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Quantifying Connectivity: the causal effect of railway accessibility on local industrial economic outcomes, France 1846-1865

Josephine Precetti

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Economic History Department, London School of Economics and Political Science, Houghton Street, London, WC2A 2AE, London, UK. T: +44 (0) 20 7955 7084.

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Abstract

France's railway expansion following the Law of 11 June 1842 significantly reshaped nationwide connectivity and economic opportunities. This dissertation investigates the causal impacts of railway access between 1846 and 1861 on city-level industrial development. Using a dataset combining industrial surveys with digitized railway records, it employs a robust Difference-in-Differences approach, leveraging the quasi-exogenous roll-out of the centrally planned 'étoile de Legrand' railway network. Empirical results show railway access increased industrial activity primarily extensively: railway-connected cities saw approximately a 20% rise in the number of factories and workers, especially in labour-intensive sectors like textile in Lille and ceramics in Limoges. Yet, intensive effects such as factory size, productivity, and wages remained statistically and economically negligible. Contrary to theoretical predictions from trade and New Economic Geography models, capital-intensive sectors, such as metallurgy in Lorraine, did not exhibit statistically significant responsiveness. These findings reframe the role of transport infrastructure from being a deterministic catalyst to being better understood as a conditional enabler. While railways expanded market potential, their short to medium term transformative impact critically depended on complementary institutional frameworks notably financial markets and property rights, technological readiness, and regional contexts. Acknowledging the historical data limitations, this study underscores that transport infrastructure alone is insufficient for structural economic upgrading without the appropriate institutional, technological, and human capital conditions in place at the right time.

1. Introduction

The rapid expansion of France's railway network following the Railway Act of June 11th, 1842, significantly transformed the nation's economic and spatial landscape. As Émile Zola vividly depicts in *La Bête Humaine*, the railway emerged as a powerful force capable of conquering geographical constraints, symbolising modernity and progress. Yet, behind this compelling imagery lies a critical

empirical question: What were the short and medium-term causal impacts of railway accessibility on city-level industrial growth in mid-19th century France?

This dissertation investigates precisely these causal impacts by examining the railway boom between 1846 and 1861 on industrial activity at the city level. It contributes to an expanding literature addressing the economic effects of transport infrastructure, notably studies by Fogel, Donaldson, Rosés, Jedwab and Moradi, and Berger and Enflo.[1] The French context in the 19th century offers a valuable empirical setting due to its centralised yet fragmented industrial geography, combined with a predominantly state-led model of infrastructure development, providing distinct historical nuances and spatial variations. These are crucial for investigating the conditional effects of infrastructure-driven economic growth.

The identification strategy leverages the quasi-exogenous timing of the French railway expansion, structured around the centrally planned *étoile de Legrand* network radiating from Paris. Although not entirely random as some strategic, military, and economic factors shaped line placements, the rapid and varied railway expansion introduces substantial variation in railway access across comparable cities within a limited timeframe. This quasi-exogenous roll out justifies a robust Difference-in-Differences analytical approach. However, whether enhanced market access alone sufficiently drove substantial industrial transformation or merely facilitated modest expansions and spatial reallocations remains an open question.

The dissertation builds upon core theoretical frameworks including the Heckscher-Ohlin trade model, Krugman and Venables' New Economic Geography framework,

[1] Robert W. Fogel, *Railroads and American Economic Growth* (Baltimore: Johns Hopkins Press, 1964); Dave Donaldson, "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure," *American Economic Review* 108, no. 4–5 (2018): 899–934.; Remi Jedwab and Alexander Moradi, "The Permanent Effects of Transportation Revolutions in Poor Countries," *Review of Economics and Statistics* 98, no. 2 (2016): 268–284;Joan R. Rosés, "Why Isn't the Whole of Spain Industrialized? New Economic Geography and Early Industrialization, 1797–1910," The Journal of Economic History 63, no. 4 (2003): 995–1022.; Thor Berger and Kerstin Enflo, "Locomotives of Local Growth: The Short- and Long-Term Impact of Railroads in Sweden," *Journal of Urban Economics* 98 (2017): 124–138.

and Marshallian agglomeration theory.[2] According to these theoretical frameworks, railway connectivity should stimulate industrial growth by reducing trade friction and facilitating economies of scale. Nevertheless, these theoretical models rest on assumptions of frictionless factor mobility and quick technological adoption. These are conditions that are not relevant in the rural, institutionally uneven, and capital-constrained context of mid-19th-century France. Hence the importance of observing responsiveness differences between capital- and labour-intensive industries. Capital-intensive industries, characterized by substantial fixed investments, theoretically benefit in the longer run from expanded markets through economies of scale. This constitutes a limitation of my research which focuses on the medium rather than longer run. Whereas labour-intensive industries, with lower entry barriers and greater flexibility, might respond more quickly to reduced transportation costs.

To empirically evaluate these dynamics, I construct a comprehensive dataset combining harmonised industrial surveys by Chanut (1839–1847, 1860–1865) with historical cartographic data on railway networks over time. Using a DiD methodology, I estimate the causal impact of rail connectivity on various city-level industrial outcomes in the short to medium-run including the number of factories, industrial employment, factory size, male wages, and production output. I distinguish between labour-intensive and capital-intensive sectors classified according to computed production-to-worker ratios.

The findings reveal a nuanced empirical reality. Railway access significantly increased the number of factories and industrial workers in connected cities, predominantly within labour- intensive sectors. However, the analysis finds little evidence of corresponding improvements in factory size, labour productivity, or wages. Capital-intensive industries exhibited limited responsiveness in the medium run. These results indicate that railway infrastructure in France facilitated predominantly extensive-margin economic growth, marked by increased

[2] Paul Krugman and Anthony J. Venables, "Globalization and the Inequality of Nations," *Quarterly Journal of Economics* 110, no. 4 (1995): 857–880.

entry and spatial dispersion, without initiating in the short to medium term deeper intensive-margin transformations predicted by agglomeration-based growth models.

This nuanced empirical outcome underscores infrastructure's conditional economic role. The transformative potential of railway investments was determined by contingent factors notably technological availability, institutional contexts including fragmented financial markets, varied regional governance, property rights structures, and demographic conditions like limited rural-to-urban migration.

Acknowledging methodological and empirical limitations further enhances analytical credibility, including constraints from historical data availability and measurement challenges, alongside potential longer-term agglomeration effects beyond the chosen temporal scope. By combining causal inference methods, detailed historical and spatial data, and sectoral disaggregation, this dissertation contributes to a more nuanced understanding of how infrastructure influences economic development. It is not automatic, but it is through complex interactions among technological capabilities, institutional frameworks, and sector-specific characteristics.

This dissertation proceeds as follows: Section 2 reviews the relevant literature. Section 3 outlines the historical context and theoretical foundations, presenting three central hypotheses guiding the empirical analysis. Section 4 describes the dataset and empirical strategy. Section 5 presents the main empirical results. Section 6 explores underlying mechanisms and detailed interpretations. Section 7 discusses broader implications for infrastructure-led economic development. Section 8 concludes.

2. Literature Review

2.i Defining Core Terms

This dissertation investigates the *causal impact of railway access*, defined as statistically measurable changes in city-level industrial outcomes attributable to the arrival of railways, controlling for confounding factors such as pre-treatment population growth, access to ports and navigable waterways, and regional infrastructure endowments. It distinguishes between *extensive growth*, which are the increases in the number of factories and industrial employment, and *intensive growth*, which entails gains in average factory size, output per worker, and wages. It further differentiates between labour-intensive industries (textiles, food, construction) and capital-intensive sectors (metallurgy, chemicals), using sectoral production- to-worker ratios drawn from Chanut's CODBRAG classification. *Transformative growth* refers to structural upgrading of the industrial base, while *diffusion* denotes the spatial spread of industrial activity without compositional change. *Market access* is defined simply as a city's access to demand for its output.

2.ii Railways and Economic Development: General Theories

Traditional economic models, including Ricardian and Heckscher-Ohlin frameworks, treat transport infrastructure as a foundational enabler of regional growth. Lower trade costs are expected to promote regional specialisation according to comparative advantage, increasing aggregate welfare. Capital-abundant regions should develop capital-intensive industries, while labour-rich areas expand labour-intensive production. Donaldson applies a Ricardian general equilibrium model to colonial India, showing that railway expansion reduced trade costs and increased real incomes by 16%.[3]

Yet these models rest on assumptions that rarely hold in historical settings. Mid-19th- century France was marked by institutional fragmentation, technological dualism, and demographic inertia. Litvine shows how overlapping jurisdictions and fiscal fragmentation undermined infrastructure rollout. Zobl documents that

[3] Donaldson, "Railroads of the Raj," 899-934.

productivity gains clustered in cities with early steam power access, while others remained trapped in low-productivity equilibria. Schwartz, Gregory and Thévenin note that rural-to-urban migration remained subdued. By 1911, only 45% of French citizens lived in urban areas. Hohenberg finds that railway access often reinforced, rather than disrupted, existing regional economic structures.[4] These frictions cast doubt on whether trade cost reductions alone can drive transformative growth.

2.iii Path Dependence, Agglomeration, and NEG Models

New Economic Geography framework, as theorized by Krugman and Venables, predicts that falling transport costs can generate endogenous spatial concentration via increasing returns, labour pooling, and circular causation. Evidence from several European countries supports this dynamic but only under specific structural preconditions. In Sweden, Berger and Enflo show that early railway access led to persistent industrial and demographic growth. In Britain, Shaw-Taylor and You link railway access to increased industrial density using isochronic mapping.

