopting before 1960.

To limit endogeneity from firms anticipating pipeline access, I take two measures. First, I exclude municipalities within 30 miles of the destination cities, where firms may have had advance knowledge of pipeline routes and timing. Second, I measure firm characteristics in 1926, before pipeline construction, so these covariates are predetermined with respect to adoption.

By reducing the adoption decision as a function of firm characteristics fixed at 1926 values, the problem reduces to a single period estimation. I set adopted by 1960 as the base category since this the latest period in which I observe when firms switch to natural gas. The probabilities of being in a specific outcome are:

$$\Pr(y_i = j) = \frac{e^{\beta_j' x_i}}{1 + \sum_{k=0}^{J} e^{\beta_k' x_i}} \quad \text{for } j \in \{1, 2, 4\} \tag{4}$$

$$\Pr(y_i = 3) = \frac{1}{1 + \sum_{k=0}^{J} e^{\beta'_k x_i}} \tag{5}$$

The maximum likelihood estimates of the multinomial logit model are reported in Table 7. Column (1) reports the estimates using the variables described above and column (2) implements state indicators in order to help control for differences across firms in different states. Column (2) is my preferred specification and I report the marginal effects for column (2) in Table 8. Being within sixty miles raises the probability of adoption by 1938 by 27.5 percentage points and lowers the probabilities of adoption for the later periods. This effect is statistically significant at the 95 percent confidence level for the adopted by 1938, by 1950, and after 1960 categories. These patterns align with the view that lower connection costs are tied to earlier switching. The miles of local mains have a positive marginal effect for adoption by 1950 of about 13.4 percentage points, being statistically significant at the 90 percent confidence level, while small and imprecise effects for the other categories. This suggests that switching costs associated with existing infrastructure is associated with increased adoption in the initial period after the adoption of the Natural Gas Act.

When considering the role of demand in determining whether a firm is an earlier adopter, the log of population has a negative marginal effect for adoption by 1950 at the ten percent level and near zero elsewhere. Log annual gas production has a small negative effect for adoption by 1938 at the ten percent level and is near zero for the other categories. These results suggest that local demand may have not been a primary factor in driving the adoption of natural gas. For ownership, affiliation with a holding company is associated with a 13.8 percentage point increase in the probability of adoption by 1938. This is significant at the 99 percent confidence level. Being owned by a holding company is associated with a 9.5 and 5.3 percentage point decrease in the probability of adoption by 1950 and after 1960. Both of these are statistically significant at the 90 percent confidence level. Public ownership shows imprecise estimates across all categories. These results suggest that in the period before federal regulation, being owned by a holding company helped overcome incumbent delay perhaps through the ease of securing financing and through the coordination of the logistics of switching services.

Table 7: Multinomial Logit Estimates of Factors of Natural Gas Adoption

| | (1) | (2) |
|---|---|---|
| *Adopted by 1938* | | |
| Within 60 Miles of Straight-line Path | 1.801*** | 1.566*** |
| | (0.346) | (0.464) |
| Log Population | -0.250 | 0.223 |
| | (0.425) | (0.547) |
| Log Miles of Gas Mains | 0.827** | 0.451 |
| | (0.412) | (0.524) |
| Log Annual Gas Production | -0.321* | -0.327 |
| | (0.169) | (0.260) |
| Owned by a Holding Company | 0.360 | 0.517 |
| | (0.346) | (0.390) |
| Publicly Owned | -2.041* | -1.658 |
| | (1.196) | (1.506) |
| *Adopted by 1950* | | |
| Within 60 Miles of Straight-line Path | 0.285 | 0.177 |
| | (0.340) | (0.452) |
| Log Population | -0.944** | -0.449 |
| | (0.433) | (0.525) |
| Log Miles of Gas Mains | 1.388*** | 0.959* |
| | (0.418) | (0.508) |
| Log Annual Gas Production | -0.162 | -0.182 |
| | (0.172) | (0.261) |
| Owned by a Holding Company | -0.421 | -0.290 |
| | (0.347) | (0.372) |
| Publicly Owned | -1.654 | -0.541 |
| | (1.170) | (1.454) |
| *Adopted after 1960* | | |
| Within 60 Miles of Straight-line Path | -2.016** | -1.670* |
| | (0.801) | (0.904) |
| Log Population | 0.418 | 0.809 |
| | (0.683) | (0.864) |
| Log Miles of Gas Mains | 0.044 | -0.180 |
| | (0.619) | (0.779) |
| Log Annual Gas Production | -0.296 | -0.430 |
| | (0.275) | (0.346) |
| Owned by a Holding Company | -1.287** | -1.169* |
| | (0.583) | (0.637) |
| Publicly Owned | 0.027 | 0.135 |
| | (1.026) | (1.209) |
| State Indicators | No | Yes |
| Observations | 341 | 341 |
| Log Likelihood | -357.94 | -316.31 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Switched by 1960 is the base category. Standard errors are in parentheses. The dependent variable is an indicator that is equal to 1 if a municipality first receives natural gas service by 1938, equal to 2 if a municipality first receives natural gas service by 1950, equal to 3 if a municipality first receives natural gas service by 1960, and equal to 4 if a municipality first receives natural gas service after 1960. *Within 60 Miles of Straight-line Path* equals 1 if a municipality lies within 60 miles of the straight-line pipeline path after the completion of the first wave of natural gas pipelines in 1932. *Population* is the municipality's population in 1926. *Miles of Gas Mains* is total miles of local gas distribution mains in 1926. *Annual Gas Production* is the total gas produced for sales in 1926 and is in units of millions of cu. ft. *Owned by a Holding Company* equals 1 if the utility was owned or controlled by a holding company in 1926. *Publicly Owned* equals 1 if the utility was owned and operated by the municipality. Values are population-weighted for firms serving multiple municipalities.

