The Erie Canal and the Economic Transformation of Nineteenth-Century New York State

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Abstract

This paper identifies the impact of canals on sectoral transition, urbanization, and banking during the early stages of economic modernization. Using difference-in-differences and instrumental variable approaches, I find that: first, canal towns experience a transition from employment in agriculture to manufacturing and commerce, larger manufacturing mills, and more commercial activities; second, canals promote long-term population growth in existing towns and the formation of new towns; third, canals encourage the entry of new banks and increased bank size in canal towns; moreover, the geographic influence of the canal is limited in terms of employment and population growth.

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1 Introduction

It is well known that developing and developed countries devote substantial fractions of their public budgets to transportation projects to transform economies. Transportation infrastructure increases welfare through its reductions in commuting and shipping costs. It has ancillary effects, as well, in that it can influence the location of populations, employment, sectoral activities, and productivity. In regions where weigh-to-value ratios are high, the arrival of transportation infrastructure that reduces the costs of handling and moving bulky, heavy, relatively low-value agricultural and primary products can fundamentally reshape rural economies.

Much of the modern literature on transportation infrastructure investments focuses on the suburbanization or "decentralization" effects identified by (Baum-Snow, 2007; Baum-Snow et al., 2017). The modern debate concerns the effect of transportation on the mid to late-twentieth-century dispersal of urban populations and employment and its attendant effects on sectoral activities. This paper shows, however, that the early massive transportation investment had the opposite effect. The opening of the Erie Canal led to population growth and growth in employment in commerce, manufacturing, and agriculture in towns proximate to the canal relative to towns between 5 and 15 kilometers from the canal. While the share of workers engaged in agriculture declined, overall agricultural employment increased, which is consistent with a rapid reorientation of agriculture from subsistence to market farming. In the early nineteenth century, three products - wheat, wheat flour, and lumber - accounted for the bulk of goods moved to urban markets in northeastern America. In 1829, millers shipped about 4,000 barrels of flour eastward; in 1835, they shipped more than 150,000 barrels. The canal promoted the growth of high weight-to-value industries and sectors, which is consistent with theoretical results from (Duranton et al., 2014). The canal also promoted local specialization in finance and services in nodal cities and towns, which is also consistent with findings in the study of transportation and urbanization (Atack et al., 2014).

Understanding the effect of canals is important for a number of reasons. First, compared with railroads and highways, canals have not received much academic attention, and the reduction in transportation costs provided by canals, relative to wagon haulage, was more substantial than the subsequent reduction associated with the railroads (Goodrich et al., 1961; Fogel, 1964). Second, the construction and maintenance of canals are among our most costly policy endeavors, and our understanding of the effects of such investments remains unclear. Historically, about 56% of New York State's expenditure went for the Erie Canal construction in eight years (Roberts, 1897). Nowadays, China is investing 120 billion dollars in canal construction in 2024 domestically and is involved in canal construction internationally.

Identifying the causal effects of canals is challenging, mainly because there is a potential selection problem that canals may have been constructed in populated areas with active commercial, manufacturing, and banking activities. To address the potential selection problem, I use the rollout of the canal as a quasi-experiment. My context is the Erie Canal in nineteenth-century New York State. The design and construction of the Erie Canal was led by the state. Unlike private enterprises, the state had a heightened capacity to navigate regional disputes, reconcile political rivalries, and pursue larger-scale construction. The goal was to connect several targeted towns from the West to the East. Consequently, many non-targeted towns incidentally gained access to the canal, which alleviates some endogeneity concerns.

I begin by studying the canal's effects on the sectoral transition from agriculture to manufacturing and commerce. First, I use a difference-in-differences (DiD) design to compare the outcomes in towns located close to the canal (termed canal towns) relative to those that were not close to the canal (termed noncanal towns), before and after its opening in 1825. I find that canal towns had lower employment shares in agriculture, higher employment shares in commerce, and faster manufacturing employment growth compared with noncanal towns that had similar town characteristics before the canal's opening. Quantitatively, canal towns had 6.9% lower employment shares in agriculture, 2.3% greater employment shares in commerce, and 41% faster manufacturing employment growth. People did not stop being or becoming farmers. The lower employment share in agriculture is driven not by decreasing employment in agriculture but rather by faster employment growth in manufacturing and commerce. These findings are consistent with Ransom (1967), Niemi (1970), and Ransom (1971)'s studies on canals. Although these articles generate similar results, this study addresses two issues of concern in these earlier studies. First, they do not pay adequate attention to the endogeneity problem. Second, instead of using county-level data, I use town-level data. Using counties as the unit of analysis rather than utilizing towns may lead to attenuation bias. If the effect of the canal is strongest proximate to a canal, towns within a county close to the canal will be affected more than towns in the same county but are not proximate to the canal. Estimates based on county units will be downward biased by the near-zero effect of relatively distant towns. Smaller-scale geography enables me to test the extent of the canal's effects more precisely. I find the sectoral transition effect on employment and the population growth effect disappear in areas that are located more than 15 km or 20 km from the canal, and there are many towns within canal counties that lie outside the 15 km zone.

Second, I provide more evidence on the sectoral transition by collecting data on manufacturing mills and commercial activities. While the same DiD analysis shows canal towns did not have a greater number of manufacturing mills, I find canal towns had larger sizes of manufacturing mills in output by utilizing an instrumental variable (IV) approach. This finding supplements Atack et al. (2011)'s finding regarding railroads increasing manufacturing establishment size by recognizing the role that canals played in America's infant manufacturing development before 1850. Furthermore, I find canal towns had greater numbers of inns & taverns, wholesale stores, retail stores, and groceries. This finding, with data on types of articles shipped through the canal, suggests canal towns became commercial centers and regional distributional hubs where merchants might purchase local agricultural or manufactured goods for sale elsewhere via the canal. The result of trade is consistent with

Duranton et al. (2014)'s model, although I do not provide a formal test due to data limitation. These findings underscore the commercial revolution preceding America's second industrial revolution and delineate the role canals play in it, which is consistent with Sellers (1991)'s view of market revolution and Taylor (1951)'s interpretation of merchant capitalism in early nineteenth-century America.

The second part of the paper studies the canal's effects on long-run population growth and the formation of new towns. First, an event study between 1790 and 1870 shows that for towns that existed before the canal opened, canal towns witnessed an average of 39% faster population growth than noncanal towns. Papers studying canals' causal effect on population are rare (Flückiger and Ludwig, 2019; Chang et al., 2023; Alvarez-Palau et al., 2023). The most relevant is Alvarez-Palau et al. (2023) where they study town-level population growth and occupation changes in England and Wales. We differ in methods and context, which provides an opportunity to compare the effects of transportation improvement between the early stages of industrial development in England and in the United States. Second, I provide a new finding regarding the canal's effects on promoting new town formation where new towns that formed after the canal opened were more likely to be located close to the canal and larger in population than noncanal towns. Third, I study the potential local displacement effect of whether there was a re-allocation of population occurring between canal towns and noncanal towns. Contrary to Bogart et al. (2022)'s findings that railroad led to spital population divergence in England and Wales and Baum-Snow et al. (2020)'s finding that hinterland cities losing population with better access to highways, I find canals did not lead to local population displacement in nineteenth-century New York State. In other words, the gains to areas near canals did not come from the cost of faraway areas.

The third part of the paper studies the canal's effects on banking development from 1810 to 1860. First, I find canals did not significantly increase town-level bank capital for towns with banks before the canal opened. Second, I include new bank towns in the analysis and find canal towns gradually had faster growth in bank capital especially after the late

1830s when New York State entered the Free-Banking era. This suggests canals mainly increase bank development by promoting new bank towns near the canal and increasing bank capital in canal towns. These findings are relevant to Atack et al. (2014)'s finding of mutual reinforcement between county-level banking and railroads in 1837-61 Midwest and Chan (2024)'s finding that railroads increased national banks in counties during the Gilded Age. Thus, this paper adds canals to the discussion by identifying the effects of canals on banking development and financial modernization before railroads. Third, a more granular town-level analysis enables me to test the extent of the canal's effects on banking more preciously. I find the effects diminish in towns as they were located increasingly distant from the canal and disappear when towns located beyond 70 km from the canal. Compared with the extent of the canal's effects on sectoral transition and long-term population growth, the canal's effect on bank development is larger in geographic scales.

The estimated sectoral transition, urbanization, and banking development effects are robust to multiple robustness checks under the DiD setting and the IV strategy. First, I exclude towns immediately adjoining the treated areas from the control group to address potential spillover effects. Second, I exclude targeted towns that were selected by the government to be passed through from the treatment group to further mitigate the potential selection problem. Third, I exclude towns in the middle section of the canal that were completed in 1820 from the treatment group to mitigate the potential anticipation issue. Fourth, I construct an alternative control group that includes towns that share similar pre-existing characteristics across the New York State by using a propensity score matching approach. Fifth, I reestimate the DiD regressions using an IV.

Besides the contribution mentioned above, this paper generally speaks to the literature studying the economic impact of historical transportation infrastructure. A significant portion of existing research is centered on railroads (Taylor, 1951; Fogel, 1964; Fishlow, 1965; Atack et al., 2010; Atack and Margo, 2011; Donaldson and Hornbeck, 2016; Donaldson, 2018; Berger, 2019; Banerjee et al., 2020; Bogart et al., 2022) and highways (Fernald, 1999; Baum-

Snow, 2007; Michaels, 2008; Faber, 2014; Baum-Snow et al., 2020; Asher and Novosad, 2020; Valenzuela-Casasempere, 2024). Recognizing that canals serve as the main transportation medium before railroads and long-haul trucking, this paper introduces insights from the pre-railroad era to the discourse on transportation infrastructure. It also enriches existing canal literature. Previous studies looked at the effects of canals on market integration (Albion, 1939; Whitford, 1906), agricultural productivity (Chankrajang and Vechbanyongratana, 2020), inventive activity (Sokoloff, 1988), and health (Zimran, 2020), government promotion of canals (Goodrich, 1960), and public financing of canals (Wallis, 2003).

This paper also generally speaks to the literature on understanding the process and determinants of economic modernization, especially in the antebellum New York State (Albion, 1939; Ellis, 1946; Miller, 1962; Gunn, 2001; Bodenhorn and Cuberes, 2018) which was a leading economy in the nineteenth-century U.S.. Economic modernization is a complex and varied process typically encompassing sectoral transition, urbanization, technological innovation, financial development, institutional changes, and infrastructure development. This paper identifies the causal effects of transportation infrastructure on other elements during economic modernization.

2 Background

Built between 1817 and 1825, the Erie Canal stretched 586 kilometers, connecting the Hudson River with Lake Erie. Before 1860, the ton-kilometers of shipping of the Erie Canal consistently surpassed that of any other singular transportation route (Poor, 1860). Unlike the railroads that emerged later, the Erie Canal epitomized state-led intervention. One outstanding characteristic of New York State's economic landscape during this period was the government's promotional role, underscored by state subsidies, such as state-backed loans to manufacturing corporates, tax exemption granted to certain manufactories, and financial support to agricultural societies (Miller, 1962). Canal construction and operation would only entail a change in form and scale of prevailing government interference.

There were two main reasons favoring state-led construction of the canal over private enterprises. First, private entities grappled with financial limitations. Before the state's takeover of the Erie Canal's construction, two private companies tried to construct and operate specific sections of the canal, but both failed due to the reluctance of private investment to finance the projects. The Western Inland Lock Navigation Company and the Northern Inland Lock Navigation Company received authorization in 1792 to sell up to 1,000 shares at an introductory price of $25 each, alongside a state grant of $12,500 to facilitate canal work. Subsequent financial strain prompted the state to acquire 200 shares from each company and extend a $37,500 loan to the Western Company. Nonetheless, the canal still could not be completed because of shortages of funds despite the state's assistance.