However, cumulative effects depend on local capacity. Rosés shows that in Spain, early- connected cities only benefited when endowed with capital stock and dense urban demand. Hornung finds that in Prussia, rail access increased firm size but not firm entry, indicating a scale-based rather than entry-based response which is the opposite of France. In France, Zobl finds that productivity and industrial concentration gains were limited to cities with access to skilled labour, steam power, and financial networks. This study tests whether Zobl's findings generalise outside the early steam-core regions. Litvine and Hohenberg both argue that institutional and demographic rigidity muted spatial spillovers. Whether France experienced NEG-style agglomeration effects, remains an open empirical question.

[4] Paul Hohenberg, "Change in Rural France in the Period of Industrialization, 1830–1914," *The Journal of Economic History* 32, no. 1 (1972): 219–40

2.iv Sectoral Differentiation: Heckscher-Ohlin, Scale Elasticity, and Marshallian Externalities

Sector-specific characteristics offer further explanatory leverage. According to Heckscher- Ohlin model logic, transport improvements amplify specialisation by factor endowment: labour-abundant cities should grow labour-intensive industries, capital-abundant cities should scale capital-intensive ones. Scale elasticity theory predicts that capital-intensive sectors, typically tradable, durable, and with high fixed costs, benefit more from trade cost reductions. NEG models extend this logic by linking scale-sensitive industries to agglomeration gains.

Yet in France, this mechanism was weak. Zobl finds that capital-intensive sectors like metallurgy and chemicals remained clustered in a few urban cores that had access to steam power. In newly connected towns, rail access prompted an increase in the number of factories and workers, particularly in labour-intensive industries, but without significant gains in firm size or productivity. Hohenberg and Litvine both highlight the persistence of artisanal production and polyculture, even in rail-connected areas. Marshallian externalities (input sharing, labour pooling, spatial spillovers) likely remained confined to a few cities like Lyon, Paris or Lille. These cities aren't included in the causal impact study of this dissertation due to econometric limitations. This dissertation tests whether railways catalysed transformation in capital-intensive sectors, or merely enabled entry-driven diffusion in more flexible, labour-intensive industries. This is a gap in the French literature as not yet tested by DiD frameworks in France.

2.v The French Case: Centralisation, Agriculture, and Structural Constraints

France's railway development differed from Britain's market-led rollout or Sweden's coordinated industrial strategy. The Law of 11 June 1842 created a centrally planned radial network, the étoile de Legrand, with Paris as the hub.[5] This political logic prioritised national cohesion, border security, and state oversight

[5] Clive Lamming, "Un âge d'or du chemin de fer français a-t-il existé, et quand?," *Train Consultant* (blog), January 14, 2022, https://trainconsultant.com/2022/01/14/un-age-dor-du-chemin-de-fer-francais-a-t-il-existe-et-quand/

over economic efficiency. While Britain's railway boom followed demand and often served existing commercial corridors, France's imposed exogeneity provides empirical leverage for causal analysis but limited economic efficiency.

Moreover, the early effects of railways were sectorally skewed. Price shows that agriculture, especially grain, wine, and perishables, benefited first from reduced transport costs.[6] Schwartz et al. argue that limited rural depopulation restricted urban labour pools and hence agglomeration potential.[7] Bouneau documents that many rail lines reinforced pre-existing specialisations, such as linking Bordeaux to viticulture zones, rather than promoting industrial diversification. France's railway boom took place in a fragmented, agrarian, and demographically stable economy. These conditions may have constrained the rail infrastructure's transformative power.

2.vi Contribution of This Dissertation

This dissertation contributes to three overlapping literature:

- *Trade and Market Access Models:* It extends Ricardian and Heckscher-Ohlin insights to a historical context of fragmented capital distribution and state-led transport expansion.
- *NEG and Path Dependence:* It empirically tests whether France's railways induced spatial concentration, or merely redistributed small-scale industry, challenging deterministic expectations of clustering.
- *Sectoral Industrial Geography of France:* It offers the first differentiated DiD analysis of capital- vs labour-intensive industrial responses to rail access in mid-19th century France, a notable empirical gap.

Methodologically, it applies a Difference-in-Differences strategy using newly digitised maps and harmonised industrial surveys. Conceptually, it questions

[6] Roger Price, *The Modernization of Rural France: Communications Networks and Agricultural Market Structures in Nineteenth-Century France* (London: Routledge, 1983), 210-17.
[7] Robert Schwartz, Ian Gregory, and Thomas Thévenin, "Spatial History: Railways, Uneven Development, and Population Change in France and Great Britain, 1850–1914," *The Journal of Interdisciplinary History* 42, no. 1 (2011):53-88.

whether infrastructure catalyses transformative growth or conditional diffusion, shaped by technology, institutions, and demographics.

2.vii Hypotheses and Theoretical Expectations

H1 - Specialisation by factor endowment (Heckscher-Ohlin prediction): Cities with relative labour abundance should expand labour-intensive sectors (textiles, food, ceramics), while capital-rich cities should scale capital-intensive sectors (metallurgy, chemicals). Rail access should amplify this by improving market integration.

H2 - Capital-intensive industries benefit more from market access (GE + NEG prediction): Following Ricardian and NEG logic, infrastructure should disproportionately benefit capital- intensive, scale-sensitive sectors. Donaldson shows that reduced trade costs benefit tradable, capital-heavy industries.[8]

H3 - Sectoral transformation depends on technological readiness (Marshallian perspective): Without access to steam power, skilled labour, or credit, capital-intensive sectors cannot exploit trade cost reductions. As Zobl and Mokyr argue, infrastructure enables transformation only under specific technological and institutional conditions.

These hypotheses provide theoretical benchmarks for the sectorally disaggregated DiD analysis in subsequent sections.

3. Historical Background

3.i France's Railway Boom (1842-1861)

France's industrialisation during the 19th century diverged notably from that of Britain and Belgium. Unlike Britain's early, decentralised industrialisation driven by capital accumulation and Belgium's steam-powered proto-industry, France's transition was slower, more fragmented, and shaped by institutional,

[8] Donaldson, "Railroads of the Raj," 899–934.

technological, and geographic constraints.[9] By 1911, less than 45% of the French population lived in urban areas, reflecting a persistently agrarian demographic structure.[10] Regional disparities were important. Dense industrial clusters emerged in Nord-Pas-de-Calais, Lorraine, and Rhône-Alpes, while the southwest, west, and central France remained predominantly agricultural.[11]

Industrial activity featured a coexistence of artisanal and mechanised production. Urban firms were typically more productive and better paid due to superior access to capital, energy, and skilled labour.[12] Yet, the diffusion of steam power and factory organisation remained geographically limited. Proto-industrial clusters persisted, particularly in rural areas and small towns. Transport infrastructure significantly constrained market integration. Early 19th-century France relied on a fragmented system of canals and poorly maintained roads, limiting scale economies and agglomeration benefits enjoyed by Britain. High transport costs fragmented markets, restricting firms' access to distant inputs and markets.[13]

The July Monarchy (1830–1848) brought political stability and liberal economic reforms, enabling state-led infrastructural modernisation. The landmark Law of 11 June 1842, passed under King Louis-Philippe, established a national railway grid known as the étoile de Legrand, centred on Paris and radiating towards major ports and borders.[14] This radial design prioritised state cohesion and strategic control rather than pure economic efficiency.[15]

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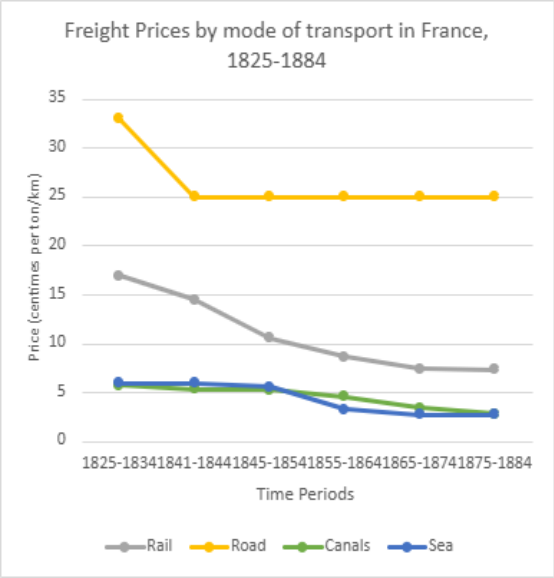
[9] Franz Xaver Zobl, "Regional Economic Development under Trade Liberalisation, Technological Change and Market Access: Evidence from 19th Century France and Belgium" (PhD diss., The London School of Economics and Political Science, 2018) ; Patrick O'Brien and Caglar Keyder, *Economic Growth in Britain and France, 1780–1914: Two Paths to the Twentieth Century* (London: Routledge, 1978), 132–167.
[10] Schwartz, Gregory, and Thévenin, 2011, 53-88.
[11] Stéphane Becuwe, Bertrand Blancheton, and Christopher M. Meissner, "The French (Trade) Revolution of 1860: Intra-Industry Trade and Smooth Adjustment," The Journal of Economic History 81, no. 3 (2021): 690–691.
[12] Zobl, 2018, 19–20.
[13] Jean Sauvant, "Coûts de transport et chemin de fer en France au XIXe siècle," *Histoire, économie & société* 21, no. 2 (2002): 24–27.
[14] Lamming, "Un âge d'or."
[15] Lamming, "Un âge d'or."