Table 8: Marginal Effects for Factors of Natural Gas Adoption

| | (1) Adopted by 1938 | (2) Adopted by 1950 | (3) Adopted by 1960 | (4) Adopted after 1960 |
|---|---|---|---|---|
| Within 60 Miles of Straight-line Path | 0.275*** | -0.121** | -0.059 | -0.095** |
| | (0.051) | (0.058) | (0.049) | (0.040) |
| Log Population | 0.086 | -0.128* | -0.002 | 0.044 |
| | (0.075) | (0.076) | (0.059) | (0.037) |
| Log Miles of Gas Mains | -0.031 | 0.134* | -0.072 | -0.030 |
| | (0.068) | (0.069) | (0.057) | (0.032) |
| Log Annual Gas Production | -0.033* | 0.012 | 0.035 | -0.014 |
| | (0.020) | (0.022) | (0.032) | (0.013) |
| Owned by a Holding Company | 0.138*** | -0.095* | 0.011 | -0.053* |
| | (0.052) | (0.053) | (0.041) | (0.027) |
| Publicly Owned | -0.235 | 0.090 | 0.113 | 0.031 |
| | (0.245) | (0.252) | (0.141) | (0.056) |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Average marginal effects from multinomial logit estimates. Standard errors are in parentheses. The dependent variable is an indicator that is equal to 1 if a municipality first receives natural gas service by 1938, equal to 2 if a municipality first receives natural gas service by 1950, equal to 3 if a municipality first receives natural gas service by 1960, and equal to 4 if a municipality first receives natural gas service after 1960. *Within 60 Miles of Straight-line Path* equals 1 if a municipality lies within 60 miles of the straight-line pipeline path after the completion of the first wave of natural gas pipelines in 1932. *Population* is the municipality's population in 1926. *Miles of Gas Mains* is total miles of local gas distribution mains in 1926. *Annual Gas Production* is the total gas produced for sales in 1926 and is in units of millions of cu. ft. *Owned by a Holding Company* equals 1 if the utility was owned or controlled by a holding company in 1926. *Publicly Owned* equals 1 if the utility was owned and operated by the municipality. Values are population-weighted for firms serving multiple municipalities.

# 7 Conclusion

In this paper, I analyze the role of incumbent manufactured gas firms in America's transition to natural gas utility service during the first half of the 20th century. Specifically, I test how the decision of incumbent manufactured gas firms to switch to natural gas service was influenced by the market structure and regulatory environment. During the initial unregulated period (1920-1938), incumbents delayed adopting natural gas despite geographic proximity. In the subsequent regulated period (1938-1960) following the passing of the Natural Gas Act, incumbents accelerated adoption suggesting that regulatory oversight changed the economic environment in a way that reduced barriers and pricing uncertainty allowing incumbents to facilitate the energy transition. Furthermore, while proximity strongly influenced adoption likelihood initially, this effect diminished after the implementation of federal regulation. Through the implementation of federal pricing regulation, the incentives incumbents faced changed to become active facilitators in the transition.

What makes the transition from manufactured to natural gas energy unique was how quickly it was completed taking only around three decades. For the Midwestern, Southern, and Western United States it was largely completed by the mid-1950's. The Northeastern states were not far behind following the completion of the emergency wartime pipelines (Castaneda & Pratt, 1989). The implementation of federal pricing regulation with the Natural Gas Act in 1938 and the expansion of the regulatory powers in the mid-1950s ensured an environment where making the transition was the profitable move for all incumbent gas utility firms. Regulation was so effective in keeping the prices of natural gas low across the whole distribution chain that it helped spur the gas shortage that would later occur in 1970s.