When state involvement in canal construction grew, New York State briefly harbored aspirations of acquiring federal support, particularly when President Jefferson advocated for reallocating surplus Treasury revenue to internal improvements. However, hopes of federal intervention waned due to inter-state rivalry and the War of 1812, propelling the state to assume full responsibility. Legislation enacted in 1816 established the Canal Fund, designated to finance the canal's construction through revenue streams such as canal tolls, a tax on steamboat passengers, and a levy on salt production in the western district, among others. Further legislation in 1817 permitted loans on the credit of the state that allowed the Board of Commissioners of the Canals Fund to issue state bonds. Consequently, the Erie Canal reached completion in eight years at an expenditure of $7.143 million, approximately $185 million when adjusted to 2022 values. Furthermore, the Erie Canal was enlarged between 1836 and 1862 at a cost of nearly $32 million, or four and a half times the amount spent to build the original canal.

Second, the state, in contrast to private companies, was better positioned to reconcile regional disputes and political rivalries. Although residents in western New York State wanted the canal, Long Island residents and Mid-Hudson Valley farmers resisted it, fearing competition from the influx of Midwestern and Upstate produce into New York City. People in the Southern Tier of New York State along the Pennsylvania boundary complained that the canal would be of no use to them because its benefits would be limited to areas proximate to the canal. Political rivalries further complicated matters. There were different political groups that tried to take credit for the canal. One group, led by DeWitt Clinton, who took office as Governor in 1817 and served until 1822, consisted of wealthy Federalist landholders in the West, great merchants in the towns, and western farmers who expected the canal to increase their land value and boost in-state commerce (Rubin, 1961). Counteracting this was a group led by Martin Van Buren that comprised the majority of Democrats who were in control of New York City and towns in the Hudson River Valley. To reconcile these political and regional differences, Governor Clinton built a political coalition that transcended pure political allegiances and overcame regional disputes about financing and routing the canal.

In planning the route of the canal, the overriding objective was its engineering feasibility, especially given the imperative of connecting the Hudson River to the Great Lake and certain targeted towns: Buffalo, Syracuse, Utica, and Albany. Commercial employment spillovers to local regions were a secondary consideration at the early stage. Surveys were conducted by appointed canal commissioners and engineers[1]. Their expeditions, often conducted by land or along water routes, took them from the Mohawk River to Rome, from there to Oswego, and further from Three River Point to Geneva where the boats were sold, and the party proceeding by carriage to the Niagara (Kirkland, 1934). These surveys ascertained vital details such as the consistent availability of water throughout the year without depleting hydraulic works and the practicality of constructing essential infrastructure including stone locks, culverts, and aqueducts (Laws of the State of New-York, 1828). Many of the tools and machinery used for land clearing and initial groundwork were repurposed for canal construc-

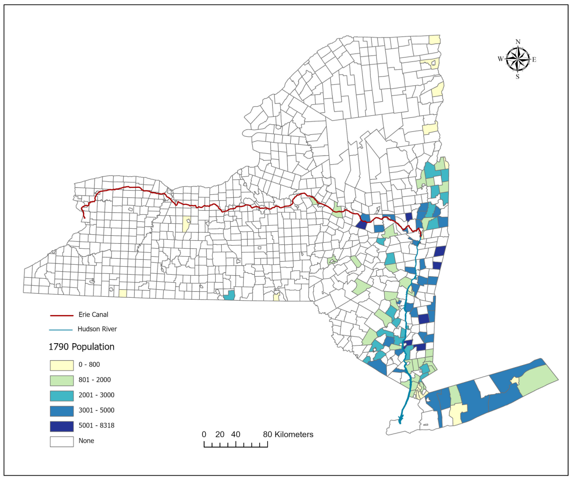
[1]Initial commissioners in 1811 included Gouverneur Morris, De Witt Clinton, Stephen Van Rensselaer, Simeon De Witt, William North, Thomas Eddy, and Peter B. Porter. By 1816, the roster had changed to feature De Witt Clinton, Stephen Van Rensselaer, Samuel Young, Joseph Ellicott, and Myron Holley. Notable engineers involved were James Geddes and Benjamin Wright, often dubbed the "father of American Civil Engineering".

tion. For instance, with the right apparatus—a combination of rollers, cables, wheels, and cranks—a single individual could fell a large tree. Additionally, specialized equipment like the narrow plow was devised to cut through the dense mesh of roots and fibers on the surface (Canal Commissioners, 1817). Given the commissioners's objective of identifying a feasible and low-cost route, the canal's path was exogenous to most areas that were proximate to the canal. This exogeneity affords the opportunity to determine its effects on growth and development.

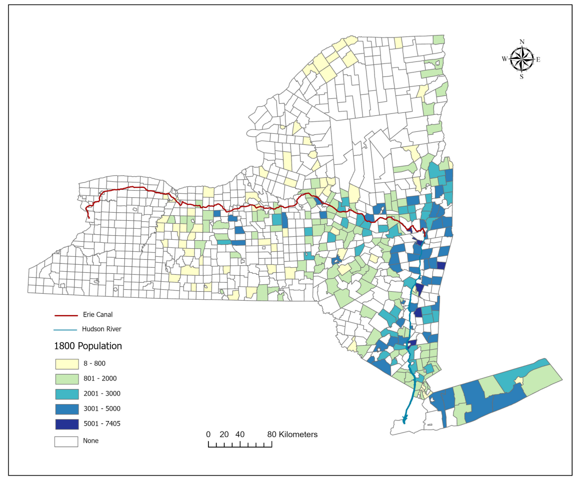
2.1 New York State before the Canal

The drive for internal improvement was spurred by two primary factors: western expansion and the evolution of intra-state and international trade. Between 1790 and 1814 New York City's population more than doubled, from 54,182 to 123,980. Concurrently, it became one of the nation's primary ports, a status indicated by the number of exports and imports loaded and unloaded at its wharves. By 1821, the port of New York was responsible for approximately 20% of total U.S. exports and 37% of its total imports by value. The tonnage entered from foreign countries and cleared for foreign counties accounted for 20% and 19% of the U.S. totals, respectively (Albion, 1939). Yet, this commercial expansion was not confined to the city. Towns further north along the Hudson and Mohawk Rivers emerged as vital hubs, serving either as markets or as pivotal points in river trade, bolstered by their growing hinterlands.

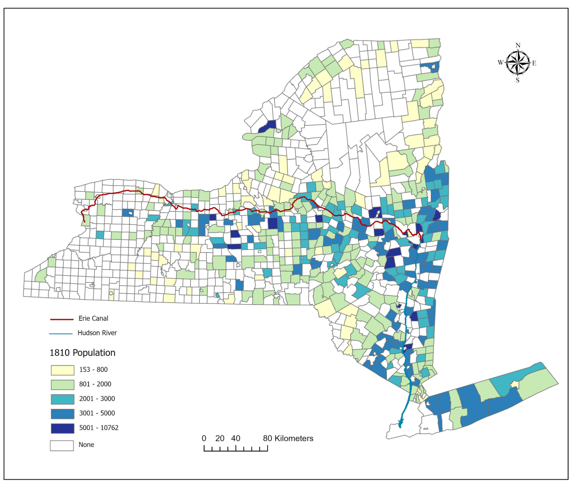
The rapid western expansion, with New York State's population tripling from 339,582 in 1790 to 1,038,058 in 1814, heightened the demand for a market in rural New York State, and signified a state-wide shift towards a higher level of economic integration. In 1790, the majority of the population was clustered on Long Island and in the Hudson River Valley, with burgeoning towns such as Palatine, Canajoharie, German Flattes, Herkimer, and Whitestown emerging along the Mohawk River. By 1800 even more towns surfaced in the Mohawk River Valley, notably Rome, which later became a significant stop on the Erie Canal. The westward



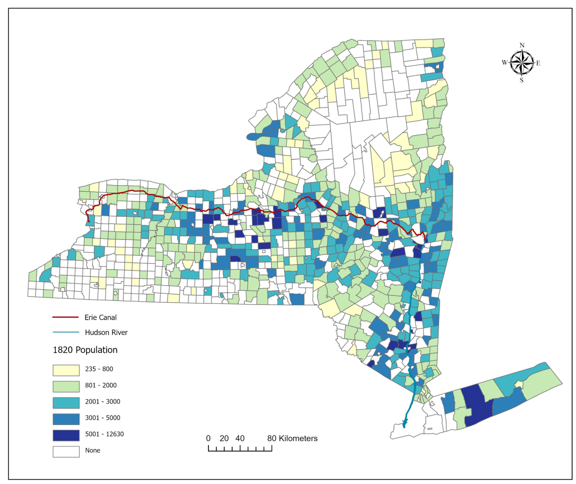
(a) 1790 Population



(b) 1800 Population



(c) 1810 Population



(d) 1820 Population

Figure 1: Town-level population in New York State from 1790 to 1820

Notes: The town boundaries maps shown here are from the year 2021. Town boundaries do change from the study period to now. The details of boundary adjustment are in section 3. New York City is excluded from the sample because of its extremely large population. The population in New York City was 54,182, 83,849, 125,805, and 123,980 respectively in the above 4 years. The population in the second largest town is shown in the maps as indicated by the changing number of the upper bar of the legend. Towns in white did not have population data in corresponding years.

migration continued, with settlers establishing themselves around present-day Syracuse and in towns dotting the Finger Lakes Region. By 1810 settlers had made their way to Buffalo, and by 1820, the population centers emerged across the state (see Figure 1).

Populated towns were concentrated in three areas with navigable waters: the Hudson

River Valley, the Mohawk River Valley, and the Finger Lakes Region. For merchants and farmers within these towns and their surrounding regions, the growing demand for enhanced transportation became increasingly evident.

2.2 New York State after the Canal

The Erie Canal helped New York City establish its dominance as the nation's primary port. By 1840, the port of New York was responsible for approximately 26% of total U.S. exports and 56% of its total imports value. The tonnage entered from foreign countries and cleared for foreign counties accounted for 24% and 17% of the U.S. totals, respectively (Albion, 1939).

The post-1825 period is referred to as the era of market revolution (Sellers, 1991). During this time, nascent manufactures developed around the port towns, the adjacent countryside became specialized in producing perishable items such as vegetables, fruits, and dairy products for urban populations. Simultaneously, grain and livestock production extended farther out, with interior towns taking on the role of processing lumber, hides, and grain. The reduction in transportation costs gave areas a comparative advantage in more specialized production. Ellis (1946) describes this era as an agricultural revolution where by 1850 the old life of self-sufficiency was vanishing and all but the most isolated farmers were raising foodstuffs for sale. During the navigable season from late April to early December, the Erie Canal witnessed a bustling flow of boats. For instance, the total number of boats passing lock No. 26, located 5 kilometers west of Schenectady, surged from 6,166 in 1824 to 35,981 in 1854.

The Erie Canal facilitated a surge of western produce into the Hudson and Mohawk Valleys. In 1829, raw materials and basic resources cleared at Buffalo, such as 311,256 feet of lumber, 3,640 bushels of wheat, 4,335 barrels of flour, 4,754 barrels of provisions (comprising pork and beef), and 1,705 tons of agricultural ashes, were transported eastward on the Erie Canal. By 1835, the canal saw double the provisions, fourfold agricultural ashes, sevenfold lumber, twenty-three-fold flour, and forty-six-fold wheat moving from Buffalo (refer to Table 12 in appendix). Observations from 1830 to 1832 highlighted a similar product composition flowing through Utica. On the other hand, 7,151 tons of merchandise, 935 tons of furniture and mechanics' tools, and 65,431 barrels of salt were shipped to Buffalo from the East via the Erie Canal in 1830. These numbers increased by 1835, with salt inflow growing by 20%, merchandise by 300%, and furniture and tools by 800%. The goods arriving at Buffalo were consumed not just within New York State, but also in Upper Canada, Pennsylvania, Ohio, Michigan, Indiana, and Illinois. The wide variety of articles shipped on the Erie Canal—lard, cheese, flax seed, hops, oysters and clams, whiskey, quinces, horn tips, wool, brick, iron ore, soap, plows, window sash, wooden ware, shingles, posts, and rails, etc.—paints a vivid picture of the goods make available to the households in early nineteenth-century New York State.

