Erie Canal and the Transformation of Early Nineteenth-Century New York

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Abstract

Whether canals encourage or mitigate regional specialization was a debate in the 1970s and remains unsolved. This paper provides a clearer picture of the transformation of early nineteenth-century New York state in terms of population and structural transformation. A network of least cost paths is created to exploit the feature that the state-owned canal traversed towns that were not targeted by planners. The IV-DiD estimates show areas "accidentally" traversed by the canal experienced more rapid population growth, lower employment share in agriculture, and higher employment shares in manufacturing and commerce. The lower employment share in the agriculture sector in canal towns was not driven by the decreasing employment in the agriculture sector but because of the increasing flow of population. The mechanism of structural transformation is that agricultural staples are processed into derivatives having higher value per unit by manufacturing workers and are shipped along the canal by businessmen.

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1 Introduction

Canals have not received their fair share of academic attention. The canal-building boom predated the railroad boom by a generation or more and canals were equally as transformative as railroads. The increased interregional trade and the reduction of transportation costs caused by the railroad have been well documented by economic historians (Fishlow, 1965; Fogel, 1964). It is worth to know that the reduction in transportation costs provided by canals, as compared with wagon haulage, was more substantial than the subsequent differential between railroads and canals (Goodrich et al., 1961).

There are studies that look at the effects of canal on market integration (Albion, 1939), government promotion of canals (Goodrich, 1960), public finance of canals (Wallis, 2003), and its association to inventive activity (Sokoloff, 1988). However, the causal effects of canal operation on structural transformation has not been studied in depth.

Ransom (1967) and Niemi (1970) study the effects of canals on regional specialization using shipment data and county-level employment data. I see two potential shortcomings in their studies. The first is the potential selection problem that the Erie canal may have been constructed in populated areas with active commercial or manufacturing activities. The second is that counties as analysis units are too broad when investigating the canal effects in the early nineteenth-century given that the complementary land transportation is mainly wagon haulage[1]. Neither of these issues was addressed in the literature.

This paper attempts to solve these potential problems and provides a clearer picture of the transformation of early nineteenth-century New York State, using the rollout of the Erie canal[2] as a quasi-natural experiment. This setting offers a useful feature

[1] Erie canal passed southern part of Herkimer County which is narrow in direction of north and south. 3/4 of the county gets access to the Erie canal with high transportation costs. In the early nineteenth-century a wagon traveled 2 to 3 miles per hour depending upon weather, roadway conditions, and the health of the travelers.

[2] Built between 1817 and 1825 and operated by the state, it was 364 miles in length and linked the Hudson River to Lake Erie. "The ton-mileage upon the Erie was always greater before 1860 than upon any other single transportation route."–Henry V. Poor

to identify the impacts of the canal. Unlike private transportation companies whose priority is to maximize profits by constructing canals in populated places with active commercial activities, the design and construction of the Erie canal were led by the state. The goal was to connect several consequential cities from the west to the east. Consequently, many non-targeted cities and towns gained access to the canal, which alleviates some endogeneity concerns.

I construct a dataset on population, manufacturing activity, employment in three broad sectors of the economy, and other socioeconomic characteristics for towns and cities before and after canal operation took place. I use a difference-in-differences design to estimate changes in sectoral employment, population, and structural transformation in employment between 1820 and 1840 among towns that were traversed by the canal relative to those that were not proximate to the canal. OLS estimates reveal a lower employment share in agriculture and higher employment shares in manufacturing and commerce in areas neighboring the canal. These effects are highly localized. Effects of structural transformation in employment attenuate in towns that are located more than 9 km away from the canal. Further estimates show the higher employment shares in manufacturing and commerce were attributed to the increasing employment in both sectors, while the lower employment share in agriculture is not driven by the decreasing total employment in agriculture but because of the increasing population and more rapid growth in other sectors. The mechanism is agricultural staples are processed into goods having higher value per unit by manufacturing workers and are shipped along the canal by businessmen.

An important empirical concern, however, is that OLS estimates are potentially biased if the canal traversed towns with better or worse growth prospects. To address this issue, I follow the approach of Berger (2019) and Bogart et al. (2022) and use an instrumental variable strategy that exploits the fact that the canal was explicitly to be built along the shortest route between the endpoints. I construct Least Cost

Paths (LCPs) that correspond to the canal that state planners would have built if the sole objective had been cost minimization subject to connecting the consequential cities along the route. Those inconsequential towns are traversed LCPs only because of their geography, which places them on a cost-minimizing route. Using this source of exogenous variation, IV-DiD estimates reveal large increases in population, employment in manufacturing and commerce, and structural transformation of employment in areas traversed by the canal. IV-DiD estimates are consistently larger in magnitude than the corresponding OLS estimates, showing the OLS estimates are downward biased.

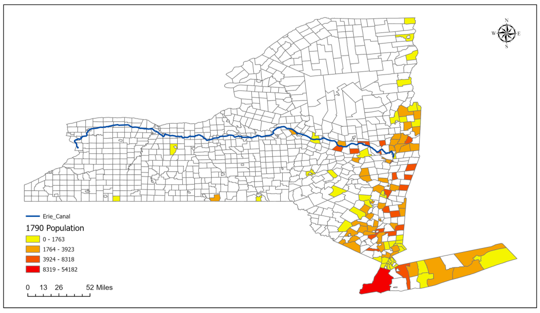
A key contribution of this paper is to identify the causal effect of the canal on the transformation of employment and long-term economic growth. Because population is discussed in this paper to better understand transformation and sectoral employment is used by scholars to measure other variables of interest, this paper also relates to the literature on canals' other economic impacts: accelerating western settlement, market integration, and regional specialization (Whitford, 1906; Albion, 1939; Goodrich et al., 1961; Ransom, 1967; Niemi, 1970)

2 Background

Between 1790 and 1814 the population of New York City doubled from 54,182 to 123,980 and it emerged as the nation's chief port as measured by the number of exports and imports loaded and unloaded at its wharves. In the year 1821, New York port accounted for approximately 20% of U.S. total exports and 37% of total imports. Tonnage entered from foreign countries and cleared for foreign counties accounted for 20% and 19% of total U.S. respectively (Albion, 1939). This commercial expansion was not limited to the city. Farther north on the Hudson River and Mohawk River were emerging towns with local hinterlands that served as markets or as transshipment points in the river trade.

The rapid western expansion, with the population of the state, tripling from 339,582 to 1,038,058 during this time, heightened the market consciousness of rural New York, and signified that the state as a whole was moving toward a higher level of economic complexity and integration. [Figure 1] Population concentrated in Long Island and Hudson Valley in 1790 with several towns, like Palatine, Canajoharie, German Flattes, Herkimer and Whitestown, along the Mohawk river. Whitestown was the most western town in Mohawk Valley at that time with an 1891 population. Canandaigua with a population of 464 was located lonely in west New York State. Only ten years later, in 1800, there were more towns emerging in Mohawk Valley. Population more than doubled in Whiterstown. Rome with a population of 1479, one of the important stops of the Erie canal later, was emerging during that 10 years. People kept moving to the western towns around nowadays Syracuse and towns around Finger Lakes Region. In the Finger Lakes region, the population in Canandaigua is 2.5 times more than 10 years ago, and many towns with more than 3,000 population were built like Junius, Aurelius, Scipio, and Genoa. By 1810, people reached Buffalo, and by 1820, the population sprawled the state. Populated towns were concentrated in three areas with water navigation: Hudson Valley, Mohawk Valley, and Finger Lakes Region. For merchants and farmers of these towns and surrounding areas, the need for improved transportation to maintain contact between the west-expanding line of commercial agriculture and the river towns increased steadily as time passed.

One outstanding characteristic of the economy of New York State during this period is mercantilism which emphasizes the state's entrepreneurial role in economic activity in terms of state loans to manufacturing corporates, taxation exemption of certain manufactories, contributing funds to agricultural societies (Miller, 1962). Before the construction of the Erie canal was taken over by the state, two private companies, the Western Inland Lock Navigation Company and the Northern Inland Lock Navigation Company tried certain sections of the canal but both failed due to financial constraints.



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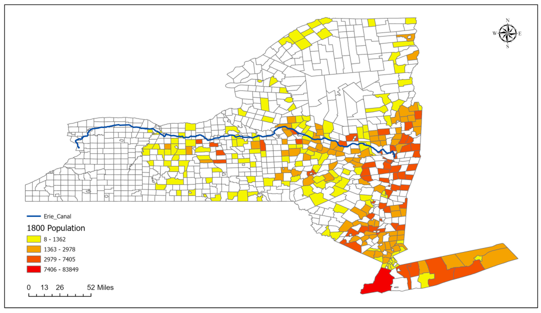

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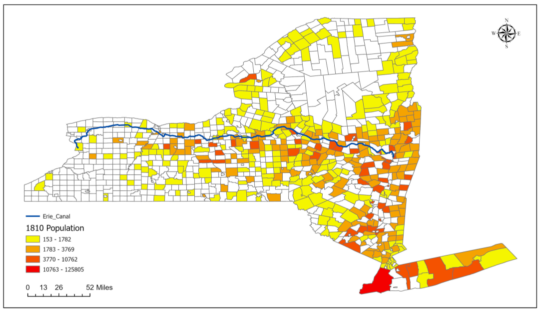

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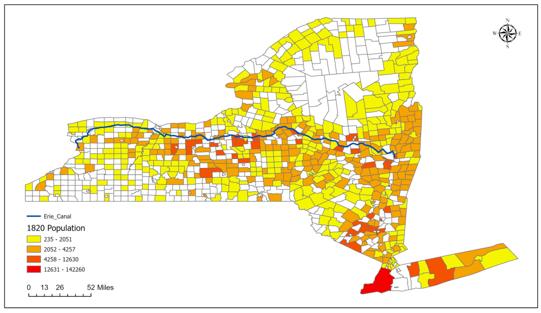


(d)

Figure 1: Population changes from 1790 to 1820

Canal construction and operation would entail only a change in form and extent of prevailing government interference. Built from 1817 to 1825 and operated by the state, the Erie canal, 364 miles in length, linked the Hudson river to Lake Erie.

The New York government at that time period was really controlled by some influential politicians and their political and economic networks. DeWitt Clinton, who took office as Governor of New York State on July 1, 1817, and served until December 31, 1822, was the president of canal commissioners. Before 1817, which was the year construction of the Erie Canal started, Clinton's faction in the Democratic party had been beaten by the Tammany organization. He was removed as mayor of New York City and was left without a party or a fraction of one, and deeply in debt. He started to forge a movement on the Erie Canal that drew supporters from all the parties and factions of the state. By taking the public leadership of the canal forces, he saved both the project and his career. Clinton with the Federalist minority leader of the Senate sent invitations to about one hundred prominent men of New York City. A meeting was held under the chairmanship of a prominent New York City banker and a member of the Society of the New York Hospital. Clinton was appointed chairman of a committee to memorialize the Legislature and took full advantage of the opportunity. Copies of his "New York Memorial", which recalled the uncompleted canal project by private companies, sent throughout the state evoked a response of remarkable power in view of the pessimism that had just previously prevailed. Public meetings in almost every city and village along the route of the proposed canal produced similar memorials. Over one hundred thousand signatures were sent to the next legislature. Wealthy Federalists-large landholders in the west and great merchants in the cities-as well as western farmers and Irish immigrants (in reaction to Tammany's nativist policy) were attracted to Clinton's banner, as the canal would increase their land value and boost in-state commerce.