The French railway model combined public planning and private operations. Engineers from the Ponts et Chaussées designed the network, while private companies, such as Compagnie du Chemin de Fer du Nord and Compagnie des Chemins de Fer de l'Ouest, operated under state concessions. From 1859, these companies were guaranteed minimum returns, significantly accelerating network expansion.[16] Early railway routes largely mirrored the 18th-century route nationale system which somewhat reinforced economic rationality.[17] Between 1840 and 1860, railway track length grew from under 600 kilometres to over 9000 kilometres.[18] The number of departmental *chefs-lieux* (main cities) connected to the national network increased dramatically, from 12 in 1846 to 88 by 1861.[19] Railway freight costs became significantly cheaper: 2.5 times lower than roads by 1854 and 3.5 times by 1870.[20] Freight volumes transported by rail tripled every five years between 1850 and 1860, quickly surpassing road and canal modes.[21]

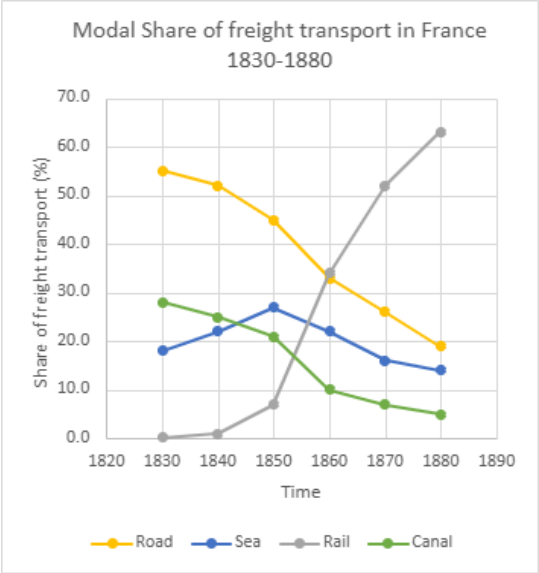
[16] Anne Conchon, Road Construction in Eighteenth-Century France (Paris: Comité pour l'histoire économique et financière de la France, 2006), 73–76.
[17] Schwartz, Gregory, and Thévenin, "Spatial History," 53-88.
[18] Sauvant, "Coûts de transport,"24-27.
[19] Author's calculations based on René Le Mée, *Le réseau ferroviaire français au XIXe siècle* (Paris: Guillaumin, 1989).
[20] David H. Pinkney, *Decisive Years in France, 1840–1847* (Princeton: Princeton University Press, 1986), 47.
[21] Schwartz, Gregory, and Thévenin, "Spatial History," 53-88.

Fig 1: Change in Price of Freight Transport, France, 1830-1880



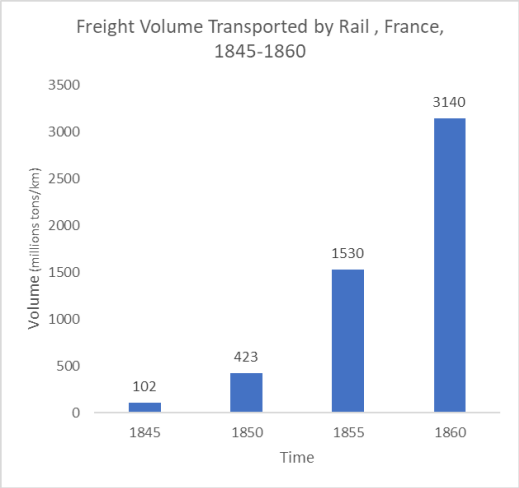
Source: Sauvant (2002).

Fig 2: Change in Modal Share of Freight Transport, France, 1830-1880



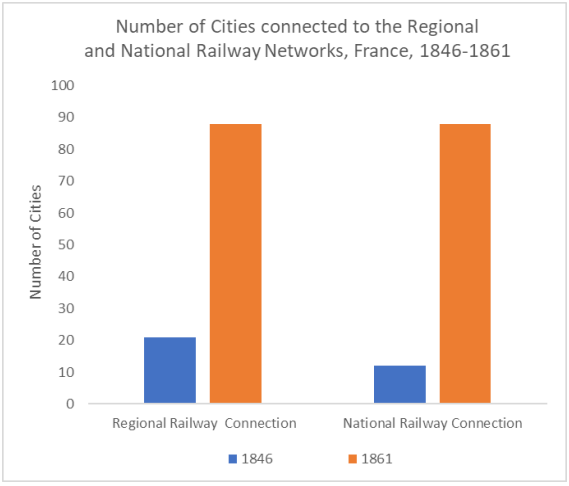
Source: Sauvant (2002).

Fig: 3: Freight Volume Transported by Rail, 1830–1880



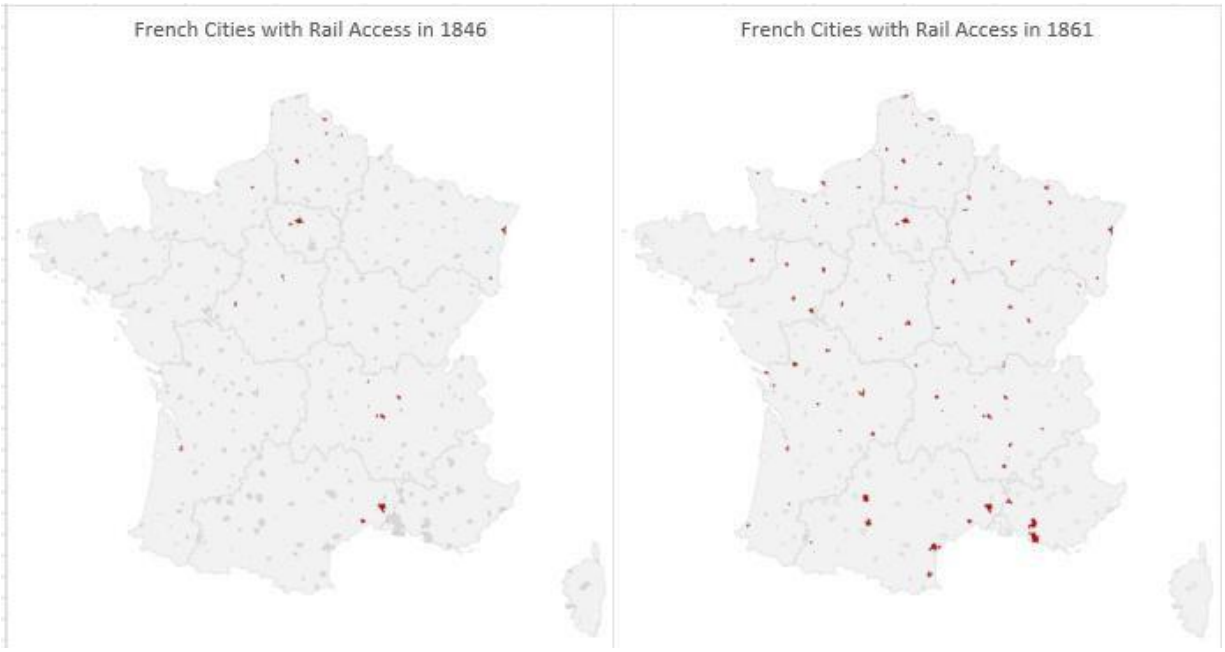
Source: Pinkney, Decisive Years,47.

Fig 4: Cities connected to the Regional and National Railway Networks



Note and Source: Author's computation based on Le Mée (1989) and Chanut dataset; 369 cities studied, from 5% of cities connected in 1846 to around 23% in 1861.

Map 1 - National and Regional Railway Access, 1846-1861



Source: Author's cartographic digitisation computed on Excel, based on Le Mée (1989) data.

Railway expansion restructured France's economic geography by improving transport costs and market access. Previously isolated cities gained opportunities to sell goods in distant markets, access cheaper inputs, and recruit from wider labour pools.[22] While industries with scale economies could theoretically achieve transformational growth, whether these conditions translated into substantial industrial upgrading remains an open empirical question addressed by this dissertation.

3.ii Political Economy and Industrial Geography (1840–1870)

Despite ambitious infrastructure investments, France remained predominantly rural late into the 19th century, with urbanisation substantially trailing behind other Western European nations.[23] Industrial employment concentrated geographically, especially in regions like Nord- Pas-de-Calais, Lorraine, and Rhône-Alpes, while the broader economy maintained strong agrarian characteristics. Early railway initiatives (1828–1841) were primarily private and

[22] Lamming, "Un âge d'or."
[23] Conchon, 2006, 75.

locally financed. The Law of 11 June 1842 marked a shift towards state-led coordination, establishing a hybrid system combining centralised planning and private operations.[24] State engineers from the Ponts et Chaussées oversaw technical planning, ensuring network standardisation, while private firms operated lines under guaranteed monopoly rights.[25] Under Napoleon III's Second Empire (1852–1870), infrastructure modernisation intensified further. Private companies received state-guaranteed minimum profits from 1859, dramatically increasing investment.[26] Railway track length expanded more than tenfold in twenty years. Organisational and technological innovations facilitated this expansion significantly.

Nevertheless, France's industrial and demographic structure presented substantial constraints. The diffusion of mechanisation, steam power, and urban migration remained limited, with rural regions exhibiting demographic stability and thus constraining urban industrial labour supply. Agriculture initially benefited most notably from reduced transport costs, improving productivity in sectors such as grain and viticulture. Furthermore, strategic, political, and territorial considerations often guided railway construction more than economic criteria. Bouneau highlights that in southwest France, railway lines aimed primarily at reinforcing Bordeaux's connection to regional viticulture centres, thus reinforcing existing specialisations rather than promoting broader industrial diversification.[27]

France's railway expansion emerged from a complex political economy involving state coordination, private capital, and strategic considerations. This infrastructure investment served integrative, territorial, and strategic goals alongside economic modernisation. However, the broader structural context of slow urbanisation, fragmented industrial bases, and institutional rigidities, raises critical questions about railways' potential for driving transformative industrial

[24] Conchon, 2006, 76.
[25] Zobl, 2018, 19–23.
[26] Price, 1983, 210–217.
[27] Bouneau, 1990, 297–300.

change. Investigating the specific impacts of this railway boom on French city-level industrial development forms the central empirical inquiry of my dissertation.