3 Data

To analyze the economic impact of the Erie Canal, I employ a town-level dataset about the nineteenth-century New York State. Most of the variables like employment, population, and bank capital are collected and put together by Bodenhorn and Cuberes (2018) from different sources. The employment data originates from the federal census and the federal government only canvassed employment in the years 1820 and 1840. Population data from 1790 to 1870 were drawn from both federal and state censuses. The federal government conducted decennial population in years ending with a zero. Beginning in 1825, New York State conducted statewide canvasses of its population every ten years in years ending in five and also held a census in 1814. Information on the location of banks from 1810 to 1860 is taken from Weber (2011) census of banks supplemented with chartering acts reported in the New York Assembly Journals, the annual session acts, and data provided by Root (1895). Their dataset includes other town characteristics in 1824 that originate from the Gazetteer of the State of New York 1824 (Spafford, 1981), which includes economic indicators like public expenditure, the value of the taxable property, and number of clothes made, geographical information like the access to old transportation routes, political information like county seat and number of people who are eligible to vote, educational information like the number of schools and students, religious information like the number of churches, and the number of different manufacturing mills. These variables in 1824 provide a variety of information that were used in balance tests.

I supplemented their data with manufacturing mill and commercial activities data from 1821 to 1845. Town-level manufacturing data in terms of numbers and value of outputs are collected from the 1835 and 1845 New York State Census, supplemented by one additional year's number of manufacturing mills in 1824. Commercial activities like the number of inns & taverns, wholesale stores, retail stores, and groceries are collected from the 1845 New York State Census. Data on articles transported through the Erie Canal from 1829 to 1835 are collected from the Annual Report of the Canal Commissioners.

I then merge this dataset with Geographic Information System (GIS) data. The boundary data for cities and towns within New York State are from the NYS Office of Information Technology Services GIS Program Office (GPO). Due to the absence of historical boundary data, the 2021 boundaries serve as the base map. Over time, the delineations of town boundaries have experienced modifications. The dataset shows usable information on cities and towns, which increased from 131 in 1790 to 573 in 1820 to 977 in 1870. In 2021, this number stands at 932 towns and 62 cities. One notable transformation is the establishment of new towns carved out from existing ones. To make the map consistent over time, data from newer towns are incorporated into their originating towns. For example, Middletown in Orange County was part of Newburgh in Orange County before 1888. In such cases, Middletown's data is merged with that of Newburgh. Another trend is that some regions have been incorporated as cities within their original town boundaries, as observed with Amsterdam city in Montgomery County, incorporated in 1885. In these scenarios, data are aligned with the contemporary township. I made town boundary adjustments in reference to the Gazetteer of the State of New York 1824 and Wikipedia.

Using Geographic Information System (GIS) tools, I measure the Euclidean distance between towns and the Erie Canal. The reference point for each town is its respective town hall. Distances are computed either perpendicularly from these halls to the canal or directly to the nearest canal vertex. The data for the historical Erie Canal path is from (Atack, 2015). Mohawk River, Hudson River, and New York State Thruway are from the New York State GIS Clearinghouse or the ArcGIS online portal. For the instrumental variable construction, I use the Digital Elevation Model with a ten-meter pixel resolution from the U.S. Geological Survey.

4 Methods

4.1 Difference-in-Differences Strategy

To examine the economic impacts of the Erie Canal, the main empirical analysis is based on a difference-in-differences design. This design compares variables of interest in towns located close to the canal (termed "canal towns") with towns that shared similar characteristics but were not proximate to the canal (termed "noncanal towns") in periods before and after 1825, the year that the Erie Canal commenced operations. The main model is specified as

$$Y_{ijt} = \alpha + \beta Post_t Canal_{ij} + \gamma X_{i1824} + \theta_i + \phi_t + \lambda_{jt} + \epsilon_{ijt}, \tag{1}$$

where Y_{it} either corresponds to log(population), log(employment), the share of employment in three sectors, the number of manufacturing mills, or log(bank capital) for town i in county j in year t. $Canal_i$ is an indicator taking the value 1 for canal towns, defined as those located within 5 km of the canal, and 0 for noncanal towns, defined as those located between 5 and 15 km from the canal. Alternative distances to the canal were used to assess the sensitivity of the DiD estimates. $Post_t$ is an indicator variable equal to 1 after the year 1825 and 0 otherwise. X_{i1824} include variables that differ between canal towns and noncanal towns in 1824 interacted with year fixed effects. θ_i is the town fixed effects that captures any town-specific characteristics that are constant over time. ϕ_t is the year fixed effects that captures any unobserved factors that are constant across all towns in a given year. λ_{jt} is the county-year fixed effects that captures unobserved factors that vary both across counties and over time. Standard errors are clustered at the county level. α is a constant term common for all towns.

The DiD design rests on three core identification assumptions: the stable unit treatment value assumption (SUTVA), the no-anticipation assumption, and the parallel trends assumption. The SUTVA assumption implicitly implies that potential outcomes for unit i are not affected by the treatment of unit j. In other words, SUTVA rules out interference across units and spillover effects. This assumption likely held in the early nineteenth century when a wagon traveled only 3 to 5 kilometers per hour depending upon weather, roadway conditions, and the health of the travelers. To further mitigate concerns over spillover effects, I exclude areas immediately adjoining the treated towns from the control group in the robustness checks.

The non-anticipation Assumption is likely to hold given that the Erie Canal commenced operations in 1825 and the pre-treatment year considered is 1820. While the canal might have influenced the occupational choices of the population by adjusting the occupational rewards, I posit that such a transformation was less probable five years prior in early nineteenth-century New York State. As a robustness check, I will segment the data, excluding towns located in the middle section of the Erie Canal, which began operations before 1820. The Parallel Trends Assumption is tested by estimating the effect of the canal on population using population data from 1790 to 1820. I also provide a balance test between the treated control groups by comparing the pre-treatment town characteristics using data from the years 1820 or 1824.

Table 1: Balance test of dependent variables before canal operation between canal towns (0-5km) and noncanal towns (5-15km)

	Canal towns	Obs.	Noncanal towns	Obs.	Diff.	p-value
Population	2750.09	48	3115.11	54	365.03	0.32
Total Employment	647.92	48	720.15	54	72.23	0.34
Employment in agriculture	483.58	48	565.57	54	81.99	0.16
Employment in manufacturing	144.98	48	137.56	54	-7.42	0.81
Employment in commerce	19.35	48	17.02	54	-2.34	0.85
Agriculture employment share	0.75	48	0.81	54	0.06	0.12
Manufacturing employment share	0.22	48	0.17	54	-0.05	0.11
Commerce employment share	0.03	48	0.02	54	-0.01	0.29
Number of mills	18.79	48	23.15	54	4.36	0.15
Bank capital (thousand dollar)	44.79	48	24.44	54	-20.35	0.59

Notes: Population, employment, and bank capital data were in the year 1820. Mill data were in the year 1821.

Table 1 demonstrates that there are no significant baseline differences between canal towns and noncanal towns among ten dependent variables: population, total employment, employment shares in three sectors, employment count in three sectors, number of mills, and bank capital. Table 2 shows the balance test in 1824 between canal towns and noncanal towns concerning other town characteristics: economic indicators (such as the public expenditure, taxable property value, and number of cloth made), old transportation access (the Iroquois trail and turnpike), political influence (the county seat status and the number of residents eligible to vote), education (number of schools and people were taught), religious institutions (the number of churches), and others like elevation. Table 2 shows there are no significant differences in most town characteristics before the canal operation. However, there are significant differences regarding the access to the Iroquio Trial, the county seat status, and elevation. And there is evidence that shows these three factors matter. North American towns tended to locate at native portage points, as demonstrated by (Bleakley and Lin, 2012). The Iroquois Trail was an ancient Native-American trade route used by colonial military forces in troop deployments that crossed several rivers. Elevation not only presented

Table 2: Balance test of other town characteristics in 1824 between canal towns (0-5km) and noncanal towns (5-15km)

	Canal towns	Obs.	Noncanal towns	Obs.	Diff.	p-value
Economic indicator						
Public expenditure	301.03	35	678.10	41	377.07	0.14
Taxable property (thousand dollar)	410.34	43	400.85	51	-9.50	0.92
No. of cloth made (thousand yards)	15.19	43	38.11	51	22.92	0.20
Old transportation						
Iroquois trail(0/1)	0.25	48	0.11	54	-0.14	0.07
Turnpike(0/1)	0.44	48	0.59	54	0.16	0.20
Political influence						
County seat(0/1)	0.17	48	0.06	54	-0.11	0.07
No. of electors	516.30	44	575.06	48	58.77	0.40
Education						
No. of schools	10.02	48	12.76	54	2.74	0.09
No. of students	495.21	48	667.37	54	172.16	0.10
Religion						
No. of churches	3.00	11	4.53	15	1.53	0.18
Others						
Elevation(feet)	488.17	48	735.07	54	246.91	0.00
Custom(0/1)	0.02	48	0.02	54	-0.00	0.93
No. of children age 5-15	733.54	35	807.49	39	73.94	0.47

Notes: Data in the table are from the Gazetteer of the State of New York 1824.

engineering challenges for canal construction but also potentially influenced economic development (Nunn and Puga, 2012). The Erie Canal's construction was influenced by political dynamics, as noted by (Rubin, 1961). Whether a town functioned as a county seat (i.e., a regional governmental center, which typically included the county courthouse, the county jail, and other administrative offices) may influence canal construction. While differences in the access to the Iroquois Trail, elevation, and county seat exist between groups, these are accounted for in the town fixed effects, as they remained constant from 1820 to 1840. The data also provide weak evidence of differences in the number of schools and students, with respective p-value of 0.09 and 0.10. To account for this, I include the interaction of the education variable in 1824 with year fixed effects as additional controls.

4.2 Alternative Identification Strategy: Instrumental Variables

I construct least-cost paths as an instrument for the actual canal route to mainly analyze variables not feasible to DiD design. It can also act as a robustness check for variables that are feasible for DiD design.

Consistent with facts of the Erie Canal construction and the methodologies of Faber (2014), Berger (2019), and Bogart et al. (2022), I leverage variation induced by geographic location as an instrument for canal accessibility. Specifically, towns situated near least-cost paths (LCPs) had a higher likelihood of canal connection. The LCP approach fits well with my context, particularly since the primary goal of the Erie Canal is to connect the Hudson River to Lake Erie. As the basis of the IV strategy, I constructed a hypothetical network that connects the Hudson River to Lake Erie and targeted places on the canal. These were only a few targeted places selected by the state to pass through because of their existing traffic volumes and/or their potential to generate freight traffic. Conversely, many other locations were incorporated into the canal's route solely due to geographic convenience. They bridged the targeted places in a cost-minimizing manner. Such areas were not directly targeted by planners and were "accidentally" traversed by the canal.

To construct the instrument, I adhere to a three-step process. The first step is to choose places that LCPs need to traverse. Incorporating more such places imposes stricter constraints on LCPs, reducing the likelihood of accidental canal towns. I commence by selecting only the canal's origin, Buffalo, and its terminal, Waterford, which is situated adjacent to Albany County, Saratoga County, Rensselaer County, and the Hudson River. Second, to discern the LCPs bridging Buffalo and Waterford, I employ Digital Elevation Models, which provide elevation data at a resolution of approximately 10 meters (U.S. Geological Survey, 1995). These LCPs, in their effort to minimize construction expenses, naturally align with ruggedness as calculated from elevation data. Third, I adapt the methodology of Bogart et al. (2022) to test the validity of the LCPs from an economic perspective. A simple gravity equation[2] and Flater (2022)'s algorithm is utilized to estimate the relative significance of connecting various town pairs. I measure town distances using the Euclidean distance and employ population data from the 1820s, reflecting the Erie Canal's construction era (1817-1825). Consequently, I produce a gravity index matrix for all towns from 1820, excluding New York City, given its disproportionate population size. Subsequently, I rank gravitational values relative to Waterford, pinpointing Halfmoon as the town with the highest value. I then determine the town that has the largest gravitational value with Halfmoon. If the town that has the largest gravitational value with Halfmoon is Waterford, then I choose the town that has the second-largest gravitational value with Halfmoon. I persist with this iterative process until Buffalo is integrated. Inherent to the canal's design is its reliance on water; hence, I introduce a constraint. When faced with towns having comparable gravitational values, preference is given to the one in closer proximity to water resources. LCPs do not necessarily traverse the center parts of the selected towns. If LCPs approximate to those towns, it's inferred that their design factored in economic considerations like population and topographical variables like ruggedness.