The role of coordination in facilitating a quick transition is mirrored in the United Kingdom's transition from manufactured to natural gas service in the later 1960s. Directly overseen by its central government from the beginning, the United Kingdom completed its own transition in about a decade (Arapostathis, Laczay, & Pearson, 2019). In contrast in the disaggregated energy markets today, we encounter many settings the incentives of firms do not align with the shortest and most direct time line to completing the transition (Hausman, 2024; Kemfert, Präger, Braunger, Hoffart, & Brauers, 2022; Smil, 2014).

Overall, this analysis highlights the significant role that regulatory frameworks and market structures play in energy transitions. The relatively swift transition from manufactured gas to natural gas in the United States was driven in part by federal which helped curtail the monopoly power of pipelines and increase the certainty in the future availability of the natural gas supply. Understanding these historical dynamics provides valuable insights for policymakers and industries seeking similarly efficient transitions to sustainable energy sources today.

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## A.1 Appendix Figures

Figure A.1: Progression of natural gas pipeline construction for pipelines in the analysis.

(a) 1920 – 1928

(b) 1930

(c) 1932 – 1944

(d) 1946 - 1948

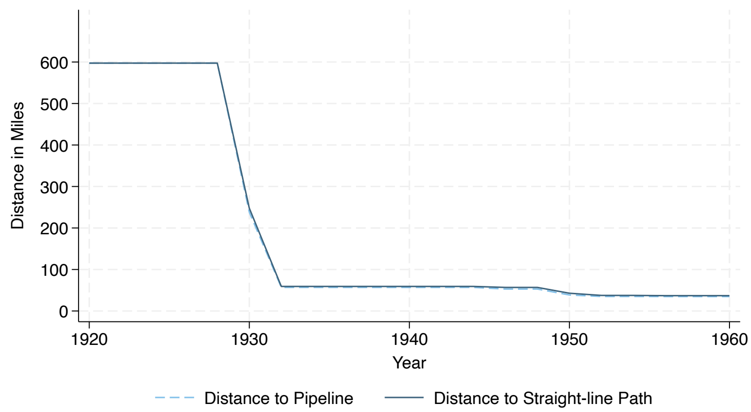
(e) 1950

(f) 1952 - 1954

(g) 1956 - 1960

Sources: Federal Trade Commission (1940) and Federal Power Commission (1956).
Notes: Map of natural gas pipelines built over the period 1926–1956. Includes only the primary natural gas pipeline artery; off-shoot pipelines are not mapped.

Figure A.2: Average Distance to Natural Gas Pipeline and Straight-line Path




Notes: Average distance in miles to the nearest natural gas source. Distance to Pipeline is the distance to a natural gas pipeline or distance to southwestern natural gas field. Distance to Straight-line is the distance to the straight-line path of the pipeline.

## A.2 Appendix Tables

Table A.1: Robustness – Probit Estimates

| **Panel (a): Probit Estimates** | **Unregulated Period 1920 – 1938** | **Regulated Period 1938 – 1960** |
|---|---|---|
| | Municipality Receives Natural Gas Service | |
| | (1) | (2) |
| Incumbent Manufactured Gas Firm | -0.298** | 0.115 |
| | (0.132) | (0.148) |
| Within 60 Miles of Pipeline | 0.699*** | 0.347*** |
| | (0.134) | (0.054) |
| Incumbent Firm × Within 60 Miles of Pipeline | 0.037 | 0.385** |
| | (0.150) | (0.164) |
| Log of Population | -0.038 | 0.088*** |
| | (0.034) | (0.032) |
| Observations | 2,762 | 5,656 |

| **Panel (b): Marginal Effects** | **Unregulated Period 1920 – 1938** | **Regulated Period 1938 – 1960** |
|---|---|---|
| | Municipality Receives Natural Gas Service | |
| | (1) | (2) |
| Incumbent Manufactured Gas Firm | -0.052** | 0.020 |
| | (0.023) | (0.025) |
| Within 60 Miles of Pipeline | 0.122*** | 0.060*** |
| | (0.022) | (0.016) |
| Incumbent Firm × Within 60 Miles of Pipeline | 0.006 | 0.066** |
| | (0.026) | (0.028) |
| Log of Population | -0.006 | 0.015*** |
| | (0.006) | (0.005) |
| Observations | 2,762 | 5,656 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are in parentheses and clustered at the county level. Panel (a) reports the coefficients of the probit estimates and panel (b) reports the marginal effects. The dependent variable for all regressions is an indicator that is equal to 1 if a municipality receives natural gas in that year and equal to 0 otherwise. *Within 60 Miles of Pipeline* is an indicator variable equal to 1 if a municipality lies within 60 miles of the straight-line path of the natural gas pipeline. *Incumbent Manufactured Gas Firm* is an indicator variable equal to 1 if a municipality ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. *Log of Population* is the log of a municipality's population. All regressions include municipality-level random effects and year indicators.