On the other hand, a powerful opposition arose from rival interests, both individual and sectional, and from political differences. The Democrats led by Martin Van Buren, which was in control of the city, were instinctively opposed so as to prevent any political credit from accruing to their rival party. Political battles were taking place in the legislative stage. Although a bill authorizing a loan of $2 million for immediate construction of the Champlain Canal and part of the Erie canal between Rome and the Seneca River (the middle section) passed the Assembly in February 1816, an amendment for a local tax on lands lying within twenty-five miles of the canal had allayed some opposition in the Senate. The Senate, on Martin Van Buren's motion, deleted the authorization of construction on the grounds that more detailed and accurate surveys were required. The Long Island counties and mid-Hudson valley farmers were opposed to the canal because of the threat of extensive Midwestern and upstate produce entering New York City. Eventually, the bill for Erie canal construction passed in 1817 where the vote in favor of the bill was eighteen to nine, and five of those eighteen were zealous anti-Clintonians.

Van Buren shifted not only because he was actually convinced but because the project had become too popular to oppose (Rubin, 1961).

When it came to building the canal, given the minimum expectation of connecting several major cities like Buffalo, Syracuse, Utica, and Albany, engineering feasibility rather than local commerce employment (evidence shown in section 4) is the main priority before breaking ground. Surveys were caused by canal commissioners[3] and made by competent engineers[4]. The canal commissioners went by land or by boat up the Mohawk River to Rome and thence down to Oswego, and up from Three River Point to Geneva, where the boats were sold, the party proceeding by carriage to the Niagara (Kirkland, 1934). The surveys determined whether a sufficient supply of water for all seasons can be obtained without diminishing the supply of water to hydraulic works, the feasibility of constructing a stone lock, a culvert, and an aqueduct, and any other plans.[5] The majority of contracts of excavation, embankment, and stone locks are assigned to native farmers, mechanics, merchants, and professional men, residing in the vicinity of the line. Three-fourths of all the laborers involved were born locally. Machinery has been used in the heavy business of grubbing and clearing. For example, by means of an endless crew, connected with a roller, a cable, a wheel, and a crank, one man is able to bring down a tree of the largest size. The narrow plow was invented for cutting small roots and fibers which overspread the surface. [6]

The period after 1825 was referred to as the agricultural revolution where the old life of self-sufficiency was vanishing and all but the most isolated farmers were raising foodstuffs for sale by 1850 (Ellis, 1946). In the navigable season from April to December, thousands of boats passed on the Erie canal. The total number of boats and other floats

[3]They were Gouverneur Morris, De Witt Clinton, Stephen Van Rensselaer, Simeon De Witt, William North, Thomas Eddy, and Peter B. Porter in 1811. In 1816, the new commissioners are De Witt Clinton, Stephen Van Rensselaer, Samuel Young, Joseph Ellicott, and Myron Holley.

[4]James Geddes and Benjamin Wright, father of American Civil Engineering, for examples.

[5]Laws of the State of New-York, 1828.

[6]State of New York. *Annual Report of the Canal Commissioners.* Columbia University.

passed at lock No. 26, 3 miles west of Schenectady, increased from 6,166 in 1824 to 35,981 in 1854, with almost even distribution among each month.

Flood of western produce poured into the Hudson-Mohawk valley by the way of the Erie canal. Raw materials and basic resources, such as 311,256 feet of lumber, 3,640 bushels of wheat, 4,335 barrels of flour, 4,754 barrels of provisions (pork and beef), and 1,705 tons of ashes, which listed top 5 among properties cleared at Buffalo were passing east on Erie canal in 1829. By 1835, double amounts of provision, 4 times more ashes, 7 times more lumber, 23 times more flour, and 46 times more wheat were passing east on the Erie canal from Buffalo. Similar composition of articles passed Utica was observed from 1830 to 1832. On the other hand, 7,151 tons of Merchandize, 935 tons of furniture and mechanics' tools, and 65,431 barrels of salt were shipped to Buffalo from the east on the Erie canal in 1830. By 1835, 1.2 times more salt, 4 times more merchandise, and 9 times more furniture and mechanics' tools arrived at Buffalo from the east. Properties that arrived at Buffalo were not only consumed for New York State but also destined out New York State to places like Upper Canada, Pennsylvania, Ohio, Michigan, Indiana, Illinois, Virginia, Kentucky, Tennessee, Missouri, and Alabama.[7] The wide variety of articles passing on the Erie canal, including 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. portrays a lifelike early 19th century New York state.

[7] State of New York. *Annual Report of the Canal Commissioners.* Columbia University.

3 Empirical approach

The relationship of interest is the effect of the Erie canal operation on local employment in different sectors.

$$Y_{ijt} = \alpha + \theta_j + \phi_t + \beta Canal_{ij} + \delta X_i + \epsilon_{ijt} \quad (1)$$

where Y_{ijt} is the sectoral employment of town i in county j in year t. I use employment share in different sectors and (log) the sectoral employment as the dependent variables. α is a constant term common for all towns, θ_j is a county fixed effect to capture county invariant characteristics, ϕ_t is a year fixed effect to model possible nonlinearities common for all towns in the evolution of employment not captured by linear time trends, X_i is a vector of town characteristics that include population, and ϵ_{ijt} is a mean-zero error term. The town-fixed effect is not included because it is collinear with the canal dummy in this regression, but I will include the town-fixed effect in later regressions. County seats served as governmental and political centers in which employment may concentrate. And the success of the construction of the Erie canal was determined in large part by politics (Rubin, 1961). Bleakley and Lin (2012) show that North American cities tended to locate at native portage points and the Iroquois Trail was an ancient, Native-American trade route used by colonial military forces in troop deployments that crossed several rivers.[8] A town's elevation is included following Nunn and Puga (2012), which discusses the importance of terrain irregularities on local economic development. $Canal_{ij}$ is an indicator variable equal to one if a town located less or equal to 9 kilometers from the canal after the completion of the canal, and zero otherwise. If it is not emphasized, the regression is always clustered at the town-level to allow for arbitrary auto-correlation for the outcomes for the same units across time periods. The OLS estimate of β is unbiased

[8] County-seat dummy and Iroquois trail dummy were not included in the regression but they are captured by the county fixed effects.

if $Canal_{ij}$ is orthogonal to ϵ_{ijt}, that is if the construction of the canal is unrelated to local factors that would also affect the employment. In general, this assumption is unlikely to hold because employment shocks that result in an increase of employment in the commerce sector, for example, will probably influence the construction location choice of the canal.

3.1 Difference in Differences

A solution to the probable endogeneity of canal location is to employ a difference-in-differences (DiD) framework to compare employment changes in towns that are physically close to the canal (treated towns) and towns that share similar characteristics but physically far away from the canal (control towns) in the period before and after the year 1825. Cities and towns treated by the canal are defined by the following method: I calculate the planar (straight-line Euclidean) distance between the city/town hall and the Erie canal. It is completed by calculating the distance from the multipoint to the perpendicular or the closest vertex of a polyline in ArcGIS. Cities and towns whose distance is less or equal to 9 kilometers are defined as treated by the canal.

$$Y_{ijt} = \alpha + \eta_i + \theta_j + \phi_t + \beta Post_t Canal_{ij} + \epsilon_{ijt} \tag{2}$$

where η_i, θ_j, and ϕ_t are town, county, and year fixed effects respectively. Under the DiD approach, the identification assumptions are stable unit treatment value assumption (SUTVA), no-anticipation assumption, and 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 the interference across units and spillover effects. This assumption likely held in the early nineteenth-century when a wagon traveled 2 to 3 miles per hour depending upon weather, roadway conditions, and the health of the travelers. I will also change the distance that defines the control towns to test SUTVA. The idea is it's more unlikely that town j will be affected by town i as they are further away. The non-anticipation assumption is highly likely to hold since the year of operation of the whole Erie canal is 1825 and the pre-treatment year I utilize is 1820. Even though people in the agriculture sector or commerce sector were incentivized by the construction of the Erie canal to change jobs, the assumption here is people seldom made decisions 5 years before. I will also create subsets of the data, and remove towns located beside the middle section of the Erie canal which operated before 1820, for robustness. The "parallel trends" assumption is tested by comparing the pre-treatment town characteristics using 1820 federal census data and the 1824 Gazetteer of the State of New York.

Even though I can reduce the potential spillover effect by choosing towns that were far away from the canal-towns (evidence shown in section 5.2), it is difficult to make sure the noncanal-towns followed the same trend as canal-towns after the operation of the canal. Take population, one of the outcome variables of interest, for illustration. If the population migrated from noncanal-towns to canal-towns after the operation of the canal, the DiD estimates are overestimated. If the population in noncanal-towns saw a higher growth rate than in canal-towns after the operation of the canal because of other factors, the DiD estimates are underestimated.

3.2 IV-DiD

Another empirical concern, however, is that OLS estimates are potentially underestimated or overestimated if the canal traversed towns with better or worse growth prospects. A solution to the endogeneity of canal operation to future employment is to use the state-planed feature of the canal which generated plausibly exogenous variation in the incidence of canal construction. The least cost path (LCP) that builds on the inconsequential places approach will be used as an instrument variable. The key idea, applied to my setting, is that some spatial units were selected by canal builders to pass through because of their existing traffic volumes and/or their potential to generate freight traffic. They are known as consequential places, like Albany, Utica, Rome, Syracuse, and Buffalo. There were also inconsequential places receiving canal only because of their geography, which places them on a cost-minimizing canal route connecting the consequential places. Areas that were not directly targeted by planners "accidentally" traversed by the canal.

Most studies select major or historic cities to serve as consequential places (Atack et al., 2008; Bogart et al., 2022). I follow a similar approach as explained below. Supposing that two consequential places are to be connected, then what is the best route? The original approach is to use straight lines. Subsequent studies use slope and geographic impediments to create LCPs (Faber, 2014; Berger, 2019). I modify Bogart et al. (2022)' method to avoid loops that are common in railways networks and use slope and closeness to water resources to create LCPs linking consequential places.

The first step is to choose the start and end points of the Erie canal and get the gravity index for all the towns. I choose Albany as the starting point and Buffalo as the endpoint. A simple gravity equation[9] is used to approximate the relative value of connecting town pairs. A planar distance is used to measure the distance of town pairs. I use the 1820's population in the gravity equation because the Erie canal was constructed from 1817 to 1825, and the year 1820 lies between them. Using Flater (2022)'s algorithm in ArcGIS, I get a 562×562 table of gravity index for all the cities and towns that have population data in 1820 except New York City. New York City has a 142,260 population which is 11 times more than the second-largest town, Albany. I exclude New York City, which is not along the canal, from the dataset.

The second step is to select towns to which LCPs should pass through or close. using the gravity index calculated in the first step. I rank the gravitational value of

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

the other 561 towns that pair with Albany and find the town, Rensselaer, that has the largest gravitational value and connect them. Then find the town that has the largest gravitational value with Rensselaer. If the town that has the largest gravitational value with Rensselaer is Albany, then select the town that has the second-largest gravitational value with Rensselaer. Continue this process until the endpoint, Buffalo, is included in the constructed path. Considering the nature of the canal, which needs to be supplied with water, a constraint is being considered in this process. If two candidate towns have similar gravitational values, I choose the town close to the water resources. LCPs are not necessarily passing through the center of selected towns.

The third step is to take construction costs into consideration and get the least cost path. The least cost path does not need to be straight, instead, it should follow the topographical features to maintain low construction costs. Digital Elevation Models (DEM) having a pixel resolution of approximately 10 meters are used (Survey, 1995). Elevation data is first transformed into slope data which is used later as the cost raster to get the distance accumulation raster. The LCP (in red) is constructed by considering economic features like population from the benefit side and topographical features like elevation from the construction costs side.