As depicted in Figure 2, the LCPs traverse all targeted towns, including Waterford, Utica, Syracuse, and Buffalo. The LCPs almost overlap with the eastern section of the Erie Canal, exhibit slight deviations from its middle section, and largely diverge from the western section. The LCPs fit gravity towns, selected by gravity index, very well. An instructive point of reference for the LCP's plausibility is the New York State Thruway, which was constructed in 1954 by the New York State Thruway Authority. Given the technological advancements by 1954 relative to 1820, this thruway offers a more cost-efficient layout. Notably, the thruway's path largely coincides with the LCP.

To interpret β as the local average treatment effect (LATE) of being treated by LCPs, the IV approach requires the following identifying assumptions: first stage, monotonicity,

[2] $G_{ij} = (population_i * population_j)/distance_{ij}$

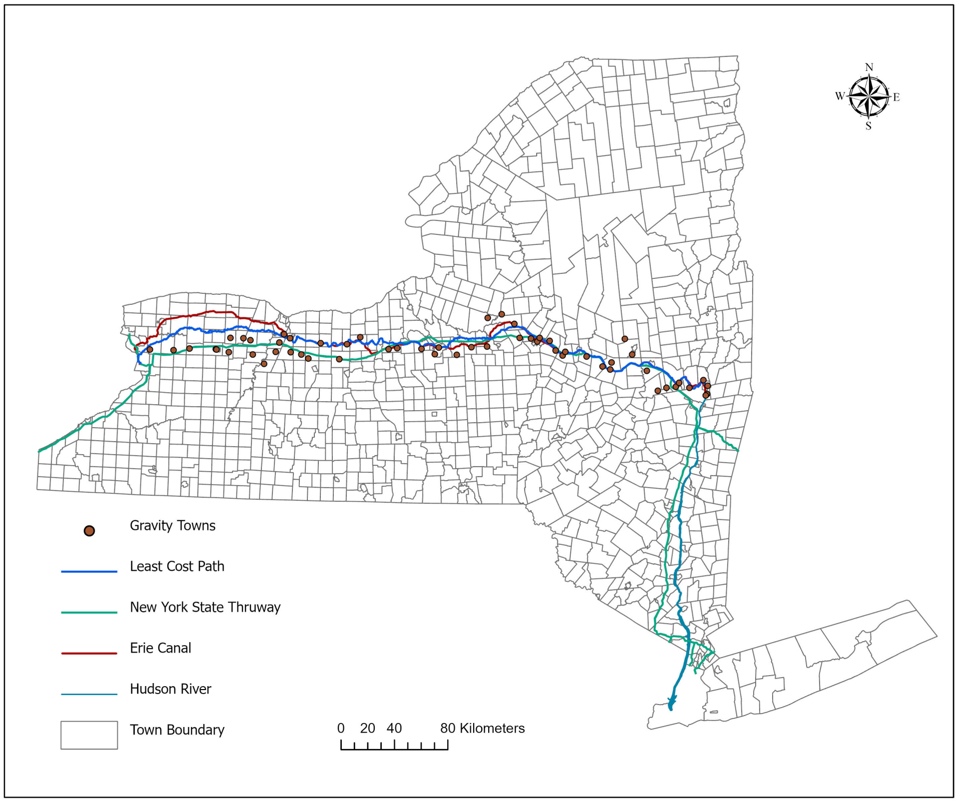
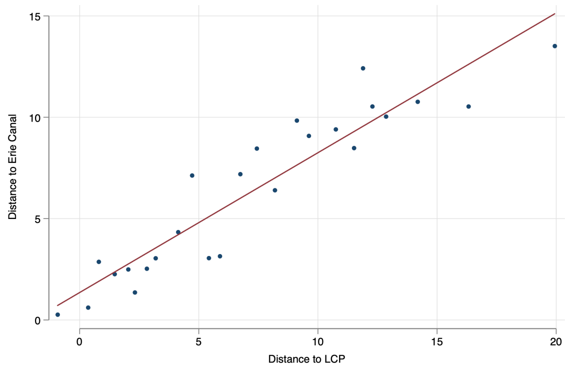


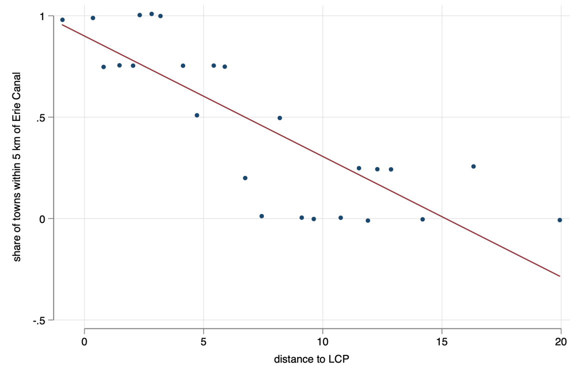
Figure 2: Least cost path

conditional independence, and exclusion. In the subsequent sections, I present empirical evidence that supports the validity of these assumptions.

First Stage. To demonstrate that towns proximate to the LCPs have a higher likelihood of being intersected by the Erie Canal, refer to Figure 3. This figure presents binned scatterplots for clarity. The towns used here align with those in the DiD estimates. Towns are grouped into 25 equal-sized bins based on the distance to the nearest LCP. In these scatterplots, each dot presents the mean distance to the closest point on the Erie Canal (panel a) or the share of towns situated within 5 km of the Erie Canal (panel b) against the mean distance to the nearest LCP for each bin. Also shown are the estimated best-fit lines. Evidently, towns closer to the LCPs are more likely to be traversed by the Erie Canal, accounting for county fixed effects.



(a) Distance to the Erie Canal



(b) Share of canal towns

Figure 3: First stage

Table 3: First stage regression

	(1) Canal (dummy)	(2) Canal (dummy)	(3) Distance to canal	(4) Distance to canal
Distance to LCP	-0.056***	-0.076***	0.675***	0.806***
	(0.009)	(0.007)	(0.080)	(0.067)
Observations	102	101	102	101
County FE	No	Yes	No	Yes
R-squared	0.379	0.590	0.596	0.748
F-statistics	34.843	106.643	71.165	145.672

Table 3 displays the results from the first-stage regression. As demonstrated in Columns (1) and (2), the likelihood of a town being traversed by the canal diminishes as its distance from the LCP increases. Notably, the distance to the closest LCP emerges as a significant predictor for the actual canal constructed, even after controlling for county fixed effects. The $F-$statistics provided are always sufficiently large to satisfy the weak instrument criterion (Stock and Yogo, 2005), namely a first-stage $F-$statistics in excess of 10.00. Furthermore, a strong correlation is evident between a town's proximity to the Erie Canal and its distance to the nearest LCP, as detailed in Columns (3) and (4) of Table 3.

In the presence of heterogeneous treatment effects, the monotonicity assumption is essential to interpret IV estimates as a LATE, i.e., the average causal effect among towns induced by the instrument into being treated by the canal. In my setting, this monotonicity implies a negative correlation between a town's likelihood of canal treatment and its distance from the LCPs. Subfigure (b) of Figure 3 lends support to this assumption, demonstrating a decrease in the proportion of towns traversed by the Erie Canal as their distance from LCPs grows.

Balance Tests. For the instrument to be valid, it requires that there is no correlation (conditional on county fixed effects) between factors that affect a town's potential outcomes and its proximity to the LCPs. To interpret the IV estimates as identifying the causal effect of being treated by the Erie Canal, the exclusion restriction must hold; specifically, the LCP should only influence town outcomes via the Erie Canal, without other intervening channels. As an indirect test of these two assumptions, I present evidence indicating no significant correlation between observed town characteristics before canal opening and the instrument.

Table 4 presents OLS estimates derived from regressing outcome variables and a variety of town characteristics on the distance to the nearest LCP, conditioning on county fixed effects. Town observed characteristics are well balanced across the instrument, the distance to a LCP, with two exceptions. Towns situated closer to the LCPs reported a lower employment share in agriculture (column 6 in panel A) and a higher employment share in manufacturing (column 1 in panel B). However, the coefficients, 0.006 and -0.005 are relatively small when considering that initial employment shares in agriculture and manufacturing stood at 75% and 22%, respectively, in 1820. Given these findings, the instrument is presumably valid conditional on county fixed effects. Again, to account for the difference in education, I include the interaction of the education variable in 1824 with year fixed effects as additional controls.

Table 4: Balancedness of instrument

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A			
	log(population)	log(employment) total	log(employment) in agriculture	log(employment) in manufacturing	log(employment) in commerce	Agriculture employment share
Distance to LCP	-0.015	-0.012	0.006	-0.029	-0.016	0.006*
	(0.012)	(0.013)	(0.015)	(0.019)	(0.025)	(0.003)
Observations	102	102	102	102	102	102
County FE	Yes	Yes	Yes	Yes	Yes	Yes
			Panel B			
	Manufacturing employment share	Commerce employment share	Number of mills	log(bank capital)	Public expenditure	Taxable property
Distance to LCP	-0.005*	-0.001	0.289	-0.129	10.928	-16.027
	(0.002)	(0.001)	(0.306)	(0.077)	(14.658)	(9.469)
Observations	102	102	102	13	74	92
County FE	Yes	Yes	Yes	Yes	Yes	Yes
			Panel C			
	Number of cloth made	Number of electors	Number of schools	Number of students	Number of churches	Number of children 5-15
Distance to LCP	0.470	-8.767	0.353**	16.865	-0.048	1.452
	(0.382)	(6.196)	(0.150)	(10.173)	(0.077)	(7.623)
Observations	98	100	100	100	90	100
County FE	Yes	Yes	Yes	Yes	Yes	Yes

5 Impact on Sectoral Transition

5.1 Employment

Table 5 presents the estimated effects of the Erie Canal on sectoral transition in employment based on Equation 1 by using employment data in 1820 and 1840. Because one advantage this paper provides is the use of smaller-scale geography in the form of towns over counties, I present the results in two forms that depend on whether controlling for county-year fixed effects. Panel A does not control county-year fixed effects, allowing comparison of towns across counties. Panel B with county-year fixed effects shows that the results survive within counties.

In Panel A, columns (1), (2), and (3) assess the canal's influence on employment shares in agriculture, manufacturing, and commerce respectively. Columns (1) and (3) reveal that canal towns had a lower employment share in agriculture and a higher employment share in commerce. Column (2) shows no significant difference in manufacturing employment

Table 5: DiD estimates of canal's effects on sectoral transition in employment

	(1) Agriculture employment share	(2) Manufacturing employment share	(3) Commerce employment share	(4) log(employment) in agriculture	(5) log(employment) in manufacturing	(6) log(employment) in commerce	(7) log(total employment)	(8) log(population)
Panel A: without county-year fixed effect								
PostCanal	-0.069**	0.015	0.023***	0.027	0.345**	0.856**	0.231**	0.342***
	(0.025)	(0.022)	(0.008)	(0.116)	(0.134)	(0.332)	(0.097)	(0.072)
Observations	204	204	204	204	204	204	204	204
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-year FE	No	No	No	No	No	No	No	No
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel B: with county-year fixed effect								
PostCanal	-0.053*	-0.002	0.021***	0.004	0.177	0.643**	0.206*	0.309***
	(0.025)	(0.024)	(0.007)	(0.134)	(0.147)	(0.299)	(0.109)	(0.068)
Observations	202	202	202	202	202	202	202	202
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The row of PostCanal shows the effect of the canal, β, on different outcomes of interest from the DiD estimates. The constant term is estimated but not shown in the table. Standard errors in parentheses are clustered in counties. The education-year fixed effects include the interaction of the education variable (the number of schools and the number of people taught repectively) in 1824 with year fixed effect as additional controls. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

shares. Quantitatively, canal towns recorded 6.9% less employment share in agriculture and 2.3% more employment share in commerce when compared with noncanal towns. In 1820, five years before the Erie Canal's operation, canal towns had 75%, 22%, and 3% across agriculture, manufacturing, and commerce, respectively.