Table A.2: Robustness – IV Estimates

| | **Unregulated Period 1920 – 1938** | **Regulated Period 1938 – 1960** |
|---|---|---|
| | Municipality Receives Natural Gas Service | |
| | (1) | (2) |
| Within 60 Miles of Pipeline | 0.274*** | 0.052 |
| | (0.041) | (0.054) |
| Incumbent Firm × Within 60 Miles of Pipeline | -0.099** | 0.396*** |
| | (0.048) | (0.096) |
| Observations | 6,257 | 6,440 |
| First-stage F-stat | 252.2 | 35.7 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are in parentheses, robust to heteroskedasticity, and clustered at the county level. Two stage least squares regression, with second stage results and cluster-robust Kleibergen-Paap Wald rk F statistic from 1st stage reported. The dependent variable for all regressions is an indicator that is equal to 1 if a municipality receives natural gas in that year and equal to 0 otherwise. *Within 60 Miles of Pipeline* is an indicator variable equal to 1 if a municipality lies within 60 miles of the straight-line path of the natural gas pipeline. *Incumbent Firm* is an indicator variable equal to 1 if a municipality ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. The independent variables are full interaction of indicators with an indicator variable equal to 1 if a municipality lies within 60 miles of the straight-line path of the natural gas pipeline. All regressions include municipality and year fixed effects. Control variables include the log of population.

## A.3 Data Digitization

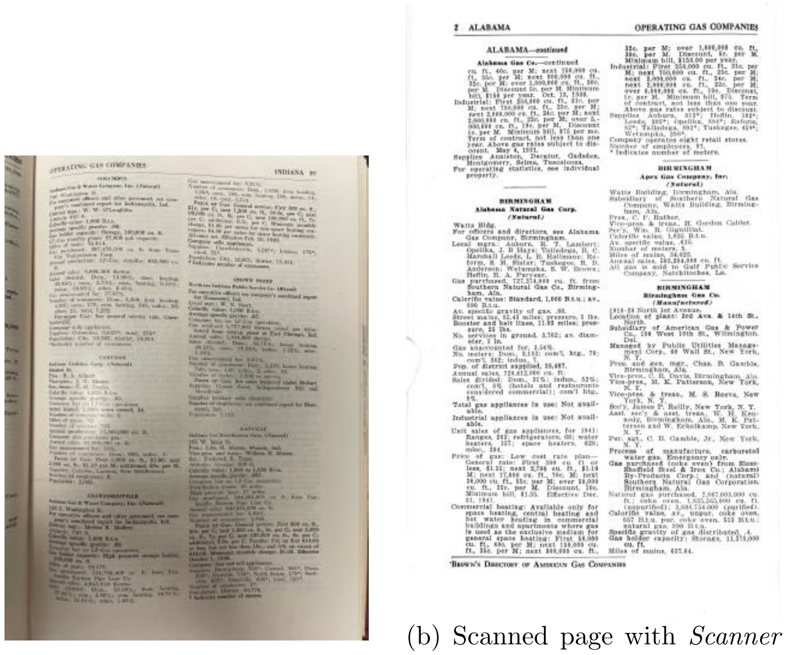
This appendix section documents the digitization process for Brown's Directory of American Gas Companies. The workflow consisted of five steps: (1) obtaining digital scans of the physical books, (2) preparing the scans for optical character recognition (OCR), (3) processing the scans with OCR, (4) separating the OCR output into firm-specific text files, and (5) extracting information from these text files using Python.

The first step was to obtain scans of the physical Brown's Directory volumes. While some editions published before 1925 have been digitized by Google Books and certain university libraries, no editions after 1924 are available online. I therefore created scans for all post-1924 editions. I used an iPhone 14 with the *Scanner Pro* application. The iPhone camera produces sufficiently high-quality images, and *Scanner Pro* automatically flattens, straightens, and increases the black-and-white contrast of each page as the image is taken. Figure A.3 illustrates the improvement compared to using the iPhone camera alone. Although similar adjustments can be applied with Python modules, they are difficult to do simultaneously with a large set of images because different pages often require distinct settings. By processing each image at the time of capture, *Scanner Pro* added time during scanning but reduced time during later preparation.

The second step of my digitization process was preparing the images for processing with OCR. The main challenge in preparing the scans was segmenting the page into columns, since Amazon's *Textract* cannot detect columns automatically. I therefore the cropping of pages in two stages. First, I removed the page headers and footers. This involved dilating the image so that near-white pixels became black and near-black pixels became white, horizontally blurring the text to produce continuous white bands across the page, and then detecting the narrow, wide regions corresponding to headers and footers. These regions were cropped from the original image.