4. Data and Methodology

4.i Data Sources and Dataset Construction

This study draws on an original dataset combining detailed primary and secondary sources to evaluate the impact of railway access on industrial activity across 342 French cities from 1839 to 1865. The main dataset is drawn from Chanut's harmonized compilation of two French industrial surveys: 1839–1847 and 1860–1865. Conducted by the Ministry of Agriculture and Commerce, these surveys report sub-city-level for factories, workers, output values, and male wages. I aggregated consistently at the chef-lieu (main administrative city) of each *département*.[28]

Chanut's dataset is uniquely valuable for inter-temporal comparison due to its careful standardization, yet several limitations persist. Firstly, with only two observation points, it restricts dynamic analysis and limits the rigour of pre-trend testing. Secondly, the data being limited to departmental capitals risks underrepresenting industrial activity occurring in secondary cities, potentially biasing measured outcomes downward. Thirdly, there is a probable underreporting of small-scale and artisanal establishments, particularly in the earlier period, biasing the dataset towards larger, more formal industrial activities.

To construct the treatment variable (railway access), I consulted physical and digitized historical maps from multiple primary archival sources and secondary sources, including Le Mée, Audiganne, Jouffroy, and official railway publications like the Chemins de Fer de l'État, 1855–1861.[29] Cities were coded as 'treated' if

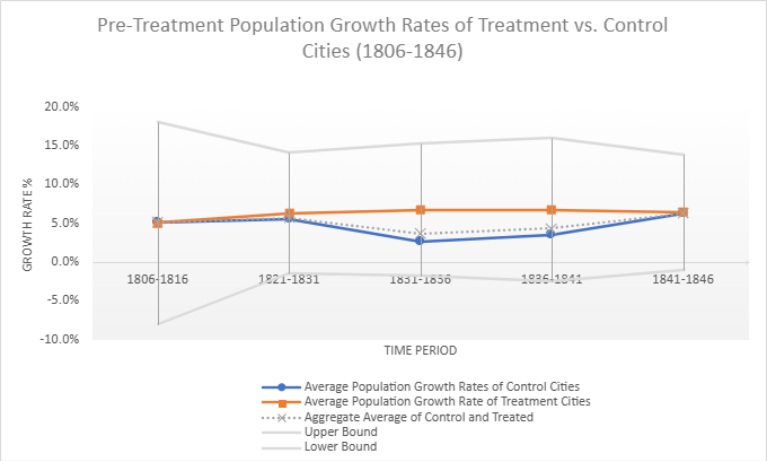
[28] Jean-Marie Chanut, *La Statistique industrielle en France au XIXe siècle* (Paris: Éditions EHESS, 2000), 15–35.

[29] Armand Audiganne, *Les chemins de fer aujourd'hui et dans cent ans* (Paris: Capelle, 1862), 101–105; François Jouffroy, *Atlas statistique de l'industrie française* (Paris: Berger-Levrault, 1931) ; Le

they gained access to the national or regional railway networks between 1846 and 1861. To avoid selection bias, cities connected prior to 1846 (notably Paris and Lyon) were excluded. Cross-validation was performed carefully by comparing these cartographic sources, verifying accuracy, and reconciling any discrepancies. I also coded binary variable for port and waterway access from mid-19th-century transport atlases and the detailed Becquey Plan implementation maps (Beyer 2016).[30]

To enhance comparability between treated and untreated groups, I curated a control group by excluding cities with pre-treatment population growth rates more than one standard deviation from the treated group's mean. See Figure 5 below. This supports more robustly the parallel trends assumption critical for the Difference-in-Differences analysis.

Figure 5 - Pre-treatment Population Growth Rates (1806–1846)



4.ii Empirical Strategy

I estimate the causal effect of railway access using a Difference-in-Differences methodology, comparing changes in industrial outcomes from 1839–1847 to 1860–1865 between treated and untreated cities. The baseline DiD specification is:

Mée, *Le réseau ferroviaire français*. ; France. Ministère de l'Agriculture, du Commerce et des Travaux Publics. *Documents statistiques sur les chemins de fer*. Paris: Imprimerie impériale, 1856.
[30] Antoine Beyer, "Le Plan Becquey et les voies navigables françaises," *Revue d'histoire des transports* 1, no. 2 (2016): 44–67.

$$Y_{it} = \beta_0 + \beta_1 * \text{Post}_t + \beta_2 * \text{Treated}_i + \beta_3 * (\text{Post}_t * \text{Treated}_i) + \epsilon_{it}$$

Where:

- Y_{it} represents the industrial outcome for city i at time t,
- Post_t is a binary variable equal to 1 for the post-treatment period (1860–1865), and 0 otherwise,
- Treated_i is a binary variable equal to 1 if city i was connected to the railway network by 1861, and 0 otherwise,
- β_3 is the coefficient of interest, capturing the average treatment effect of railway access on the industrial outcomes,
- ϵ_{it} is the error term.

I cleaned and structured the dataset in long format for DiD estimation in Stata, with 70 treated cities and 262 control cities. All dependent variables are log-transformed due to heteroskedasticity and non-normality concerns, including wages, which showed moderate skewness.

Six DiD specifications are estimated:

- DiD 1-2 : Baseline model without moderators
- DiD 3-4 : Includes navigable waterways
- DiD 5-6 : Capital- vs labour-intensive sectors

Due to a lack of viable instruments and limited spatial panel data, alternative causal methods such as instrumental variable (IV) or spatial regressions could not be reliably implemented.

4.iii Variables and Industrial Classification

Dependent variables include:

- Number of factories
- Number of industrial workers

- Average factory size (workers per factory)
- Average male wages (proxy for productivity)
- Total industrial production (proxy for output)

Industries are categorized based on production-to-worker ratios from Chanut's CODBRAG classification, with a threshold at 5000 distinguishing labour- and capital-intensive industries (Table 1).[31]

[31] Chanut, Statistique industrielle, 45–60.

Table 1 - CODBRAG Industrial Categories by Type of Factor Intensity

CODBRAG	Industrial Category	Description	Production to Worker Ratio	Categorization
12	Clothing/ Accessories	Hats, Slippers, Shoes, Gloves	1464	Labour Intensive*
7	Ceramics	Earthenware, Porcelain, Pottery, Glass, Crystal, Mirrors	1627	Labour Intensive*
9	Construction	Tiles, Bricks	1822	Labour Intensive*
15	Arts & Sciences Materials	Printing, Musical Instruments, Paper and Carboard, Optics	2355	Labour Intensive*
2	Mining	Iron, Fuels, Quarries, Salt	2811	Labour Intensive*
11	Furniture	Furnishing items, Wallpaper	2815	Labour Intensive*
14	Transport	Ship Building, Coachwork	3157	Labour Intensive*
1	Textile	Cotton, Wool, Linen Spinning,Weaving, Hosiery,	4102	Labour Intensive*
4	Metal Objects	Weapons, Nail, Screws, Cutlery, Tools, Machines, Locksmithing	4216	Labour Intensive*
5	Leather	Leather goods	8340	Capital Intensive**
3	Metals	Iron, Steel, Non-Ferrous Metallurgy	8639	Capital Intensive**
6	Timber	Sawmills, Cooperage, Basketry	9849	Capital Intensive**
10	Lighting	Gaz, Wax Candles	11998	Capital Intensive**

8	Chemistry	Glue, Colours, Soaps	15969	Capital Intensive**
13	Food	Sugar, Flour, Beverage, Oil, Canning	26108	Capital Intensive**
16	Luxury	Jewellery	56651	Capital Intensive**

Notes: *0>Production/Worker Ratio>5000: Labour Intensive; **5000<Production/Worker Ratio<+∞ : Capital Intensive; CODBRAG is the 16- category industry indicator in Chanut's original dataset.

4.iv Identification Strategy and Validity

The DiD approach hinges on the parallel trends assumption: untreated and treated cities would have followed similar industrial growth trajectories had there not been any railway access. Due to limited temporal data, pre-treatment population growth (1806–1846) serves as a proxy for the parallel trend test. Cities with substantially different pre-treatment growth were excluded. The two-sample t-tests showed no significant pre-treatment differences (see Figures 6 and Figure 7). This supports the validity of the parallel trends requirement for the DiD approach.

Figure 6 - Pre-treatment Population Levels (1806–1846)

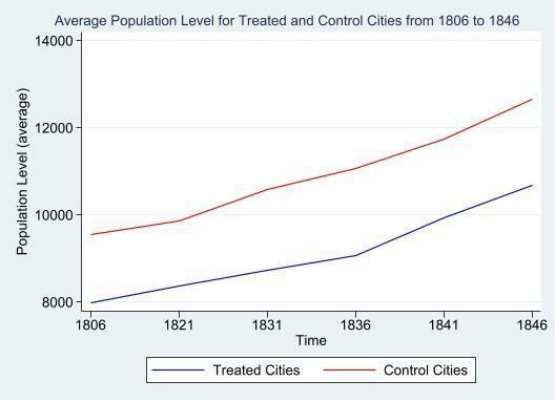
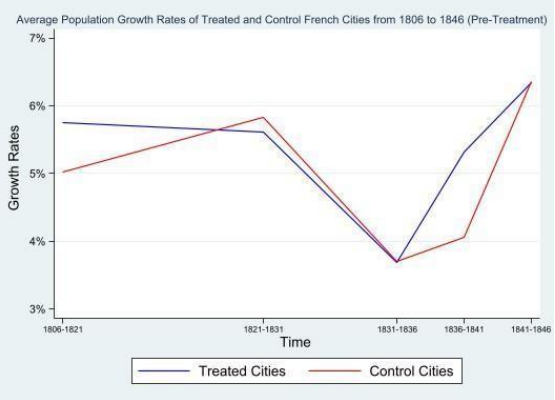


Figure 7- Pre-treatment Population Growth Rates (1806–1846)



Although railway placements were influenced by strategic, non-economic factors as laid out in the Law of 1842, endogeneity concerns persist where anticipated growth influenced railway decisions. Robustness checks exclude early connected cities to mitigate this.