LCP passes through consequential towns like Albany, Utica, Rome, Syracuse, Rochester, and Buffalo. It also fits selected towns, selected by gravity index, very well. The New York State Thruway (in green) operated by the New York State Thruway Authority (NYSTA) and constructed in 1954 when the cost-minimized technology was improved relative to the 1820s, can be a good reference to the reasonableness of the LCP. The thruway mostly overlaps with the LCP.

Town-level Commerce employment ratio, employment in the commerce sector divided by total employment, is shown in Figure 2. Towns had a higher employment ratio in the commerce sector in 1820 located in Hudson Valley, Long Island, and several towns close to St. Lawrence River, Lake Erie, Lake Ontario, Lake Champlain, and Finger Lakes.

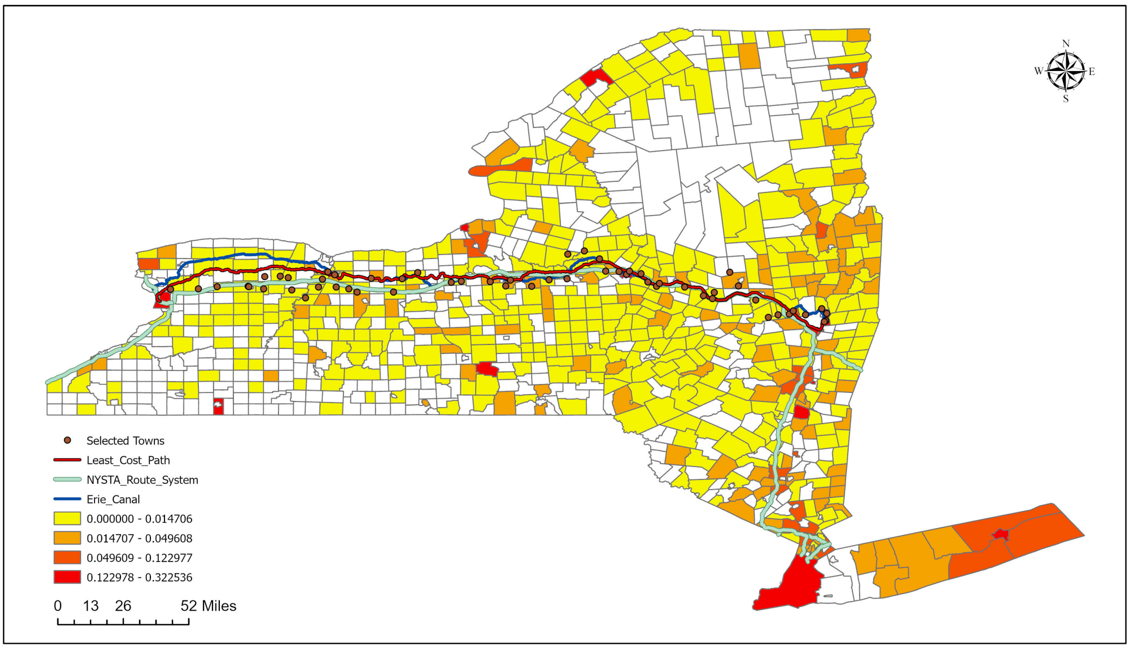


Figure 2: Least cost path and the employment share in commerce sector in 1820

Towns had the Erie canal and LCP passed through did not have significantly higher employment share in the commerce sector (statistical evidence will be shown in section 5).

The least cost path constructed early taking pre-treatment economic features, the population in 1820, and topographic features, elevation, into consideration can serve as an instrument for canal construction. If the state of New York considers towns through which the Erie canal pass, towns where the least cost path passes through were highly likely chosen. I, therefore, estimate the first-stage regression of the form:

$$PostCanal_{ijt} = \mu + \gamma_i + \tau_j + \kappa_t + \delta PostLCP_{ijt} + \nu_{ijt} \tag{3}$$

where γ_i, τ_j, and κ_t are town, county, and year fixed effects respectively. PostLCP is an indicator variable that equals one if LCP equals one and the year corresponds to 1840 after the canal was operated. LCP equals one when towns whose distance from the least cost path is less or equal to 9 km. The first-stage prediction of the PostLCP variable is then used to estimate the second-stage IV regression using DiD equation given in equation 4.

$$Y_{ijt} = \alpha + \eta_i + \theta_j + \phi_t + \beta Post_t\hat{C}anal_{ij} + \epsilon_{ijt} \quad (4)$$

where η_i, θ_j, and ϕ_t are town, county, and year fixed effects respectively. $Post_t\hat{C}anal_{ij}$ is the predicted values of the first-stage regression (3).

The IV estimate turns on whether the local average treatment effect (LATE) is identified from LCP-inducted canal construction. The towns are divided into four groups: compliers, defiers, never-takers, and always-takers. Compliers, the subpopulation of interest, are those whose treatment status is affected by the instrument in the right direction. In this case, compilers are those towns that are more likely to be treated with the canal because the LCP passes through. There are 91 towns out of 112 towns that are complier, which accounts for approximately 81.25% towns. A defier is a town whose treatment status is affected by the instrument in the wrong direction, which would imply a town that the LCP passes through but the Erie canal does not pass through. There are 11 towns that are defier. A never-taker is a town that never construct a part of the Erie canal independent of being passed through by LCP. The set of always-takers is the set of towns in which the canal is constructed independently of being passed through by LCP. The obvious always-takers are towns at the start and end points of the Erie canal, like Buffalo and Albany. Towns around Buffalo city and Albany city have a high probability to be passed through by the canal regardless of being affected by the instrument (i.e. the LCP passes through). I exclude towns located within 9km from the LCP in Albany county and Erie county from regression.

4 Data

The New York State town-level population data are from Bodenhorn and Cuberes (2018). The federal government only canvasses employment of sector data in the years 1820 and 1840. The year of completion of the Erie canal, 1825, lies in the interval. The 1820 federal census records sectoral employment in agriculture, commerce, and manufacturing. The 1840 federal census also includes sectoral employment in mining, ocean navigation, inland navigation, and profession. The transformation of cities and towns is indicated by the change of employment from 1820 to 1840. Shown by Figure 3, cities and towns that located within 9km from the Erie canal, labeled by 1, experienced increasing employment share in the commerce sector and a higher decrease in employment share in the agriculture sector than other cities and towns, labeled by 0.

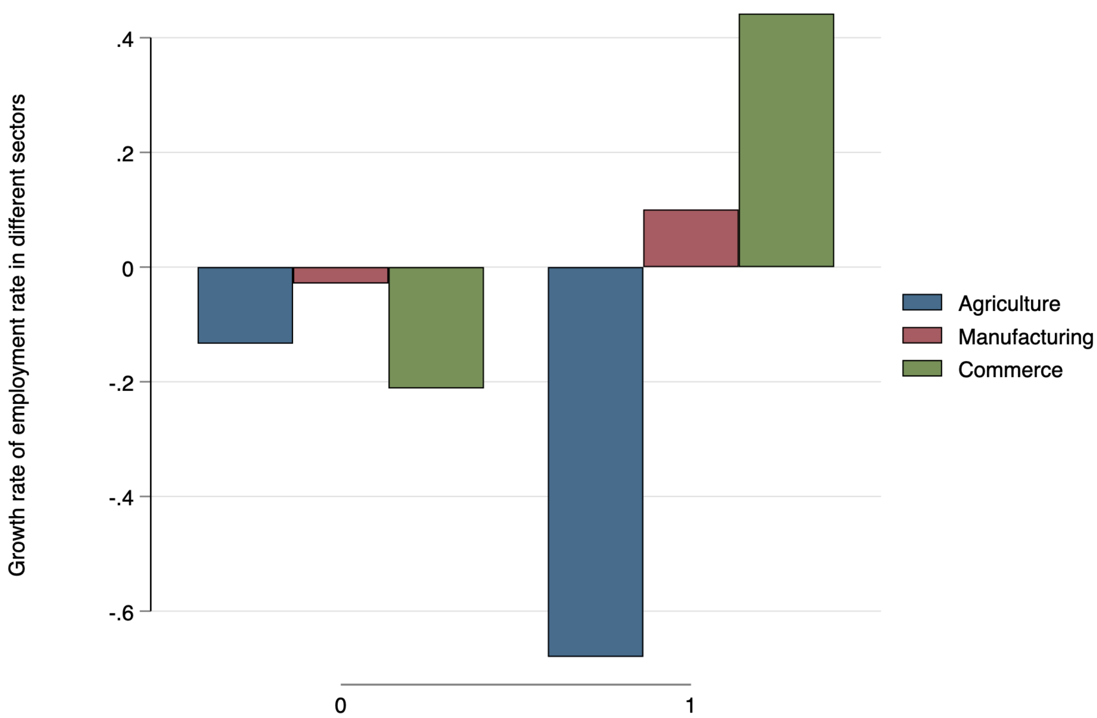


Figure 3: Change of employment share in different sectors by town group

The New York State city and town boundaries data are from the NYS Office of

Information Technology Services GIS Program Office (GPO). Since there is no historical New York State civil boundaries data available, I use the year 2021' boundaries as the base map. City and town boundaries do change from the study period to now. There were 985 towns back in the 19th century. There are 62 cities and 932 towns in 2021. One of the trends of township change is they are new towns established from existing towns from the 19th century. For example, Middletown in Orange County was part of Newburgh in Orange County before 1888; then, I add the population of Middletown to Newburgh. Another trend is there are places incorporated as a city within original towns. For example, Amsterdam city in Montgomery County was incorporated as a city in 1885. To deal with these cases, I put the historical population data to the town nowadays and leave the city blank. City and town boundaries are adjusted according to the Gazetteer of the State of New York 1824 and Wikipedia.

The historical canal path is from ArcGIS online portal named 19thC_Canals_March2017 (in blue). Other data like Mohawk river, Hudson River, New York State Thruway, etc., are from ArcGIS online portal as well. Data of articles traded through the Erie canal are digitalized from the Annual Report of the Canal Commissioners. Other socioeconomic data before 1825 are from the Gazetteer of the State of New York 1824 (Spafford, 1981). All the cities and towns are geocoded to points by name and county in ArcGIS, with some tied and unmatched towns matched by hand. ArcGIS automatically use the longitude and latitude of city hall or town hall as the points to represent cities and towns.

5 Empirical Results

5.1 DiD Estimates

I first test whether there were preexisting differences in sectoral employment, as well as other available town characteristics, between towns that would eventually be treated by the Erie canal and those that would not. That is, I examine whether eventual treatment in the Erie canal is correlated with covariates before 1825 and changes in employment measures of interest before the intervention was formally in place. Table 1 presents these results.

The results from Table 1 demonstrate that there are not highly significant baseline differences in employment measures of interest; transportation, Iroquois trail; political influence, the county seat and number of electors; economy, the value of taxable property; the number of a variety of manufacturing establishment; education, schools and number of people were taught. Figure 4, which includes town county, and year fixed effects[10], show that towns that located within 9km of the canal were initially no larger than towns that located between 9km and 15km from the canal. There is no significant difference in population between treated towns and control towns from 1790 to 1840.