The second step is similar to the first. I dilate the page as before, but this time blurred vertically to generate continuous white bands corresponding to columns. This is depicted in Panel A of Figure A.4. It is important to not blur the pixels in the horizontal direction to preserve the separate columns. I then detect the continuous set of white pixel columns and draw a bounding box around them. This is depicted in Panel B of Figure A.4. Using the location these bounding boxes, I crop each page. I perform these last two steps individually for each page giving me a resulting

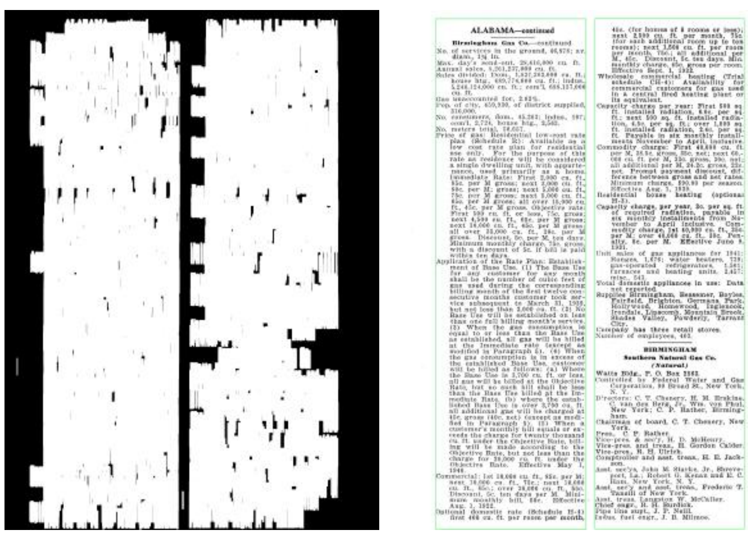
Figure A.3: Comparison of a page scanned with a standard camera versus *Scanner Pro*.



(a) Scanned page with iPhone

(b) Scanned page with *Scanner Pro*

Figure A.4: Column detection example



(a) Dilated page.

(b) Page with bounding boxes

set of images that are just the individual columns.

The third step of my digitization is processing the resulting images with Amazon's *Textract*. Most of the critical work has already been done to ensure that the resulting text file is with minimal errors. I chose *Textract* over other OCR options due to its ability to successfully recognize faint or

Figure A.5: Final individual firm text file example

```
ANNISTON
Alabama Gas Co.
(Natural)
For officers and directors, see Alabama
Gas Company, Birmingham.
1221 Noble St.
Local mgr., R. A. Puryear, Jr.
Gas purchased from Southern Natural
Gas Co.
Annual sales, 1,135,751,000 cu. ft.
Sales divided: Dom., 13%; indus. and
com'l, 85%, space heating, 2%.
No. meters: Dom., 2,900; indus. and com'l,
356, space heating, 24.
Miles of gas mains, 116.1 (3 in. equiv.)
Av. sp. gravity of gas distributed, .6.
No. of services in the ground, 3,215.
Calorific value: Average, 990 B.t.u.
Pop. of district supplied, 27,935.
Gas unaccounted for, 4%
Price of gas: See rates for Alabama Gas
Company, Birmingham.
Unit sales of gas appliances sold, 1941,
ranges, 238; refrigerators, 84; water
heaters, 178; misc., 519.
Supplies Anniston, Oxford and Blue
Mountain.
Company operates one retail store.
Number of employees, 45.


File: page_2.pdf
```

partially degraded characters. Using the *Textract* API in Python I was able to easily batch process all images.

The fourth step was to separate the OCR output into firm-specific files. The goal of this step is to end up with a text file that contains the entry of a single firm. Since my source often has firm information extend across multiple columns and pages yet only include the firm's name and location at times at the top of the entry. For the 1942 edition shown in the Figures, the municipality is consistently printed in all capital letters at the start of each firm entry. I used this formatting feature to detect boundaries between entries. Python scripts then combined and segmented the OCR text into individual firm files. Figure A.5 shows an example of one such file.

The final step was to extract relevant variables from the firm-level text files. Most variables were identified by searching for consistent text label strings and capturing the text that followed. For example, to extract "Miles of gas mains," I used the Python re module to identify the string "Miles of gas mains," and capture the following value "116.1 (3 in. equiv." These values were then cleaned as needed. Because the *Brown's Directory* used relatively consistent labeling conventions across editions, it was feasible to compile a complete list of label variants for each variable of interest. While this method was effective, recent advances in generative AI have made rule-based extraction increasingly obsolete. Modern large language models can be prompted to extract structured variables directly from firm entries, often more efficiently than pattern matching. As these tools improve, extracting data from historical sources will become simpler and more feasible.