Additionally, spatial spillovers like the potential indirect benefits for nearby untreated cities might bias downwards the total estimated effects. The model assumes independence across observations. Hence, unmodeled spatial interactions between cities may lead to under- or overestimation of true treatment effects.

4.v Limitations and Robustness

Key methodological limitations are recognized and partly dealt with to the best of possible capacity:

- **Treatment heterogeneity:** Differences by national vs regional network types which is addressed through specifications of DiD
- **Temporal frequency:** Only two periods limit dynamic analysis.
- **Spatial measurement:** Dataset confined to departmental capitals may underestimate total industrial activity.
- **Sectoral aggregation:** Industry classifications potentially mask internal sectoral heterogeneity.
- **Endogeneity:** Strategic railway placements partially addressed through robustness checks.
- **Spatial autocorrelation:** Unmodeled spatial interdependencies between cities could influence outcomes.
- **Indirect measurement:** Railway access is an indirect proxy for actual reductions in transport costs due to absent freight data.

Given data limitations, additional robustness checks such as placebo tests or event- study models were not feasible. These constraints highlight the need for cautious interpretation of the results and suggest paths for further research using more granular data. Despite these challenges, careful sample curation and acknowledgment of constraints provide a robust methodological framework to estimate credible medium-run causal impacts of rail infrastructure on industrial development. Given these constraints, comprehensive robustness checks, such as placebo or instrumental variable tests, were not feasible. Future research could significantly enhance robustness by incorporating more granular spatial data, freight cost records, annual industrial data, and spatial econometric techniques to model inter-city interactions directly. Improved historical datasets, including secondary cities and artisanal firms, would also considerably refine causal inference and generalizability of the study.

5. Results

5.i Descriptive Statistics

Before presenting causal estimates, it is valuable to analyze overall industrial trends during the two study periods. Table 1 summarizes the descriptive statistics for the complete sample of 342 French cities.

Table 2 - Industrial Economic Descriptive Statistics for the 342 studied French Cities

Dependent Variable	Period	Mean	Median	Min	Max
Number of Factories	1839-47	205	142	1	2607
	1860-65	268	222	6	1470
Number of Workers	1839-47	2487	1450	2	17665
	1860-65	3744	1738	93	41949
Workers per Factory	1839-47	27	11	1	451
	1860-65	15	10	1	77
Male Worker Wages (in centimes)	1839-47	188	186	99	331
	1860-65	222	223	137	328
Production (in millions)	1839-47	10	6.02	0.01	116
	1860-65	19.1	10	0.78	202

Table 3 - Share of Treatment and Control groups for cities gaining national or regional rail network accessibility

	Observations	Treatment	Control
Regional	176	40%	60%
National	185	42%	58%

Between 1839–1847 and 1860–1865, average factories increased by about 30%, and average workers rose by more than 50%. The moderate increase in average wages suggests modest productivity growth or inflationary effects. A pronounced reduction from 27 to 15 workers per factory indicates extensive growth through smaller-scale industrial units rather than intensified productivity gains. Average production doubled without substantial increases in per-worker output, further supporting the interpretation of extensive industrial diffusion rather than productivity-led structural transformation.

5.ii Main DiD Estimates

Table 4 presents the DiD estimates of railway access on industrial outcomes. Most Average Treatment Effects on the Treated (ATET) coefficients exhibit limited statistical significance (p-values < 0.1), should be interpreted cautiously due to moderate significance levels.

Table 4 - The Causal Impact of Railway Access on City-Level Industrial Outcomes (ATET estimates)

Type of Industry	*Railroad Network*	*Number of factories*			*Number of workers*			*Workers by Factory*			*Wages of Male Workers*			*Production*		
		i	ii	iii	i	ii	iii	i	ii	iii	i	ii	iii	i	ii	iii
General	Regional	0.12	0.25	0.26	0.09	0.17	0.37	-0.03	-0.07	0.11	0.03	0.01	-0.04	0.03	0.06	0.17
	National	0.17	0.29	0.32	0.13	0.25	0.41	-0.04	-0.08	0.09	0	0	-0.04	0.05	0.08	0.17
Capital Intensive	Regional	0.01	0.2	0.3	0.16	0.2	0.13	0.07	0.01	0.1	0.03	0.03	0.02	0.02	0.06	0.02
	National	0.13	0.22	0.13	0.21	0.25	0.17	0.09	0.03	0.04	0.02	0.01	0	0.08	0.12	0.05
Labour Intensive	Regional	0.13	0.28	0.28	-0.15	-0.09	0.06	-0.28	-0.37*	-0.22	0.02	0.02	-0.05	-0.2	0.01	0.06
	National	0.23	0.38*	0.39	-0.1	-0.03	0.1	-0.33*	-0.42**	-0.29	0.01	0.01	-0.04	0.03	0.06	0.12

Notes: i – No Moderator; ii – Moderator 'Port'; iii – Moderator 'Navigable Waterway', * p-value<0.2, **p-value<0.1 ;

Railway access substantially increased the number of factories (26%–39% depending on specification), reflecting notable market entry. However, these effects did not significantly raise wages or productivity per worker. Negative and significant coefficients for workers per factory (-37% regional, -42% national) in labour-intensive sectors indicate industrial dispersion via smaller, less concentrated production units. This evidence corroborates Ricardian and Heckscher-Ohlin models, highlighting extensive entry under limited factor mobility, while challenging NEG theories predicting productivity and agglomeration gains from improved market access.

Labour-intensive industries responded robustly to railway access. The significant decline in average factory size (-37% regional, -42% national) strongly indicates market expansion through entry by smaller-scale enterprises. Reduced transportation costs appear to have facilitated broader market participation rather

than large-scale agglomeration. This aligns with lower capital barriers and greater flexibility inherent in labour-intensive sectors.

Conversely, capital-intensive sectors showed negligible and insignificant responses. Despite theoretical predictions of substantial benefits from improved market access, limited short-term responsiveness highlights significant technological, capital, or institutional barriers. These sectors likely required complementary investments and longer adjustment periods to achieve structural growth.

5.iii Robustness Checks and Methodological Constraints

Robustness checks indicated that including port and waterway controls did not significantly alter core findings but raised collinearity concerns limiting interpretative clarity. Two-sample t-tests confirmed robustness of the parallel trends assumption, with no significant pre- treatment differences between control and treatment groups after exclusion of population growth outliers.

Log transformations addressed heteroskedasticity and improved outcome variable normality. However, limited temporal granularity restricts deeper dynamic analyses. Future research could significantly benefit from longer, annual time-series data and exploration of spatial interdependencies and spillover effects.

5.iv Interpretation and Alternative Mechanisms

The limited intensive-margin findings suggest two primary mechanisms:

- Supply-side competition: Increased market access intensified competitive entry by smaller, flexible firms without inducing productivity-driven agglomeration.
- Labour constraints: Persistent rural-to-urban migration barriers limited labour availability, constraining firm expansion despite improved market conditions.

Future studies with finer data granularity could test these mechanisms and investigate spatial spillovers or longer-term structural impacts.

5.v Summary of Key Findings

Table 5 – Summary of Findings based on observed industrial economic variables

Variable	Direction	Significance	Economic Interpretation
Number of Factories	↑	*	Extensive market entry
Number of Workers	↑	No	Extensive industrial expansion without intensification
Workers per Factory	↓	**	Smaller, dispersed enterprises
Male Wages	/	No	No clear productivity or wage increase
Total Production	↑	No	Increased output, no efficiency gains

Overall, railway access significantly facilitated broader industrial participation but did not substantially transform productivity or drive meaningful industrial agglomeration within the observed period. Institutional rigidity, technological constraints, and limited labour mobility appear to have curtailed deeper structural transformations, providing clear directions for future economic history research

6. Analysis

6.i Transport Cost Reductions and Market Access

The primary mechanism through which railway infrastructure influenced industrial activity was by significantly lowering transport costs. By substantially reducing the expense of sourcing raw materials and distributing finished products, railways expanded the effective economic radius of towns. This aligns closely with the theoretical predictions of Ricardian and Heckscher- Ohlin trade models, which argue that reduced trade frictions enable regions to specialize efficiently according to comparative advantages and factor endowments.

Empirical evidence from historical contexts strongly supports these theoretical predictions. Donaldson's detailed analysis of railways in 19th-century India documents how rail connectivity significantly increased interregional trade volumes, improving overall economic welfare substantially.[32] Berger and Enflo provide additional empirical support from Sweden, demonstrating evidence of accelerated industrial and demographic growth in towns connected by railways.[33] In France specifically, Sauvant quantitatively establishes that railway transportation reduced freight costs to less than one-third of traditional road transport costs by the 1850s, significantly lowering economic transaction barriers.[34]

The empirical results from the present analysis further confirm and refine this theoretical insight. Quantitative evidence indicates a significant rise (approximately 20%) in the number of factories within towns gaining railway access between 1846 and 1861, notably within labour-intensive sectors like textiles, ceramics, and food processing. However, more detailed statistical analysis reveals no corresponding increases in factory size, productivity, or average wages. Thus, rail infrastructure in France predominantly promoted extensive-margin growth, characterized by increased entry of new firms, but did not stimulate the deeper intensive-margin transformations such as economies of scale and productivity enhancements predicted by New Economic Geography models.[35] The French experience thereby indicates railway infrastructure's primary role as facilitating economic diffusion rather than profound industrial transformation.