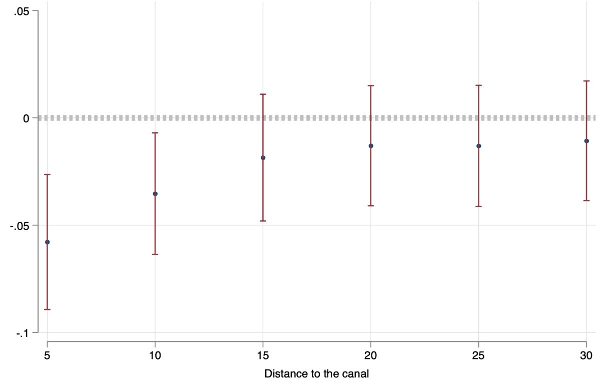
I shift the dependent variable to *log*(employment) in three sectors, *log*(total employment), and *log*(population) to analyze the composition change of total employment in each sector. Column (4) indicates that the Erie Canal's operation did not significantly decrease employment in agriculture in canal towns. As the agricultural employment share is quantified as the ratio of agricultural employment to total employment, the lower agriculture employment share in canal towns was not due to declining employment in agriculture, but rather the increasing employment in total employment. In other words, people did not stop being or becoming farmers. Column (5) reflects a growth in manufacturing employment in canal towns. However, this growth, though significant, was relatively small to the growth of total employment, which explains the insignificant change in the sector's employment share. Column (6) attributes the higher commerce employment share in canal towns to the sector's growing employment. Quantitatively, compared to noncanal towns, canal towns exhibited 41% faster employment growth in manufacturing, 135% faster employment growth in commerce, 26% faster total employment growth, and 41% faster population growth. The 1820 employment counts for agriculture, manufacturing, commerce, total employment, and population stood at 484, 145, 19, 648, and 2750 respectively.

Panel B shows the within-county estimates. Canal's effects on all the same variables become smaller, which is not surprising because the within-county estimates prevent comparisons of towns across counties. All the significant estimates in panel A survive in panel B, except the log(employment) in manufacturing. Column (5) in panel B shows that canal towns did not have faster employment growth in manufacturing compared with noncanal towns in the same county. The canal's effect of faster employment growth in manufacturing mainly comes from the comparison between canal towns and noncanal towns in different counties. I did an additional analysis of the manufacturing sector using other manufacturing data in the next section. Before that, I assess the sensitivity of estimates to the choice of canal town definition.

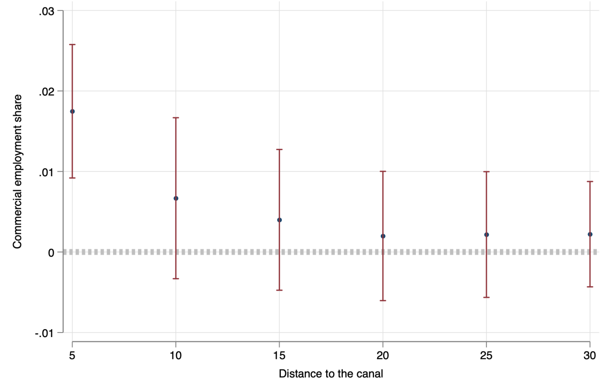
5.1.1 Sensitivity Checks and the Extent of Canal's Effects

First, each subfigure in Figure 4 displays 6 separate DiD regressions, derived from Equation 1, adjusting the definition of canal towns in 5km-increments from 5 km to 30 km. Noncanal towns—serving as the control group—are those located within 60 km of the canal but not categorized as canal towns. The time frame for this analysis spans 1820 to 1840. Subfigures are shown in order of significant variables in Table 5. The collective findings from Figure 4 show that the main results, determined by a 5 km canal town definition, are robust and not sensitive to marginal distance change. Canal towns, in comparison to their noncanal counterparts, experienced lower agricultural employment share, higher commerce employment share, and faster growth in manufacturing employment, commercial employment, total employment, and population.

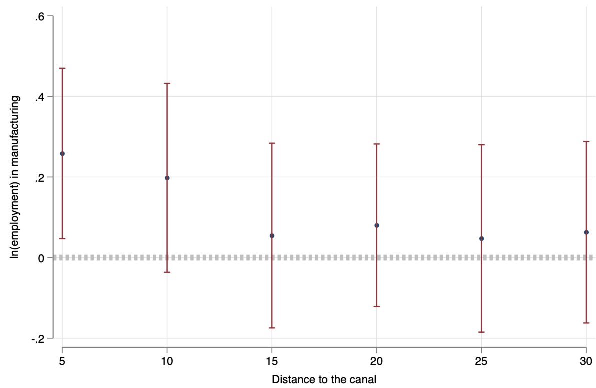
Second, Figure 4 suggests the extent of the canal's impact on sectoral transition and



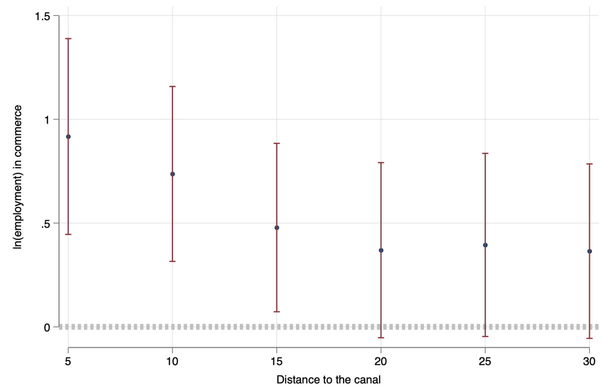
(a) Agricultural employment share



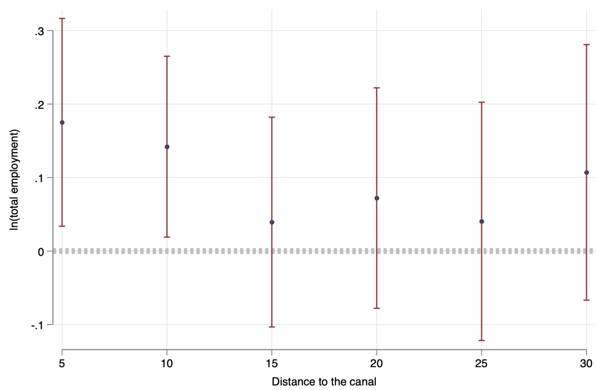
(b) Commercial employment share



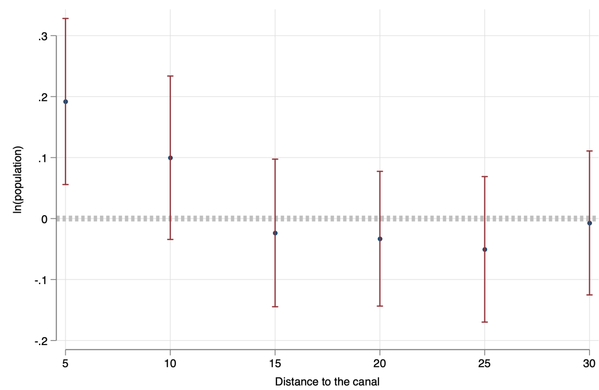
(c) log(employment) in manufacturing



(d) log(employment) in commerce



(e) log(total employment)



(f) log(population)

Figure 4: Sensitivity of DiD estimates to the choice of canal towns definition and the extent of canal's impact

Notes: The horizontal axis is the definition of canal towns by using 5km-increments from 5 km to 30 km. The distance is in kilometers. Each point is estimated by Equation 1 with a 90% confidence interval, controlling for education-year fixed effects. Due to the purpose of studying the extent, I did not control the county-year fixed effects. Standard errors are clustered at the county level.

population growth from 1820 to 1840. Collectively, subfigures indicate those effects diminish in towns as they are located increasingly distant from the canal. Although there are slight differences in those effects regarding either becoming insignificant or disappearing, most of them disappear when towns are located beyond 15-20 km from the canal.

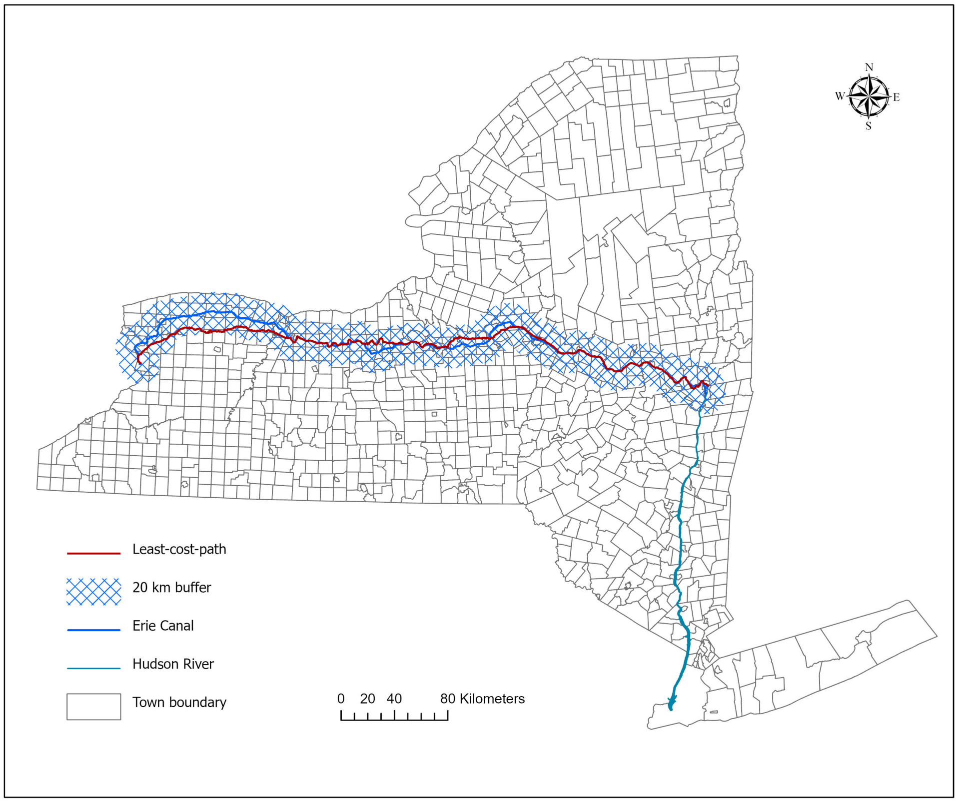


Figure 5: The extent of canal's effects, 20 km

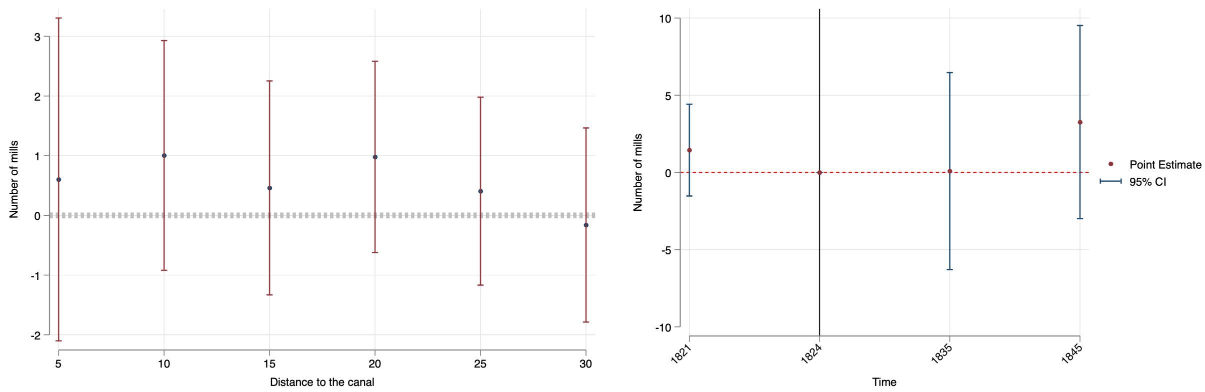
Given the era's transportation limitations—absent cars and trains—a 15 to 20 km distance was consequential. In the early nineteenth century, a wagon traveled 3 to 5 kilometers per hour depending upon weather, roadway conditions, and the health of the travelers. Evaluating transportation costs, wagon transport rates ranged from 9 to 13 cents per ton-kilometer during this period (McClelland, 1968). Consequently, the cost associated with this 15 to 20 km journey was between 135 to 260 cents per ton, exclusive of the time investment—approximately 3 to 6 hours for a horse or mule. To contextualize the transportation cost from a wage perspective, the daily wage for common labor in the northeast U.S. was 69 cents in 1830 (Ba4254 in Historical Statistics of the U.S.).