## A.4 Role of Pipeline Proximity

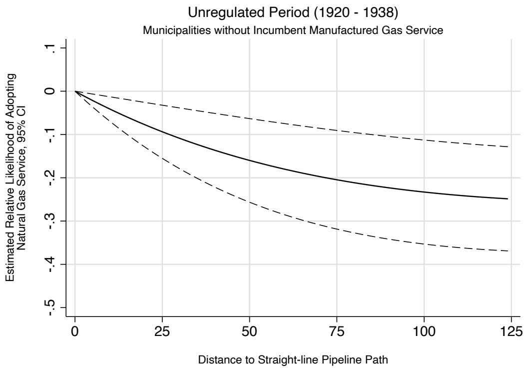
In the main analysis, I treated distance as a discrete variable by classifying municipalities as either near to or far from the natural gas pipeline. However, distance may have influenced adoption decisions more continuously. To better understand the role that pipeline proximity played in adoption decisions during the unregulated period, I estimate a variant of the primary specification in which distance enters the linear probability model as a flexible polynomial, as shown below in equation (6).

$$\begin{aligned} natural\_gas_{mt} = {} & \beta_1\, manufactured\_gas_m \cdot F(distance_{mt}) \\ & + \beta_2 \cdot F(distance_{mt}) + \gamma X_{mt} + \lambda_t + \alpha_m + \varepsilon_{mt} \end{aligned} \tag{6}$$

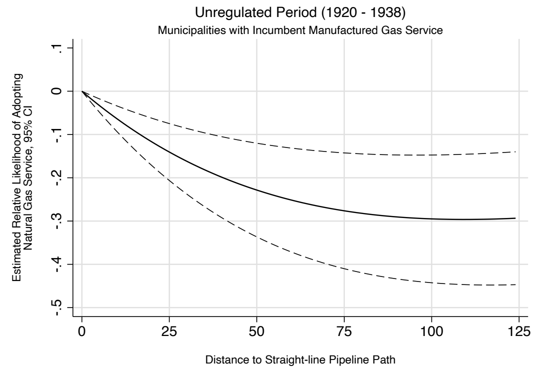
The dependent variable $natural\_gas_{mt}$ is an indicator equal to one if municipality $m$ receives natural gas service in year $t$ and is equal to zero otherwise. $manufactured\_gas_m$ is an indicator variable that is equal to one if a municipality received manufactured gas service before 1930, the first year of treatment, and is equal to zero otherwise. $distance_{mt}$ is the distance in miles to the straight-line path from the southwestern natural gas fields to the principal destination cities. *F()* is a flexible polynomial to the sixth degree. $X_{mt}$ is a matrix of controls that includes a municipality's population. $\lambda_t$ and $\alpha_m$ are year and municipality fixed effects, respectively. The error term $\epsilon_{mt}$ captures the unobservable municipality characteristics not accounted for by the set of fixed effects and controls and is clustered at the county level.

I estimate equation (6) where distance from the straight-line path is implemented using a sixth degree polynomial. I implement such a high degree polynomial in order to ensure sufficient curvature of the results. Because the full set of estimated $\beta$ coefficients is difficult to interpret directly, I present the results graphically in Figure A.6. The estimated coefficients from equation (2) are reported in Table A.3. The solid line in each panel shows the estimated effect of distance on the likelihood of adopting natural gas, relative to a municipality located directly along the pipeline's path. The dashed lines denote the 95% confidence interval. I estimate equation (2) with the unregulated period sample since the earlier results suggest that distance was particularly

Figure A.6: Estimated Relative Likelihood of Adopting Natural Gas Service Across Incumbency Status




(a)




(b)

Notes: Estimates of equation (2). The 95% confidence interval is indicated by dashed lines. Standard errors are robust to heteroskedasticity, and clustered at the county level. The dependent variable for all regressions is an indicator that is equal to 1 if a municipality receives natural gas in that year and equal to 0 otherwise. *Distance to Straight-line Pipeline Path* is the distance in miles to the straight-line path from the southwestern gas fields and the principal destination cities. All regressions include state and year fixed effects. Control variables include the log of population. All distances are calculated in miles. (a) depicts the effect of the distance from the natural gas pipeline on the likelihood of adopting natural gas service for municipalities that had no previous gas service relative to a municipality located in the pipeline's direct path during the unregulated period. (b) depicts the effect of having an incumbent manufactured gas firm and the distance from the natural gas pipeline on the likelihood of adopting natural gas service relative to a municipality with no incumbent gas service located in the pipeline's direct path during the unregulated period.

important for adoption in this initial period.