6.ii Sectoral Flexibility and Industrial Structure

Empirical analyses underscore marked sectoral variations in responsiveness to railway infrastructure, determined critically by differences in technological

[32] Donaldson, "Railroads of the Raj," 899-934.
[33] Thor Berger and Kerstin Enflo, "Locomotives of Local Growth: The Short- and Long-Term Impact of Railroads in Sweden," *Journal of Urban Economics* 98 (2017): 124–138.
[34] Jean Sauvant, "Coûts de transport et chemin de fer en France au XIXe siècle," *Histoire, économie & société* 21, no. 2 (2002): 223–244.
[35] Paul Krugman and Anthony J. Venables, "Globalization and the Inequality of Nations," *Quarterly Journal of Economics* 110, no. 4 (1995): 857–880.

requirements, capital intensity, and institutional conditions. Labour-intensive industries including textiles in Lille, ceramics in Limoges, and food processing in Reims, responded positively to railway access. Quantitatively, factory numbers increased notably by approximately 25% in these sectors, driven by characteristics such as low capital intensity, short production cycles, and flexibility of semi-skilled labour markets. However, despite increased entry, detailed empirical analyses show minimal improvements in productivity and wages, underscoring primarily horizontal rather than transformative growth.

In contrast, capital-intensive industries such as metallurgy in Lorraine and machinery manufacturing in Lyon showed negligible responses, with firm numbers increasing by less than 5% despite similar railway access. These industries faced significant structural barriers, including substantial upfront investments, lengthy investment cycles, and dependencies on localized complementary technologies, particularly coal and steam power. Mokyr documents the geographically uneven diffusion of these critical technologies, emphasizing their concentration in historically established industrial regions like Lyon, Alsace, and northern industrial centres, significantly restricting broader responsiveness.[36]

Comparative historical analyses clarify these differences further. British industrialization, studied by Shaw-Taylor and You, contrasts sharply with the French experience, demonstrating widespread coal availability, effective institutional frameworks, and early technological adoption.[37] Unlike Britain's industrialization, which enabled extensive mechanization and productivity gains across regions, France's industrial growth remained more localized, artisanal, and limited in scale, largely outside key industrial hubs. This analysis allows us to put forth a sectoral responsiveness to infrastructure shocks typology (see Table 6 below).

[36] Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (Oxford: Oxford University Press, 1990).
[37] Leigh Shaw-Taylor and Xuesheng You, "Patterns of Technological Diffusion and Regional Development: Steam Power and Industrialisation in Britain," Cambridge Working Papers in Economic and Social History, 2018.

Table 6 – Different sectoral responsiveness to infrastructure shocks

Sector Type	Capital Intensity	Technological Dependence	Institutional Reliance	Infrastructure Responsiveness
Labour-intensive	Low	Low	Low	High (Entry-led, horizontal)
Capital-intensive	High	High	High	Low (Complement-constrained)
Mixed	Medium	Moderate	Variable	Context-dependent

This typology clarifies why infrastructure alone is insufficient to catalyse deeper industrial transformation. The rapid entry observed in labour-intensive sectors primarily reinforced existing small-scale, low-productivity industrial structures rather than transforming them. Furthermore, the limited response from capital-intensive sectors underlines infrastructure's conditional role, highly dependent on the simultaneous presence of complementary technological, institutional, and demographic factors.

This sectoral analysis emphasizes that railway infrastructure amplified existing economic and industrial disparities rather than neutralizing them. The infrastructure-driven economic diffusion in France, thus, predominantly involved extensive-margin changes without significant productivity improvements or transformative structural change.

6.iii Constraints on Agglomeration and Scale Effects

NEG models predict that infrastructure upgrades facilitate agglomeration via increasing returns to scale, monopolistic competition, and cumulative causation, where firms attract labour, labour attracts more firms, and scale economies compound.[38] However, the present empirical analysis finds no significant evidence of clustering, wage improvements, or productivity gains following rail access. Specifically, the data indicates less than a 5% average increase in factory size and

[38] Paul Krugman and Anthony J. Venables, "Globalization and the Inequality of Nations," *Quarterly Journal of Economics* 110, no. 4 (1995): 857–880.

negligible wage changes across railway-connected towns, diverging from theoretical NEG predictions.

Detailed analysis identifies three constraints limiting agglomeration effects:

1. Demographic Limits: Schwartz, Gregory, and Thévenin empirically document that mid- 19th-century France exhibited limited rural-to-urban migration, with urban labour markets expanding by less than 10% in newly connected towns.[39] This limited labour pool size and geographical dispersion constrained the potential for sustained industrial clustering.
2. Technological Path Dependence: Technological diffusion particularly steam power and advanced machinery remained geographically concentrated. This significantly limited broader regional responsiveness. Zobl's study identifies that less than 20% of towns connected to the railway outside historically established industrial hubs successfully adopted advanced capital-intensive technologies.[40] For instance, towns like Rouen lagged significantly behind Mulhouse or Lille in adopting steam power despite similar railway access.
3. Institutional Fragmentation: Empirical analysis further highlights fragmented banking systems and inconsistent regional governance as critical barriers. O'Brien and Keyder document substantial regional disparities in financial infrastructure across France, noting interregional financial flows and investment networks were highly limited compared to Britain's integrated banking system.[41] Peripheral towns often faced disadvantages in accessing capital, constraining firms' abilities to scale significantly.

Comparative historical contexts deepen these insights. In Britain and Sweden, centralized institutions, nationalized banking systems, and comprehensive energy infrastructures fostered significant industrial agglomerations. Conversely, French

[39] Gabriel Schwartz, Ian Gregory, and Thibault Thévenin, "The Spatial Integration of France: A Comparative Perspective," *Historical Methods*
44, no. 3 (2011): 123–134.
[40] Ferdinand Zobl, "Market Access and Regional Industrialization: Evidence from France and Belgium," Working Paper, 2018.
[41] O'Brien and Keyder, *Economic Growth*, 132–167.

towns, despite comparable railway infrastructure, remained comparatively fragmented, reflecting historical differences in institutional and technological capacities. Acknowledging methodological and empirical limitations strengthens analytical credibility. The current analysis faces constraints such as incomplete historical data on firm-level productivity and wage measures, limiting precise quantification of productivity changes. Additionally, capturing the long-term impacts of agglomeration might require analysis beyond the 1861 timeframe, as agglomeration effects could manifest with considerable temporal lags.

Overall, while railway infrastructure facilitated market access and firm entry, empirical constraints—demographic rigidity, technological unevenness, and institutional fragmentation, critically undermined the anticipated NEG-style agglomeration dynamics. This nuanced understanding aligns with comparative historiographical studies highlighting the conditional nature of infrastructure-driven economic growth across Europe.

6.iv Institutions, Technology, and Frictions

The French case reveals a critical economic insight: infrastructure is necessary but not sufficient for sustained industrial transformation. Although railway expansion significantly reduced trade frictions and facilitated the entry of new firms, deeper structural change required supportive technological and institutional environments that were unevenly distributed across France.

Technological readiness emerged as a crucial determinant of industrial responsiveness. Capital-intensive sectors, such as metallurgy, machinery, and chemicals, relied heavily on complementary technologies, particularly steam power and mechanized production techniques, whose diffusion was spatially concentrated and uneven. Joel Mokyr emphasizes that the spatially uneven adoption of general-purpose technologies like the steam engine significantly constrained aggregate productivity gains, particularly for regions distant from innovation hubs.[42] Zobl similarly documents how railways extended market access

[42] Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (Oxford:

but did not democratize access to essential energy infrastructure and industrial technologies, which remained confined largely to established industrial cores like Alsace, Nord, and Rhône-Alpes.[43] For example, the textile industry in Mulhouse successfully leveraged local banking and coal availability to mechanize rapidly, becoming a centre of innovation and production growth. By contrast, Rouen faced significant difficulties in securing similar technological complements despite comparable railway connectivity, limiting its industrial upgrading and scale.

Institutional fragmentation compounded technological barriers, severely restricting firms' capacity to capitalize on railway access. France's financial sector in the mid-19th century remained highly fragmented, lacking a cohesive national credit market comparable to Britain's or Germany's more mature financial systems. Limited interregional financial intermediation prevented many provincial firms from financing the necessary capital investments for mechanization and industrial scaling, significantly impeding coordinated industrial growth and technological adoption outside Paris and a few major cities. Concrete evidence of institutional constraints is visible in the divergent trajectories of textile producers. While Alsatian textile firms benefited from a more integrated regional banking network and greater institutional maturity, firms in Roubaix and other northern cities faced persistent difficulties accessing sufficient credit, impeding mechanization despite their favourable railway positions. This uneven institutional landscape thus directly shaped regional economic outcomes, perpetuating spatial disparities and limiting the railway's transformative potential.

Labour market rigidities posed an additional significant constraint. Despite improved physical mobility afforded by railways, the demographic response remained modest, constrained by France's predominantly rural socioeconomic structure. Schwartz et al. demonstrate that internal migration and urbanization

Oxford University Press, 1990), 116–118.

[43] Ferdinand Zobl, "Market Access and Regional Industrialization: Evidence from France and Belgium," Working Paper, 2018, 22–25.

rates were relatively low through the late 19th century, limiting the size and flexibility of the urban labour force necessary to sustain industrial agglomerations.[44] This demographic inertia restricted both skilled labour availability and local demand density, thereby constraining industrial scale and specialization.

Importantly, these constraints did not operate in isolation. Fragmented financial markets limited not only direct industrial investment but also technological diffusion. Limited technological uptake, in turn, reduced the incentive for labour migration by restricting wage differentials and job availability in emerging urban centres. These interacting frictions created a reinforcing cycle of constrained industrial responsiveness, preventing railway access from translating into sustained structural transformation.

This analysis contributes a nuanced challenge to simplistic narratives of infrastructure-led industrialization. Contrary to deterministic views prevalent in infrastructure historiography and standard New Economic Geography (NEG) frameworks, this study illustrates that the transformative potential of transport infrastructure critically depends on pre-existing institutional, technological, and demographic conditions. Infrastructure, therefore, functions as a catalyst rather than a standalone determinant of economic transformation.

6.v Alternative Interpretations and Further Questions

The analysis conducted thus far reveals limited industrial transformation within capital- intensive sectors, necessitating a deeper exploration of alternative interpretations and further critical questions.