To provide context regarding the value of goods transported via the canal, I reference the wholesale prices of wheat and wheat flour (Cc206 and Cc211 in Historical Statistics of the U.S.). In 1830, in the northern U.S., the wholesale price for one ton of wheat stood at \$39.31. Thus, the cost of transporting this commodity 15 to 20 km by wagon amounted to between 3.4% and 6.6% of its wholesale value. Meanwhile, in New York City, the wholesale price for one ton of wheat flour was \$50.92. This implies that transportation costs, for the same distance by wagon, equaled 2.7% to 5.1% of its wholesale value in 1830. Incorporating time costs would amplify these figures. In 2023, the truck freight rates of shipping one ton of wheat from farms in Kansas State to the Pacific Northwest is around 3% of its landed costs that include farm value and other transportation costs like rail freight rates (U.S. Department of Agriculture, 2023).

5.2 Manufacturing Mills

Although the employment data are only available for 1820 and 1840, I collected two other town-level manufacturing mill data to provide additional details about the canal's impact on the manufacturing sector.

First, I apply the same DiD analysis to the number of manufacturing mill data in the years 1821, 1824, 1835, and 1845. Panel A in Figure 6 presents the DiD estimates by adjusting the definition of canal towns in 5km increments from 5 km to 30 km. Although all 6 separate estimates show canal towns had a higher number of manufacturing mills, the effects are not significant. Panel B in Figure 6 presents an event study on the mill numbers. After the canal operation, canal towns did not experience faster manufacturing development in terms of manufacturing mills at least before 1845. There might have been an upward trend that canal towns had more manufacturing mills after 1845. Given I only have two point estimates after canal operation and the railroad expansion after the 1850s, I will not make an inference. The weak evidence and the upward trend are consistent with Atack et al. (2011)'s finding that it was after 1850 that manufacturing establishments evolved from artisan shops to factories.



(a) DiD estimates of mill numbers

(b) Event study of mill numbers

Figure 6: Canal's effects on the number of manufacturing mills

Second, I collected town-level data on the manufacturing mill's output in the years 1835 and 1845. Since the output data are only available from 1835, I can not apply the same DiD analysis. To solve the potential endogeneity problem, I construct the least-cost paths as an instrument for the actual canal route and apply an IV approach to identify the canal's effect on mill output.

The first three columns in Table 6 present the IV estimates on the number of mills, the dollar value of mill output, and the value of output per mill using 5 km to define a canal dummy variable. Column (1) shows canal towns had a higher number of manufacturing mills, but the effect is insignificant which is consistent with the DiD estimate. Column (2) shows canal towns did not have significantly greater mill output in terms of dollar value. Column (3) shows canal towns had larger sizes of manufacturing mills measured by the ratio of mill output value to the number of mills. Next, I changed the canal dummy to a continuous measurement which is the town's distance to the canal. Columns (6) shows towns had smaller manufacturing mills as they were located far away from the canal.

Taken together, the evidence on manufacturing employment and manufacturing mills shows that canals had positive effects on the manufacturing sector in terms of faster manu-

Table 6: IV estimates of canal's effect on manufacturing mills

	(1) Number of mills	(2) log(value of output)	(3) log(output per mill)	(4) Number of mills	(5) log(value of output)	(6) log(output per mill)
$\widehat{Canal(dummy)}$	0.206	0.391	0.617***			
	(2.483)	(0.239)	(0.184)			
$\widehat{Distance\ to\ canal}$				-0.020	-0.037	-0.059***
				(0.237)	(0.022)	(0.016)
Observations	586	293	293	586	293	293
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes

facturing employment and larger manufacturing mills at least before 1845 when the United States experienced its infant manufacturing development.

5.3 Commercial Activities

This section provides additional evidence about the canal's effects on the commercial sector besides employment. First, I applied the same IV approach to four variables related to commercial activities in 1845. Using 5 km to define a canal dummy variable, panel A in Table 7 shows canal towns had a higher number of inns and taverns, wholesale stores, retail stores, and groceries compared with noncanal towns in the same county. Panel B changes the canal dummy to the distance, the canal's effects on those variables still exist. Towns had less number of inns and taverns, wholesale stores, retail stores, and groceries as they were located far away from the canal. This evidence shows canal towns became commercial centers and regional distributional hubs where merchants might purchase local or manufactured goods for sale elsewhere via the canal

Second, Table 8 presents evidence about the types of goods transported by merchants through the Erie Canal. Processing agricultural staples such as wheat, corn, and meat into higher value-per-ton goods can mitigate their otherwise elevated transportation costs. For instance, wheat and corn were transformed into flour and whiskey, respectively. Livestock such as swine and cattle were processed into meat products for eastern transport via the Erie Canal. Similarly, deer skins and raw hides underwent tanning processes, and sheep-derived products like wool were manufactured in fulling mills. Raw timber was processed

Table 7: IV estimates of canal's effect on commercial activities

	(1) Inns and taverns	(2) Wholesale stores	(3) Retail stores	(4) Groceries
Panel A				
$Canal(\hat{dummy})$	6.018**	8.212	21.811**	21.508**
	(2.658)	(5.087)	(9.942)	(8.624)
Observations	167	167	167	167
County FE	Yes	Yes	Yes	Yes
Panel B				
$Distan\hat{c}e\ to\ canal$	-0.570**	-0.777	-2.065**	-2.036**
	(0.252)	(0.477)	(0.933)	(0.804)
Observations	167	167	167	167
County FE	Yes	Yes	Yes	Yes

Table 8: Types of articles that shipped by merchants through the canal

Types of main manufacturing mills	Types of articles on the canal
Grist mill	flour, starch, bran, wheat, rye, corn, barley, oats, bran, coarse grain
Saw mill	boards and scantling, shingles, timber, lumber, staves, furniture
Ashery	ashes, potash, pearl
Oil mill	lard oil, tallow
Clover mill	clover and grass seed, flax seed
Fulling mill	wool, cotton
Tannery	Hide, leather, fur and peltry
Iron works	pig iron, bar and pig lead, castings
Distillery	whisky
Brewery	hops, beer, cider
Glass factory	glass
Product of animals:	hogs, pork, ham, cattle, beef, bacon, sheep, cheese, butter, fish, oyster, clam, beeswax
Vegetables and fruits:	beans, apple, peach, sundries, hemp, flax, tobacco,
Others:	salt, stone, brick, lime and clay, gypsum, coal, soap

Notes: Data are from the Annual Report of the Canal Commissioners.

into lumber, staves, shingles, and other wood products in sawmills. These manufacturing endeavors, driven by the abundant local agricultural produce, facilitated the shipment of processed goods to eastern New York State through the Erie Canal.

6 Impact on Urbanization

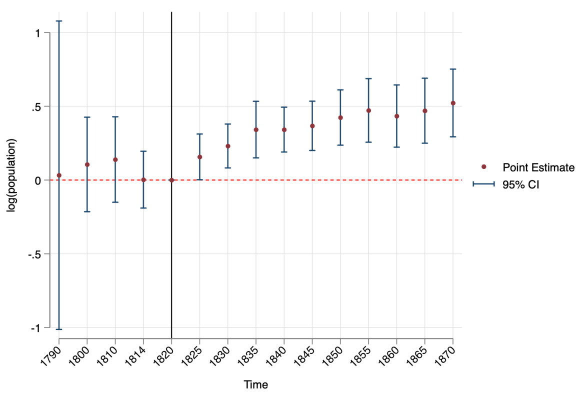
In this section, I present evidence of the canal's effect on long-term economic growth in terms of population growth and the newly formed towns.

6.1 Long-term Population Growth

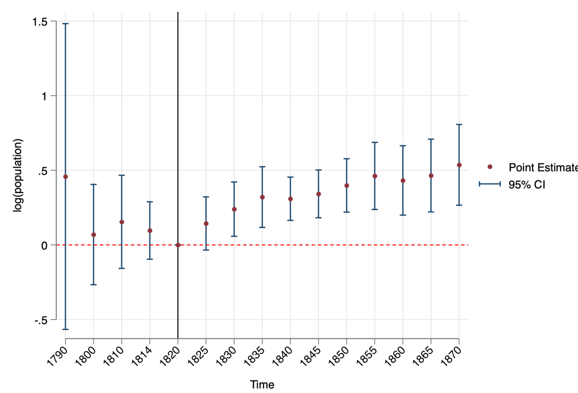
I apply an event study to estimate the canal's effects on population records from 1790 to 1870, employing the subsequent approach

$$log(Population)_{ijt} = \alpha + \sum_{k=1790}^{1820} \beta_k lead_k Canal_i + \sum_{k=1825}^{1870} \beta_k lag_k Canal_i + \gamma X_{i1824} + \theta_i + \phi_t + \lambda_{jt} + \epsilon_{it}, \tag{2}$$

where $lead_k$ is the time indicator for years before 1825. The $lead_k$ variable includes years of 1790, 1800, 1810, and 1814. lag_k is the time indicator for years after the operation of the canal. The lag_k variable includes years from 1825 to 1870 with 5-year intervals. Other parameters and variables are defined as the same as in Equation 1.



(a) No county-year fixed effects



(b) With county-year fixed effects

Figure 7: The event study of canal's effect on long-term population growth

Figure 7 shows the results from event studies of the population between 1790 and 1870. The within-county estimates from subfigure (b) are similar to the estimates in subfigure (a) that allow comparison between different counties. Both subfigures control the baseline difference in education in 2824. There is no significant difference in population between canal towns and noncanal towns from 1790 to 1820, which provides further evidence for the validity of the parallel trend assumption. Following the Erie Canal's completion, canal towns registered a pronounced acceleration in population growth from 1825 to 1870, in contrast to their noncanal counterparts with similar characteristics. The canal's enduring growth ramifications spanned at least 45 years, within the confines of this study's timeframe. Transforming natural *log* to exponential form, canal towns witnessed a faster population growth at rates of 19%, 30%, 50%, 50%, 56%, 69%, 83%, 72%, 82%, and 98% from 1825 to 1870 respectively, given 1820 as the benchmark year. By substituting $log(population)_{it}$ for Y_{it} in Equation 1, the DiD estimate of β is 0.329. By transforming natural *log* to exponential form, canal towns witnessed 39% faster population growth.