The baseline estimates of the impact of the Erie canal on local employment, from estimating equation (2), are presented in Table 2. Column (1) (2) (3) test whether the Erie canal operation had a significant impact on the employment share of the agriculture sector, manufacturing sector, and commerce sector respectively. The results suggest that towns experiencing Erie canal operation had a lower employment share in the agriculture sector and a higher employment share in the commerce sector. In 1840,

[10]

$$Population_{ijt} = \alpha + \eta_i + \theta_j + \phi_t + \sum_{k=1790}^{1814} \beta_k PostCanal_{ijk} + \sum_{k=1825}^{1870} \beta_k PostCanal_{ijk} + \epsilon_{ijt}$$

was used in figure 3. Population data is only available for years shown in the figure.

Table 1: Comparison of town characteristics before 1825 between canal-towns (9km) and noncanal-towns (15km)

	Treated towns	Obs.	Control towns	Obs.	Diff.	p -value
population(N)	2827.25	64	3150.31	36	323.06	0.40
log empl_agri(N)	6.06	66	6.10	36	0.03	0.82
log empl_comm(N)	2.12	48	2.02	30	-0.10	0.73
log empl_manu(N)	4.50	66	4.57	36	0.07	0.74
empl_agri(r)	0.78	66	0.79	36	0.01	0.70
empl_comm(r)	0.02	66	0.02	36	-0.00	0.98
empl_manu(r)	0.20	66	0.19	36	-0.01	0.64
public money(Dollar)	534.78	51	413.48	27	-121.30	0.64
taxable property(k)	387.77	62	415.44	35	27.67	0.77
iroquois trail(Dummy)	0.96	24	1.00	8	0.04	0.57
county seat(Dummy)	1.00	13	1.00	4	0.00	.
schools(N)	12.48	58	14.50	32	2.02	0.19
taught(N)	712.65	52	856.93	27	144.27	0.20
custom	0.02	108	0.02	59	-0.00	0.94
children age 5-15(N)	761.64	50	750.12	26	-11.52	0.91
electors(N)	537.79	62	545.36	33	7.57	0.92
distillery(N)	1.50	64	2.19	36	0.69	0.11
grist mill(N)	3.91	64	3.69	36	-0.21	0.76
saw mill(N)	7.50	64	8.67	36	1.17	0.35
oil mill(N)	0.56	64	0.22	36	-0.34	0.08
fulling mill(N)	1.98	63	2.56	36	0.57	0.24
carding machine(N)	1.95	63	2.94	36	0.99	0.20
ashery(N)	2.09	64	3.06	36	0.96	0.12
cotton woollen factory(N)	0.40	62	0.56	36	0.15	0.53
tannery(N)	0.05	62	0.17	36	0.12	0.41
trip hammer(N)	0.44	62	0.39	36	-0.05	0.84
cloth made(yard_k)	17.35	61	44.25	35	26.89	0.14
churches(N)	3.33	15	4.33	12	1.00	0.37
iron works(N)	0.23	61	0.44	36	0.21	0.18

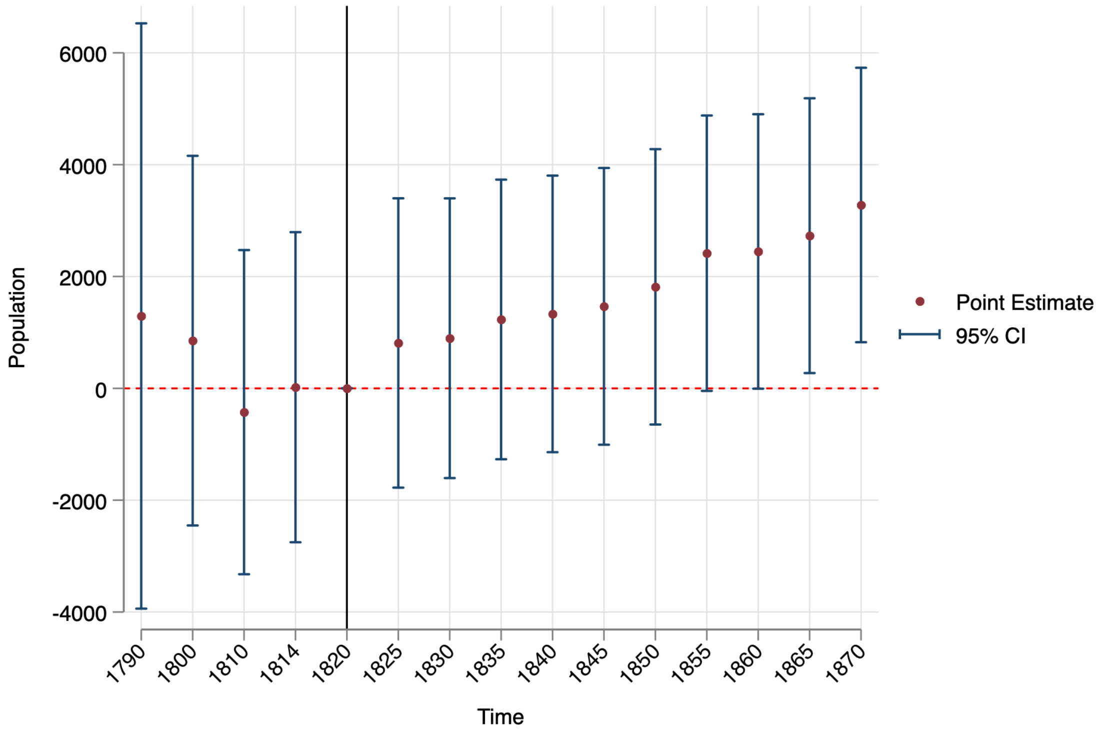


Figure 4: Control towns: 9km to 15km

the average town located within 9km from the canal had 8.8% less employment share in agriculture and 2.7% more employment share in commerce compared with towns located between 9km and 15km from the canal, given the employment shares in agriculture, manufacturing, and commerce sector are 77.5%, 19.6%, and 1.7% respectively in 1820. The operation of the Erie canal did not have a significant effect on employment share in the manufacturing sector. I change the dependent variable to (log) sectoral employment to study the employment change within each sector. Columns (4) (5) (6) (7) show the higher employment share in the commerce sector in canal towns was attributed to the increasing employment in the commerce sector. The lower employment share in the agriculture sector in canal towns was not driven by the decreasing employment in the agriculture sector but because of the increasing population base. Towns located within 9km from the canal had 202% more employment in commerce and 67.2% more

Table 2: DiD estimates of effects of canal operation on local employment structure using 15km as control towns

	(1) empl_agri(s)	(2) empl_manu(s)	(3) empl_comm(s)	(4) log empl_agri(N)	(5) log empl_manu(N)	(6) log empl_comm(N)	(7) log pop
PostCanal	-0.088***	0.034	0.027***	0.058	0.514***	1.106***	0.341***
	(0.024)	(0.023)	(0.010)	(0.153)	(0.184)	(0.323)	(0.117)
Constant	0.775***	0.196***	0.017***	6.202***	4.662***	2.200***	7.816***
	(0.008)	(0.007)	(0.003)	(0.049)	(0.060)	(0.103)	(0.037)
Observations	204	204	204	204	204	144	200
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

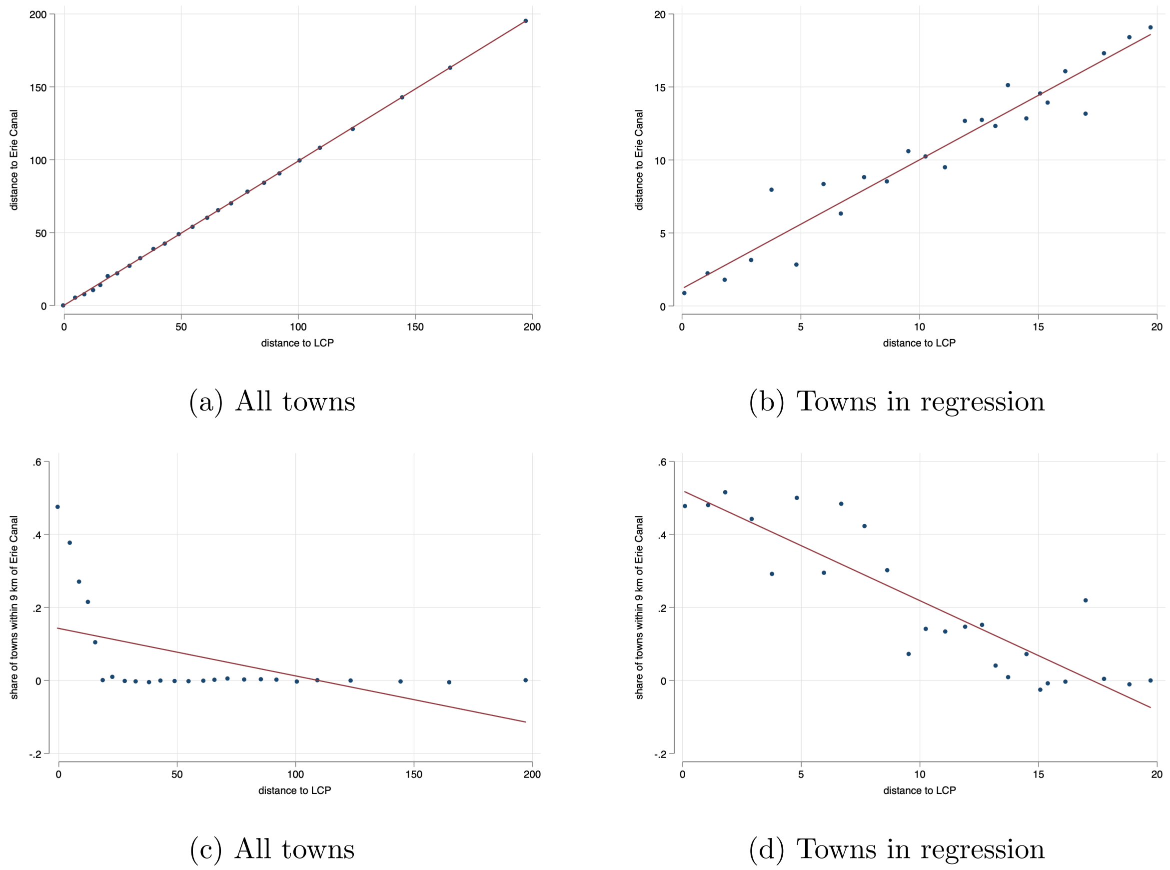
employment in the manufacturing sector in 1840, given the town-average employment in agriculture, manufacturing, and commerce sector are 494, 106, and 9 respectively in 1820.

5.2 IV-DiD Strategy

To interpret β as the LATE of being treated by LCP, the IV approach requires identifying assumptions: first stage, monotonicity, conditional independence, and exclusion. In this section, I summarize empirical evidence that supports the validity of the identifying assumptions.

5.2.1 First Stage

To document that towns along the LCPs also are more likely to be traversed by the Erie canal, Figure 5 visualizes the first stage using binned scatterplots. All towns are grouped into 25 equal-sized bins based on the distance to the nearest LCP (a and c). In regression below, I exclude towns that are always takers and towns where Erie canal was completed and operated before 1820. Towns in regression are also grouped into 25 equal-sized bins based on the distance to the nearest LCP (b and d). Each dot denotes to the mean distance to the nearest Erie canal (a and b) or the share of towns winthin 9



(a) All towns (b) Towns in regression

(c) All towns (d) Towns in regression

Figure 5: First stage

km of the Erie canal (c and d), and the mean distance to the nearest LCP respectively within each bin. Also shown are the best-fit lines estimated. Areas in proximity to the LCPs are clearly more likely to be traversed by the Erie canal, including town, year, and county fixed effects.