Panels (a) and (b) of Figure A.6 present the estimates. Panel (a) gives the effect of distance from the natural gas pipelines' path on the likelihood of adopting natural gas for municipalities that had previous gas service relative to a municipality located in the pipeline's direct path. Panel (b) presents the effect of having an incumbent manufactured gas firm and the distance from the natural gas pipeline on the likelihood of adopting natural gas service relative to a municipality with no incumbent gas service located in the pipelines' direct path. At each respective distance, municipalities with incumbent manufactured gas service see a larger decrease in the probability of adopting natural gas. These results imply that distance was a significant barrier to early adoption. During the unregulated period, being close to the pipeline was an important determinant of adoption, but its benefit was weaker for municipalities with existing manufactured gas service.

Table A.3: Role of Distance – 6th Degree Polynomial

| | Municipality Receives Natural Gas<br>(1) |
|---|---|
| Distance to Straight-line Pipeline Path | -0.00439*** |
| | (0.00159) |
| Distance to Straight-line Pipeline Path Squared | 2.77e-05* |
| | (1.54e-05) |
| Distance to Straight-line Pipeline Path Cubed | -8.35e-08 |
| | (6.16e-08) |
| Distance to Straight-line Pipeline Path Quartic | 1.36e-10 |
| | (1.17e-10) |
| Distance to Straight-line Pipeline Path Quintic | -1.10e-13 |
| | (1.04e-13) |
| Distance to Straight-line Pipeline Path Sextic | 3.44e-17 |
| | (3.54e-17) |
| Incumbent Firm × Distance to Straight-line Path | -2.48e-03 |
| | (2.13e-03) |
| Incumbent Firm × Distance to Straight-line Path Squared | 2.65e-05 |
| | (1.89e-05) |
| Incumbent Firm × Distance to Straight-line Path Cubed | -9.25e-08 |
| | (7.25e-08) |
| Incumbent Firm × Distance to Straight-line Path Quartic | 1.50e-10 |
| | (1.34e-10) |
| Incumbent Firm × Distance to Straight-line Path Quintic | -1.18e-13 |
| | (1.19e-13) |
| Incumbent Firm × Distance to Straight-line Path Sextic | 3.63e-17 |
| | (4.01e-17) |
| Observations | 6,257 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are in parentheses, robust to heteroskedasticity, and clustered at the county level. The dependent variable equals 1 if a municipality receives natural gas in that year and 0 otherwise. *Incumbent Manufactured Gas Firm* equals 1 if a municipality ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. *Distance to Straight-line Pipeline path* is the distance in miles to the straight-line path of the natural gas pipeline. All regressions include municipality and year fixed effects. Controls include log population.

## A.5 Role of the 1938 Natural Gas Act

In the main analysis, I examined only two periods: before and after the 1938 Natural Gas Act. In this section, I conduct a year-by-year analysis to identify when the Natural Gas Act began to bind as a regulatory constraint and when incumbents shifted from delaying adoption to facilitating a more rapid transition. In order to perform this analysis, I estimate equation (1) separately for each year from 1932 to 1960. For each year I limit the sample to include only the municipalities that had received gas utility service of any type by that year.[5] As in my main specification, municipalities are removed from the panel after receiving natural gas service. The increasing sample, year-by-year estimation should reveal when the interaction term, capturing the role of incumbent firms near the pipeline, shifted from a negative to a null or positive effect.

For a visual comparison, figure A.7 plots the interaction term estimates with 95% confidence intervals. Table A.4 in the appendix reports the estimates for all years and coefficients. Indicative of the increasing sample size, is the decreasing confidence intervals as the year increases. From 1932 through 1946, municipalities within 60 miles of the pipeline that had incumbent manufactured gas firms had a lower likelihood of adopting natural gas service relative to municipalities previously without gas utility service. This negative effect persisted for several years after the passage of 1938 Natural Gas Act. Not until 1946, did the effect of an incumbent begin to converge to zero. By 1958, having an incumbent manufactured gas firm increased the likelihood of adopting natural gas.

These results point to a period of regulatory lag between the passage of the Natural Gas Act and its effective implementation. Initially, incumbents' sunk costs in manufactured gas and uncertainty regarding future prices forestalled early transition to natural gas. This remained true for about a decade after the introduction of federal regulation. However, after this initial period, federal price controls and regulatory clarity lowered the risk and costs of transitioning. Incumbent firms became facilitators in accelerating natural gas adoption, providing a setting documenting how regulation can help align incumbent incentives to support technological transitions.

[5]For example, the 1932 sample includes only municipalities that received any gas utility service by 1932. municipalities without service by that year are excluded. For 1934, the sample includes all the municipalities in the 1932 sample as well as the additional municipalities which received gas utility service by 1934.