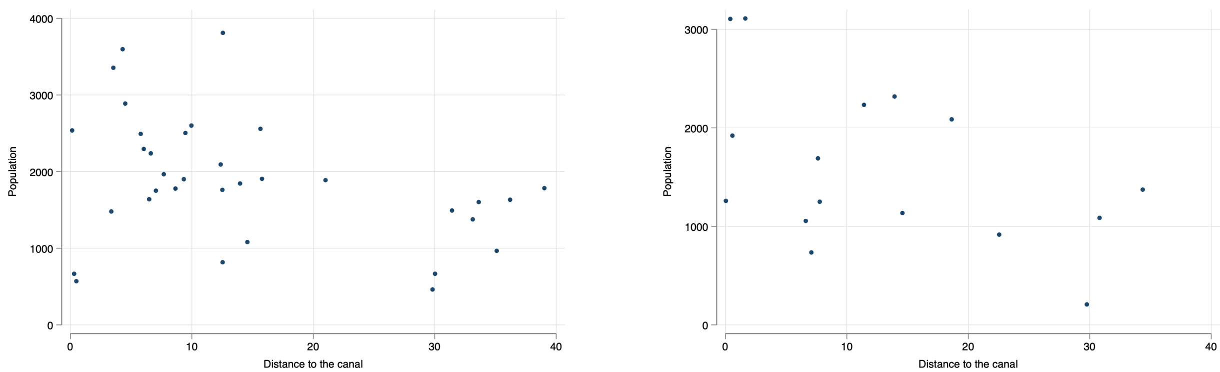
6.2 Formation of New Towns

Due to the nature of the DiD setup, the analysis regarding employment and population only includes towns that already existed before the canal operation and excludes newly formed towns that did not have data before the canal operation. In 1820, there were 48 canal towns and 54 non-canal towns. By 1840, these numbers grew to 66 canal towns and 89 non-canal towns. By 1870, they further expanded to 71 canal towns and 96 non-canal towns.

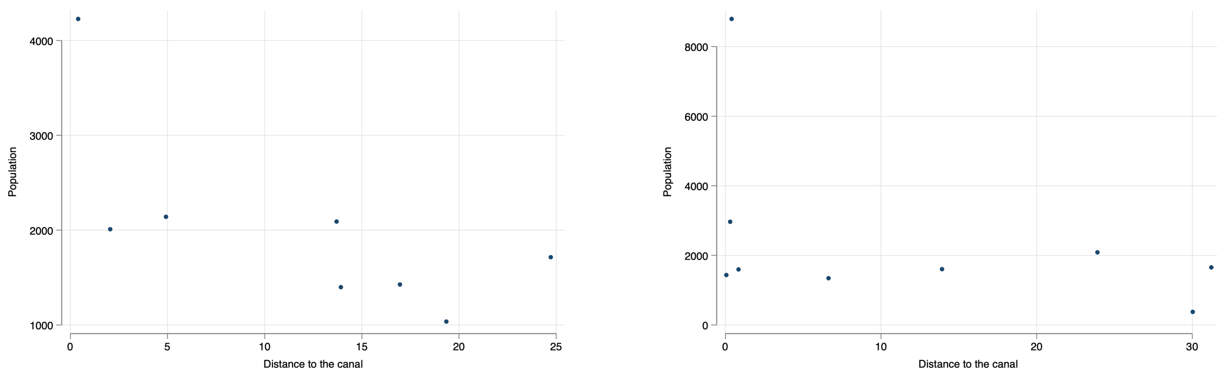
Table 9: Balance test of new towns in 1840 between canal towns (0-5km) and noncanal towns (5-15km)

	Canal towns	Obs.	Noncanal towns	Obs.	Diff.	p-value
Population	4145.94	18	2262.46	35	-1883.49*	0.02
Total Employment	1190.61	18	660.09	35	-530.53**	0.01
Employment in agriculture	644.28	18	502.89	35	-141.39	0.13
Employment in manufacturing	421.56	18	123.23	35	-298.33*	0.01
Employment in commerce	64.17	18	16.23	35	-47.94*	0.04
Agriculture employment share	0.66	18	0.79	35	0.13*	0.02
Manufacturing employment share	0.26	18	0.17	35	-0.10*	0.02
Commerce employment share	0.04	18	0.02	35	-0.02	0.10

A closer look at the towns that formed after the canal is useful (see Table 9). There were 53 towns—comprising 18 canal towns and 35 noncanal towns—emerged between 1820 and 1840. A balance test for 1840 shows that, on average, the newly formed canal towns exhibited a larger population, total employment, and employment in manufacturing and commerce. They also displayed lower agricultural employment shares and higher manufacturing employment shares. These findings suggest the DiD estimates present a lower bound for the canal's effects on sectoral transition in terms of employment and long-term population growth.



(a) New towns in 1830 (b) New towns in 1840



(c) New towns in 1850 (d) New towns in 1860

Figure 8: Number and size of the new towns

However, dropping the newly formed towns might drop an interesting part of the narrative that the Erie Canal might promote the formation of new towns. Next, I analyze the newly formed towns after the opening of the canal regarding their distance to the canal and their population size.

Figure 8 shows the new towns in 1830, 1840, 1850, and 1860 respectively. New towns are defined in a 5-year interval due to the data feasibility. For example, new towns in 1830 were towns that had population records in 1830 but did not have population records in 1825. Three trends can be summarized from the figure. First, among new towns formed in 5 years, they were more likely to be located close to the canal, which means the canal promoted the formation of new towns. Second, new towns that were located close to the canal were larger in terms of population, which is consistent with the balance test in Table 9. Third, there were fewer new towns as time went by.

6.3 No Displacement Effects

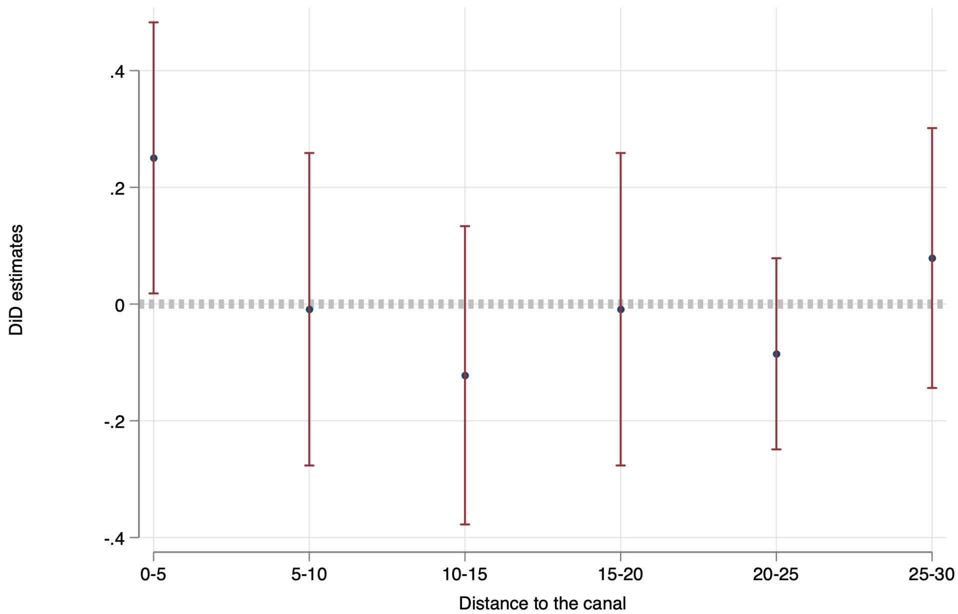


Figure 9: No local population displacement effect

Next, I study whether or not there is a re-allocation of the population between canal towns and noncanal towns. It is possible that the population gain in the canal towns came from the population loss in noncanal towns, which means there were displacement effects caused by the canal operation.

To test it, I applied the DiD specification by using 5 km distance bins that interacted with the post dummy as the treatment variable. These distance bins start with 0 to 5 km, 5 to 10 km, and go up to 25 to 30 km. The comparison group is towns located more than 30 km from the canal. Figure 9 shows towns that located more than 5 km from the canal did not have a significant difference relative to towns located more than 30 km from the canal, which suggests there is no local population displacement effect.

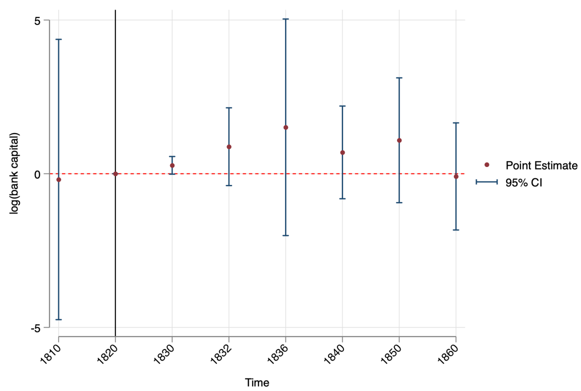
It is highly likely that the population gain in canal towns was from the European immigrants. As a leading economy in the nineteenth-century U.S., New York State was a prosperous place where European immigrants and people in other states in the U.S. migrated to it for opportunities. New York State, for most of the immigrants, was the first place they arrived in the U.S. and was a large labor market with ready employment for immigrants (Ferrie, 1999). Towns in this time period were small towns with an average of 2750 population size, canal towns in 1820, for example.

7 Impact on Banking Development

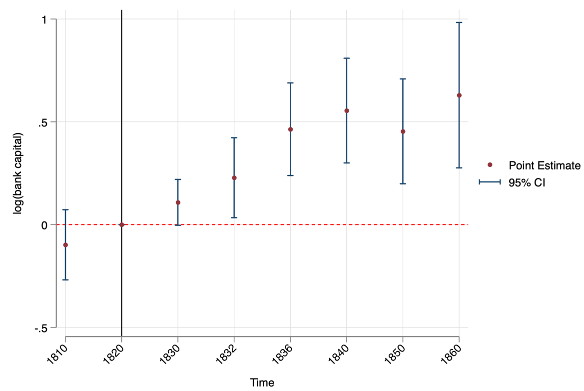
In this section, I study the canal's effects on town-level banking development. Canals concentrated people and economic activities into canal towns by reducing transportation costs. The increase in commercial activities may result in the expansion of existing banks. At the same time, new banks were attracted to urban areas to meet manufacturing and commercial businesses' needs for loans and deposits.

Figure 10 presents event studies of the canal's effects on town-level banking development from 1810 to 1860 in terms of bank capital, the difference between a bank's assets and liabilities. Subfigure (a) restricts the analysis to towns that had banks before the canal operation. In 1810, there were only 5 towns in New York State that had banks among which there were 3 canal towns located near the Hudson River. In 1820, 18 towns had banks among which there were 9 canal towns. There was no significant difference between canal towns and noncanal towns regarding bank capital before the canal operation. There was weak evidence that among towns with existing banks, canal towns experienced faster growth in bank capital given the insignificantly positive estimates.

To include the canal's effect on promoting new banks in the analysis, I set the bank capital of towns that did not have banks and towns that had not yet been formed before canal operation to zero. Subfigure (b) in Figure 10 shows there was no difference between



(a) Towns with existing banks before the canal



(b) All towns until 1860

Figure 10: The event study of canal's effect on bank capital growth

Notes: Subfigure (a) does not control the county-year fixed effects due to the limited observations. Subfigure (b) controls the county-year fixed effects, and the results are similar without the county-year fixed effects.

canal towns and noncanal towns before the canal opened. After the canal opened in 1825, canal towns gradually had faster growth in bank capital compared with their noncanal counterparts. Given the evidence earlier that the canal's effect on towns with existing banks is insignificant, subfigure (b) suggests the canal mainly increased bank capital in new towns that were close to the canal but did not exist before the canal opened. Transforming natural *log* to exponential form, canal towns witnessed a faster growth in bank capital at rates of 12%, 29%, 80%, 110%, 78%, and 140% from 1830 to 1860 respectively, given 1820 as the benchmark year. The insignificant and relatively smaller effect in the early 1830s is consistent with Bodenhorn (2006) and Bodenhorn (2021)'s findings that the entry of banks was manipulated by Martin Van Buren's Democratic coalition until the late 1830s when New York State entered the free-banking era.