In the presence of heterogeneous treatment effects, we need to assume monotonicity 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, monotonicity requires that the probability of being treated by Erie canal is negatively correlated with the distance with LCPs. I examine monotonicity assumption by subfigure c and d in Figure 5. The share of towns treated by Erie canal declines as distance to LCPs increases.

Columns (1) and (2) in Table 3 present the first-stage OLS regression using all towns.

Table 3: First stage: Erie canal and distance to LCPs

	(1) PostCanal	(2) distance to Erie canal	(3) PostCanal	(4) distance to Erie canal
distance to LCP	-0.002***	0.989***	-0.027***	0.879***
	(0.000)	(0.004)	(0.002)	(0.040)
Constant	0.200***	0.261	0.489***	1.223***
	(0.018)	(0.284)	(0.023)	(0.469)
Observations	1850	1850	370	370
Time FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.306	0.999	0.520	0.862
F-statistics	76.585	57779.579	174.282	477.655

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Columns (3) and (4) present the results using sample towns in later regression where the always takers and towns in the middle section of Erie canal are excluded. Distance to the nearest LCP is a statistically significant predictor of the actual Erie canal constructed. The $F-$statistics reported at the bottom are always sufficiently large to satisfy the (Stock and Yogo, 2005) weak instrument criterion, namely a first-stage $F-$statistics in excess of 10.00.

5.2.2 Balance Tests

For the instrument to be valid, it requires that there is no correlation (conditional on county fixed effects) between factors that affect the potential outcomes of a town and proximity to these LCPs. Interpreting the IV estimates as identifying the causal effect of being treated by the Erie canal requires an exclusion restriction. That is, the LCP only impacts town potential outcomes through the Erie Canal, not through any other channels. As an indirect test of these two assumptions, I next provide evidence showing that there is no significant correlation between a variety of town's observable characteristics and proximity to a LCP at baseline in 1820.

Table 4: Balancedness of instrument

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A					
	log empl_agri(N)	log empl_manu(N)	log empl_comm(N)	empl_agri(s)	empl_manu(s)	empl_comm(s)
distance to LCP	0.004	-0.022	-0.028	0.006**	-0.005**	-0.001
	(0.010)	(0.016)	(0.025)	(0.003)	(0.002)	(0.001)
Constant	6.074***	4.614***	2.216***	0.756***	0.217***	0.027***
	(0.116)	(0.178)	(0.286)	(0.029)	(0.022)	(0.008)
Observations	115	113	83	115	115	115
County FE	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B					
	log pop	public money(Dollar)	taxable property(k)	taught(N)	children age 5-15(N)	churches(N)
distance to LCP	-0.013	0.766	-12.282	3.439	-3.614	0.029
	(0.009)	(5.448)	(7.655)	(9.367)	(8.592)	(0.102)
Constant	7.905***	308.080***	492.768***	684.859***	737.813***	3.645***
	(0.105)	(60.563)	(86.164)	(104.122)	(96.494)	(1.065)
Observations	116	88	111	88	85	24
County FE	Yes	Yes	Yes	Yes	Yes	Yes
	Panel C					
	iroquois trail(Dummy)	distillery(N)	grist mill(N)	saw mill(N)	fulling mill(N)	cotton woollen factory(N)
distance to LCP	0.004	-0.011	-0.020	0.056	0.056	0.007
	(0.005)	(0.034)	(0.059)	(0.117)	(0.039)	(0.016)
Constant	0.932***	1.926***	3.994***	7.353***	1.522***	0.288
	(0.059)	(0.383)	(0.660)	(1.308)	(0.433)	(0.180)
Observations	33	114	114	114	114	113
County FE	NO	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4 presents OLS estimates from regressing outcomes variables and a variety of town characteristics on the distance to the nearest LCP, while conditioning on county fixed effects. Town observed characteristics are well balanced across the instrument, the distance to a LCP, with two exceptions. Towns closer to the LCPs had lower employment share in agriculture sector (column 4) and higher employment share in manufacturing sector (column 5). Yet the coefficients, 0.006 and -0.005, are relatively small given the initial level of employment shares in agriculture and manufacturing sector are about 77% and 20% respectively at baseline in 1820. Thus, the instrument is presumably valid conditional on county fixed effects.

5.2.3 IV-DiD Estimates

As an alternative to DiD analysis Table 5 provides instrumental variables (IV) estimates based on the first- and second-stage system defined by equations (3) and (4). IV-DiD estimates are consistently larger in magnitude than the corresponding OLS estimates, showing the OLS estimates are underestimated. IV-DiD estimate in columns (1) (2) (4) shows towns that located within 9km from the canal had 23.4% less employment share in agriculture, 15.2% more employment share in manufacturing, and 3.9% more employment share in commerce compared with other towns. Same as baseline DiD estimates, IV-DiD also shows the higher employment share in manufacturing and commerce sector in canal towns was attributed to the increasing employment in manufacturing and commerce sector in columns (5) and (6). The lower employment share in the agriculture sector in canal towns was not driven by the decreasing employment in the agriculture sector but because of the increasing population base (column 7).

Table 5: IV-DiD estimates of effects of canal operation on local employment structure

	(1) empl_agri(s)	(2) empl_manu(s)	(3) empl_comm(s)	(4) log empl_agri(N)	(5) log empl_manu(N)	(6) log empl_comm(N)	(7) log pop
$Post\hat{Canal}$	-0.234***	0.152***	0.039*	-0.074	0.957***	1.489**	0.575**
	(0.070)	(0.045)	(0.020)	(0.276)	(0.331)	(0.695)	(0.233)
Constant	0.829***	0.152***	0.010**	6.254***	4.466***	1.986***	7.684***
	(0.015)	(0.010)	(0.004)	(0.059)	(0.071)	(0.152)	(0.049)
Observations	290	290	290	290	289	232	291
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.3 Robustness Analysis

In this section I provide alternative estimates of DiD regression to document that the main results are robust by enlarging control towns, using subsamples and matching methods. First, I extend the control group to towns located between 20km to 55km from the canal. By enlarging the control towns, I try to reduce potential spillover effects as evidence to one of the DiD assumptions, SUTVA. The idea is that even if there are spillover effects among towns that are located within 15km of the canal, the potential spillover effects are diminishing as towns are located further away. This highly likely held in the early nineteenth-century when a wagon traveled 2 to 3 miles per hour depending upon weather, roadway conditions, and the health of the travelers.

Table 6 presents the DiD estimates results of eight different control groups by extending the control-group distance from 20km to 55km. The signs of the effects of canal operation on local employment are still the same. Take the 9km-to-20km control group for an example. In 1840 the average town located within 9km from the canal had 7.2% less employment share in agriculture and 2.2% more employment share in commerce compared with towns that located between 9km and 20km from the canal. Towns located within 9km from the canal had 134% more employment in commerce and 69% more employment in the manufacturing sector in 1840. The magnitude of the negative effect of canal operation on employment share in the agriculture sector is declining as the control group is expanding. The magnitudes of positive effects of canal operation on employment share and employment in the commerce sector are stable. Noted the difference between treated towns and control towns using the same characteristics was becoming bigger as the control group expanded (Table 11 to Table 16 in appendix). There are few highly significant baseline differences in employment measures of interest and other town characteristics between treated towns and control towns that are located less than 35km from the canal if focusing on employment in the agriculture and commerce sectors instead of the manufacturing sector. When looking at the effect of canal operation on employment in the manufacturing sector, it is better to choose towns that are located less than 25km from the canal as the control group. The estimates using control towns that are located more than 35km from the canal may involve selection problems.

The middle section of the Erie Canal from Utica in county Oneida to Salina (Syracuse) in county Onondage was firstly constructed in the year 1817 and was completed and operated immediately in 1820. The middle section also passed through several towns in Oswego county and Madison county. Towns located within 9km from the canal in these counties may have already been treated in 1820 depending on how quickly em-

Table 6: DiD estimates of effects of canal operation on local employment structure using 20km to 55km as control towns separately

	(1) empl_agri(r)	(2) empl_manu(r)	(3) empl_comm(r)	(4) log empl_agri(N)	(5) log empl_manu(N)	(6) log empl_comm(N)
			Control towns: 20km			
PostCanal	-0.072***	0.020	0.022***	-0.000	0.527***	0.852***
	(0.021)	(0.019)	(0.006)	(0.089)	(0.136)	(0.193)
Constant	0.782***	0.190***	0.017***	6.221***	4.580***	2.118***
	(0.005)	(0.005)	(0.002)	(0.038)	(0.056)	(0.079)
Observations	264	264	264	333	332	278
			Control towns: 25km			
PostCanal	-0.064***	0.015	0.019***	0.010	0.550***	0.803***
	(0.019)	(0.018)	(0.005)	(0.085)	(0.133)	(0.189)
Constant	0.785***	0.187***	0.017***	6.222***	4.577***	2.139***
	(0.004)	(0.004)	(0.001)	(0.033)	(0.050)	(0.069)
Observations	314	314	314	387	385	323
			Control towns: 30km			
PostCanal	-0.061***	0.014	0.017***	-0.007	0.570***	0.788***
	(0.019)	(0.018)	(0.005)	(0.084)	(0.133)	(0.187)
Constant	0.790***	0.182***	0.017***	6.211***	4.531***	2.146***
	(0.003)	(0.003)	(0.001)	(0.030)	(0.049)	(0.067)
Observations	370	370	370	447	443	367
			Control towns: 35km			
PostCanal	-0.056***	0.009	0.017***	0.014	0.585***	0.770***
	(0.018)	(0.017)	(0.005)	(0.082)	(0.132)	(0.185)
Constant	0.793***	0.179***	0.017***	6.199***	4.504***	2.135***
	(0.003)	(0.003)	(0.001)	(0.027)	(0.045)	(0.061)
Observations	420	420	420	508	504	407
			Control towns: 40km			
PostCanal	-0.056***	0.009	0.017***	0.004	0.568***	0.784***
	(0.018)	(0.017)	(0.004)	(0.082)	(0.131)	(0.185)
Constant	0.798***	0.175***	0.016***	6.175***	4.469***	2.124***
	(0.002)	(0.002)	(0.001)	(0.025)	(0.042)	(0.057)
Observations	478	478	478	577	569	454
			Control towns: 45km			
PostCanal	-0.062***	0.014	0.017***	0.001	0.559***	0.798***
	(0.018)	(0.017)	(0.004)	(0.080)	(0.129)	(0.181)
Constant	0.801***	0.172***	0.016***	6.163***	4.441***	2.082***
	(0.002)	(0.002)	(0.001)	(0.024)	(0.041)	(0.054)
Observations	534	534	534	634	628	497
			Control towns: 50km			
PostCanal	-0.058***	0.013	0.016***	0.010	0.560***	0.786***
	(0.018)	(0.017)	(0.004)	(0.080)	(0.128)	(0.181)
Constant	0.801***	0.171***	0.016***	6.139***	4.415***	2.091***
	(0.002)	(0.002)	(0.000)	(0.023)	(0.039)	(0.053)
Observations	584	584	584	695	687	546
			Control towns: 55km			
PostCanal	-0.054***	0.009	0.016***	0.013	0.544***	0.773***
	(0.018)	(0.017)	(0.004)	(0.079)	(0.127)	(0.180)
Constant	0.802***	0.170***	0.016***	6.135***	4.406***	2.098***
	(0.002)	(0.002)	(0.000)	(0.023)	(0.038)	(0.052)
Observations	626	626	626	741	733	578
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: DiD estimates of effects of canal operation on local employment structure with dropping the middle section towns

	(1) empl_agri(r)	(2) empl_manu(r)	(3) empl_comm(r)	(4) log empl_agri(N)	(5) log empl_manu(N)	(6) log empl_comm(N)
	Control towns: 15km					
PostCanal	-0.086***	0.041*	0.023**	0.058	0.502***	0.761***
	(0.027)	(0.024)	(0.010)	(0.111)	(0.170)	(0.263)
Constant	0.789***	0.183***	0.016***	6.187***	4.542***	2.118***
	(0.008)	(0.007)	(0.003)	(0.048)	(0.072)	(0.120)
Observations	172	172	172	220	220	180
	Control towns: 20km					
PostCanal	-0.070***	0.027	0.018***	-0.001	0.474***	0.823***
	(0.024)	(0.021)	(0.006)	(0.100)	(0.158)	(0.225)
Constant	0.795***	0.179***	0.016***	6.214***	4.538***	2.081***
	(0.005)	(0.004)	(0.001)	(0.040)	(0.058)	(0.085)
Observations	232	232	232	296	295	242
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

ployment responded to canal operation. I exclude towns located in those counties from the dataset. In Table 7, columns (1) to (3) take towns located between 9km to 20km from the canal as control towns. Excluding the middle section, the average town located within 9km from the canal had 7% less employment share in agriculture and 1.8% more employment share in commerce compared with towns that located between 9km and 20km from the canal. Columns (4) to (6) take towns located between 9km to 15km from the canal as control towns. Excluding the middle section, the average town that is located within 9km from the canal had 8.6% less employment share in agriculture and 2.3% more employment share in commerce compared with towns located between 9km and 15km from the canal. These results are very similar to the baseline DiD estimates.