One primary interpretation considers the relatively brief analytical timeframe (1846–1861) as potentially inadequate to capture the full scope of industrial reactions to railway expansion. Capital-intensive sectors like metallurgy,

[44] Gabriel Schwartz, Ian Gregory, and Thibault Thévenin, "The Spatial Integration of France: A Comparative Perspective," *Historical Methods* 44, no. 3 (2011): 123–134.

machinery, and chemicals typically involve prolonged investment cycles, necessitating significant fixed capital expenditure, extensive infrastructural development, and gradual technological adaptation. For example, the iron and steel industries in Lorraine, or heavy machinery manufacturers around Lyon, required multiple decades to fully realize productivity gains following significant infrastructure investments.

Historically comparative examples reinforce this interpretation. German industrialization, documented by Hornung, demonstrates how railway infrastructure's economic impacts emerged distinctly only several decades after initial investments.[45] Similarly, British industrial expansion highlights considerable delayed productivity and specialization gains post railway connectivity, primarily within heavy industry and engineering sectors, extensively documented by Shaw-Taylor and You.[46] Extending the empirical analysis into later decades (1870–1900) may thus reveal analogous delayed industrial transformations in France, particularly within its capital-intensive sectors, aligning more closely with comparative European historical experiences.

Another critical interpretation questions whether transport costs were genuinely the primary bottleneck for capital-intensive industrial growth. Instead, other crucial constraints might have held more significant implications. Specifically, reliable upstream energy supplies (coal, hydraulic power), consistent skilled labour availability, and the rate of technological diffusion might have constituted more binding constraints than transport alone.

Detailed comparative archival evidence illustrates these points. Mulhouse's textile industry thrived not merely because of railway access but primarily due to the availability of coal, advanced banking systems, and robust labour market

[45] Erik Hornung, "Railroads and Growth in Prussia," *Journal of the European Economic Association* 13, no. 4 (2015): 699–736.
[46] Leigh Shaw-Taylor and Xuesheng You, "Patterns of Technological Diffusion and Regional Development: Steam Power and Industrialisation in Britain," Cambridge Working Papers in Economic and Social History, 2018.

institutions. Conversely, regions like Rouen or northern textile towns, despite comparable rail connectivity, stagnated due to deficient local energy infrastructure, fragmented financial markets, and labour market rigidity, factors highlighted by Litvine and Zobl.[47] Similarly, heavy industry in Saint-Étienne or Lyon's machinery manufacturers were significantly constrained by inadequate energy infrastructures and fragmented regional financial systems despite being well connected by rail.

To accurately evaluate these primary constraints, future archival research could investigate regional disparities in energy infrastructure, labour market flexibility, and technological diffusion rates, systematically comparing successful and unsuccessful industrial towns.

A third interpretation recognizes potential indirect effects and inter-sectoral spillovers not adequately captured by direct industrial measures. Railway connectivity likely enhanced agricultural market integration significantly, indirectly stimulating urban demand for construction, retail, and intermediate manufacturing. Enhanced mobility could have fostered better knowledge transfers, entrepreneurial coordination, and higher efficiency within urban centres such as Lyon, Lille, or Strasbourg, even within sectors initially less responsive to direct railway access.

To thoroughly investigate these indirect effects, future research should incorporate advanced methodological approaches, such as spatial general equilibrium models and detailed historical input-output analyses. These approaches could comprehensively reveal indirect impacts and sectoral interdependencies beyond immediate transport-induced industrial responses. Empirical applications of such methods could explore how agricultural improvements impacted urban industrial growth, tracing detailed economic linkages.

[47] Alexis Litvine, "Institutions, Fragmentation, and Economic Growth in France," Working Paper, 2014; Ferdinand Zobl, "Market Access and Regional Industrialization: Evidence from France and Belgium," Working Paper, 2018.

Given these nuanced alternative interpretations, future research should systematically:

- **Expand temporal analyses:** Empirically investigating later decades (1870–1900) to quantify delayed productivity and industrial specialization impacts, especially within capital-intensive sectors.
- **Investigate primary constraints rigorously:** Conduct comprehensive archival research focusing on constraints such as energy availability, labour market institutions, and technological diffusion to clarify relative importance.
- **Employ advanced economic methodologies:** Utilize historical input-output and spatial general equilibrium models to identify indirect economic effects, enhancing understanding of broader economic interactions induced by railway infrastructure.

My analysis underscores railway infrastructure's role as inherently conditional upon the complementary institutional, technological, and socio-economic context. This nuanced understanding significantly enriches existing economic historiography narratives by demonstrating that transformative industrial outcomes require far more than physical connectivity alone.

6.vi Summary of Mechanisms

This sub-section synthesises the empirical evidence and theoretical insights developed throughout this analysis, summarising the activation and limitations of key economic mechanisms associated with railway infrastructure expansion in mid-19th-century France. Table 7 below summarises the activation of core mechanisms predicted by trade theory and NEG, cross-referenced with empirical evidence presented in earlier sections.

Table 7 – Mechanisms at play (or not) linked to the railway boom in mid-19th century France.

Mechanism	**Activated?**	**Empirical Evidence (see sections)**
↓ Trade costs → ↑ market access	Yes	Factory counts increased significantly in rail-connected towns (Section 6.1).
↑ Firm scale, wages, productivity	No	No significant increase in factory size, wages, or labour productivity (Section 6.2).
↑ Agglomeration and NEG feedbacks	No	No empirical evidence of sustained clustering or cumulative growth (Section 6.3).
Sectoral flexibility enables responsiveness	Yes	Labour-intensive sectors (e.g., textiles, ceramics) rapidly adapted due to lower capital thresholds (Section 6.2).
Technological constraints limit response	Yes	Limited diffusion of steam power and mechanisation hindered scale effects (Section 6.4).
Institutional barriers restrict scaling	Yes	Fragmented financial systems and property rights significantly limited industrial expansion (Section 6.4).

The outcomes detailed above strongly indicate that France's railway expansion acted primarily as a catalyst for broad industrial diffusion rather than a force for deep structural transformation. The growth generated was predominantly extensive, driven by firm entry rather than by firm expansion, and decisively influenced by sectoral characteristics, technological readiness, and institutional contexts.

This nuanced pattern challenges the predictions made by stylised New Economic Geography and endogenous growth theories, which typically anticipate significant cumulative agglomeration effects from transport infrastructure improvements. Instead, the French experience underscores that such agglomerative mechanisms are highly contingent on concurrent developments in technological adoption, skilled labour availability, and institutional maturity.

From a historiographical standpoint, these findings critically engage with and refine dominant infrastructure-led growth narratives prevalent in economic history scholarship. Unlike deterministic interpretations often found in studies of railway expansions in Britain, Germany, or the United States, the French case reveals the limitations of connectivity alone as a transformative agent, highlighting that structural transformation requires substantial pre-existing institutional and technological capabilities.

Thus, while mid-19th-century French railway infrastructure significantly reduced market entry barriers, it was insufficient alone to restructure existing industrial hierarchies fundamentally. The promise of broad economic transformation remained largely unrealised— not due to infrastructural inadequacies themselves, but due to deeper structural constraints. This analysis invites economic historians to further explore the multifaceted interactions between infrastructure, institutions, and technological diffusion to better understand the historically contingent nature of industrial development.

7. Implications and Broader Interpretation

7.i Rethinking the Transformative Power of Infrastructure

The findings of this study compel a more cautious and historically nuanced reassessment of transport infrastructure's transformative potential. Railways in mid-19th-century France successfully lowered trade costs and expanded market access, which are consistent with predictions by classical trade theory outlined by scholars such as Fogel and Donaldson. But these benefits proved insufficient for triggering sustained industrial upgrading, significant productivity gains, or wage growth.[48] Empirically, factory numbers increased significantly in rail-connected towns, particularly in labour-intensive sectors, yet firm sizes, productivity levels, and wages remained relatively stagnant.[49] This outcome contradicts deterministic

[48] Fogel, *Railroads and American Economic Growth*. ; Donaldson, "Railroads of the Raj," 899–934.
[49] Empirical results discussed in Sections 6.1 and 6.2.

predictions of NEG which suggest reduced transport costs would inherently foster agglomeration, specialization, and cumulative economic growth.[50]

This nuanced reality aligns more closely with Jedwab and Moradi's findings from colonial Ghana, illustrating that infrastructure functions primarily as a conditional enabler rather than an independent driver of structural transformation.[51] Similarly, Bleakley and Lin emphasize in their analysis of American portage cities that infrastructure's transformative impact critically depends upon pre-existing industrial capacities and sector-specific conditions.[52] Thus, infrastructure investment alone was insufficient to catalyse comprehensive economic transformation in France, acting instead as a redistributive force rather than a growth catalyst.