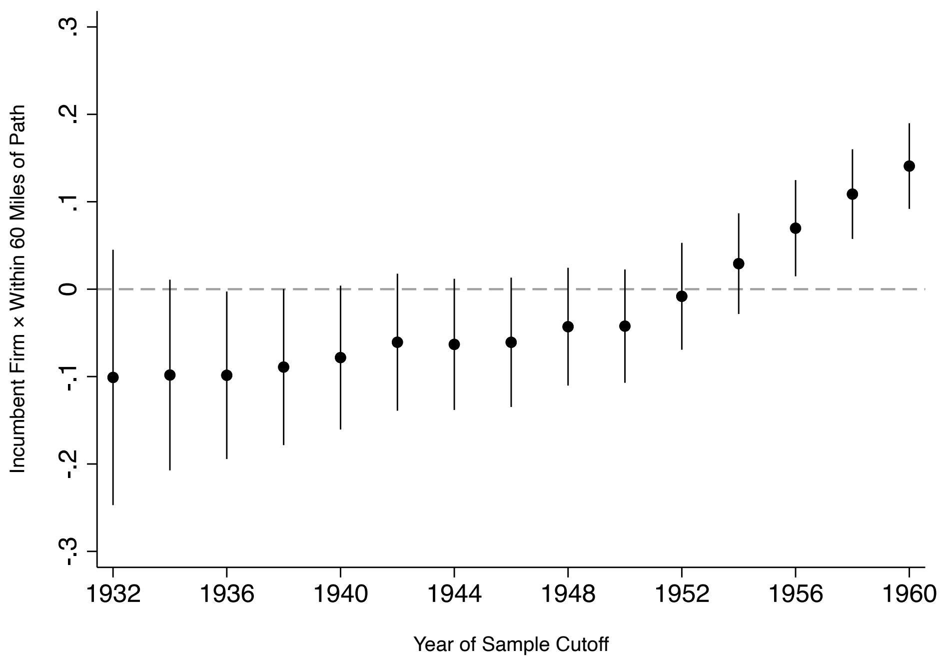
Table A.4: Effect of Incumbent Manufactured Gas Firm Over Time

| | (1) 1932 | (2) 1934 | (3) 1936 | (4) 1938 | (5) 1940 | (6) 1942 | (7) 1944 | (8) 1946 | (9) 1948 | (10) 1950 | (11) 1952 | (12) 1954 | (13) 1956 | (14) 1958 | (15) 1960 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Incumbent Firm × Distance to Straight-line Path | -0.101 | -0.098* | -0.099** | -0.089* | -0.078* | -0.061 | -0.063* | -0.061 | -0.043 | -0.042 | -0.008 | 0.029 | 0.070** | 0.109*** | 0.141*** |
| | (0.074) | (0.055) | (0.049) | (0.045) | (0.042) | (0.040) | (0.038) | (0.038) | (0.034) | (0.033) | (0.031) | (0.029) | (0.028) | (0.026) | (0.025) |
| Distance to Straight-line Pipeline Path | 0.266*** | 0.258*** | 0.242*** | 0.223*** | 0.213*** | 0.196*** | 0.195*** | 0.189*** | 0.176*** | 0.172*** | 0.159*** | 0.132*** | 0.102*** | 0.075*** | 0.055*** |
| | (0.057) | (0.045) | (0.039) | (0.037) | (0.034) | (0.032) | (0.030) | (0.029) | (0.026) | (0.025) | (0.023) | (0.020) | (0.018) | (0.015) | (0.013) |
| Observations | 4,478 | 5,223 | 5,766 | 6,257 | 7,068 | 7,592 | 8,010 | 8,303 | 8,788 | 9,167 | 9,829 | 10,917 | 12,347 | 14,023 | 16,153 |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Standard errors are in parentheses, robust to heteroskedasticity, and clustered at the county level. Estimates of equation (1) with different cut-off years for sample. Each year's sample consists of all municipalities which received gas utility service of any type by the indicated year. The dependent variable equals 1 if a municipality receives natural gas in that year and 0 otherwise. *Incumbent Manufactured Gas Firm* equals 1 if a municipality ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. *Within 60 Miles of Straight-line Path* equals 1 if a municipality lies within 60 miles of the straight-line pipeline path. All regressions include municipality and year fixed effects. Controls include log population.

Figure A.7: Effect of Incumbent Manufactured Gas Firm Over Time




Notes: Error Bars indicate 95% Confidence Interval. Estimates of equation (1) with different cut-off years for sample. Each year's sample consists of all municipalities which received gas utility service of any type by the indicated year. The dependent variable for all regressions is an indicator that is equal to 1 if a municipality receives natural gas in that year and equal to 0 otherwise. The reported coefficient is *Incumbent Firm* $\times$ *Within 60 Miles of Path* which is an indicator variable that is equal to 1 if a municipality lies within 60 miles of the straight-line path of the natural gas pipeline and ever received manufactured gas service and did not also receive natural gas service in the pre-treatment period. All regressions include state and year fixed effects. Control variables include the log of population and a flexible polynomial of latitude and longitude. All distances are calculated in miles. Standard errors are clustered at the county level.