Towns shared similar preexisting employment structures in terms of sectoral employment and sectoral employment share may be scattered over New York State. That is, candidate control towns located more the 15km from the Erie canal were excluded from the analysis. Another way to choose control towns is using the matching method. I first use propensity score matching (PSM) to choose control towns. Population, employment share, and (log) employment in the agriculture sector, employment share, and (log) employment in the commerce sector in the pre-treatment year, 1820 year, were used in the matching process. Towns with extreme propensity scores that were lower than 0.01 and higher than 0.9 were excluded. Figure 8 in the appendix compares propensity scores between treated towns and control towns. Then I deploy DiD (equation 2) using unweighted regression and weighted regression by propensity score respectively. Table 8 presents the unweighted and weighted (by propensity score) PSM-DID estimates. The effects of canal operation on local employment are still significant. Column (1) shows the average town that located within 9km from the canal had 7% and 7.3% less employment share in the agriculture sector using unweighted and weighted PSM-DiD respectively. The average town that located within 9km from the canal had 2.3% and 2.7% more employment share in the commerce sector using unweighted and weighted PSM-DiD respectively. These magnitudes of effects are very close to the baseline DiD estimates. The lower employment share in the agriculture sector in canal towns was not driven by the decreasing employment in the agriculture sector but because of the increasing population base. Towns located within 9km from the canal had 63.8% and 67.1% more employment in the commerce sector using unweighted and weighted PSM-DiD respectively.

6 "K9" and Agricultural-Manufacturing

6.1 K9

How to define the canal-towns matters to the DiD estimates. It is also important to understand the scale of the effects of canal operation on the transformation of early nineteenth-century New York State. This section studies the scale of canal-operation effects on local employment structure by adjusting the distance to define canal towns.

Based on the comparison of town characteristics between canal towns and non-canal

Table 8: PSM-DiD estimates of effects of canal operation on local employment structure using all towns

	(1) empl_agri(r)	(2) empl_manu(r)	(3) empl_comm(r)	(4) log empl_agri(N)	(5) log empl_manu(N)	(6) log empl_comm(N)
	Unweighted					
PostCanal	-0.070***	0.015	0.023***	-0.094	0.208	0.638***
	(0.026)	(0.024)	(0.006)	(0.109)	(0.135)	(0.189)
Constant	0.778***	0.183***	0.021***	6.169***	4.599***	2.217***
	(0.001)	(0.001)	(0.000)	(0.005)	(0.006)	(0.009)
	Weighted					
PostCanal	-0.073***	-0.003	0.027**	0.066	0.400***	0.671***
	(0.026)	(0.035)	(0.012)	(0.159)	(0.134)	(0.228)
Constant	0.728***	0.226***	0.027***	6.228***	4.966***	2.490***
	(0.002)	(0.002)	(0.001)	(0.010)	(0.008)	(0.016)
Observations	806	806	806	808	800	676
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

towns in the pretreatment year, towns that located within 35km from the canal were chosen as the potential pool due to few highly significant baseline differences, at least in terms of employment measure of interest in agriculture and commerce sectors. The difference in agriculture employment does not affect the sign of canal-operation effect on agriculture employment, since agriculture employment in non-canal towns is higher than in canal towns.

Table 9 shows the effects of canal operation on local employment structure at the margin of 9km distance. The positive effects of canal operation on employment in manufacturing and commerce sectors exist by adjusting the treatment distance from 6km to 12km, which is implied by columns (5) and (6). However, the transformation effect of canal operation on local employment structure measured by the employment share disappeared when the treatment distance exceeds 9km, which is implied by columns (1) and (3). The insignificant effects of canal operation on employment shares in agriculture and commerce sectors hold for distances exceeding 12km. There is a potential endogenous problem regarding the positive effect of canal operation on employment in

Table 9: DiD estimates of effects of canal operation on local employment structure using 35km as control towns

	(1) empl_agri(r)	(2) empl_manu(r)	(3) empl_comm(r)	(4) log empl_agri(N)	(5) log empl_manu(N)	(6) log empl_comm(N)
	Treated towns: 6km					
PostCanal	-0.060***	0.007	0.018***	0.025	0.735***	0.992***
	(0.021)	(0.020)	(0.005)	(0.089)	(0.141)	(0.191)
Constant	0.792***	0.180***	0.017***	6.198***	4.509***	2.137***
	(0.003)	(0.003)	(0.001)	(0.027)	(0.042)	(0.059)
	Treated towns: 7km					
PostCanal	-0.066***	0.013	0.018***	0.077	0.735***	0.970***
	(0.020)	(0.019)	(0.005)	(0.083)	(0.135)	(0.186)
Constant	0.793***	0.179***	0.017***	6.189***	4.499***	2.126***
	(0.003)	(0.003)	(0.001)	(0.027)	(0.043)	(0.059)
	Treated towns: 8km					
PostCanal	-0.062***	0.011	0.018***	0.011	0.601***	0.811***
	(0.019)	(0.018)	(0.005)	(0.083)	(0.137)	(0.187)
Constant	0.793***	0.179***	0.017***	6.200***	4.509***	2.138***
	(0.003)	(0.003)	(0.001)	(0.027)	(0.044)	(0.060)
	Treated towns: 9km					
PostCanal	-0.056***	0.009	0.017***	0.014	0.585***	0.770***
	(0.018)	(0.017)	(0.005)	(0.082)	(0.132)	(0.185)
Constant	0.793***	0.179***	0.017***	6.199***	4.504***	2.135***
	(0.003)	(0.003)	(0.001)	(0.027)	(0.045)	(0.061)
	Treated towns: 10km					
PostCanal	-0.034*	-0.002	0.007	0.014	0.579***	0.662***
	(0.018)	(0.016)	(0.006)	(0.079)	(0.124)	(0.173)
Constant	0.791***	0.181***	0.018***	6.198***	4.489***	2.138***
	(0.003)	(0.003)	(0.001)	(0.028)	(0.046)	(0.064)
	Treated towns: 11km					
PostCanal	-0.028	-0.007	0.006	0.016	0.541***	0.551***
	(0.018)	(0.016)	(0.006)	(0.076)	(0.123)	(0.177)
Constant	0.790***	0.182***	0.018***	6.198***	4.491***	2.160***
	(0.003)	(0.003)	(0.001)	(0.028)	(0.047)	(0.065)
	Treated towns: 12km					
PostCanal	-0.022	-0.010	0.006	0.025	0.532***	0.557***
	(0.017)	(0.015)	(0.005)	(0.073)	(0.120)	(0.174)
Constant	0.789***	0.183***	0.018***	6.195***	4.483***	2.146***
	(0.003)	(0.003)	(0.001)	(0.029)	(0.048)	(0.066)
Observations	420	420	420	508	504	407
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Town FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

the manufacturing sector because canal towns had significantly higher employment in the manufacturing sector than non-canal towns when the non-canal towns were defined by a distance larger than 25km (Table 12 to Table 16 in appendix).

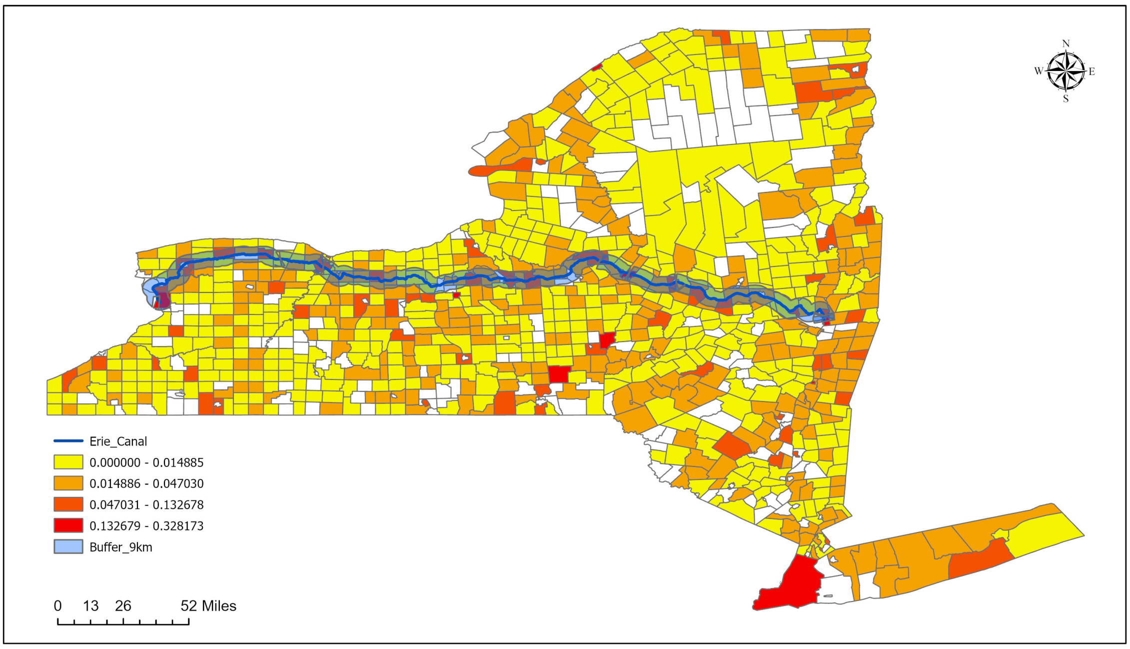


Figure 6: K9 and the employment share in commerce sector in 1840

6.2 Agricultural-Manufacturing

The increasing employment in the manufacturing sector does not necessarily in response to the development western market (Niemi, 1970). As Ransom (1971) pointed out manufacturing - like agriculture - developed in response to eastern demands for western agriculture staples. This processing manufacturing is an extension of the western comparative advantage in agriculture, and the canal encourage regional economic specialization by integrating west and east New York State.