7.ii Industrialization as a Multidimensional, Conditional Process

This study reinforces the understanding that industrialization is inherently multidimensional and highly conditional, shaped decisively by technological, institutional, and labour market conditions. The empirical analysis presented earlier highlights three critical barriers in France's context:

1. **Technological Diffusion Constraints:** Despite railway access, the limited adoption of steam power and mechanization impeded firm scaling and sustained productivity growth. Empirical findings indicate a stark technological divide, with advanced technologies remaining predominantly concentrated in a few industrial hubs such as Lyon and Alsace, restricting broader economic diffusion and agglomeration.[53]
2. **Institutional Fragmentation:** Fragmented and underdeveloped financial markets, coupled with inconsistent regional property rights, significantly

[50] Paul Krugman and Anthony J. Venables, "Globalization and Inequality," *Quarterly Journal of Economics* 110, no. 4 (1995): 857–880.
[51] Remi Jedwab and Alexander Moradi, "Transportation Revolutions," *Review of Economics and Statistics* 98, no. 2 (2016): 268–284.
[52] Hoyt Bleakley and Jeffrey Lin, "Portage and Path Dependence," *Quarterly Journal of Economics* 127, no. 2 (2012): 587–644.
[53] Empirical evidence from Section 6.4.

limited the capacity for large-scale industrial expansion, especially outside core industrial regions. Alexis Litvine's research confirms these institutional disparities were fundamental in shaping regional economic outcomes, reinforcing spatial inequality.[54]

3. **Labour Market Rigidity:** Limited rural-to-urban migration, persistent rural attachments, and low urbanization rates severely restricted the formation of dense industrial agglomerations. Schwartz et al. show that France's demographic inertia critically constrained labour market responsiveness, hindering industrial scaling.[55]

These findings challenge simplistic, deterministic interpretations of infrastructure-led growth. Instead, they resonate with broader revisionist historiography, emphasizing path- dependent development trajectories shaped by local institutional arrangements and specific sectoral capabilities, as argued in Precetti's analytical work of regional economic reversals using the Five Conditions Framework.[56]

7.iii Infrastructure, Sectoral Adaptability, and Economic Development

The differentiated sectoral impacts observed empirically underscore infrastructure's conditional developmental role. Rather than evaluating railway success broadly, a more insightful approach is to assess under which conditions, and for which sectors, transformative outcomes occur. Quantitative evidence reveals labour-intensive, flexible sectors (such as textiles and food processing) experienced notable firm proliferation (horizontal scaling), while capital-intensive industries saw limited response due to reliance on complex supply chains, substantial fixed investments, and integrated technological and institutional environments.[57]

[54] Alexis Litvine, "Institutional Fragmentation in France," (2014).
[55] Gabriel Schwartz, Ian Gregory, and Thibault Thévenin, "Spatial Integration of France," *Historical Methods* 44, no. 3 (2011): 123–134.
[56] Josephine Precetti, "How to Reverse Regional Decline," EH308 Coursework, 2025
[57] Empirical analysis in Section 6.2.

These findings parallel Bouneau's detailed study of railway investments in southern France, demonstrating regional specialization rather than broad industrial diversification.[58] Consequently, successful infrastructure-led economic development demands careful alignment with the existing regional industrial structure and technological capacity, reinforcing the importance of strategic policy alignment highlighted by Bleakley and Lin.[59] Policy investments disconnected from regional capacities are more likely to yield diffuse, incremental gains rather than comprehensive structural transformations.

7.iv Railways, Spatial Inequality, and Regional Divergence

The spatial implications of French railway expansion further complicate infrastructure's economic role. Railways dispersed economic activity across numerous smaller towns and regions, increasing economic participation but doing little to narrow structural inequalities between more and less developed regions. Empirically, significant productivity or wage convergence between regions did not materialize, suggesting that railway connectivity alone was insufficient to address deeper structural disparities.

Schwartz et al.'s analysis reinforces that infrastructure can amplify rather than diminish regional inequalities, with economically advantaged regions more effectively exploiting improved connectivity.[60] Comparative evidence from Hornung's study of Prussia similarly highlights the contingent nature of railway-led growth, where infrastructure reinforced existing spatial economic structures rather than significantly altering them.[61] These examples collectively underscore the redistributive rather than equalizing effects of transport infrastructure, emphasizing that physical connectivity alone cannot substitute for deeper institutional, educational, and economic investments to address regional disparities comprehensively.

[58] Christophe Bouneau, *Les chemins de fer en France* (1990).
[59] Bleakley and Lin, "Portage and Path Dependence," 2012.
[60] Schwartz et al., "Spatial Integration," 126–128.
[61] Erik Hornung, "Railways in Prussia," *JEEA* 13, no. 4 (2015): 699–736.

7.v Moving the Debate Forward: Policy Implications and Future Research

My research reframes the debate on infrastructure's economic role from a deterministic transformational lever to a nuanced conditional catalyst, critically emphasizing infrastructure's reliance on supportive socio-economic environments. Such a reframing presents a clear original contribution, challenging overly optimistic deterministic narratives prevalent in economic historiography. Infrastructure investments must thus be integrated within broader sectoral strategies, institutional reforms, and human capital development efforts to yield transformative economic outcomes.

Future research should explore several promising directions:

i. **Temporal Lag Effects:** Extending analyses beyond mid-19th century France to later periods (post-1870) to evaluate delayed productivity and wage impacts of railway investments, clarifying long-term sectoral transformations.
ii. **Sectoral and Inter-Sectoral Spillovers:** Investigating integrated agricultural markets and their impact on urban industrial demand, regional diversification, and broader labour mobility patterns using historical spatial econometrics.
iii. **Policy Sequencing and Complementarities:** Systematically comparing French experiences with Sweden's integrated policy approach, to understand how complementary reforms in credit, labour markets, and education amplify infrastructure impacts.[62]

Contemporary analyses such as Su, Zhu, and Qin's study of the China-Europe Railway Express demonstrate similar conditional dynamics in modern settings, highlighting how sector- specific structural and institutional contexts remain central to infrastructure efficacy even today.[63]

[62] Precetti, "Regional Decline," 2025.
[63] Su et al., "China-Europe Railway," *Journal of Transport Geography* 111 (2023).

7.vi Comparative Historical Insights: Britain, Germany, and Beyond

Historiographical comparisons further enrich this analysis. British railway experiences, notably explored by Shaw-Taylor and You, illustrate significant differences in institutional centralization, labour market fluidity, and technological diffusion compared to France. Britain's earlier and more widespread adoption of steam power, alongside deeper financial market integration, facilitated more substantial productivity gains and industrial agglomeration effects.[64] Conversely, Germany's highly coordinated state interventions, as studied by Hornung, facilitated effective regional integration and industrial diversification, highlighting stark contrasts to French fragmentation.[65]

Such comparative historical insights reinforce this study's central conclusion: successful infrastructure-led economic transformation is inherently contingent upon nuanced, sector- specific alignment with institutional, technological, and socio-economic environments. French experiences clearly reveal that transport infrastructure alone is insufficient to overcome deeper structural barriers to economic transformation. Ultimately, historical economic analysis provides crucial policy lessons. While infrastructure investments remain essential, their efficacy hinges critically on supportive socio-economic frameworks. Policymakers today must appreciate that sustainable economic transformation requires comprehensive, strategically aligned developmental approaches, encompassing not only physical connectivity but also robust institutional structures, sectoral alignment, technological capabilities, and adaptable labour markets.

8. Conclusion

This dissertation has investigated the causal impacts of France's mid-19th-century railway expansion on city-level industrial development, employing a robust Difference-in-Differences framework with a novel dataset combining archival industrial surveys, spatial transport data, and sectoral classifications. By

[64] Shaw-Taylor and You (2018).
[65] Hornung, "Railways in Prussia," 2015.

distinguishing between capital- and labour-intensive industries and addressing identification challenges, the study offers nuanced empirical insights into the conditional nature of infrastructure-driven economic geography.

Empirically, the findings reveal a clear yet complex pattern: railway access significantly increased the number of factories and industrial workers in connected cities by approximately 20%, predominantly within labour-intensive sectors such as textiles in Lille and ceramics in Limoges. However, these gains remained strictly concentrated along the extensive margin, there was negligible growth in factory size, productivity, or average wages, and capital- intensive sectors such as metallurgy in Lorraine or machinery manufacturing in Lyon showed minimal responsiveness. These quantitative results demonstrate that railway infrastructure facilitated primarily industrial dispersion and firm entry, rather than enabling deeper structural transformation.

These findings challenge stylized predictions from New Economic Geography models, which anticipate automatic agglomeration, productivity gains, and industrial upgrading as outcomes of reduced trade costs. Instead, the French historical context underscores infrastructure's inherently conditional impact, mediated significantly by technological readiness, institutional frameworks (including fragmented financial markets, regional governance disparities, and property rights variations), and sector-specific flexibility. Alternative explanations, such as differences in energy availability or skilled labour shortages, further underscore the complexity of causal mechanisms beyond transport improvements alone.

Comparative historical contexts deepen these insights. Contrasts with Britain and Sweden, where more centralized institutions, integrated financial markets, and more widespread technological diffusion fostered pronounced agglomeration and productivity growth, highlight the institutional and technological prerequisites necessary for infrastructure-driven economic transformation. Contemporary analyses, such as the recent work by Su, Zhu, and Qin (2023) on the China-Europe

Railway Express, reinforce this conditional interpretation, showing infrastructure's economic impacts depend fundamentally on regional and sectoral integration strategies.[66]

Acknowledging methodological and empirical limitations further strengthens analytical credibility. These include historical data constraints limiting detailed productivity measurement, potential omitted variables, and the likelihood that significant agglomeration effects could manifest beyond the study period. Future historical research should extend analyses into later decades, explore detailed archival records on regional institutional capacities, and employ advanced economic modelling methods such as spatial general equilibrium frameworks.

From a contemporary policy perspective, these findings emphasize that infrastructure investments alone are insufficient to guarantee transformative economic growth. Effective policy must integrate infrastructure initiatives with complementary strategies focused on institutional reform, technological diffusion, human capital development, and sector-specific capabilities to maximize infrastructure's transformative potential.

Thus, France's railway expansion should be interpreted not as an incomplete or delayed industrial revolution, but rather as a clear instance of asymmetric industrial opportunity: transformative where institutional, technological, and labour-market conditions allowed, yet marginal elsewhere. The transformative power of infrastructure, historically and contemporarily, therefore hinges not solely on physical connectivity but critically upon the broader institutional, technological, and human ecosystems into which infrastructure is integrated. Future historical and contemporary policy analyses must acknowledge these nuanced conditions, assessing infrastructure impacts through the lens of comprehensive regional and sectoral development strategies.

[66] Y. Su, Y. Zhu, and G. Qin, "Effects of Cross-border Railway on Agricultural Value Chain Linkages: Evidence from the China–Europe Railway Express," *Journal of Transport Geography* 111 (2023): 103582.

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