Next, I explore the extent of the canal's effect on town-level bank capital. Figure 11 displays the DiD estimates by adjusting the definition of canal towns in 5km increments from 5 km to 80 km. Noncanal towns—serving as the control group—are those located within 100 km of the canal but not categorized as canal towns. First, it shows that the results are robust and not sensitive to marginal distance change. Canal towns, in comparison to their

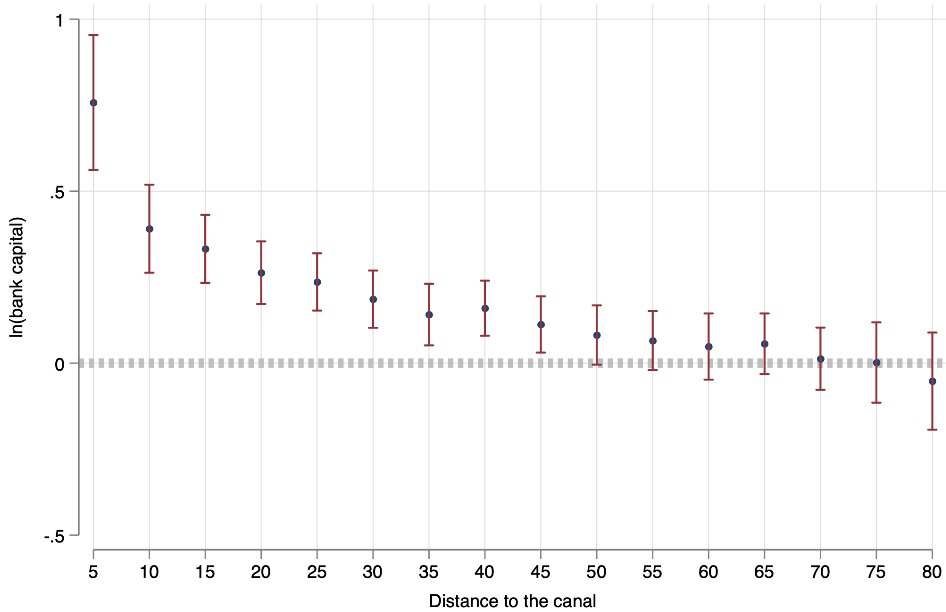


Figure 11: The extent of canal's effect on town-level bank capital

noncanal counterparts, experienced faster growth in bank capital. Second, Figure 11 suggests the extent of the canal's impact on bank development from 1810 to 1860. It indicates the effects diminish in towns as they are located increasingly distant from the canal and disappear when towns are located beyond 70 km from the canal. Compared with the extent of the canal's effects on sectoral transition and long-term population growth, the canal's effect on bank development is larger.

8 Robustness Checks

8.1. Excluding the Immediately Adjoining Towns to Tackle the Potential Spillover Effects. A potential issue to consider is the bias in the estimates due to spillover effects between canal towns and noncanal towns. Take population, one of the outcome variables of interest, for illustration. If migration occurred from noncanal towns to canal towns post-canal operation, the DiD estimates would be upward biased. Conversely, the DiD estimates would be downward biased if there had been a migration from canal towns to noncanal

Table 10: Robustness checks for DiD estimates

	(1) Agriculture Employment share	(2) Manufacturing employment share	(3) Commerce employment share	(4) log(employment) in agriculture	(5) log(employment) in manufacturing	(6) log(employment) in commerce	(7) log(total employment)	(8) log(population)	(9) log(bank capital)
Panel A: Excluding adjoining towns									
PostCanal	-0.050*	-0.009	0.018***	0.181	0.280	0.763*	0.288**	0.295**	0.882**
	(0.028)	(0.029)	(0.004)	(0.139)	(0.188)	(0.377)	(0.131)	(0.127)	(0.396)
Observations	142	142	142	142	142	142	142	917	568
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel B: Excluding targeted towns									
PostCanal	-0.047**	0.008	0.011***	0.031	0.143	0.577*	0.144	0.231**	0.644**
	(0.021)	(0.021)	(0.003)	(0.116)	(0.145)	(0.306)	(0.113)	(0.106)	(0.240)
Observations	192	192	192	192	192	192	192	1254	768
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel C: Excluding the middle section									
PostCanal	-0.079**	0.025	0.018*	-0.092	0.232	0.595*	0.172	0.226**	0.907**
	(0.027)	(0.021)	(0.010)	(0.160)	(0.176)	(0.331)	(0.134)	(0.090)	(0.334)
Observations	176	176	176	176	176	176	176	1152	704
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel D: Matching method									
PostCanal	-0.063***	-0.018	0.022**	0.081	0.375***	0.810***	0.429***	0.544***	1.516***
	(0.023)	(0.024)	(0.011)	(0.151)	(0.105)	(0.303)	(0.116)	(0.152)	(0.493)
Observations	1082	1082	1082	1084	1048	1090	1082	1098	1100
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

towns. In addressing this concern, I exclude areas immediately adjoining the treated towns from the control group to mitigate spillover effects. The assumption here is that while migration may have occurred between canal towns and their neighboring noncanal towns, such movement was less probable between canal towns and more distant noncanal towns, given the substantial wagon transportation costs in early nineteenth-century New York State.

In the baseline DiD estimates, control towns are those located between 5 km and 15 km from the canal. I split the control towns into two parts and excluded those from 5 km to 10 km. Now the control towns are solely those situated from 10 km to 15 km away from the canal. The effects of canal operation on sectoral transition, population, and bank capital remain significant with the same signs and similar magnitudes, as evidenced in Panel A of Table 10.

8.2. Excluding the Targeted Towns. In the process of constructing the canal, several towns were planned to be traversed by the canal. They were Buffalo, Syracuse, Utica, and

Waterford. Many other towns were either of lesser importance or did not exist when the canal was constructed like Lockport. A potential issue arises if employment in manufacturing and commerce in these major towns was already higher than in other control towns, which would create a selection bias. To address this concern, I exclude these four targeted towns from the treated group. Panel B in Table 10 provides the DiD estimates in the absence of these towns. The impacts of canal operation on sectoral transition, population, and bank capital persist, exhibiting consistent significance and direction, with marginally reduced magnitudes.

8.3. Excluding Towns in the Middle Section. The middle section of the Erie Canal, extending from Utica in Oneida County to Montezuma in Seneca County, began its construction in 1817 and was operational by 1820. This segment traversed various towns within the counties of Cayuga, Madison, Oneida, and Onondaga. Towns situated within 5 km of the canal in these counties might have experienced the canal's effects as early as 1820, contingent on the immediacy of employment reactions to canal operations. Consequently, I remove from the treated group those towns lying within this 5 km proximity in the aforementioned counties. The resultant impacts of canal operation remain significant, with consistent direction and comparable magnitudes, as illustrated in Panel C of Table 10.

8.4. Changing Control Towns Using Matching Approach. Towns shared similar pre-treatment employment structures and populations may be located across New York State. That is, candidate control towns located more the 15 km from the Erie Canal were previously excluded from our analyses. An alternative approach to selecting a control group by including those towns is to employ the matching method. I first use propensity score matching (PSM) to choose suitable control towns. For the matching process, data from the pre-treatment year, 1820, including population, employment shares, log(employment) in both agriculture and commerce, and bank capital were utilized. Towns with extreme propensity scores, falling below 0.01 or exceeding 0.9, were excluded. Subsequent to this, I apply the DiD method, as articulated in Equation 1, utilizing propensity score-weighted regressions.

Table 11: IV estimates of canal's effect on employment, population, and bank capital

	(1) Agriculture employment share	(2) Manufacturing employment share	(3) Commerce employment share	(4) log(employment) in agriculture	(5) log(employment) in manufacturing	(6) log(employment) in commerce	(7) log(employment total)	(8) log(Population)	(9) log(bank capital)
					Panel A				
$\widehat{Canal(dummy)}$	-0.133***	0.084***	0.025***	-0.090	0.509***	0.885***	0.221**	0.416***	0.938***
	(0.035)	(0.026)	(0.008)	(0.137)	(0.149)	(0.224)	(0.095)	(0.109)	(0.319)
Observations	256	256	256	256	256	256	256	1847	1336
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
					Panel B				
$\widehat{Distance\ to\ canal}$	0.012***	-0.008***	-0.002***	0.008	-0.048***	-0.083***	-0.021**	-0.039***	-0.089***
	(0.003)	(0.002)	(0.001)	(0.013)	(0.014)	(0.021)	(0.009)	(0.010)	(0.029)
Observations	256	256	256	256	256	256	256	1847	1336
County-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel D in Table 10 presents the PSM-DID estimates. The canal's operational effects on sectoral transition in employment and population persist in significance, maintaining consistent directions.

8.5. IV Estimates for DiD Feasible Variables. I apply the IV approach to variables that I have analyzed using the DiD approach as further robustness. Panel A in Table 11 Uses 5 km to define a canal dummy variable and panel B changes the canal dummy to the distance. Both show canal towns had a higher level of transition from agriculture to manufacturing and commerce, faster population growth, and faster growth in bank capital.

9 Conclusion

The nineteenth-century New York State serves as an example to study how transportation infrastructure plays a role in the early stage of economic modernization. During that time, New York State witnessed a western expansion where people moved into the West, a transition from agriculture to manufacturing and commerce, and it built the second-longest canal in the world. The construction of the state-led Erie Canal offers a quasi-experimental context, enabling this study to determine the causal impact of canals. Utilizing a difference-in-differences design, I compare towns located close to the canal relative to those that were not close to the canal before and after the operation of the canal. I find that: first, canal towns have a higher level of sectoral transition in employment from agriculture to manufacturing and commerce, larger manufacturing mills, and more commercial activities; second, canals promote long-term population growth in existing towns and the formation of new towns; third, canals promote new bank and increased bank capitals in canal towns. My findings also indicate the extent of canals' different effects.

Recognizing that canals serve as the main transportation medium before railroads, this paper introduces insights from the pre-railroad era to the discourse on transportation infrastructure. A notable point of comparison is the impact of the railroad. As for the long-term effects, my study shows that between 1790 and 1870, towns located close to the canal witnessed an average 39% faster population growth. In the context of railroads of Sweden, the rate stands at 25% between 1850 and 1900 (Berger, 2019). In the context of railroads of England and Wales, Bogart et al. (2022) reports a 0.875% annual population growth rate increase from 1851 to 1891. In the U.S., Donaldson and Hornbeck (2016) suggests that without railroads, the population would have declined by 58.4% in 1890, and Atack et al. (2010) shows a 3.7% higher urbanization rate in counties with railroad access. Of course, the reader should proceed with caution when comparing those figures due to differences in context, methodology, measurement, study period, and data sources.

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Appendices

Table 12: Property cleared at Buffalo and passing east on the Erie Canal from 1829 to 1835

Articles	Unit	1829	1830	1831	1832	1833	1834	1835
Flour	barrels	4335	31810	62968	21932	78666	79324	100833
Provisions(pork & beef)	barrels	4754	6675	5668	5159	4273	14590	8160
Oil	barrels	214	802	1420	44	43	221	
Wheat	bushels	3640	149219	186148	100761	114337	111798	168012
Ashes	tons	1705	2713	2502	2110	2118	1655	7304
Tobacco	tons	32	62	222	386	535	1008	1765
Hemp	tons	22	20	70	29	17	5	0.5
Pig iron	tons	235	419	409	760	1167	1128	997
Castings	tons	241		422	468	757	689	768
Household furniture	tons	42	58	69	88	134	145	355
Furs	tons	86	82	96	107	101	154	136
Lumber	feet	311256	136499	184639	251504	331140	439643	2087024
Staves	meter	510	464	568	523	699	2400	2694
Fish	barrels		851	150	276	279	346	732
Whiskey	barrels	149	4182	3750	2208	2485	1347	614
Butter & lard	tons	70	174	205	394	449	119	503
Cheese	tons	68	122	127	74	95	138	34
Wool	tons			66	22	75	73	93
Deer skins & raw hides	tons					110	141	207
Grind-stones	tons	35	39	124	110	139	126	135
Lead	tons		41	9				
Sundries	tons							242
Shingles	meter							74062
Timber	feet							61430
Corn	bushels							12193

Notes: Data are from the Annual Report of the Canal Commissioners.