The types of manufacturing establishments in canal towns shown by Table 1 gave some evidence. Averagely, canal towns had 1.5 distilleries, 4 grist mills, 7.5 sawmills, 0.5

oil mills, 2 fulling mills, 2 carding machines, 2 ashery, 0.5 cotton woollen factories, 0.05 tannery, 0.5 trip hammers, 1,735,000 yards of cloth made in the year 1824. The high transportation cost of agricultural staples like wheat, corn, and meat can be reduced by processing the staples into derivatives having higher value per ton. Wheat or corn was distilled into whiskey and ground into flour. Swine and cattle were slaughtered and sent east along the Erie canal in the form of processed meat. Deer skins and raw hides were processed in the tannery. Sheep were processed into various derivatives like butter and wool in cotton woollen factories. Raw woods were cut into lumber, staves, shingles, and timber in sawmills. Such manufacturing activities result from the locational advantage created for processors by the production of local agricultural goods. And these processed goods were shipped to east New York State using the Erie canal.

The types of goods shipped in the Erie canal gave strong evidence (Table 10)[11]. Raw materials and basic resources, such as 311,256 feet of lumber, 3,640 bushels of wheat, 4,335 barrels of flour, 4,754 barrels of provisions (pork and beef), and 1,705 tons of ashes, which listed top 5 among properties cleared at Buffalo were passing east on Erie canal in 1829. By 1835, double amounts of provision, 4 times more ashes, 7 times more lumber, 23 times more flour, and 46 times more wheat were passing east on the Erie canal from Buffalo. Similar composition of articles passed Utica was observed from 1830 to 1832.

[11]State of New York. *Annual Report of the Canal Commissioners.* Columbia University.

Table 10: 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)	do	4754	6675	5668	5159	4273	14590	8160
Oil	do	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	do	32	62	222	386	535	1008	1765
Hemp	do	22	20	70	29	17	5	0.5
Pig iron	do	235	419	409	760	1167	1128	997
Castings	do	241		422	468	757	689	768
Household furniture	do	42	58	69	88	134	145	355
Furs	do	86	82	96	107	101	154	136
Lumber	feet	311256	136499	184639	251504	331140	439643	2087024
Staves	M	510	464	568	523	699	2400	2694
Fish	barrels		851	150	276	279	346	732
Whiskey	do	149	4182	3750	2208	2485	1347	614
Butter & lard	tons	70	174	205	394	449	119	503
Cheese	do	68	122	127	74	95	138	34
Wool	do			66	22	75	73	93
Deer skins & raw hides	do					110	141	207
Grind-stones	do	35	39	124	110	139	126	135
Lead	do		41	9				
Sundries	do							242
Shingles	M							74062
Timber	feet							61430
Corn	bushels							12193

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Table 11: Comparison of town characteristics before 1825 between canal-towns (9km) and noncanal-towns (20km)

	Treated towns	Obs.	Control towns	Obs.	Diff.	*p*-value
population(N)	2827.25	64	2787.71	68	-39.54	0.90
log empl_agri(N)	6.06	66	6.08	66	0.02	0.89
log empl_comm(N)	2.12	48	1.85	54	-0.27	0.26
log empl_manu(N)	4.50	66	4.38	65	-0.12	0.48
empl_agri(r)	0.78	66	0.82	66	0.04	0.15
empl_comm(r)	0.02	66	0.02	66	-0.01	0.48
empl_manu(r)	0.20	66	0.16	66	-0.04	0.12
public money(Dollar)	534.78	51	359.35	51	-175.43	0.35
taxable property(k)	387.77	62	347.81	66	-39.96	0.58
iroquois trail(Dummy)	0.96	24	1.00	16	0.04	0.42
county seat(Dummy)	1.00	13	1.00	6	0.00	.
schools(N)	12.48	58	13.20	60	0.72	0.56
taught(N)	712.65	52	759.90	51	47.25	0.58
custom	0.02	108	0.01	110	-0.01	0.55
children age 5-15(N)	761.64	50	706.24	50	-55.40	0.51
electors(N)	537.79	62	489.16	63	-48.63	0.39
distillery(N)	1.50	64	1.96	68	0.46	0.19
grist mill(N)	3.91	64	3.66	68	-0.24	0.67
saw mill(N)	7.50	64	8.21	68	0.71	0.50
oil mill(N)	0.56	64	0.18	68	-0.39**	0.01
fulling mill(N)	1.98	63	2.35	68	0.37	0.36
carding machine(N)	1.95	63	2.57	68	0.62	0.30
ashery(N)	2.09	64	2.56	68	0.47	0.36
cotton woollen factory(N)	0.40	62	0.40	68	-0.01	0.97
tannery(N)	0.05	62	0.09	68	0.04	0.70
trip hammer(N)	0.44	62	0.26	68	-0.17	0.33
cloth made(yard_k)	17.35	61	31.88	66	14.53	0.28
churches(N)	3.33	15	3.95	20	0.62	0.52
iron works(N)	0.23	61	0.34	67	0.11	0.36

Table 12: Comparison of town characteristics before 1825 between canal-towns (9km) and noncanal-towns (25km)

	Treated towns	Obs.	Control towns	Obs.	Diff.	*p*-value
population(N)	2827.25	64	2702.63	93	-124.62	0.64
log empl_agri(N)	6.06	66	6.10	91	0.04	0.74
log empl_comm(N)	2.12	48	1.79	75	-0.33	0.13
log empl_manu(N)	4.50	66	4.39	89	-0.11	0.47
empl_agri(r)	0.78	66	0.83	91	0.05	0.06
empl_comm(r)	0.02	66	0.01	91	-0.01	0.31
empl_manu(r)	0.20	66	0.16	91	-0.04*	0.04
public money(Dollar)	534.78	51	340.40	73	-194.39	0.22
taxable property(k)	387.77	62	337.69	90	-50.08	0.43
iroquois trail(Dummy)	0.96	24	1.00	22	0.04	0.34
county seat(Dummy)	1.00	13	1.00	7	0.00	.
schools(N)	12.48	58	13.01	83	0.53	0.64
taught(N)	712.65	52	769.59	73	56.94	0.46
custom	0.02	108	0.01	143	-0.01	0.41
children age 5-15(N)	761.64	50	712.89	72	-48.75	0.52
electors(N)	537.79	62	483.02	86	-54.77	0.28
distillery(N)	1.50	64	2.02	92	0.52	0.11
grist mill(N)	3.91	64	3.52	92	-0.38	0.45
saw mill(N)	7.50	64	8.27	92	0.77	0.44
oil mill(N)	0.56	64	0.26	92	-0.30*	0.03
fulling mill(N)	1.98	63	2.27	92	0.29	0.43
carding machine(N)	1.95	63	2.58	92	0.62	0.24
ashery(N)	2.09	64	2.36	92	0.26	0.56
cotton woollen factory(N)	0.40	62	0.37	92	-0.03	0.84
tannery(N)	0.05	62	0.07	92	0.02	0.85
trip hammer(N)	0.44	62	0.26	92	-0.17	0.27
cloth made(yard_k)	17.35	61	28.67	89	11.31	0.33
churches(N)	3.33	15	3.76	25	0.43	0.64
iron works(N)	0.23	61	0.25	91	0.02	0.83

Table 13: Comparison of town characteristics before 1825 between canal-towns (9km) and noncanal-towns (30km)

	Treated towns	Obs.	Control towns	Obs.	Diff.	*p*-value
population(N)	2827.25	64	2575.36	121	-251.89	0.33
log empl_agri(N)	6.06	66	6.04	119	-0.02	0.82
log empl_comm(N)	2.12	48	1.81	96	-0.32	0.12
log empl_manu(N)	4.50	66	4.31	115	-0.20	0.18
empl_agri(r)	0.78	66	0.83	119	0.05*	0.02
empl_comm(r)	0.02	66	0.01	119	-0.01	0.27
empl_manu(r)	0.20	66	0.15	119	-0.05*	0.01
public money(Dollar)	534.78	51	328.53	97	-206.26	0.14
taxable property(k)	387.77	62	344.29	119	-43.48	0.52
iroquois trail(Dummy)	0.96	24	1.00	23	0.04	0.33
county seat(Dummy)	1.00	13	1.00	10	0.00	.
schools(N)	12.48	58	12.84	111	0.36	0.74
taught(N)	712.65	52	737.89	98	25.23	0.74
custom	0.02	108	0.01	179	-0.01	0.30
children age 5-15(N)	761.64	50	696.21	96	-65.43	0.38
electors(N)	537.79	62	463.22	113	-74.57	0.12
distillery(N)	1.50	64	1.92	121	0.42	0.18
grist mill(N)	3.91	64	3.44	121	-0.47	0.32
saw mill(N)	7.50	64	8.44	121	0.94	0.35
oil mill(N)	0.56	64	0.24	121	-0.32**	0.01
fulling mill(N)	1.98	63	2.15	121	0.16	0.62
carding machine(N)	1.95	63	2.46	121	0.51	0.29
ashery(N)	2.09	64	2.17	121	0.08	0.85
cotton woollen factory(N)	0.40	62	0.33	120	-0.08	0.60
tannery(N)	0.05	62	0.06	120	0.01	0.90
trip hammer(N)	0.44	62	0.27	120	-0.17	0.24
cloth made(yard_k)	17.35	61	26.37	118	9.02	0.37
churches(N)	3.33	15	3.67	30	0.33	0.70
iron works(N)	0.23	61	0.20	119	-0.03	0.77

Table 14: Comparison of town characteristics before 1825 between canal-towns (9km) and noncanal-towns (35km)

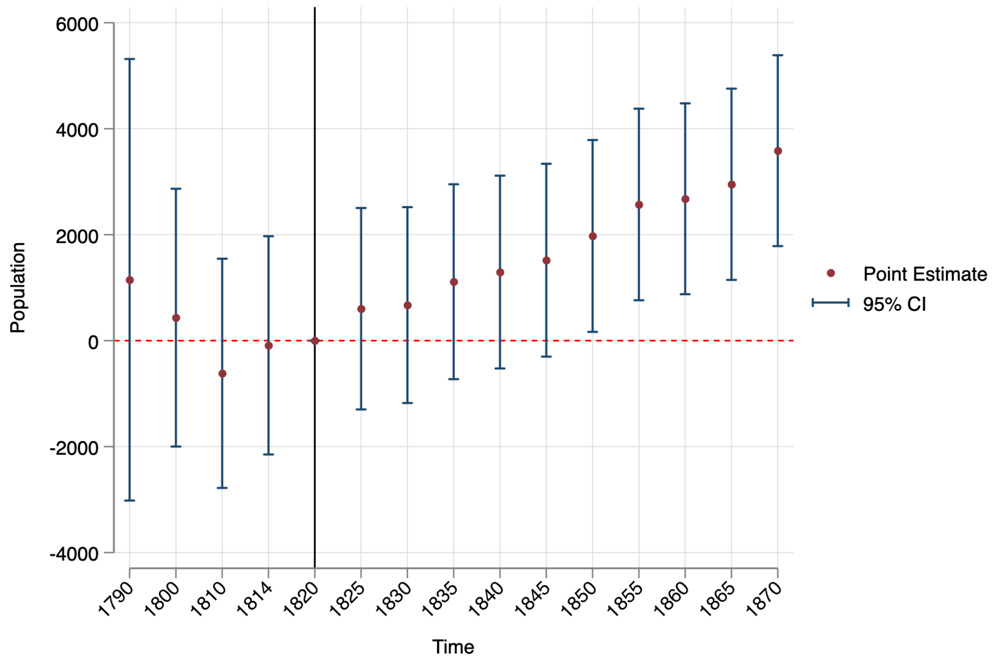
	Treated towns	Obs.	Control towns	Obs.	Diff.	p -value
population(N)	2827.25	64	2534.02	146	-293.23	0.22
log empl_agri(N)	6.06	66	6.05	144	-0.01	0.91
log empl_comm(N)	2.12	48	1.75	117	-0.37	0.05
log empl_manu(N)	4.50	66	4.28	140	-0.23	0.11
empl_agri(r)	0.78	66	0.84	144	0.06**	0.01
empl_comm(r)	0.02	66	0.01	144	-0.01	0.17
empl_manu(r)	0.20	66	0.15	144	-0.05**	0.00
public money(Dollar)	534.78	51	329.29	119	-205.49	0.10
taxable property(k)	387.77	62	328.49	143	-59.29	0.34
iroquois trail(Dummy)	0.96	24	1.00	24	0.04	0.32
county seat(Dummy)	1.00	13	1.00	12	0.00	.
schools(N)	12.48	58	12.70	135	0.22	0.83
taught(N)	712.65	52	739.00	121	26.35	0.72
custom	0.02	108	0.00	220	-0.01	0.21
children age 5-15(N)	761.64	50	698.06	119	-63.58	0.37
electors(N)	537.79	62	458.82	136	-78.97	0.08
distillery(N)	1.50	64	1.99	145	0.49	0.12
grist mill(N)	3.91	64	3.48	145	-0.43	0.34
saw mill(N)	7.50	64	8.25	145	0.75	0.43
oil mill(N)	0.56	64	0.24	145	-0.32**	0.01
fulling mill(N)	1.98	63	2.14	145	0.15	0.62
carding machine(N)	1.95	63	2.40	145	0.45	0.32
ashery(N)	2.09	64	2.32	145	0.22	0.58
cotton woollen factory(N)	0.40	62	0.31	144	-0.10	0.49
tannery(N)	0.05	62	0.11	143	0.06	0.50
trip hammer(N)	0.44	62	0.25	143	-0.18	0.17
cloth made(yard_k)	17.35	61	25.33	142	7.98	0.39
churches(N)	3.33	15	3.67	36	0.33	0.69
iron works(N)	0.23	61	0.18	142	-0.05	0.55

Table 15: Comparison of town characteristics before 1825 between canal-towns (9km) and noncanal-towns (40km)

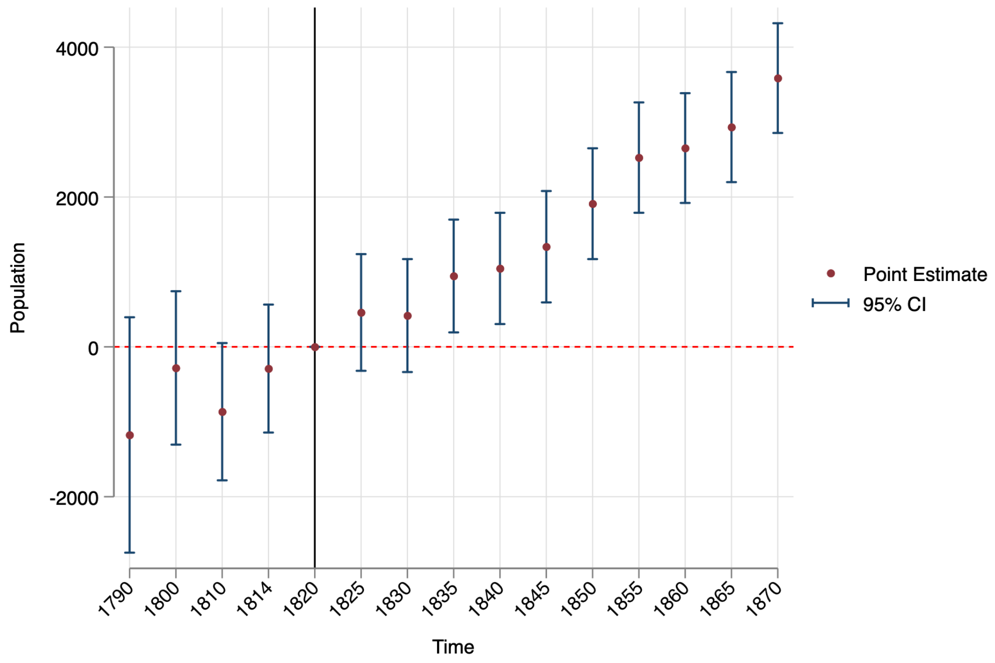
	Treated towns	Obs.	Control towns	Obs.	Diff.	p -value
population(N)	2827.25	64	2402.86	176	-424.39	0.06
log empl_agri(N)	6.06	66	6.02	174	-0.05	0.61
log empl_comm(N)	2.12	48	1.77	136	-0.35	0.06
log empl_manu(N)	4.50	66	4.22	166	-0.28*	0.05
empl_agri(r)	0.78	66	0.84	174	0.06**	0.00
empl_comm(r)	0.02	66	0.01	174	-0.01	0.16
empl_manu(r)	0.20	66	0.15	174	-0.05***	0.00
public money(Dollar)	534.78	51	305.63	147	-229.15*	0.04
taxable property(k)	387.77	62	310.82	170	-76.95	0.18
iroquois trail(Dummy)	0.96	24	1.00	24	0.04	0.32
county seat(Dummy)	1.00	13	1.00	14	0.00	.
schools(N)	12.48	58	12.27	163	-0.21	0.83
taught(N)	712.65	52	786.05	149	73.39	0.66
custom	0.02	108	0.01	260	-0.01	0.36
children age 5-15(N)	761.64	50	650.71	147	-110.93	0.10
electors(N)	537.79	62	437.46	164	-100.33*	0.02
distillery(N)	1.50	64	1.98	173	0.48	0.12
grist mill(N)	3.91	64	3.40	173	-0.50	0.24
saw mill(N)	7.50	64	8.01	173	0.51	0.57
oil mill(N)	0.56	64	0.23	173	-0.34**	0.00
fulling mill(N)	1.98	63	2.06	173	0.07	0.80
carding machine(N)	1.95	63	2.33	173	0.38	0.37
ashery(N)	2.09	64	2.18	173	0.09	0.81
cotton woollen factory(N)	0.40	62	0.28	172	-0.12	0.36
tannery(N)	0.05	62	0.11	171	0.06	0.49
trip hammer(N)	0.44	62	0.25	171	-0.19	0.13
cloth made(yard_k)	17.35	61	23.80	170	6.45	0.44
churches(N)	3.33	15	3.55	38	0.22	0.79
iron works(N)	0.23	61	0.15	170	-0.08	0.31

Table 16: Comparison of town characteristics before 1825 between canal-towns (9km) and noncanal-towns (45km)

	Treated towns	Obs.	Control towns	Obs.	Diff.	p-value
population(N)	2827.25	64	2333.97	204	-493.28*	0.02
log empl_agri(N)	6.06	66	6.00	201	-0.07	0.46
log empl_comm(N)	2.12	48	1.73	154	-0.39*	0.03
log empl_manu(N)	4.50	66	4.16	194	-0.34*	0.02
empl_agri(r)	0.78	66	0.84	202	0.06**	0.00
empl_comm(r)	0.02	66	0.01	202	-0.01	0.08
empl_manu(r)	0.20	66	0.15	202	-0.05**	0.00
public money(Dollar)	534.78	51	302.89	171	-231.90*	0.03
taxable property(k)	387.77	62	298.99	196	-88.78	0.10
iroquois trail(Dummy)	0.96	24	1.00	24	0.04	0.32
county seat(Dummy)	1.00	13	1.00	16	0.00	.
schools(N)	12.48	58	12.17	187	-0.32	0.74
taught(N)	712.65	52	766.42	173	53.76	0.73
custom	0.02	108	0.01	291	-0.01	0.30
children age 5-15(N)	761.64	50	643.43	171	-118.21	0.07
electors(N)	537.79	62	426.53	190	-111.26**	0.01
distillery(N)	1.50	64	1.96	199	0.46	0.12
grist mill(N)	3.91	64	3.35	199	-0.55	0.17
saw mill(N)	7.50	64	7.77	199	0.27	0.76
oil mill(N)	0.56	64	0.23	199	-0.33**	0.00
fulling mill(N)	1.98	63	2.03	199	0.04	0.89
carding machine(N)	1.95	63	2.27	199	0.31	0.43
ashery(N)	2.09	64	2.09	199	-0.00	0.99
cotton woollen factory(N)	0.40	62	0.28	198	-0.12	0.33
tannery(N)	0.05	62	0.11	197	0.06	0.50
trip hammer(N)	0.44	62	0.26	197	-0.17	0.17
cloth made(yard_k)	17.35	61	22.81	196	5.46	0.49
churches(N)	3.33	15	3.37	43	0.04	0.96
iron works(N)	0.23	61	0.13	195	-0.10	0.19



(a) Control towns: 9km to 20km



(b) Control towns: all towns except 9km towns

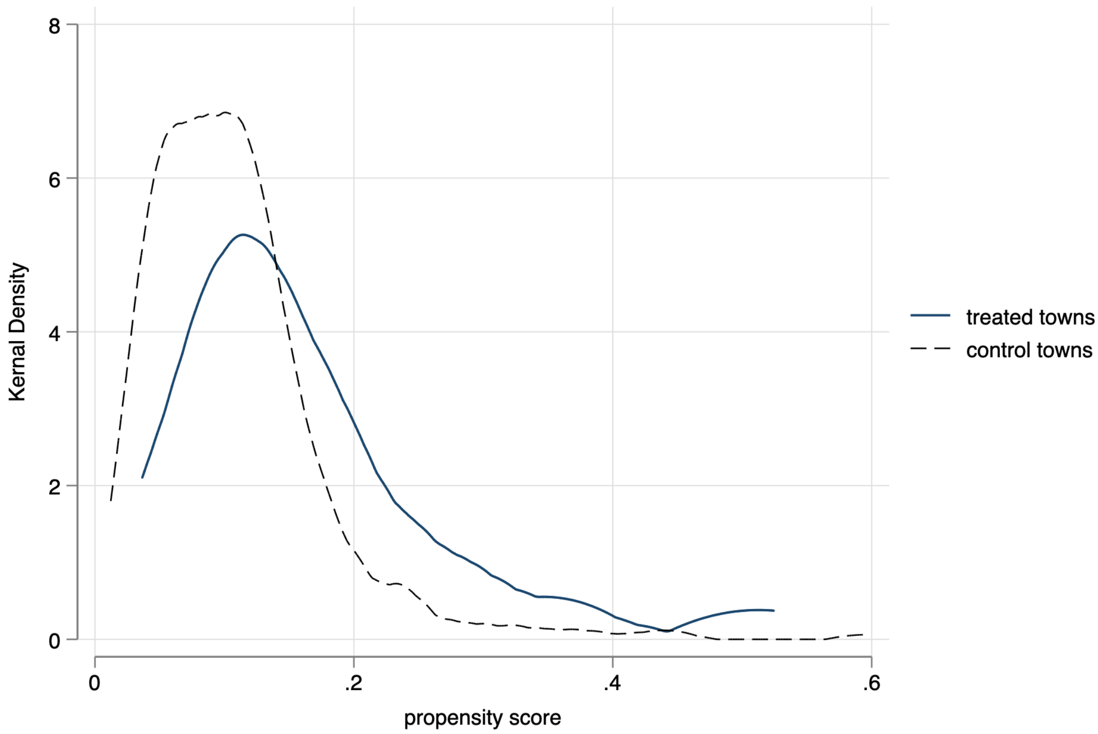


Figure 8: Density of propensity score of treated and control towns